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Asia–Pacific tropical sea cucumber aquaculture

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Editors: Cathy A. Hair, Timothy D. Pickering and David J. Mills

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Cover: Adult sandfish, Goulburn Island, Northern Territory, Australia.
(Photo: Wayne Tupper)

Foreword

Stocks of high-value sea cucumber species have been overexploited throughout the Asia–Pacific region. Their high value as a food and medicine in China and other parts of Asia, the ease of capture, the apparently insatiable demand for them and the lack of effective management indicate that this situation is unlikely to change any time soon. Better fisheries governance must be a priority; however, in many cases, the situation is beyond the point where improved management alone can restore populations.

Sea cucumber aquaculture is a recurring priority in development aspirations for Asian and Pacific island nations, driven by the depletion of stocks from overfishing and the subsequent loss of livelihoods and export dollars. Fortunately, for a small number of species, aquaculture and farming activities can assist in conserving wild stocks, while also generating income and boosting natural recovery. Consequently, there has been considerable research on the culture of tropical sea cucumbers in the past two decades.

In 2003 the United Nations Food and Agriculture Organization (FAO) held a large workshop on the advances in sea cucumber aquaculture and management in Dalian, China—the first of its kind for research in this field. Today, there is still enormous interest in the topic, and the research has reached a critical juncture. In the Asia–Pacific region, most studies have concentrated on the 'sandfish' (*Holothuria scabra*). Large numbers of juveniles can be reliably produced in hatcheries using relatively simple techniques, and these can be on-grown and transferred to ponds or suitable inshore marine habitats where they can reach commercial size in 1–3 years. The Australian Centre for International Agricultural Research (ACIAR) has provided significant, long-term research investment into sandfish culture in the region (primarily through the WorldFish Center). Projects have investigated large-scale hatchery culture of sandfish (Solomon Islands), techniques for releasing cultured juveniles into the wild (New Caledonia), and sea ranching and pond culture (the Philippines, Vietnam and Australia).

It is timely to review this work, together with recent research from other parts of the world, in order to encourage collaboration and technology transfer, and to develop an effective way to ensure that the technology can deliver real benefits to poor rural communities. To this end, ACIAR, in collaboration with the Secretariat of the Pacific Community (SPC), organised a symposium on tropical sea cucumber aquaculture at SPC Headquarters in Noumea, New Caledonia, in February 2011. Although the principal focus was on ACIAR work, particularly in the Asia–Pacific region, researchers from other parts of the world were invited to provide additional expertise.

The symposium identified knowledge gaps and highlighted researchable topics for future developments in sea cucumber aquaculture. These proceedings will be a valuable resource for all practitioners in this field.

Nick Austin
Chief Executive Officer
ACIAR

Contents

Abbreviations

1-MeA	1-methyladenine
ACIAR	Australian Centre for International Agricultural Research
Aj-GSSL	*Apostichopus japonicus* gonad-stimulating substance-like (molecule)
AVS	acid-volatile sulfur
BL	body length
BML	Bolinao Marine Laboratory
BV	body volume
BW	body weight
CFD	coelomic fluid density
CFV	coelomic fluid volume
CFW	coelomic fluid weight
CMT	customary marine tenure
DMP	dimercaptopropanol
DO	dissolved oxygen
DTT	dithiothreitol
EDTA	ethylenediaminetetraacetic acid
FSM	Federated States of Micronesia
GMP	good management practice
GSS	gonad-stimulating substance
GSSL	gonad-stimulating substance-like
GSSL-IVF	gonad-stimulating substance-like in-vitro fertilisation (technique)
GVBD	germinal vesicle breakdown
HACCP	hazard analysis critical control point
ind	individuals
IVF	in-vitro fertilisation
LMMA	locally managed marine area
MPA	marine protected area
MH-IVF	IVF technique developed at Madagascar Holothurie S.A.
MH.SA	Madagascar Holothurie Société Anonyme
MIS	maturation inducing substance
NGO	non-government organisation
NPV	net present value
NT	Northern Territory
OFCF	Overseas Fishery Cooperation Foundation (Japan)
OMI	oocyte maturation inductor
PCF	perivisceral coelomic fluid
PICs	Pacific island countries
PICTs	Pacific island countries and territories
PNG	Papua New Guinea
RIA3	(Vietnamese) Research Institute for Aquaculture No. 3
SD	standard deviation
SE	standard error
SEAFDEC–AQD	Southeast Asian Fisheries Development Center – Aquaculture Department
SPC	Secretariat of the Pacific Community
TMD	Trans'Mad-Développement
UPMin	University of the Philippines Mindanao
UPMSI	University of the Philippines Marine Science Institute
USP	University of the South Pacific
UVSW	UV-treated sea water
WorldFish	WorldFish Center

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The symposium was made possible through funding from the Australian Centre for International Agricultural Research (ACIAR) and the Secretariat of the Pacific Community (SPC). Particular thanks to Dr Chris Barlow, ACIAR Fisheries Program Leader, who originally suggested convening a group of experts to review the status and future of tropical sea cucumber aquaculture research. We also wish to acknowledge Mike Batty and Robert Jimmy of SPC for their invaluable support and in-kind assistance, including providing the venue for the symposium (the Jacques Iekawé Conference Centre at the SPC headquarters in New Caledonia) and use of the secretariat. Various SPC staff members assisted with other important tasks—thanks go to the translation team, the travel desk and the information section. In particular, we thank Genevieve Mirc, who worked tirelessly to smooth the way for international participants and coordinate the logistics associated with holding the symposium. We extend our gratitude to Aymeric Desurmont for preparing the symposium website and Mrs Helena Heasman for producing the book of abstracts. The symposium was chaired by Dr Geoff Allan (of ACIAR at that time) and Dr Tim Pickering (SPC). We appreciate the efforts of several colleagues who also provided support and advice before, during and after the symposium, especially Dr Steven Purcell of the Southern Cross University's National Marine Science Centre.

We thank all the participants for their enthusiasm, and for freely sharing their expertise and ideas to make the symposium a success. Their combined efforts show the way forward for the next decade of research into the dynamic and promising field of culture and grow-out of sea cucumbers for improved livelihoods of coastal communities.

Photographs are by the author(s) of papers unless otherwise stated.

Regional overviews

Farmers gutting cultured sandfish after harvesting from ponds in Van Ninh, central Vietnam (Photo: David Mills)

Overview of sea cucumber aquaculture and stocking research in the Western Pacific region

Robert A. Jimmy[1*], Timothy D. Pickering[1] and Cathy A. Hair[2]

Abstract

Sea cucumbers represent an important income source to coastal communities in many Pacific islands, but is now worth only a fraction of historical values. Sea cucumbers have been harvested for hundreds of years for trade with Asia and were probably one of the first real 'exports' from the Pacific islands. Unfortunately, the increase in demand and price, combined with the development of cash economies and growing coastal populations in many islands, has led to widespread overfishing of the resource across much of this region. There is a high level of interest in adoption of aquaculture techniques to restore production levels, but different capacity levels require implementation of different techniques. Some Pacific island countries and territories have completed successful research trials of hatchery and release techniques, and now have capacity to scale up this activity. Factors that work in favour of successful aquaculture include pristine marine environments, long familiarity with sea cucumbers as a commodity, and traditional marine tenure systems that in some places can provide a basis for management of released sea cucumbers. Challenges include lack of technical capacity, unproven effectiveness of sea cucumber releases and poaching.

Introduction

On 14 February 2011, prior to the Asia–Pacific Tropical Sea Cucumber Symposium, Noumea, official representatives of Pacific island countries and territories (PICTs) that are members of the Secretariat of the Pacific Community (SPC) met to discuss sea cucumber resources and aquaculture. This paper represents a synthesis of their status, and was presented on the first day of the symposium. When participants' experiences were compared and discussed, a number of common themes emerged:

- Sea cucumber represents an important income source to coastal communities in many Pacific islands. Sea cucumbers have been harvested for hundreds of years for trade with Asia and were probably one of the first real 'exports' from the Pacific islands.
- This is mainly an export market commodity, but it is also a subsistence food fishery in some Pacific island countries and communities; for example, as a whole cooked sea cucumber, as 'sashimi' (sliced raw meat), or as marinated guts and gonads in salt and lime.
- Catches from the Asian and Pacific regions are known to be the highest, with about 36 species being harvested in the Pacific region.
- Stocks are under heavy pressure with increases in demand and price, combined with the development of cash economies and growing coastal populations in many islands. This has led to widespread overfishing of the resource across much of this region. Through time, smaller individuals and lower valued species are forming a steadily increasing proportion of the total catch.
- Management of the fishery has essentially failed, for a number of reasons. PICTs are resorting to the extreme measure, and 'blunt instrument' management, of imposing fishing moratoria for extended periods (years at a time) to bring about stock recovery.

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- Concern about overexploitation has led to initiatives to promote sea ranching and restocking as an income-generating activity and a means to increase the production of wild stocks.

PICT status reports

Although there are similarities, differences also exist between PICTs—both in the species of interest for sea cucumber aquaculture and in the level of capacity to implement aquaculture techniques to increase production. A number of PICTs have made progress on sea cucumber aquaculture on a few key species. Key points about the main PICTs involved or interested in sea cucumber aquaculture are summarised in Table 1.

Research in PICTs

Despite the majority of PICTs having limited capacity for research and development of sea cucumber aquaculture, it is worth highlighting the notable exceptions where targeted research effort has been made. The countries with some history or current activity in the area are Kiribati, Federated States of Micronesia (FSM), Palau, Fiji, Solomon Islands and New Caledonia. Sandfish continues to be the focus of research and development activity in FSM, Fiji and New Caledonia. Substantial research was done in the late 1990s in Solomon Islands on sandfish culture (e.g. Battaglene et al. 1999), but Japan is now funding research into peanutfish or dragonfish (*Stichopus horrens*) production. Kiribati is the first (and only) country to consistently produce high-value white teatfish (*Holothuria fuscogilva*) juveniles (Friedman and Tekanene 2005; Purcell and Tekanene 2006) (Figure 1). Since 2009, Palau has produced surf redfish and hairy blackfish (*Actinopyga mauritiana* and *A. miliaris*) both medium-value sea cucumber species. In all the PICTs active in sea cucumber production, the emphasis is currently on production technology that has been provided either by private investment (e.g. Palau and FSM, Yap) or through the efforts of overseas aid assistance and government support (e.g. Kiribati, Fiji, Solomon Islands, FSM, New Caledonia). Hatcheries are being built, and staff are being trained or technicians imported in some cases to boost capacity.

Figure 1. Cultured white teatfish juveniles produced at Tanaea hatchery, Kiribati (Photo: Antoine Teitelbaum)

Table 1. Summary of sea cucumber aquaculture in Pacific island countries

Country	Availability of high-interest species	History of sea cucumber aquaculture	National strategy
Fiji	White teatfish Sandfish	ACIAR sandfish hatchery mini-projects at Savusavu (Vanua Levu island) and Galoa (Viti Levu island) First spawning started in 2009, training also provided to community wardens	Fisheries Department aquaculture priority included in work plan from 2011 A regulation on sea cucumber is in place. Sandfish are reserved for subsistence fishery and prohibited from export
Federated States of Micronesia (FSM)	White teatfish Sandfish *Actinopyga* spp. Lollyfish Black teatfish	Hatchery-based releasing project for sandfish and black teatfish, College of Micronesia, Land Grant Program, Pohnpei Private hatchery and sea ranching in Yap for *Actinopyga* spp. 1 staff was trained in Fiji in 2008 (ACIAR), and has transferred their knowledge to other staff	National Aquaculture Strategy (2002) identified sea cucumber as a priority for development Yap: there is a regulation on licensing system in place Pohnpei: all harvests banned since 1995 Kosrae: all exports banned Chuuk: intensive fishing activity, and no sea cucumber fisheries management systems are in place
Kiribati	White teatfish	Overseas Fishery Cooperation Foundation of Japan (OFCF) hatchery projects, initiated in 1995, started production in 1997, and released about 10,000 sea cucumbers per year from 1999–2004 and again in 2008–09 ACIAR research on release strategies	Government wishes to develop white teatfish further No specific legislation for sea cucumber Sea cucumber fishery management plan currently formulated Wish to introduce sandfish because it is more suitable than white teatfish for culture in ponds
New Caledonia	White teatfish Sandfish Black teatfish	Large WorldFish–ACIAR St. Vincent Project on juvenile grow-out, release techniques and pond trials (2001–07)	Government is supporting development with pilot projects and research for sandfish

Hatchery capacity	Community-based management capacity	Broodstock availability	Constraints
Private blacklip pearl oyster hatchery (Savusavu) with micro-algae culture facility Government shrimp hatchery (Galoa) with micro-algae culture facility Seawater laboratory at the University of the South Pacific in Suva, with micro-algae culture facility Government and private-sector staff trained on sandfish under ACIAR project, and on micro-algae	Fiji Locally-Managed Marine Area Network projects in Fiji: 259 registered marine protected areas (MPAs) Natuvu village in Cakaudrove province created an MPA especially for sandfish restocking (2008)	Sandfish are available, although there is localised scarcity White teatfish availability is unknown but probable	Government micro-algae production facility and expertise needs upgrading Need for more people to be trained on seed production and grow-out
Functional hatchery at College of Micronesia in Pohnpei There has been a hatchery facility in Yap since 2007 (*Actinopyga* spp.) There is a private hatchery in Chuuk Kosrae National Aquaculture Centre has a micro-algae culture facility	MPAs are getting support, and communities are now requesting that those MPAs be stocked with sea cucumber	Availability in Yap and Pohnpei, with sufficient sandfish in the wild. Often used 100–200 adults for spawning Kosrae and Chuuk not surveyed but likely to be the same	Lack of local investors Lack of skills and local technicians, so there is reliance on foreign technicians Need for better communication between national and local governments, private sector and traditional tenure holders
White teatfish hatchery Government pearl oyster hatchery	No community-based MPA in Gilbert and Line groups, only the Phoenix Islands Protected Area A few community-based fisheries management (CBFM) plans	White teatfish becoming difficult to find Sandfish are not present in Kiribati, so for aquaculture to become possible it would first need to be introduced	Scarcity of broodstock, so they are kept in captivity White teatfish are not suitable for pond culture High mortality rate during juvenile stage Release effectiveness unknown Very difficult to monitor post-release juveniles High staff turnover, so a continual need for training
One private sea cucumber hatchery under construction, and another being proposed Have six shrimp hatcheries and two for finfish	23 MPAs in Province Sud and 4 in Province Nord CBFM in one community	Still have good stocks, both in and out of MPAs, but high variability between sites Genetic survey of broodstock has been conducted	Spawning season may be limited by cold temperature Production and grow-out economic assessment needed Expert advice sought on protocols, especially grow-out Need to develop tagging methods for monitoring (sea ranching and restocking) Availability of juveniles for restocking and enhancement may be limited by hatchery capacity

continued …

Table 1. (continued)

Country	Availability of high-interest species	History of sea cucumber aquaculture	National strategy
Palau	White teatfish Sandfish Surf redfish Blackfish	Has had a project since 2009 producing *Actinopyga mauritiana* and *A. miliaris*	Government aims to develop sea cucumber aquaculture
Papua New Guinea	White teatfish Sandfish	None	Priority species, especially since sea cucumber harvest moratorium imposed
Samoa	White teatfish Dragonfish (*Stichopus horrens*) are targeted by the fishery Sandfish not present in Samoa	None	Sea cucumber restocking is in the Aquaculture Section Workplan for 2011–15 (subject to hatchery) Government's current main priority is management of the sea cucumber fishery A private-sector initiative to introduce sandfish for aquaculture is now underway Ban on commercial harvest for export of any sea cucumber species, ban on harvest within reserves
Solomon Islands	White teatfish Sandfish Peanutfish (dragonfish (*S. horrens*)) to be targeted in a new project developed by Japan (OFCF)	Large WorldFish–ACIAR project on hatchery techniques (1996–2000)	One of four priorities government wishes to develop, according to 2009 National Aquaculture Development Plan
Tonga	White teatfish Golden sandfish	None	Aquaculture Plan identifies sea cucumber species as highest priority. Sea cucumber plan (2009) in place for the fishery
Vanuatu	White teatfish Sandfish	Two imports of hatchery juveniles of sandfish from Australia (2006–07), but have not been effective	Sea cucumber aquaculture identified as a priority in the National Aquaculture Strategy Draft sea cucumber fishery management plan in place Moratorium on export in place for 5 years since 2008

Hatchery capacity	Community-based management capacity	Broodstock availability	Constraints
Palau has expertise in producing surf redfish and blackfish Palau Community College has a hatchery under the Land Grant System	There is active support for MPAs (e.g. HOPE Network)	Unknown but probably available, as for Pohnpei and Yap	No specific technical skills base for sea cucumber. Project run by Korean technicians Lack of micro-algae production facility and expertise
Private pearl and shrimp hatcheries New government multispecies hatchery at Kavieng	PNG Centre for Locally Managed Areas is active in New Britain and New Ireland Current moratorium on fishing will benefit release activities	Available, although overfishing will have reduced numbers of large animals	No specific expertise for sea cucumber No specific expertise for micro-algae production
Clam hatchery has been decommissioned. Does not have a mariculture hatchery facility at the moment. Proposed new hatchery not built yet	History of community-based management since 1995 (fisheries by-laws) Good success with trochus introduction and stocking onto reefs 54 village-level reserves, 2 district-level MPAs and 84 village CBFMs currently effective	Sandfish not present in Samoa White teatfish and other high-value species in good sizes very scarce	No specific expertise for sea cucumber Lack of micro-algae production facility and expertise Low biomass of high-valued species based on previous surveys
WorldFish Center Nusa Tupe clam hatchery OFCF–government sea cucumber (peanutfish) hatchery has four local technical staff, but they need training on sea cucumber	Three main active MPAs in place Solomon Islands Locally Managed Marine Areas Network and World Wildlife Fund both active in engaging with communities	Sandfish available. Severe overfishing has probably limited broodstock availability, but this needs a survey Broodstock for peanutfish readily available and will be collected from the three MPA sites	Lack of micro-algae production facility and expertise Peanutfish is a new species for aquaculture, so not much information about it yet
Trained on sandfish in 2008 under ACIAR at Department of Primary Industries in Cairns Clam and pearl oysters produced at Sopu government hatchery New micro-algae facility in place but not yet operating	History of community-based management Special Management Areas in place since 2002, regulation in 2008	Sandfish available	MPAs are not very effective due to enforcement problems Micro-algal unit not yet operating due to lack of funds.
Private shrimp hatchery Government clam/trochus hatchery	Traditional community-based *tabu* areas (closed to fishing or harvesting) and MPAs are in place (e.g. Village Based Resource Managed Areas Network) Customary Marine Tenure very active but commercial pressures intense	Probably okay Will conduct a survey in 2011–12 to determine stock status	No specific expertise for sea cucumber Lack of micro-algae production facility and expertise Lack of hatchery space

Fiji, Palau, Kiribati and New Caledonia have released locally cultured juvenile sea cucumbers into the wild, and cultured juveniles from Australia have been released in Vanuatu. Although Kiribati has had success in the spawning and rearing of white teatfish, there has been high mortality of juveniles in the hatchery. For those that reach release stage, it has been established that fluorochrome marking can successfully distinguish them from wild animals (Purcell and Blockmans 2009). However, their highly cryptic nature and the lack of appropriate release strategies have constrained efforts in that area. Despite the release of tens of thousands of juveniles of approximately 10 mm length on numerous occasions, monitoring for survival and growth has been unsuccessful. Recent attempts to release into enclosures failed due to storms that destroyed the pens (Teitelbaum and Aram 2010). In another project, over three million juvenile *A. mauritiana* and *A. miliaris* were produced and released into the wild in three states in Palau. However, the success of this release program is unknown. The results of a small pilot release of juvenile sandfish in Fiji were promising (average 28% survival after 6 months and 166 g size at 8 months: Hair et al. 2011; Hair 2012), but the project needs to be scaled up to gain commercial confidence in the activity.

FSM has not released any juveniles yet but the College of Micronesia in Pohnpei has developed a land-based system ('habitat simulator') for long-term holding of broodstock and juveniles, which uses a combination of flow-through and closed recirculating water techniques (Figure 2). Hatchery-produced juveniles were used for tagging trials (M. Ito, pers. comm., March 2011). In the habitat simulator, tag retention rates for larger individuals (ind) were 70–87% at 2 months (stocking density ~20 ind/m^2 or ~3,000 g/m^2), while for smaller sandfish it was 80% at 2 weeks (~8 ind/m^2 or 210 g/m^2). Numbers of juveniles were released into enclosures in the wild 2 months after tagging; retention rates on these are to be monitored for a period of 2 years. Batches of hatchery-produced juveniles (5,000 × 6 weeks old and 30,000 × 4 weeks old) are being maintained for large-scale tagging trials. The project will soon move to a restocking program, which will involve mass hatchery production of juveniles.

Figure 2. Habitat simulator system and hatchery technician tagging a cultured sandfish (College of Micronesia, Pohnpei, Federated States of Micronesia) (Photo: Masahiro Ito)

Much of our current knowledge regarding sandfish grow-out and release strategies was generated from research carried out between 2000 and 2006 in New Caledonia (e.g. Purcell 2004; Purcell and Simutoga 2008; Agudo 2012). Private-sector production in New Caledonia's northern and southern provinces is currently underway and, once available, cultured juveniles will be released into MPAs and grown in ponds. The experience from Vanuatu of importing juvenile sandfish and releasing them into the wild was perhaps unsuccessful because of poor release strategies, but information is lacking because post-release monitoring was not undertaken.

The problems associated with sourcing and holding broodstock have been identified as a bottleneck to developing sea cucumber aquaculture in a number of PICTs. In particular, the scarcity of white teatfish in Kiribati continues to constrain their hatchery efforts. The high cost of obtaining them and subsequent difficulty of keeping them in good spawning condition means that new broodstock have to be obtained for each hatchery run. This has led them to consider importing sandfish, which can be maintained more easily in secure pond facilities and which have well-established release strategies. In Fiji, FSM and New Caledonia, there are generally sandfish broodstock available, but stock status can be variable between locations. This is problematic if responsible release practices are being followed, since progeny should be released into the area where parent stock originated (Uthicke and Purcell 2004; SPC 2009). FSM is sourcing broodstock of black teatfish (*Holothuria whitmaei*) with the intention of culturing this species in the near future.

Discussion

There is universal interest among PICTs in the application of aquaculture techniques to increase production from sea cucumber resources. The main species of interest is sandfish, except in Kiribati (white teatfish) and Solomon Islands (peanutfish). Two countries that lie outside the natural geographical distribution of sandfish (Kiribati and Samoa) have expressed interest in introducing it for aquaculture.

The range of experiences with, and capacities in, sea cucumber aquaculture research vary greatly. Some PICTs have no capacity or experience at all. In others there has been successful completion of research projects, from which the capacity to produce juveniles in hatcheries for restocking trials on a pilot-commercial scale is now established. The leading PICTs in sea cucumber research activity to date are New Caledonia, FSM and Palau, followed by Kiribati, Fiji and Solomon Islands.

Technical capacity in-country is a vital prerequisite for successful sea cucumber aquaculture, but by itself it is not enough to guarantee success. The capacity for marine tenure systems in PICTs to deliver sufficient protection to investment in restocked or ranched sea cucumbers is another important consideration. There have been some positive experiences with management systems based on custom and traditional marine tenure, to achieve better conservation of inshore fishery resources. Community-based management provides one possible basis for protection of released sea cucumbers until ready for harvest. However, some PICTs have attempted sea cucumber aquaculture for a variety of other reasons, often with misguided intentions: for example, past experiences include projects that were very much investor-driven, with inadequate feasibility studies undertaken prior to development. The term 'aquaculture' can be used misleadingly by unscrupulous investors to lead PICT decision-makers into accepting an unsustainable development where wild stocks can be harvested at the same time as the so-called aquaculture is taking place. Policy advice and technical assistance are currently being provided by the SPC to member countries so that they can recognise and assess development proposals that are genuine and distinguish those that are purely to lure PICTs into allowing access to their wild stock (see Pakoa et al. 2012).

Taking these technical and institutional issues into account, the attributes of the Pacific islands region that lend themselves to sea cucumber aquaculture can be summarised as follows:

- Pristine marine environments and suitable marine habitat are available for restocking and sea ranching of priority species of interest.
- Community-based management systems are in place in many areas.
- Sea cucumber is an ideal commodity for rural and maritime community engagement because the harvesting techniques are simple, and because sea cucumbers do not require large investment capital for processing.
- The sea cucumber industry in this region has a history stretching over more than two centuries, so it does not require large investment in familiarisation or retraining, and it is already well-integrated within traditional lifestyles and practices.

- Sea cucumber hatchery requirements are similar to those of other species already being cultured in the region (e.g. shrimp, pearl, giant clam, trochus), so infrastructure can be shared with these other commodities.

The experiences shared by PICTs in sea cucumber aquaculture reveal some common challenges, however, including the following:

- In some places it is difficult to find sufficient numbers of broodstock-size animals for aquaculture.
- Expertise in sea cucumber aquaculture is limited.
- The effectiveness of sea cucumber releases is not yet proven: optimal release techniques are still being finetuned for some species (e.g. sandfish) and are unknown for others (e.g. white teatfish).
- Land-based nursery areas can be limiting.
- Land disputes can affect released juveniles and broodstock if release sites are open access or under dispute.
- Control and enforcement of restocked or sea-ranched populations to prevent poaching can be difficult to achieve.
- The consequences of translocation of juveniles are not yet known and could cause irreversible genetic problems, so care must be taken to preserve genetic integrity wherever possible.
- There needs to be more research into the economic feasibility of restocking.

Pacific regional priorities for sea cucumber aquaculture, to address these challenges and thereby enable PICTs to capitalise upon their favourable attributes, include:

- demonstration of the effectiveness of sea cucumber restocking and sea ranching through larger scale experimental releases and post-release monitoring
- research to develop optimal release strategies for improved survival and growth
- capacity-building and technology transfer among PICTs for sea cucumber aquaculture
- economic analysis of sea cucumber aquaculture and restocking scenarios
- social analysis of traditional marine tenure systems and of the effectiveness of community-based management, to identify the best governance and/or business models for protection of investment in sea cucumber aquaculture.

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Natuvu (Fiji) community sea ranch warden with sandfish after a cyclone (note broken pen in background) (Photo: Cathy Hair)

Overview of sea cucumber aquaculture and sea-ranching research in the South-East Asian region

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Abstract

South-East Asia has traditionally been the global centre of production of tropical sea cucumbers for Chinese markets. Early research into culture methods took place outside this region, notably in India, the Pacific region and China. However, recent investment in *Holothuria scabra* (sandfish) culture has led to some significant advances within this region. The Philippines and Vietnam have been at the forefront of recent efforts, with involvement from substantial national programs and local institutions as well as international donors and scientific organisations. Smaller programs are ongoing in Thailand, Malaysia and Indonesia. Recent advances and simplifications in hatchery techniques are a major step forward, having promoted the development of experimental-scale sea-ranching ventures, and given rise to a small, commercial pond-based culture industry in Vietnam. Technology developments in nursery systems are likely to provide opportunities for culture enterprises in a broader range of environments than is now possible. A major research thrust in the Philippines towards developing cooperative sea-ranching enterprises has demonstrated good potential, and institutional/legislative arrangements to ensure adequate property rights have been tested. Rotational culture with shrimp is proving successful in Vietnam, while the possibility of proximate co-culture of sandfish and shrimp has largely been ruled out. Small-scale experiments in the Philippines raise the possibility of co-culture in ponds with a number of finfish species. Current research directions are looking at diversifying technology to increase success in a range of coastal conditions, better understanding the social and biophysical conditions required for success, and finding ways of effectively scaling-out developed systems and technology.

Introduction

Globally, the husbandry of tropical sea cucumbers appears 'on the cusp' of success—we are starting to see the construction of commercial-scale hatcheries and farms and, at the other end of the spectrum, sustained forays into community-based culture and sea-ranching systems (e.g. see papers in these proceedings). However, most have yet to demonstrate commercial viability, and many stakeholders are interested to see the outcomes of current pilot ventures. This situation is a product of both the considerable advances that have occurred over the past decade in hatchery and grow-out technology, and the resistance of bottlenecks to unconstrained success. The widespread and growing interest in this commodity is indicative of strong market-based drivers to increase production of sea cucumber (Brown et al. 2010). This has a dual impact of increasing pressure on wild stocks already in crisis, yet also opening the door to opportunities for new coastal livelihoods based on sustainable approaches to

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culture and sea ranching. This symposium is therefore very timely, and allows researchers to take stock of current benchmarks for various stages of production, and gain a shared understanding of bottlenecks, constraints and critical areas for further research.

As the historical global centre of tropical sea cucumber harvest (e.g. Gamboa et al. 2004; Schwerdtner Máñez and Ferse 2010), countries throughout South-East Asia retain a keen interest in developments in culture and sustainable resource management, and, in many instances, sit at the forefront of industry and technology development. The precipitous decline in sea cucumber stocks throughout the region (Conand 2004; Bell et al. 2008) has had dire implications for coastal livelihoods in some areas. While not well documented (but see Shiell and Knott 2010; Wolkenhauer et al. 2010), it is likely that the wholesale removal of sea cucumbers has contributed to reduced resilience among coastal ecosystems.

Social impacts of this decline go beyond lost income. Traditionally, a significant part of the sea cucumber resource in South-east Asia has been obtained by 'gleaning' in the shallows (Choo 2008). Such fisheries provide a disproportionate social benefit, as they have no capital entry requirements (i.e. they are accessible to those without the means to invest) and are accessible to women and children. These highly vulnerable shallow resources are invariably, however, the first to disappear under conditions of uncontrolled harvesting. Harvesting deeper resources becomes more capital intensive (requiring a boat and diving gear) and is generally the exclusive domain of men. A more insidious effect of overharvesting is seen as sustained pressure drives fishers deeper in search of viable stocks; diving-related accidents leading to permanent disability or even death are all too common in villages where sea cucumber harvesting plays an important role in livelihoods. Clearly, the restoration of livelihoods based on near-shore sea cucumber harvest and improved governance of the resource have great potential to benefit coastal communities throughout the region.

In addition to sea ranching or enhancing/restocking wild stocks, sea cucumber culture can play a critical role in restoring resilient livelihoods among coastal aquaculture farmers. Shrimp production dominates this sector in much of South-East Asia. The disease-related serial boom-and-bust cycle that has characterised shrimp production globally (Dierberg and Kiattisimkul 1996) is strongly evident in this region. Such cycles leave casualties, and prominent among them are small-scale producers who typically have limited reserve capital and struggle to recover from losing entire crops to disease (Mills et al. 2011). Sea cucumbers show substantial promise as a sustainable alternative species that can be grown instead of, or with, shrimp, and should provide a more tenable risk profile. Currently, up to 12 farmers are involved in sandfish pond farming in Vietnam.

Recent developments in sea ranching and pond farming in the South-East Asian region are explored here, concentrating on *Holothuria scabra* (sandfish), as this is the focus of current development efforts. The paper does not seek to provide a comprehensive review of all activities in the region, but rather is a 'selective highlights' package that may be somewhat biased towards the lead author's experience. It is intentionally biased towards research that does not appear elsewhere in this volume; much of the current research being undertaken in the region is covered in some depth by others in this symposium. The paper is organised by ontogenic staging rather than geography, considering hatchery, nursery, growing-out and postharvest issues separately.

Hatchery and nursery production

Simplified hatchery systems

The earliest reports of hatchery research on sea cucumbers date back as far as the 1930s (see Yellow Seas Fisheries Research Institute 1991). Today, the culture of temperate species (notably *Apostichopus japonicus*) is in full-swing in China and Japan (Chen 2004), but commercial-scale hatchery production of tropical species is only now becoming a possibility. Considerable research effort in India (James et al. 1994) and the Pacific region (Battaglene et al. 1999) laid the foundations for culture of *H. scabra* on a commercial scale. These techniques were further refined through the work of the WorldFish Center and partners in New Caledonia, and published in a comprehensive hatchery manual for *H. scabra* (Agudo 2006). Recent advances have seen these techniques further refined, simplified and customised for low-investment systems suitable for developing countries (Duy 2010, 2012; Gamboa et al. 2012). Among key modifications and simplifications that have improved success rates are:

- a reduction in requirements for live feed production, to a point where a single species (*Chaetoceros muelleri*) can be used

- low-density culture of larvae (around 0.3 larvae/mL)
- the use of settlement plates coated with a dried algal (*Spirulina*) paste rather than previous techniques of natural conditioning of plates with benthic diatoms.

These techniques reduce the complexity of culture systems and the incidence of infestations by parasites or copepods, and have led to substantially increased survival rates. Experience from Vietnam and the Philippines suggests that a current 'benchmark' for survival from egg to 5-mm juveniles is around 2.5%. Experience from the increasing number of pilot-scale hatcheries developed in various locations indicates that, almost invariably, 'off-the-shelf' hatchery systems will not be adequate, and a degree of customising is required (e.g. Gamboa et al. 2012) to achieve acceptable production.

A 'state-of-the-art' hatchery system has recently been constructed at the Southeast Asian Fisheries Development Center – Aquaculture Department[a] (SEAFDEC–AQD) in the Philippines (Figure 1), and several training courses on hatchery techniques have now been conducted. The facility is set to play an important role in further training and the provision of juveniles for further sea-ranching and pond-culture trials in the Philippines.

Nursery systems

Typically, some 35 days after settling, at a length of around 5 mm, sandfish juveniles are moved from settlement tanks to a nursery system. While hatchery-based raceway systems have proven successful at an experimental scale, it is difficult to see how such systems could be workable at a commercial scale—the costs of the tank area and the water supply required are high. A range of nursery systems has been trialled in Vietnam and the Philippines under Australian Centre for International and Agricultural Research (ACIAR) and national funding. Fine-mesh nets (referred to as 'hapas') are now routinely used (Pitt and Duy 2004) and have been extremely successful in ponds in Vietnam (Figure 2, left), resulting in high survival and growth rates. Juvenile sandfish in hapas feed on algal fouling that grows on the hapa mesh. In the Philippines it has proven difficult to find ponds with adequate seawater exchange rates to maintain the salinities required for nursery stages. In response, effort has been directed at developing floating hapa systems that can be deployed in sheltered marine embayments (Figure 2, right). These systems have great potential for community sea-ranching operations—they allow the transport of juveniles from hatcheries at an early stage, resulting in low mortality; and engage communities in the production cycle at the earliest opportunity, maximising potential financial benefits (Juinio-Meñez et al. 2012a).

Hapa-based nursery systems are commonly used until juveniles reach a weight of 2–5 g. In previous pilot trials of both sea ranching (Juinio-Meñez et al. 2012a) and pond culture (e.g. Pitt and Duy 2004), and in commercial culture in Vietnam until recently, juveniles have been released to their grow-out environment at this size. An 'advanced nursery' stage has now been introduced in Vietnam. Ponds with an optimal seawater supply and muddy-sand, organically rich sediment are seeded with 2–5-g juveniles from hapas at a high density of up to 50,000 juveniles/ha (compared with 10,000 juveniles/ha for grow-out). These are grown to up to 50 g and farmers have the choice of purchasing either small juveniles or advanced juveniles for around twice the price. There are two major drivers behind the development of this system. First, the typical grow-out time from a 2–5-g juvenile to a 350–400-g saleable product in central Vietnam is around 12 months. However, in many ponds there remains some risk associated with growing sandfish through the wet season—pond stratification and low salinities may cause reduced growth rates or mortalities if not well handled (see 'Pond culture' below). By seeding ponds with advanced juveniles, the grow-out period can be reduced to 7–9 months, so that the wet season can be avoided. Second, the survival rate of larger juveniles is invariably greater following release (Purcell and Simutoga 2008), partially offsetting the additional cost of larger juveniles. This advanced nursery system allows for the ponds with the best seawater supply to be used productively for advanced nursery culture throughout the wet season, with a larger number of lower quality ponds used for grow-out in the dry season.

Grow-out

Pond culture

Pond culture of sandfish is an attractive proposition for several reasons. The high but often transient profitability of shrimp culture, combined with the

[a] Funding provided by ACIAR and Japan International Research Center for Agricultural Sciences (JIRCAS), and designed in collaboration with RIA3

Figure 1. Purpose-built sea cucumber hatchery at the Southeast Asian Fisheries Development Center – Aquaculture Department, Iloilo, the Philippines (Photos: J. Zarate)

Figure 2. Nursery hapas in a pond at the Research Institute for Aquaculture No. 3 National Seed Production Center, Vietnam (left); and floating hapas in an enclosed marine embayment established by the University of the Philippines Marine Science Institute (right) (Photos: D. Mills (left) and C. Hair (right))

extreme risk profile associated with this activity, have resulted in a situation where smallholders have tended to lose out to large corporate interests with the financial backing to recover from stock crashes. Intensification of culture methods has also led to severe fouling in ponds, resulting in anoxic sediments and the ultimate abandonment of ponds. Sea cucumbers potentially represent a lower-risk investment for smallholders. As a species that is low on the food chain, they provide better environmental outcomes than shrimp farming, and do not require feeding if stocked in ponds previously used for shrimp culture.

There are, however, biophysical issues that ultimately restrict the number of shrimp ponds suitable for sandfish culture. Most critically, the vast majority of ponds were established for growing *Penaeus monodon* (tiger shrimp); to maximise yield of this species, brackish water is required. As a result, ponds were generally located with good access to a freshwater source, and it may be difficult to maintain the salinities required to optimise sea cucumber growth. *Holothuria scabra*, while somewhat tolerant of reduced salinity (Pitt et al. 2001; Mills et al. 2008), grows best in marine conditions

(30–34 ppt as a general rule). In many culture trials, sudden salinity drops due to storm action and tropical downpours have resulted in high mortality (Pitt et al. 2001; Lavitra et al. 2009; and personal experience of two of the authors—N. Duy, Vietnam; C. Raison, Thailand). Notably, these issues have largely been circumvented in Vietnam, where several farmers are producing *H. scabra* in commercial quantities. Mills et al. (2008) assessed survival and growth of sandfish through the wet season by direct monitoring of commercial ponds and through farmer interviews. Although growth rates declined rapidly, survival of sandfish enclosed in nine pens within three operating commercial ponds was 100% through the 2007–08 wet season, which included nine consecutive days of exceptionally heavy rains. Interviews with farmers revealed that, while most lost sandfish due to freshwater ingress during their first year of production, simple management protocols such as ensuring regular tidal water changes or, in some instances, using paddlewheels to 'de-stratify'[b] pond water resulted in very high survival rates. It should be noted, however, that ponds used for sandfish culture in central Vietnam have very good canal systems, and tidal regimes mean that substantial water changes are possible on most tides. Ponds with similar characteristics have proven difficult to find in other countries.

Without a doubt, one of the greatest restrictions on profitable pond-based sea cucumber culture is density limitation of growth rates. Past research (Battaglene et al. 1999) suggests that growth rates decline when densities exceed 225 g/m^2, while empirical evidence from Vietnam suggests that a density of around 1 animal/m^2 in coastal ponds (without adding feed) provides an optimal balance between growth rates and total production for a target harvest size of 300–400 g (Pitt and Duy 2004).

Recent experiments at the Shrimp Genetic Improvement Center in Thailand (C.M. Raison, unpublished data) looked at the relationship between stocking density, feed rates, growth and survival. An orthogonal experiment compared growth and survival over 36 days among treatments comprising two densities of early juvenile sandfish (average individual weight 1.74 g at densities of about 50 and 85 g/m^2), and five feeding rates (0.05–0.25 g/treatment/day of commercial shrimp starter feed). Preliminary results indicate a strong positive relationship between feed rate and growth rate, and a weaker negative relationship between stocking density and growth rate. While by far the highest growth rates were seen among animals held at low density with high feed rates (average 234% weight gain per individual, compared with 39% for high density, low feed rate), the greatest overall gain in biomass was seen in the treatment with high density of sandfish and moderately high feeding rate. It was also clear from results that overfeeding can be an issue—survival was reduced at the highest feed rates. Where ponds already have rich organic sediments, the addition of feed may cause higher mortality rates. In addition, where nutrient conditions indicate that higher production rates might be achieved through feeding, these need to be offset against additional labour and feed costs. Results also show that organic loading in sediments can be too high for sandfish survival, so there is a limit to the effectiveness of sandfish for bioremediation in these situations.

Co-culture: Pond-based co-culture systems involving sea cucumbers are conceptually very attractive. A pond containing only sea cucumbers for the duration of a grow-out cycle 'wastes' the space available in the water column, while the pond sediment bioremediation potential of sandfish has the potential to improve pond conditions for co-cultured species. Similarly, sea cucumbers grown under sea farms are seen as having the potential to alleviate fouling problems, while enriched deposits from faeces and food waste may increase the growth rates of sea cucumbers (Slater et al. 2009). Unsurprisingly, interest in co-culture in ponds has centered on shrimp, as most coastal ponds have been constructed for shrimp culture, and shrimp are a high-value commodity. Unfortunately, this match gives way on the reality of agonistic interactions, and sea cucumbers invariably come off second best. Trials with *Penaeus monodon* (tiger shrimp; Pitt et al. 2004) and *Litopenaeus stylirostris* (Pacific blue shrimp; Purcell et al. 2006; Bell et al. 2007) showed some initial promise; however, larger scale trials proved unsuccessful.

Recent trials in Vietnam by Mills and Duy (unpublished data) on *Litopenaeus vannamei* (white leg shrimp) perhaps ended the shrimp proximate co-culture ideal. This trial was set up under parameters

[b] Stratification occurs when low salinity water sits on top of higher salinity water in the ponds, isolating the higher salinity water from the atmosphere. This may lead to reduced oxygen levels in the saline water, and a so-called 'lens effect' caused by the upper layer of less saline water. This is said to result in increased temperature in the saline water, which further increases oxygen demand and compounds depletion.

that should have greatly favoured sea cucumbers. In previous trials, postsettlement juvenile sandfish were tested with shrimp post-larvae. In the recent trials in Vietnam, larger juveniles (approx. 50 g) from 'advanced nursery' systems were tested with shrimp post-larvae, giving the sandfish a 'head start'. This system would have the advantage that both shrimp and sandfish would reach market size at around the same time, simplifying the harvest process. Small-scale tank trials again showed some promise—if shrimp were stocked at fairly low density (15 post-larvae/m^2), survival and growth of sandfish were acceptable (although lower than controls). Interestingly, survival of shrimp was higher in all treatments with sandfish than in the shrimp-only controls. These trials were scaled up in 15 × 500 m^2 ponds. The primary objective of the trial was to compare productivity and financial return from co-culture systems with that of rotational culture systems. The results were clear-cut—while growth rates were initially fastest in the co-culture treatments, after 6 weeks in ponds the shrimp had reached a size where they could prey on the sandfish, and total mortality of sandfish in co-culture ponds followed shortly thereafter. It seems that either temporal or physical separation of shrimp and sea cucumbers is required for successful production of both species in a single pond. The former (rotational culture) is already practised by a number of producers in Vietnam, and our trials have shown high sandfish growth rates in ponds recently used for shrimp culture (Mills and Duy, unpublished data). Physical separation of shrimp and sandfish grown at the same time in ponds has yet to receive attention. This is a potentially fertile area for research that has yet to be tackled at any level.

Co-culture with finfish is also a possibility. Farmers in Vietnam have successfully grown sandfish with sea bass (*Lates calcarifer* or barramundi); however, the market for this species in Vietnam is not strong, and this combination has not persisted in the industry. Recent trials at the SEAFDEC–AQD in the Philippines have highlighted several finfish species that may be compatible with sandfish. Species for the trials were selected based on commercial importance within South-East Asia. Species selected were milkfish (*Chanos chanos*), sea bass (*Lates calcarifer*), rabbitfish (*Siganus guttatus*), grouper (*Epinephelus coioides*), pompano (*Trachinotus blochii*) and mangrove red snapper (*Lutjanus argentimaculatus*). Initial trials involved tank-testing the compatibility of juvenile fish with juvenile sea cucumbers. Results were most positive for pompano, milkfish and sea bass—in all cases survival was close to 100%, although the growth rate of the sandfish was notably low (Figure 3). Rabbitfish and grouper were not compatible with sandfish. Current activities see trials with these more successful species being scaled up in experimental pond environments.

Sea ranching

Sea ranching is essentially a 'put and take' activity, where cultured juveniles are released into an area of natural habitat and harvested when they reach a commercially optimal size. Compared with pond culture, inputs are nominally lower, as the processes between release and harvest are largely left to nature. The trade-off here is that, as the level of care that can be offered to sandfish throughout the growth process is reduced, survival will be considerably lower than that seen in pond culture. In addition, property rights

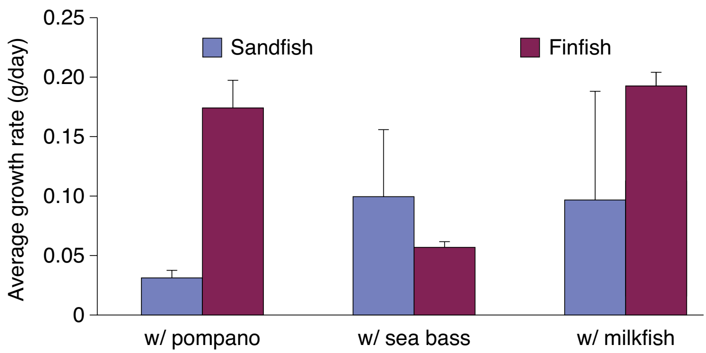

Figure 3. Average growth rates of sandfish and finfish species held in co-culture

issues are less straightforward and the social dimension of culture systems becomes as critical as the biophysical dimensions. Researchers in the Philippines (see Juinio-Meñez et al. 2012b) have been at the forefront of developing strategies for community engagement and equitable property rights, as well as developing, adopting or adapting techniques necessary to build viable sea-ranching systems (Figure 4). Specific challenges for sea-ranching systems include minimising poaching, sustaining engagement, matching environmental and social requirements, and managing severe weather events

Minimising poaching: The high value of sandfish has meant that protecting sea-ranch areas has proven difficult. Permanently manned guardhouses have been established at pilot sites in the Philippines (Figure 4) to overcome this issue. Clearly, this represents a considerable investment on the part of the group owners. However, sea ranching is being promoted as a supplemental income for small-scale fishers, and discussions with participants reveal that the opportunity cost of being one of several sea-ranch owners involved in site guarding is not high. The platform becomes a social meeting point, and fishers can just as well sit on the platform and mend nets or build gear as they could onshore.

Sustaining engagement: The time from establishing a sea ranch to the first fiscal returns in the Philippines will likely be at least 12 months and possibly closer to 18 months. Once the first batches of released sandfish have reached harvest size, regular harvests will be possible; however, the lack of any

Figure 4. Sea ranching in the Philippines: mature animals from the ranch (left), the guardhouse to counteract poaching (top right) and the leader of the sea-ranching group illustrating the principles of the ranch design. All photos from the Victory sea ranch, northern Luzon, the Philippines (Photos: D. Mills and C. Hair)

return on time or money invested during the early stages has been an issue. Pressure from participants to harvest at smaller sizes needs to be resisted in order to optimise returns from the sea ranch.

Matching environmental and social requirements: Both the engagement of strong and respected local institutions and the presence of appropriate habitat are essential preconditions for successful sea-ranching operations. Imposed on this, appropriate mechanisms for site governance must be developed. In the Philippines we have encountered a lot of enthusiasm to engage in sea-ranching activities, but a lot of energy and goodwill can be wasted if the appropriate conditions are not present. Managing expectations is a crucial part of establishing sea-ranching systems.

***Managing severe weather events**:* Of the countries engaged in active research, the Philippines is particularly prone to the impact of typhoons and flooding. The shallow inshore areas generally used for sea ranching are susceptible to physical damage and acute salinity drops from these events. In addition to damage to ranching infrastructure and possible mortality of stock, at a pilot site in the Philippines it appears that stripping of rich organic surface layers from the sediment resulted in substantial negative growth of standing stock (A. Juinio-Meñez, pers. comm.).

Restocking / stock enhancement

The biological case for active restocking of overexploited sea cucumber populations is a strong one (Bell et al. 2008). Due to the low dispersal ability and the need to be close to mates for successful reproduction, recovery from heavy overfishing will be protracted (‘allee effect’), if indeed at all possible (Friedman et al. 2011). Restocking provides a plausible route back to viable populations where no other may exist. The social case is just as strong—the potential for well-organised communities to create sustainable, supplemental livelihoods through restocking or stock enhancement appears promising. A clear risk with this approach is that it can be seen as a panacea where no other management systems have succeeded. In reality, strong and effective governance reform is an essential prerequisite for the establishment of effective restocking programs.

A lot of recent research undertaken in the development of sea-ranching systems provides essential background information on pathways to establishing restocking or enhancement programs. This includes all work on hatchery and nursery systems, tagging methods, transportation systems, release methods and monitoring. However, while the research area of restocking and enhancement remains one of keen interest, the realities to date of legitimate scientific investigation that can identify unambiguous impact mean that these areas are yet to be tackled. Unlike sea ranching, restocking is a ‘whole-of-life-cycle’ process, in which reproductive and recruitment dynamics need to be understood and accounted for in program design. Success requires that enhanced populations occupy ‘source’ areas where coastal currents carry larvae into areas of good habitat for recruitment and growth. If the choice of location is poor, larval mortality may be too high to provide any detectable enhancement effect.

Future research

The authors are aware of active research programs in the Philippines (hatchery, nursery systems, sea ranching, co-culture, pond culture), Vietnam (hatchery, pond culture, co-culture, sea ranching), Thailand (pond culture, sea ranching) and Malaysia (hatchery, sea ranching). Strong institutional support, as well as donor-funded programs in the Philippines and Vietnam, in particular, will ensure continued development of sea-ranching and pond-culture systems. Current research in these countries is focusing on technology and system development to diversify options for producers, and on further understanding the optimal socioeconomic and biophysical preconditions for successful enterprises. Models for scaling out technology and catalysing uptake by small-scale producers are being tested across broad geographic regions. The pond-culture industry in Vietnam is currently growing ‘organically’, with around a dozen farmers involved. This provides good opportunities for future research in partnership with industry. In the Philippines, a major focus in the near future will be capacity building among local institutions to support early entrants into the sea-ranching industry. The establishment of model enterprises is expected to provide a strong basis for technology uptake.

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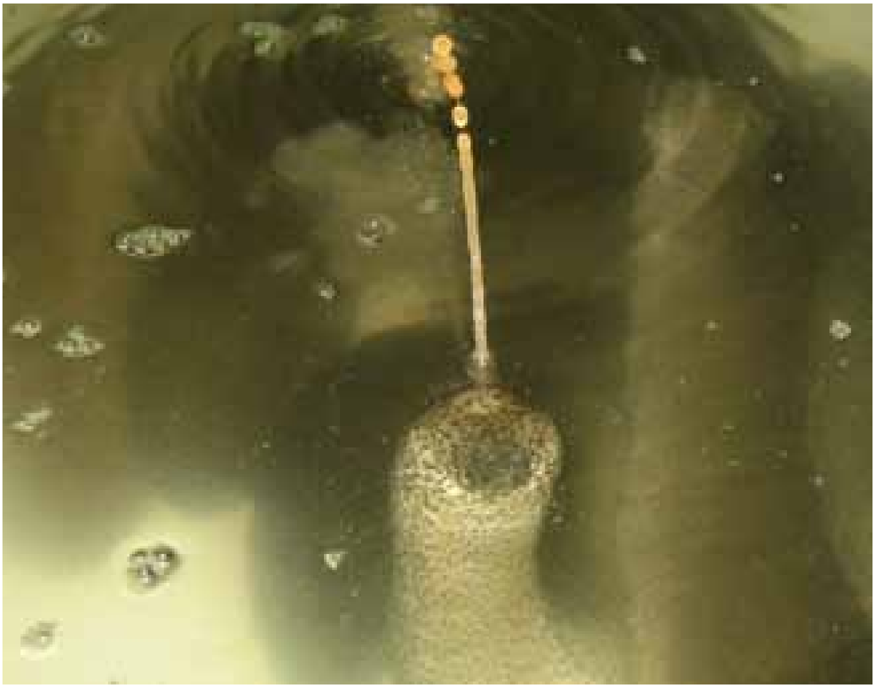
Grace Abdala (hatchery manager) at sandfish nursery hapa in a pond at the National Integrated Fisheries Technology and Development Center, the Philippines (Photo: Cathy Hair)

Sea cucumber hatchery production



Egg release from a female *Holothuria scabra* during spawning induction in a hatchery (Photo: Cathy Hair)

Large-scale sandfish production from pond culture in Vietnam

Nguyen D.Q. Duy[1]

Abstract

In recent years the farming of sandfish (*Holothuria scabra*) has been adopted by a number of farmers in south-central Vietnam. Hundreds of thousands of hatchery-produced juvenile sandfish have been stocked into ponds in the region. Broodstock were collected from the wild in Khanh Hoa province and from commercial culture ponds at 40–500 g weight. The broodstock were stored in a holding pond at a low density without adding feed. Animals of average weight (~350 g) were then transferred to conditioning tanks about 1 month prior to spawning. Indoor conditioning tanks were prepared with a sandy substrate and sand-filtered water supply. The animals were fed with fine shrimp feed. Simplified hatchery methods using cheap and basic equipment have been refined over the past decade, and consistent batches of juveniles can now be produced at will, with around 50,000 competent juveniles produced from batches of 2 million eggs.

Sandfish were cultivated in ponds with muddy-sand or coral-sand substrates using simplified techniques and locally developed management methods. The results of model sandfish culture ponds in three provinces proved that these methods can be profitable for farmers in these coastal areas. The constraints to commercial sandfish pond culture in Vietnam are no longer pond management or the price paid by the dealers, but density limits and culture duration.

Introduction

High demand for sea cucumber (e.g. sandfish (*Holothuria scabra*)) in China has resulted in overfishing in many countries in the Asia–Pacific region (Lovatelli et al. 2004). While restocking offers a plausible fast-track recovery of sandfish fisheries (Bell et al. 2007), pond culture provides livelihood options and a source of income for coastal communities engaged with faltering shrimp-farming enterprises (Mills et al. 2008).

Hatchery and juvenile production techniques have been developed, documented and carried out with a minimum of advanced infrastructure (Battaglene 1999; Pitt and Duy 2004; Duy 2005, 2010; Agudo 2006). Over the past decade, many studies on breeding and rearing sandfish have been conducted by the Vietnamese Research Institute for Aquaculture No. 3 (RIA3) sandfish hatchery in Van Ninh district, Khanh Hoa province, and the WorldFish Center (WorldFish). Other sandfish projects in Vietnam have been supported by the Australian Centre for International Agricultural Research (ACIAR), the Danish International Development Agency, the Vietnamese Government, the South East Asian Fisheries Development Center (SEAFDEC) and so on. The hatchery and juvenile production techniques developed to date have been disseminated to the project partners and other private sector operators in the Asia–Pacific region.

The large-scale production of sandfish for pond culture has been conducted in Vietnam based on knowledge developed from research collaborations between RIA3 and ACIAR–WorldFish (Pitt and Duy 2004; Bell et al. 2007; Mills et al. 2008). This paper describes the simplified techniques used in this research for seed production of sandfish and large-scale sandfish production for pond culture in

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Vietnam. The progress of research on seed production and grow-out of sandfish will support the industry's expansion in Vietnam and elsewhere in the region.

Simplified techniques for seed production of sandfish

Sandfish broodstock management

A few years ago, sandfish broodstock were collected from the wild or holding ponds and pens, and immediately induced to spawn. Various methods of spawning stimulation were trialled but proved unreliable. In recent years, however, the broodstock have been conditioned in tanks in the hatchery for a period of about 1 month to allow gonads to reach full maturity.

In the simplified techniques, concrete or fibreglass tanks placed indoors for shade were prepared with a 10–15-cm layer of cleaned dried sand, and supplied with sand-filtered sea water to a depth of 0.5 m. Adult sandfish weighing more than 350 g were transferred from holding ponds to conditioning tanks. The seawater temperature in the conditioning tanks was stable, maintained below 30 °C. The density of broodstock should be less than 2 animals/m^2. Water exchange was carried out in the morning to avoid broodstock being induced to spawn from thermal shock. Fine shrimp starter feed at 1 g/m^3 was fed twice a day. In addition, broodstock were co-cultured with the carnivorous Babylon snail (*Babylonia areolata*), providing extra protein-rich feed that contributed to sandfish growth and condition. Even when kept in good health, broodstock might lose weight in 1 month of conditioning; weight loss of less than 20% is acceptable.

After conditioning in tanks, broodstock were reliably induced to spawn, being more sensitive to thermal shock stimulation (Agudo 2006; Duy 2010). This allowed the year-round production of sandfish juveniles. Pond-held broodstock are maintained close to the hatchery for convenience of transfer to conditioning tanks. There should be sufficient animals in holding ponds to substitute a group of 50 animals after each breeding cycle in the hatchery.

Larval rearing

Optimal larval density and feed were the two main factors in maximising growth and survival. The micro-algae *Chaetoceros muelleri* was used for the swimming and settled stages in the hatchery. Using a single species of algae represented a significant simplification of the technical and infrastructure requirements for larval production, and meant that techniques could be more easily adopted by small-scale hatcheries such as former shrimp hatcheries.

The feeding rate was increased gradually during larval rearing. The optimal rearing density was at 200–300 larvae/L. At high densities of larval rearing, growth rates can decrease and high malformation rates are observed. As a result, it is better to get 10% survival (to 2–5-mm juveniles) from a starting point of 200 larvae/L in 4 weeks than 1% survival from 1,000 larvae/L in 6 weeks. In addition, faster growth of juveniles can prevent predator disasters, such as copepod infestation. Loss from copepods was also minimised by preparing settlement plates by coating them in a slurry made from *Spirulina* paste (Figure 1) rather than natural conditioning through immersion in sea water (Duy 2010).

Juvenile production

Simplified hatchery methods using cheap and basic equipment were refined, and consistent batches of juveniles can now be produced at will, with around 50,000 competent juveniles produced from batches of 2 million eggs. Hapa nets were used effectively for a low-cost nursery in ponds (Figure 2), removing the need for large raceways at hatchery facilities for juvenile rearing.

Testing economic return from large-scale production in model ponds

Design of model ponds

We used two ponds in each of three provinces (Khanh Hoa, Phu Yen and Ninh Thuan) in central Vietnam. The ponds had a coral-sand or muddy-sand substrate. The ponds in Phu Yen and Ninh Thuan were used previously to rear shrimp and swimming crab. There was a collaborating agreement between RIA3 and farmers to operate model ponds in Phu Yen and Ninh Thuan provinces. The two ponds in Khanh Hoa province were sediment settlement ponds at the National Center for Seed Production, belonging to RIA3, and were operated by project staff.

Pond preparation

All chosen ponds were located in the intertidal zone for convenient seawater exchange. The steps of pond preparation were as follows:

Figure 1. Preparation of *Spirulina*-coated settlement plates

Figure 2. Hapa nets used for a first-stage nursery of sandfish in ponds

- Dry the pond by draining through sluice-gates and pumping.
- Remove predators and unwanted seaweed.
- Till the sediment to disturb and wash the mud layer, ensuring that there is a burying layer of about 5 cm.
- Build a net pen at the sluice-gates to exclude predators, and prevent escape or massing of sandfish in this area.
- Apply lime (agriculture or hydrated) at 0.5–1.0 t/ha.
- Fill the pond with sea water 1 week prior to stocking with juvenile sandfish.

Transportation of juveniles

The 2–20-g juveniles were produced at the RIA3 sandfish hatchery from a single spawning in May 2008. They were nursed to a size of 2 g in ponds using the hapa systems described by Pitt and Duy (2004), and then grown at high density in earthen ponds to a larger size (advanced nursery) before stocking in the model ponds in Phu Yen and Ninh Thuan. They were selected and placed in bare tanks to defecate for 1–2 days prior to transferring them to the ponds. An open transportation method of juveniles in foam boxes was used effectively, with survival rates of up to 100%.

Water quality management

The biggest causes of sandfish mortality in ponds are known to be predators and the stratification of pond water in the wet season. Despite this, we did not use paddle wheels to reduce stratification in the six model ponds; it was found to be unnecessary due to the efficiency of mixing during tidal water changes and wind mixing. During culture, pond water depths were kept at 0.8–1.5 m, and the water was changed by opening and closing the sluice-gates. Water quality parameters (temperature, salinity) were monitored daily (Table 1). We found that the two model ponds in Khanh Hoa province experienced less water exchange than other ponds, which we believe was due to neap tides and hot weather. This resulted in high temperatures (up to 36 °C) and salinities (up to 41‰) in these two ponds in the dry season. Ponds in Ninh Thuan and Phu Yen provinces had daily water changes, resulting in better conditions.

Harvest

We found that sandfish in all ponds reached commercial size (>300 g) in average weight in November 2009, after 9–14 months in ponds (Table 2). The harvest was brought forward due to a significant flood event. Ponds in Khanh Hoa had endured the last wet season in 2008 without any losses. Final yields were in the range 2.61–2.80 t/ha (Table 2). Survival rates were higher for juveniles stocked at larger sizes (80%, 85% and 87% for 2-g, 10-g and 20-g juveniles, respectively). The sandfish were sold to local dealers and buyers in Ho Chi Minh City. Most of the production of this harvest was processed by a Singaporean processor using his preferred techniques to ensure higher quality. Local buyers also bought some sandfish and degutted them at the pond, then processed them using traditional methods. The dried, cultured sandfish were later seen at the market in Ho Chi Minh City, Vietnam.

Financial return from pond culture

At the harvest in November 2009, cultured sandfish were sold to processors at the ponds (Figure 3) for 35–40,000 Vietnamese dong (VND)/kg (US$2.00–2.20) whole wet weight. The profit fluctuated between 49.5% and 80.1%, and the profit margin was estimated at 33.1–45%. This is equivalent to about 30–40 million VND (US$1,700–2,200)/ha/crop.

Table 1. Mean (± SD) temperatures and salinities in model ponds in Khanh Hoa (KH), Phu Yen (PY) and Ninh Thuan (NT) provinces

Pond	Temperature (°C)	Salinity (‰)
KH1	27.4 ± 4.8	24.5 ± 8.5
KH2	27.4 ± 5.0	24.5 ± 8.4
PY1	28.2 ± 2.8	25.6 ± 6.5
PY2	28.2 ± 2.7	25.6 ± 6.6
NT1	29.5 ± 3.4	30.0 ± 2.7
NT2	29.5 ± 3.4	30.1 ± 2.7

Table 2. Results of sandfish model pond culture in three provinces, 2008–09

Province	Total area (m^2)	Mean stocking size (g)	Density (juv./m^2)	Mean weight at harvest (g)	Mean survival rate (%)	Duration (days)	Yield (t/ha)
Khanh Hoa	14,000	2	1	350	80	420	2.80
Phu Yen	10,000	10	1	310	85	305	2.63
Ninh Thuan	10,000	20	1	300	87	274	2.61

Figure 3. Processing of pond-cultured sandfish at Research Institute for Aquaculture No. 3

Discussion

The results from model ponds in Phu Yen, Khanh Hoa and Ninh Thuan provinces showed that monoculture of sandfish in ponds can be profitable to farmers in coastal areas. It was clear that the bigger the sandfish are when released, the higher the survival rates obtained. However, there was a slower growth rate at around 1.0 g/day in these ponds compared with sandfish growth rates previously reported from other pond studies. In Van Ninh, Khanh Hoa province, growth rates were 1–3 g/day or 1.0–1.8 g/day, respectively (Pitt and Duy 2004; Mills et al. 2008). In the hatchery, density affects sandfish growth at biomass levels greater than 225 g/m^2 (Battaglene et al. 1999). There may have been limited natural food and benthic organic matter in the substrates, thus affecting the growth in our model ponds when this threshold density was exceeded due to high survival rates. This led to a long culture period to attain commercial size for sandfish in the model ponds in Khanh Hoa province, while sandfish in the ponds in the two other provinces were at commercial size because of the bigger size of release. In fact, the growth of sandfish appears to depend on many factors including substrate, pond site and supply of natural feed through water exchange.

During culture, water management in the sandfish ponds requires attention by the farmers. Mass mortalities are likely if ponds are not adequately attended in the wet season; this has resulted in high mortality rates in the past. All the evidence gathered so far suggests that these problems can be cheaply and effectively overcome, even in uncharacteristically heavy and prolonged periods of rain (Mills et al. 2008). However, the relatively long duration of culture increases the expense of renting ponds and labour costs due to the high risk over the wet season. The prices paid for sandfish are increasing over the years, which will support a higher profit for the farmers in the future.

The results of the model pond trials have been encouraging for industry expansion in the region and sandfish farming is contributing to viable livelihoods for the farmers in coastal central Vietnam.

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In-vitro fertilisation: a simple, efficient method for obtaining sea cucumber larvae year round

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Abstract

Obtaining eggs and larvae in large quantities is a critical point for the economic viability of sea cucumber aquaculture. In this paper, spawning induction methods and in-vitro fertilisation (IVF) methods are presented and compared. The IVF technique developed in Madagascar (MH-IVF) is a simple, cost-efficient method that enables hatcheries to obtain clean, fertilised eggs of sea cucumbers year-round. MH-IVF does not require high-tech equipment and is applicable in small- and large-scale hatcheries. It ensures the best control at the very beginning of the work on the number and type of genitors (i.e. sex, length, weight, colour); the quality of the gonads (healthy versus parasitised); and the number, size and quality of spermatozoa and eggs. MH-IVF involves the sacrifice of very few genitors compared with the individuals obtained and sacrificed for production. Yet, it does not influence genetic drift any more than spawning induction methods.

Introduction

It is evident today from many surveys that the world's wild stocks of sea cucumbers are depleting fast, and almost everywhere this is due to the high demand from the Chinese market. The disappearance of sea cucumber wild stocks is not only a problem at the ecological level (these organisms being among the best bioturbators of the sediments in many marine ecosystems), but it is also a huge social problem as the sea cucumber trade ensures a livelihood for millions of humans in developing countries. One of the best answers to this worldwide problem is to develop efficient aquaculture systems where coastal villagers of developing countries can be involved in some phases of the farming. However, aquaculture is basically a business where the end product (i.e. the trepang) is sold into the Chinese market. The private companies that are involved in this process need benefits: preferably quickly and with a minimum of investments. It is thus crucial for the sustainability of sea cucumber aquaculture that the profitability of each step in the process—obtaining eggs, rearing larvae, pre-growing juveniles and growing adults—is optimised. Obtaining eggs and larvae in large quantities is thus a critical point for the economic viability of the industry.

Over the past 10 years, we have developed a new method based on in-vitro fertilisation (IVF) for obtaining sea cucumber larvae throughout the year in Madagascar. This method is used routinely by the company Madagascar Holothurie S.A. (MH.SA), which was created at the end of the research phase. We present here a description of this method and the various techniques that allow aquaculturists to obtain fertilised eggs of sea cucumbers. Some are still in the research phase but appear to show promise for the near future.

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There are basically three types of method: unforced spawnings, forced spawnings and IVF. The first method is used only on the East Pacific *Isostichopus fuscus* in Ecuador. There, and for that species only, spawning occurs monthly depending on the lunar cycle. There is no need to force the spawning but just to know the right time when genitors spawn (Mercier et al. 2007). To develop this method, Mercier et al. (2007) monitored several hundred individuals nearly every month over 4 years. *Isostichopus fuscus* displayed a lunar spawning periodicity: 0.7–34.9% of individuals consistently spawned 1–4 days after the new moon. Spawning occurred mostly within one evening; however, some gamete release was often recorded over two to four consecutive evenings. Individuals maintained in captivity for several months retained their spawning periodicity and timing with the lunar cycle. The percentage of spawning individuals was higher and a greater overlap between male and female peak spawning activity was observed during clear conditions compared with overcast conditions.

Aside from the *I. fuscus* case, fertilised eggs are obtained by either inducing the spawning of genitors or fertilising oocytes that have been extracted from gonads. Spawning induction methods are based mainly on mechanical stress inflicted on adult individuals, but can also be stimulated by chemical incubations or injections.

Spawning induction methods

In the very first attempt to artificially obtain viable gametes from sea cucumbers, a Japanese scientist attempted the stripping technique in the 1930s (Inaba 1937). The rate of fertilisation was only about 20%, and many of the larvae were malformed. Therefore, this method is no longer used for larval production. Today, the efficient mechanical stresses used are thermal shocks, and stimulation through drying and water pressure. Often a combination of these methods is used to force spawning.

Thermal shocks

Thermal shocks are the most widespread sea cucumber spawning induction technique in aquaculture. The method has been successful in Iran (Dabbagh et al. 2011), Mauritius (Laxminarayana 2005), India (James et al. 1994), Maldives (B. Giraspy, pers. comm.), the Philippines (R. Gamboa, pers. comm.), Vietnam (Pitt and Duy 2004), Australia (Morgan 2000a; Ivy and Giraspy 2006), Solomon Islands (Battaglene et al. 2002), Fiji (Hair et al. 2011), New Caledonia (Agudo 2006), Tanzania (G. Robinson, pers. comm.), and Japan and China (Shuxu and Gongehao 1981; Li 1987).

Thermal shocks involve placing genitors into baths of different temperatures, and the steps of the method vary from place to place. In Mauritius, for example, Laxminarayana (2005) induced the spawning of *Bohadschia marmorata* and *Holothuria atra* by decreasing the seawater temperature by 3–5 °C by the addition of ice. After 5 minutes the sea cucumbers were introduced into another tank filled with filtered sea water at normal temperature (3–5 °C higher than the first tank temperature). For *H. scabra*, the water temperature is raised by 3–5 °C for 1 hour, either by adding warmed sea water to the spawning tank or using aquarium heaters (Agudo 2006). The water temperatures should be kept within the range 28–32 °C. If the ambient water temperature is >30 °C, it is recommended to give a cold shock treatment for 1 hour before the heat shock. Sealed plastic bags containing ice are added to the tank to quickly lower the water temperature by 5 °C (Agudo 2006).

Thermal shock is the most commonly used method to induce spawning of *Apostichopus japonicus* in Japan and China. Most spawners release eggs or sperm when the water temperature is raised by 3–5 °C above the ambient temperature. The induction of spawning by sea cucumbers in Japanese and Chinese hatcheries is usually carried out by regulation of rearing conditions, such as temperature, water exchange and light intensity. In *A. japonicus* cultivation in Japan, wild-caught broodstock are induced to spawn in tanks of sea water about 5 °C higher than natural sea water and under dark conditions. However, this method has some drawbacks in that it is sometimes ineffective and the rate of spawning is inconsistent.

Water pressure and drying treatments

These methods are often used in combination with thermal shocks or if thermal shocks were unsuccessful. The broodstock are left to dry in a tank in the shade for about half an hour before subjecting them to a powerful jet of sea water for a few minutes (Agudo 2006). The broodstock are then returned to the spawning tank at ambient water temperature. During the drying treatment the broodstock are left in the shade, completely dry, or in a few centimetres of sea water, for 30–45 minutes. These methods are commonly used with *H. scabra* as well as

A. japonicus. For the latter species, the operation often starts at about 17:00 hours, when the water in the temporary stocking tank is drained away and the spawners are exposed to air for 30–60 minutes, after which they are jetted with water for about 5–10 minutes. After about 1.5–2.0 hours, the spawners move upwards, become restless and toss their head from side to side. The males begin to spawn first, followed by the females about half an hour later.

Chemical incubations and chemical injections

The addition of a food stimulant is sometimes used for inducing spawning in sea cucumbers. Dried algae (*Spirulina* at a rate of 30 g per 300–500 L, or Algamac 2000 at a concentration of 0.1 g/L) is added to the tank containing broodstock for 1 hour (Agudo 2006). After 1 hour of incubation, the water is removed from the tank and replaced with clean water at ambient temperature.

Mercier and Hamel (2002) demonstrated that the transfer of perivisceral coelomic fluid (PCF) can be used as a reliable tool to induce spawning in mature individuals. PCF collected from holothurians that had been in the typical spawning posture without shedding gametes for about 20 minutes triggered spawning in 71–100% of conspecifics. The individuals responded to the injection of a 2–3-mL aliquot by displaying the spawning posture within 30–62 minutes and by massive gamete broadcast. The inductive substance was found not to be sex-specific since positive responses were observed in individuals of the same or opposite sex as the donor. The PCF of a spawning donor was also active when added to the surrounding sea water, as it induced the typical posturing in 47–65% of mature individuals, and subsequent gamete release in 20–31% of them less than 85 minutes later.

Although most experiments were performed with *Bohadschia argus*, similar results were obtained with *B. marmorata*, *Holothuria leucospilota* and *H. atra*. Interspecific trials were also successful, implying that the chemical involved is not species-specific. Although this method is promising, it is still not applied in sea cucumber aquaculture as it relies totally on the observation of genitors in spawning posture, which is a real challenge in non-natural conditions. However, if the bioactive molecule present in PCF is identified, this method should have a great advantage over the stress-induced methods described above.

Kato et al. (2009) purified one small pentapeptide from the buccal tissues of *A. japonicus* that has a practical value to induce spawning in the hatchery setting (Fujiwara et al. 2010). Kato et al. (2009) named the identified native peptide 'cubifrin'. Mature *A. japonicus* injected with cubifrin during the reproductive season, from February to May, displayed sequential reproductive behaviours, which comprised climbing the side wall of the tank toward the water surface, waving the head and shedding gametes. Gamete shedding started about 60 and 80 minutes after the injection in males and females, respectively, and was completed almost simultaneously in both sexes about 2 hours after the administration. Repeated injections of cubifrin at intervals of about 10 days successfully induced multiple spawns in both males and females. Induction of spawning by cubifrin in *A. japonicus* is an effective, simple and cost-effective method requiring only the injection of cubifrin solution into the body cavity. Cubifrin injections, however, were not effective in other holothurians, and the possibility of using them on other sea cucumber species remains to be examined.

In-vitro fertilisation

In-vitro fertilisation is a process by which female germinal cells are fertilised by sperm in non-natural conditions; that is, outside the female genital tracts in organisms with internal fertilisation and in laboratory conditions for organisms with external fertilisation. The problem with IVF in sea cucumber aquaculture is that the development of oocytes (as is the case for the female germinal cells of all animals) is stopped during the meiosis at prophase I.

Oocyte maturation naturally concludes in sea cucumbers just before or during spawning, resulting in mature oocytes ready to be fertilised. Consequently, oocytes extracted from ovaries by dissection are not ready to be fertilised—they must undergo maturation first. In echinoderms the mechanism of maturation has been reviewed recently by Mercier and Hamel (2009), and is best understood in asteroids (sea stars). A gonad-stimulating substance (GSS) produced by the radial nerve cord (Kanatani 1964) acts on the ovarian follicle cells, which, in turn, produce a secondary substance, the maturation inducing substance (MIS), identified as 1-methyladenine (1-MeA) (Kanatani and Shirai 1967; Kanatani 1969). The 1-MeA acts on an oocyte membrane receptor to activate an intracellular maturation promoting factor (MPF) (Stevens 1970; Yamashita et al. 2000), which induces oocyte maturation involving germinal vesicle breakdown (GVBD), chromosome condensation and extrusions of the polar bodies.

This oocyte maturation process is considered to be universal, with few variations among species (Kishimoto et al. 1982; Yamashita et al. 2000). It is also presumed to occur in sea cucumbers, although this assertion is untested. Maruyama (1985) demonstrated that a GSS existed in five sea cucumber species; comprising a peptide of several thousand daltons having similar characteristics to the asteroid GSS. Smiley (1988) suggested that the MIS of *Stichopus californicus* is likely to be a 2,8 di-substituted adenine. It was demonstrated, moreover, that the action of 1-MeA can be mimicked in sea stars (Kishimoto and Kanatani 1973; Kishimoto et al. 1976) and sea cucumbers (Smiley 1990) by various molecules such as L-cysteine (Kishimoto and Kanatani 1973), dithiothreitol (DTT) (Kishimoto and Kanatani 1980) or dimercaptopropanol (DMP) (Kishimoto et al. 1976). Yet, the endocrine substances involved in natural sea cucumber oocyte maturation remain unknown.

In sea cucumber aquaculture, two methods of IVF have proven to be efficient. The first method is still in the research phase and acts in activating ovarian cells that themselves induce oocyte maturation during the spawning period. This recently discovered method involves the incubation of oocytes in a gonad-stimulating substance-like (GSSL) solution before fertilisation (GSSL-IVF) (Katow et al. 2009). The second method acts directly on vitellogenic oocytes and is efficient both during and outside the spawning period (Léonet et al. 2009). This technique has been used routinely at the MH.SA hatchery in Madagascar for several years and is referred to as MH-IVF.

GSSL-IVF

Recently, Katow et al. (2009) isolated a GSSL molecule from the radial nerve of the sea cucumber *A. japonicus* (Aj-GSSL), and its partial DNA and protein sequences were characterised. The researchers incubated tubes of ovaries full of vitellogenic oocytes with various extracts during the spawning season of the sea cucumber. Radial nerve extract at 3 mg/mL induced GVBD in 85% of immature ovarian oocytes. A synthetic 43-amino acid Aj-GSSL generated from this sequence induced GVBD in 50% of immature ovarian oocytes, and an N-terminal 21-amino acid peptide of the synthetic partial Aj-GSSL (Aj-GSSL-P1) induced GVBD in 80% of immature ovarian oocytes.

MH-IVF

Léonet et al. (2009) analysed the effects of a powerful oocyte maturation inductor (OMI) used routinely by MH.SA on oocytes of the commercial species *Holothuria scabra* and on various other species of sea cucumbers. The new bioactive molecule was isolated from echinoderm extracts and identified by mass spectrometry, and the active site of the biomolecule was synthesised (international patent number: WO 2008/003691; patent title: 'Oocyte maturation method'). The new OMI induces the maturation and fertilisation of more than 90% of oocytes, while other OMIs described in the literature (i.e. 1-MeA, DTT, DMP and L-cysteine) induce between 28–90% of oocytes to mature (Figure 1). The use of the other OMIs result in fertilisation rates that never exceed 40% (Figure 1), and the resultant larvae often present developmental abnormalities.

One of the advantages of the new OMI compared with the other methods is that it is effective throughout the year, even outside the spawning season of sea cucumbers. In *H. scabra*, the difficulty of obtaining fertilised eggs throughout the year by conventional methods such as thermal shocks varies according to the geographic location, seemingly being easier when *H. scabra* populations are closer to the equator. The reproductive cycle of *H. scabra* has been well investigated over most of its geographic range—it is known in the Southern Hemisphere for populations in Indonesia (05°S; Tuwo 1999), Solomon Islands (09°S; Ramofafia et al. 2003), New Caledonia (20°S; Conand 1981) and Australia (27°S; Morgan 2000b); and in the Northern Hemisphere for populations in India (09°N; Krishnaswamy and Krishnan 1967) and the Philippines (13°N; Ong Che and Gomez 1985). The methods used during these studies were different but, globally, they strongly suggest that at least a small proportion of *H. scabra* in these populations spawn all year round (Hamel et al. 2002). However, the intensity of spawning over a year is different from one population to another: it can be continuous; it can increase once during a period of 2–3 months (i.e. an annual reproductive cycle); or it can increase twice with one of the two peaks of spawning intensity being higher than the other (i.e. a biannual reproductive cycle).

Figure 2 shows the ovarian maturation in the *H. scabra* population around Toliara (Madagascar) (Rasolofonirina et al. 2005). Each bar represents 30 females whose ovaries have been sectioned and characterised into five stages of maturity. The ovaries

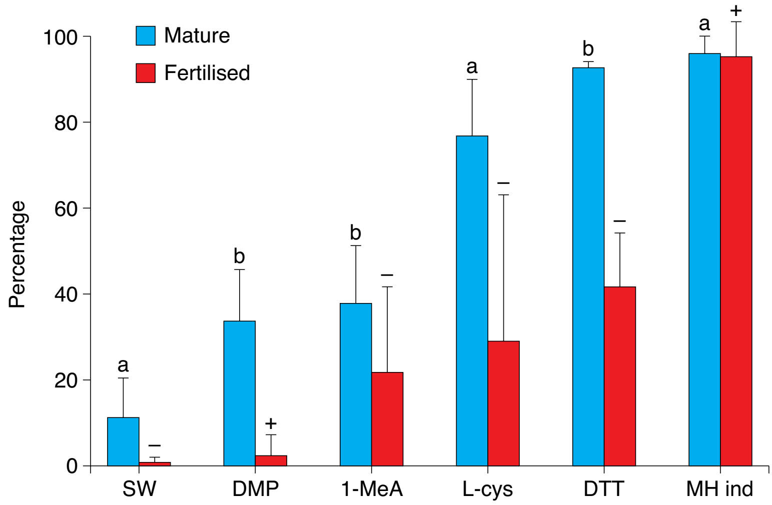

Figure 1. Comparison of the efficiency of various substances on the oocyte maturation in *Holothuria scabra* (from Léonet et al. 2009). Oocytes have been extracted from the ovaries and incubated with the following substances: SW = sea water; DMP = dimercaptopropanol; 1-MeA = 1-methyladenine; L-cyst = L-cysteine; DTT = dithiothreitol; MH ind = inductor used in Madagascar. Incubation time was 2 hours. The blue bars indicate the percentage of oocytes that were mature after incubation, and the red bars the percentage of oocytes that were fertilised after addition of spermatozoa. Small a, b, + and – indicate significant similarities or differences: two adjacent signs that are similar (e.g. b and b) indicate similarity of the effect.

of two stages, termed 'post-spawning' and 'resting', are composed mainly of oogonia and oocytes at the beginning of the vitellogenesis, and are not ready to undergo maturation. The ovaries of the three other stages, termed 'growing', 'mature' and 'spawning', include mainly oocytes at the end of the vitellogenesis, and are ready to undergo maturation under the right stimulation. The graph demonstrates how MH-IVFs are feasible monthly: it shows that batches of potentially fertilisable oocytes are present each month in ovaries of *H. scabra*. Looking at the survey results, one can observe that more than 30% of the females have batches of oocytes in their ovaries waiting to enter maturation at almost any time of the year.

Table 1 shows that the process is effective on 13 aspidochirote species tested so far (Léonet et al. 2009). The species were from the genera *Actinopyga*, *Holothuria*, *Thelenota* and *Pearsonothuria*. Interestingly, the method was successful on *H. fuscogilva*, a species of very high value. No *Stichopus* species were tested.

Figure 3 illustrates the hatchery production obtained in MH.SA from January 2009 to February 2010. During 2009, MH.SA carried out 29 IVFs, sacrificing 32 females and 24 males. The production of 4,942,876 embryos transformed into 278,486 6-day-old auricularia, then 164,545 1-day-old post-metamorphic juveniles and 48,857 1-cm-long juveniles. These juveniles were transferred into ponds for pre-growing. The average monthly production of juveniles via MH-IVF is about 4,000 1-cm-long individuals up to a maximum of 8,000 (in a hatchery where the wet room is 70 m^2).

Comparison of the methods

Spawning induction methods are not effective outside the spawning period (Table 2). The sea cucumber spawning period varies from one species to another, and seems to be extended when the population is located close to the equator. The farther the

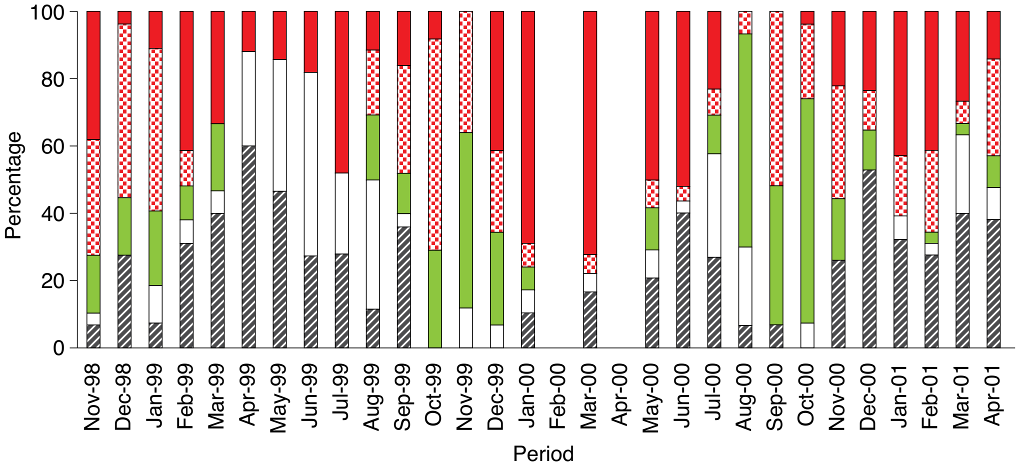

Figure 2. Ovarian maturity in the *Holothuria scabra* population of Toliara (Madagascar) (Rasolofonirina et al. 2005). At each period of the survey, the ovaries of 30 females were sectioned, analysed and characterised into five stages (post-spawning, resting, growing, mature and spawning). The ovaries of the stages post-spawning (black and white striped) and resting (white) include mainly oogonia and young oocytes. The ovaries of the stages growing (green), mature (spotted red) and spawning (plain red) include many oocytes that have completed vitellogenesis.

Table 1. Maturation rate (%) of oocytes from various sea cucumber species incubated with the MH inductor. Control is the rate of oocyte maturation in filtered sea water (n = number of individuals tested) (modified from Léonet et al. 2009)

Species	Maturation (%)	Control (%)
Actinopyga echinites (*n*=3)	81.00	31.00
Bohadschia subrubra (*n*=2)	99.00	9.00
Bohadschia vitiensis (*n*=4)	87.42	9.65
Holothuria cinerascens (*n*=3)	92.60	12.30
Holothuria edulis (*n*=2)	92.00	11.00
Holothuria forskali (*n*=2)	94.50	7.00
Holothuria fuscogilva (*n*=5)	80.00	10.00
Holothuria leucospilota (*n*=4)	70.25	6.00
Holothuria maculosa (*n*=6)	63.35	9.20
Holothuria scabra (*n*=4)	92.25	15.75
Holothuria tubulosa (*n*=4)	82.00	24.25
Pearsonothuria graeffei (*n*=3)	92.00	32.00
Thelenota ananas (*n*=3)	79.33	32.66

populations are from the equatorial line, the more difficult the spawning induction methods are to apply. For example, it is easy to obtain eggs from *H. scabra* in the Philippines with thermal shocks (R. Gamboa, pers. comm.) but hard in Toliara (Madagascar) or Mascat (Oman) with the same method. It seems also to be true for *I. fuscus*, where the spawning season extends through the year in Galapagos (Torral-Granda and Martinez 2007) but is restricted to July–September in Baja California (Herrero-Pérezrul et al. 1999).

The reliability of thermal shocks, even within the spawning period, is quite random (Table 2). The use of a substance to inject into the coelom or for incubation is much more reliable once the appropriate

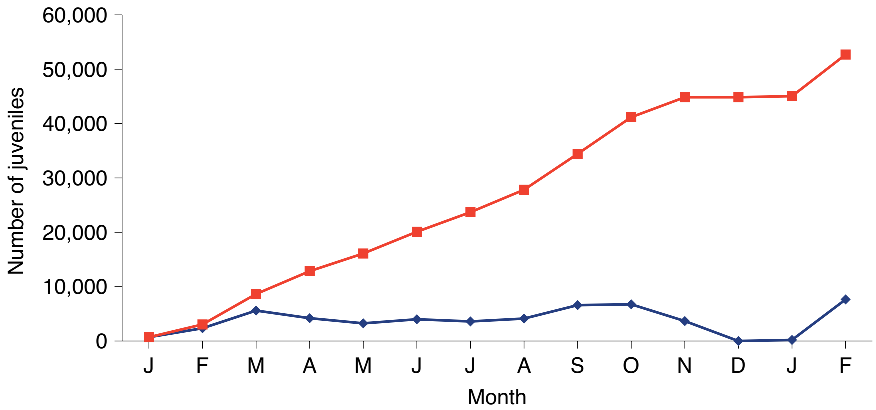

Figure 3. Production of 1-cm-long juveniles from the Madagascar Holothurie S.A. hatchery during 2009: blue line = monthly production; red line = cumulative production

concentration is known. The PCF method is actually difficult to apply in aquaculture as it requires PCF from animals in spawning posture, and that is not always easy to find. For this method to be effective in aquaculture, the bioactive molecule in the PCF needs to be identified.

The three methods of spawning induction involved genitors that are kept in a large volume of sea water (often tanks with a few hundred litres). The fertilised eggs are collected at the end of the process through the use of various filtration procedures. During filtration, all microbes (bacteria, protozoans and small metazoans such as copepods) are retained with the fertilised eggs. Non-fertilised eggs stay in the filtrates and degrade during the next hours of the process. Therefore, the risk of infestation is high with spawning induction methods and very low in IVF methods because the latter require 1–2 L of 1-µm filtered sea water at most (Table 2).

The risk of larval malformation is minimal for spawning induction methods and for both GSSL-IVF and MH-IVF. However, it is high for IVF methods that use chemicals such as DTT, dimercaptopropanol (BAL), L-cysteine or 1-MeA.

With respect to genetic issues, IVFs are no more influential on genetic drift than are the spawning induction methods. Genetic drift is a change in the frequency of alleles in a population. When populations are smaller, as is the case in aquaculture breedings, the effect of genetic drift is greater and may cause alleles to disappear completely, thus reducing genetic diversity. The reduction of genetic diversity can be a problem in the production of individuals less adapted to cope with environmental variation. In IVFs, as in spawning induction methods, genetic drift could be a problem in the future, and the only way to overcome it is to pay attention to not always using genitors from the same parental lineage. In MH.SA, IVFs are done with genitors from previous generations, but gametes are also mixed with those from wild strains: gonads of wild strains are obtained from fishermen, who usually discard them as they use only the body wall of sea cucumbers to prepare trepang.

In conclusion, IVF methods, especially MH-IVF, are simple, cost-efficient, allow the collection of fertilised eggs of sea cucumbers year round, and enable control of the basic operations in hatcheries. MH-IVF does not require high-tech equipment and is useful in both large- and small-scale hatcheries. It ensures a high degree of control at the very beginning of the work on the number and type of genitors (i.e. sex, length, weight, colour); the quality of the gonads (healthy versus parasitised); and the number, size and quality of spermatozoa and eggs. IVF necessitates the sacrifice of very few genitors compared with the individuals obtained and sacrificed for production (in 2009 the IVF sacrifices reached 0.1% of the production; the body walls of animals sacrificed for IVF were processed into trepang and entered into the production).

Table 2. Efficiency of the methods that allow sea cucumber aquaculturists to obtain fertilised eggs

Methods	Details	Useful outside spawning period	Reliability inside spawning period	Risk of infestation	Risk of larval malformations	Tested species	References
Spawning induction							
Thermal shocks	Transfer into tanks of various temperatures	–	–	+	–	Various species including *Apostichopus japonicus, Holothuria scabra* and *Isostichopus fuscus*	Hamel et al. (2002)
PCF	Injection into coelomic cavity	–	–	+	–	*Bohadschia argus* *B. marmorata* *Holothuria leucospilota* *H. atra*	Mercier and Hamel (2002)
Cubifrin	Injection into coelomic cavity	–	+	+	–	*A. japonicus*	Fujiwara et al. (2010) Kato et al. (2009)
In-vitro fertilisation							
GSSL-IVF	Incubation of gonadal tubules	–	+	–	–	*A. japonicus*	Katow et al. (2009)
MH-IVH	Incubation of oocytes	+	+	–	–	13 species (see Table 1)	Léonet et al. (2009)
DTT-IVF	Incubation of oocytes	+	+	–	+	*H. scabra* *A. japonicus* *H. leucospilota* *H. pardalis*	Léonet et al. (2009) Karaseva and Khotimchenko (1995) Maruyama (1980)
Other inductors (BAL, L-cystéine, 1-MeA)	Incubation of oocytes	–	–	–	+	*H. scabra* *H. leucospilota* *H. pardalis*	Léonet et al. (2009) Maruyama (1980)

PCF = perivisceral coelomic fluid; GSSL-IVF = gonad-stimulating substance-like in-vitro fertilisation; MH-IVH = Madagascar Holothurie S.A. in-vitro fertilisation; DTT-IVF = dithiothreitol in-vitro fertilisation; BAL = dimercaptopropanol; 1-MeA = 1-methyladenine

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Evaluation of nutritional condition of juvenile sandfish (*Holothuria scabra*)

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Abstract

It is important to accurately evaluate the wellbeing or nutritional condition of organisms when monitoring the wild stock conditions and improvement in aquaculture techniques; however, reliable nutritional condition indexes have not been established for sea cucumbers. In this study, the effects of starvation on condition factor (body weight / body volume), coelomic fluid constituent (protein, carbohydrate and cholesterol) concentrations and coelomic fluid density were analysed in an attempt to establish a method to determine nutritional condition in juvenile sandfish (*Holothuria scabra*). Body length, breadth and weight of juveniles produced at the sea cucumber hatchery of the Aquaculture Department, Southeast Asian Fisheries Development Center, were measured after anaesthetisation with 2% menthol-ethanol. Coelomic fluid protein level was analysed by the bicinchoninic acid method. Carbohydrate level was analysed by the phenol – sulfuric acid method. Cholesterol level was analysed by the Zak method. Coelomic fluid volume and coelomic fluid weight were measured. Starvation caused a concomitant decrease in body length, breadth and weight, resulting in no net change in the condition factor. This result indicated that condition factor cannot be used as a nutritional condition index. Coelomic fluid constituent level could be measured with a small volume of sample (i.e. 10–20 µL). Although no clear pattern was observed in coelomic fluid protein and cholesterol levels during the starvation trial, carbohydrate level increased, as did coelomic fluid density. These results suggest that coelomic fluid density and carbohydrate level may be used as indexes for nutritional condition of sandfish without sacrificing the animal.

Introduction

Due to overexploitation and increasing demand, fishery stocks of many tropical sea cucumber species have declined drastically in the Pacific and Indian oceans (Carpenter and Niem 1998; Hamel et al. 2001; Conand 2004). In order to increase the fishery production, many studies have been done on hatchery, aquaculture and stock enhancement methods of sea cucumbers, especially sandfish (*Holothuria scabra*), which is the most valued of tropical sea cucumbers (e.g. Battaglene et al. 1999; Mercier et al. 1999; Purcell et al. 2006; Bell et al. 2007). Nevertheless, there is a basic methodological problem: there has been no standard evaluation method developed for nutritional condition in sea cucumbers, including *H. scabra*. Hatcheries for *H. scabra* have been operating in countries such as New Caledonia, Vietnam, India and the Philippines (James 1999; Pitt and Duy 2004; Agudo 2006; Duy 2010). Slow growth and high mortality of the cultured juveniles are problematic in these hatcheries—the growth of juveniles can sometimes be faster in an earthen pond where supplemental feeding is not conducted than in concrete tanks under controlled conditions (SEAFDEC–AQD, pers. comm.; Pitt et al. 2001; Agudo 2012). Therefore, hatchery

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techniques, particularly feeding methods, should be improved. It is also crucial to establish a method to monitor the condition of released juveniles in stock enhancement programs.

In this study, attempts were made to establish a method to evaluate nutritional condition of sandfish based upon body size to weight relationship and concentration of coelomic fluid constituents.

Materials and methods

Measurements of body size, coelomic fluid volume and coelomic fluid density

In order to acquire basic information about the relationship between body size and coelomic fluid, data on *H. scabra* juveniles obtained from the sea cucumber hatchery of the Southeast Asian Fisheries Development Center – Aquaculture Department (SEAFDEC–AQD) in Iloilo, the Philippines, were collected. To increase body measurement accuracy, the juveniles were anaesthetised using a standard anaesthetic solution: ethanol saturated with menthol (i.e. 0.56 g menthol crystal dissolved in 100 mL of 99% ethanol) and diluted with filtered sea water to 2% (Yamana et al. 2005). *H. scabra* (n = 15) were placed in the solution at room temperature for 20 minutes. After blotting dry with paper towels, body length (*BL*) and body breadth at the widest point (*BB*) were measured to the nearest 0.01 mm, and body weight (*BW*) was measured to the nearest 0.01 mg. Body volume (*BV*) was calculated as a spheroid according to equation (1):

$$BV = 4/3 \times \pi \times BL \times (BB/2)^2 \quad (1)$$

Fulton's condition factor (*K*) was calculated according to equation (2):

$$K = BW/BV \times 10^4 \quad (2)$$

Holothuria scabra were then cut longitudinally at the abdomen, and total coelomic fluid was collected with a micropipette into a micro centrifuge tube. Coelomic fluid volume (*CFV*) was measured to the nearest 10 µL with micropipettes. Coelomic fluid weight (*CFW*) was measured to the nearest 0.001 mg with a microbalance.

Effects of starvation on condition of *H. scabra*

Holothuria scabra juveniles of similar sizes obtained at the SEAFDEC–AQD sandfish hatchery (n = 30) were anaesthetised as described above and body sizes were measured (i.e. *BL, BB* and *BW*). For the initial data, five individuals were stored at –80 ºC. The rest of the *H. scabra* were individually placed in containers made of PVC pipe (10 cm diameter × 5 cm length) with both ends covered with 5-mm mesh (Figure 1). The containers were placed in a 60-L fibreglass tank (5 containers in each of 5 tanks) and kept under flow-through conditions with aeration but no sediment or supplementary feeding. Tank sea water was sand-filtered, further filtered with 10-µm and 1-µm filters, and UV-treated. Size measurements were made every 2 days on the same individuals after anaesthetisation, and five individuals (i.e. one tank) were stored at –80 ºC every 2 days until day 10.

At the conclusion of the trial, the frozen samples were thawed in a refrigerator and longitudinally cut at the abdomen. Coelomic fluid was collected to measure protein, carbohydrate and cholesterol concentrations:

- Protein concentration of coelomic fluid was measured by the bicinchoninic acid (BCA) method (QuantiPro BCA Assay Kit, SIGMA-ALDRICH). A 10-µL aliquot of coelomic fluid was diluted 100 times with distilled water in 1.5-mL microtubes, and absorbance was read at 562 nm using a microplate reader.
- Carbohydrate concentration of the coelomic fluid was measured by the modified phenol – sulfuric acid method (Kushwaha and Kates 1981). A 10-µL aliquot of the coelomic fluid was mixed with 40 µL distilled water, 20 µL 5% phenol solution and 100 µL concentrated H_2SO_4 in 2-mL microtubes, vortexed, and incubated in an 80 °C block heater for 10 minutes. Absorbance was read at 490 nm against a blank, using a microplate reader.
- Cholesterol concentration of the coelomic fluid was measured by the modified Zak method (Zak 1957; Altescu 1965). A 20-µL aliquot of the coelomic fluid was mixed with 300 µL 0.2% $CuCl_2 \cdot 2H_2O$ in 99% ethanol and 200 µL concentrated H_2SO_4 in 1.5-mL microtubes, and incubated in an 80 °C block heater for 10 minutes. Absorbance was read at 540 nm against a blank, using a microplate reader.

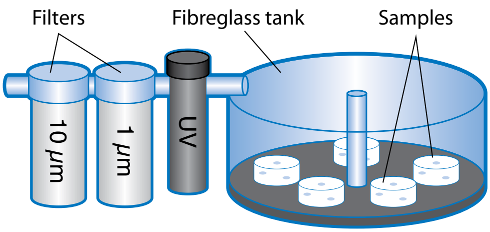

Figure 1. Schematic drawing of the sandfish rearing system used in this study

Effects of starvation on coelomic fluid volume and coelomic fluid density

To determine changes in coelomic fluid density (*CFD*) and *CFV* relative to the body size (*CFV'*), another starvation trial was conducted for 20 days. Body size measurements were made after anaesthetisation ($n = 25$) and five individuals were stored at –80 ºC for the initial data. In each of four 60-L fibreglass tanks, five individuals were placed (not individually separated). Every 5 days, five individuals (i.e. all five individuals from one tank) were measured and stored at –80 ºC. The frozen samples were thawed in a refrigerator; total coelomic fluid was drawn from the body cavity to measure *CFV* and *CFW*. *CFD* was obtained as *CFW*/*CFV*. *CFV'* was calculated as *CFV*/*BV*.

Statistical analysis

Relationships between the studied parameters were examined by linear, hyperbolic or exponential regression analyses. For comparisons of more than three datasets, ANOVA was performed followed by a Tukey test for posteriori comparisons. For comparisons of paired data sets, t-tests were used. Differences were considered significant if $P < 0.05$.

Results and discussion

Body size, coelomic fluid volume, coelomic fluid density and condition factor

CFV of *H. scabra* had a significant positive correlation with *BL* (Figure 2, equation (3)):

$$CFV = 1.73 \times e^{0.11BL} \quad (3)$$

CFV increased linearly as *BW* (Figure 2, equation (4)):

$$CFV = 123.0 \times BW - 93.7 \quad (4)$$

and *BV* (equation (5)) increased:

$$CFV = 0.01 \times BV - 60.40 \quad (5)$$

This is common for many animals since *BV* and *BW* increase exponentially with *BL*.

There were no significant correlations between *CFD* and *BL* ($r^2 = 0.13$, $P = 0.19$), *BW* ($r^2 = 0.058$, $P = 0.39$) or *BV* ($r^2 = 0.068$, $P = 0.35$).

Condition factor (*K*) had a significant negative linear correlation with *BL* (Figure 2), *BV* and *BW*, according to equations (6), (7) and (8), respectively:

$$K = -0.01 \times BL + 1.22 \quad (6)$$

$$K = -2.8 \times 10^{-6} \times BV + 1.05 \quad (7)$$

$$K = -0.0032 \times BW + 1.05 \quad (8)$$

Since *K* is correlated with *BL*, *BV* and *BW*, it must be standardised for size and weight if it is to be used for condition comparisons of *H. scabra* of different sizes.

Starvation, condition factor and coelomic fluid constituent concentrations

BV and *BW* of individual *H. scabra* decreased concomitantly during the 10-day starvation period (Figure 3). While *BW* gradually decreased over the experimental period, the trend in *BV* was less clear, perhaps due to limited accuracy of body size measurements despite anaesthetisation. The plasticity of the body shape of sea cucumbers is problematic for size measurements (Sewell 1990; Battaglene et al. 1999). Nevertheless, both mean *BV* and *BW* significantly decreased in 10 days ($P < 0.05$ and $P < 0.01$, respectively, t-test). Because of this, *K* stayed constant during the starvation period (Figure 3), with no significant difference between day 1 and day 10 ($P = 0.16$, t-test). *K* is one of the most widely used indexes for determination of condition, wellbeing or 'plumpness' of organisms in fisheries and general fish biology studies (e.g. Nash et al. 2006). However, unlike vertebrates and invertebrates with exoskeletons, *K* is not a useful index for the evaluation of nutritional condition in *H. scabra* because of the concomitant changes in body size and weight.

Protein and cholesterol concentrations in the coelomic fluid of *H. scabra* initially increased and then decreased after day 6 during the 10-day starvation period (Figure 4), according to equations (9) and (10):

$$C_p = -0.050 \times d^2 + 0.53 \times d + 2.70 \quad (9)$$

$$C_{ch} = -0.0016 \times d^2 + 0.021 \times d + 0.17 \quad (10)$$

where C_p is protein concentration and C_{ch} is cholesterol concentration, and d is day of starvation.

Therefore, it is difficult to use them as indexes of nutritional condition in *H. scabra*. On the other hand, carbohydrate concentration (C_c) increased linearly (Figure 4) as starvation continued, according to equation (11):

$$C_c = 0.076 \times d + 0.86 \quad (11)$$

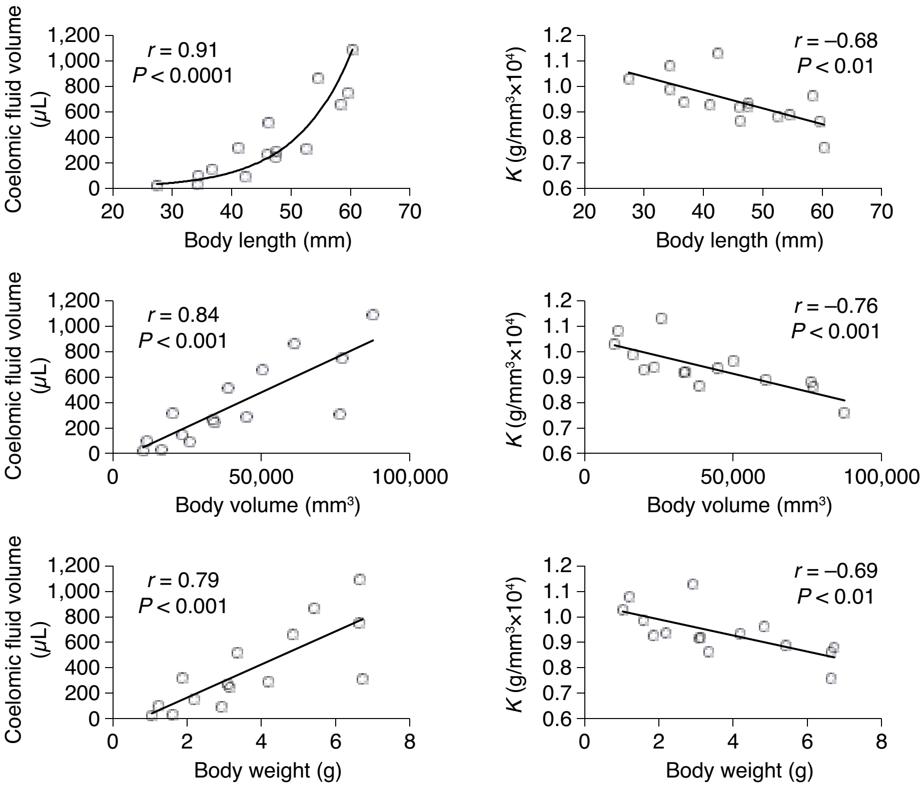

Figure 2. Relationships between body size and coelomic fluid volume and condition factor (K) in *Holothuria scabra* (n = 15)

Therefore, C_c may be suitable for determination of nutritional condition. Reasons for increased C_c despite starvation are not known. In fact, C_c in the coelomic fluid in Japanese sea cucumber *Stichopus japonicus* is reported to decrease and non-protein nitrogen level stay constant during starvation (Tanaka 1958). Further studies on the physiological processes of *H. scabra* during starvation are needed.

Starvation, coelomic fluid volume and coelomic fluid density

CFD had a significant positive linear correlation with the starvation period (Figure 5), according to equation (12):

$$CFD = 0.0087 \times d + 0.92 \qquad (12)$$

CFV', on the other hand, had a significant negative linear correlation with the starvation period (Figure 4) according to equation (13):

$$CFV' = -0.0015 \times d + 0.084 \qquad (13)$$

These relationships may indicate that increased C_c due to starvation may be related to thickening of the coelomic fluid. In addition, since protein is reported to be the major energy source for small *Apostichopus japonicus* (synonym for *S. japonicus*) during aestivation (Yang et al. 2006), the protein concentration may increase during the initial phase of starvation due to thickening of the coelomic fluid, and subsequently decrease due to energy consumption.

Recommended index for nutritional condition

Although mechanisms of changes in coelomic fluid constituent concentrations during starvation are not understood, the C_c seems to be a good indicator of nutritional condition in *H. scabra*. Since it requires a very small amount of coelomic fluid sample (10 µL) for the colorimetric carbohydrate measurement, it

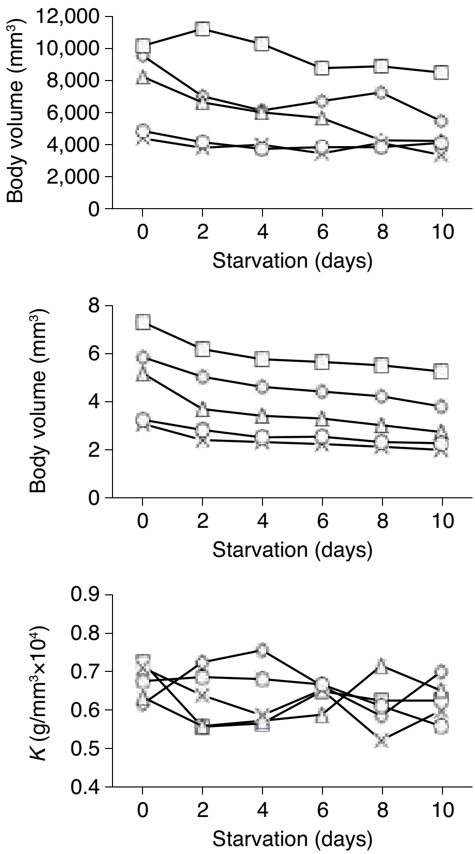

Figure 3. Changes in body volume, body weight and condition factor (*K*) of *Holothuria scabra* ($n = 5$) during a 10-day starvation trial. Different symbols refer to specific individuals.

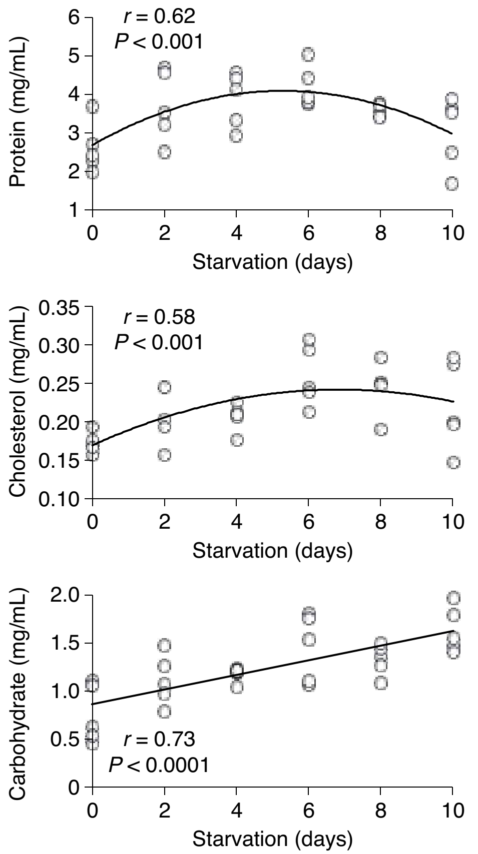

Figure 4. Relationships between starvation period and levels of protein, cholesterol and carbohydrate in the coelomic fluid of *Holothuria scabra*

may be possible to monitor the time-course change of nutritional condition of an individual without sacrificing it. A method to sample the coelomic fluid using cannulation from live specimens should be further investigated. Although *CFD* may also be a good indicator of nutritional condition, it requires a larger amount of sample for the measurement. In this study, the entire coelomic fluid of each individual was used for the density measurement to increase accuracy of the measurements. While the use of more sensitive devices may increase the measurement accuracy of *CFD*, colorimetric methods are recommended.

Studies on improvement of *H. scabra* production at hatcheries and aquaculture facilities, as well as stock enhancement technologies, should be carried out with the methods for monitoring *H. scabra* conditions described here.

Acknowledgments

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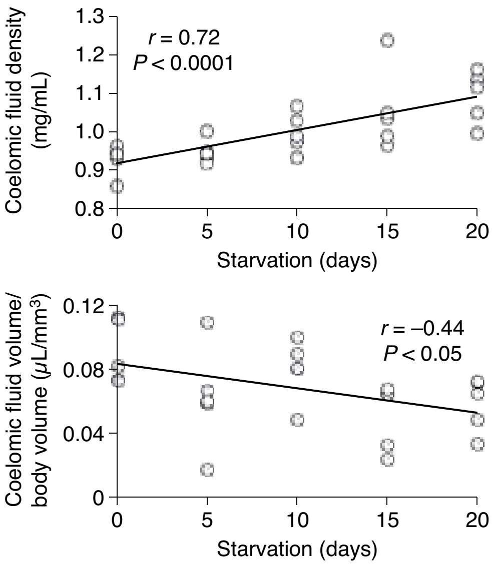

Figure 5. Relationships between starvation period and coelomic fluid density and coelomic fluid volume relative to body volume of *Holothuria scabra*

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Ocean nursery systems for scaling up juvenile sandfish (*Holothuria scabra*) production: ensuring opportunities for small fishers

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Abstract

Cost-effective production of juveniles to release size (>3 g) is a primary objective in the culture of *Holothuria scabra*. Ocean nursery systems were developed to help overcome the space limitations of a small hatchery set-up and shorten the rearing period in the hatchery. The growth and survival of first-stage juveniles (4–10 mm) in two ocean nursery systems—floating hapas and bottom-set hapa cages—were compared with those reared in hapa nets in a marine pond. Juveniles reared in these nursery systems were healthy and in good condition. Survival was not substantially different in hapa nets in marine ponds and floating hapas. However, growth in pond hapa nets was higher than in the two ocean nursery systems. Nonetheless, the estimated cost of producing juveniles in the floating hapa system is considerably cheaper compared with those reared in the other systems. Moreover, local community partners easily maintained the floating hapas and reared the juveniles to release size. Further, the effects of sand conditioning on juvenile quality were also investigated. The growth of sand-conditioned juveniles was higher than unconditioned ones in hatchery tanks, and more conditioned juveniles buried within the first hour of release in the field. From floating hapas, juveniles can be conditioned in sea pens for at least 1 week, or reared to bigger sizes for 1–2 months (>20 g) prior to release. However, whether this intermediate rearing procedure will be practical with large numbers of juveniles needs to be considered. Results show that ocean nursery systems are simple and viable alternative systems for scaling up juvenile sandfish production compared with hapas in marine ponds, which might not be available and accessible to small fishers.

Introduction

The sea cucumber fishery is a source of livelihood to many coastal dwellers and the basis of a multi-million dollar trepang industry in the Philippines (Gamboa et al. 2004). Various coastal towns, cities and provinces all over the country have been reported to engage in significant sea cucumber collection and processing activities (e.g. Trinidad-Roa 1987). Intense harvesting, unsustainable fishery practices and increasing demand for sea cucumber products in international trade have resulted in a progressive decline in sea cucumber stocks and the overexploitation of high-value species.

With the decline in the sea cucumber stocks, restocking hatchery-produced juvenile sea cucumbers is seen as a means to rebuild wild stocks (Battaglene 1999). At present, *Holothuria scabra* is the only species of tropical sea cucumber that can be mass cultured in the hatchery (see references in Lovatelli et al. (2004)).

The culture technology for sandfish was initially developed in India (James 1999, 2004) and then in Solomon Islands (Battaglene 1999). Culture protocols were further refined in New Caledonia (Agudo 2006) and Vietnam (Pitt and Duy 2004; Duy 2010).

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In the Philippines, experimental-scale trials of sandfish culture were initiated in 2000 (Gamboa and Juinio-Meñez 2003), and efforts to scale up juvenile production and expand community-based sea-ranching activities are ongoing. Hatchery culture protocols based on various methods reported from other hatcheries were modified and adapted to optimise larval and early juvenile rearing at the University of the Philippines Marine Science Institute's (UPMSI) Bolinao Marine Laboratory (BML). However, the costs of producing juveniles in the hatchery and marine ponds were high. Scaling up production was further constrained by space limitations in a small hatchery set-up. Given these considerations, ocean nursery systems designed to shorten the juvenile rearing period in the hatchery and reduce the cost of production were investigated. In addition, since production of juveniles is intended primarily for community-managed sea ranching, mechanisms to engage local partners in early juvenile rearing were deemed to be strategic in enhancing ownership of these initiatives.

Hatchery culture of *H. scabra* at the UPMSI Bolinao Marine Laboratory

The current techniques used for broodstock spawning and rearing juvenile sandfish are described here. For each spawning induction, 40–50 wild broodstock (>200 g) are acquired from fishers, and are maintained in sea pens near the hatchery facility or in concrete tanks in the hatchery for 2–4 weeks prior to spawning induction. Broodstock are successfully induced to spawn within 3–4 days using a combined treatment of desiccation, thermal shock and food shock (*Spirulina*) (Agudo 2006) at any time of the year.

The developing larvae are reared in larval tanks with moderate aeration and shading at a stocking density of 0.3–0.5 fertilised egg/mL. Larvae are cultured in static conditions with daily partial water change (30–50%) using UV-treated sea water (UVSW). A mixture of *Isochrysis galbana* and *Chaetoceros calcitrans* at a density of 10,000–15,000 cells/mL is fed to the larvae twice a day as they develop. Under optimal conditions (28–30 °C and 32–34 ppt), the auricularia larvae start to metamorphose to doliolaria stage by day 10. General cleaning of the tanks is done prior to introduction of *Spirulina*-coated settlement plates in the larval rearing tanks. The plates are introduced when >50% of the larvae have reached the pentactula stage, usually within 12 days of fertilisation. Both sides of the corrugated plastic settlement plates are coated with *Spirulina* paste (i.e. *Spirulina* powder dissolved in a small volume of fresh water) and air-dried for 30–60 minutes (Duy 2010). Before being placed in the larval-rearing tanks, settlement plates are soaked in tanks with flow-through UVSW for 30 minutes. The amount of *C. calcitrans* and *I. galbana* provided to the larvae twice a day is adjusted to 20,000–30,000 cells/mL when most larvae have settled by day 15. The diatom *Navicula ramossissima* and *Sargassum* extract are also provided as supplemental food for the post-settled juveniles.

This method resulted in a fivefold increase in survival from fertilised eggs to second-stage juveniles from year 1 to year 3 (Table 1). This is attributed to the low initial stocking density currently being used in the facility (0.3–0.5 fertilised egg/mL), the use of *Spirulina*-coated plates to induce settlement, and the extended use of *C. calcitrans* combined with *N. ramossissima* to feed the newly settled juveniles. Periodically, *Sargassum* extract was also provided as supplemental food. Survival from first-stage to second-stage also improved by 95% by year 3. Increase in the number of second-stage and release-size juveniles was largely due to the development of ocean nursery systems in Bolinao, which addressed the problem of slow growth and low survival due to limitation in hatchery space (i.e. high density stocking in tanks) as described below. As a result, fewer batches of larvae had to be reared per year, significantly reducing time and effort in the hatchery operations.

Ocean nursery systems

In the first year of production, early juveniles were reared to a release size of >3 g in the land-based hatchery tanks. Rearing to release size in the hatchery involved growing post-settled juveniles in settlement tanks with benthic diatoms and supplementing with *Sargassum* extract up to 90 days until the juveniles reached ~1.0 g. The juveniles were then transferred to tanks with sediment and sand-filtered sea water. Daily feeding of diatoms and periodic addition of ground *Sargassum* enriched the sediment in the tanks. Both growth rate and survival were low due to difficulties in producing sufficient benthic diatoms and maintaining good water quality in the tanks with

Table 1. Juvenile production in the Bolinao outdoor hatchery facility from May 2007 to April 2010

Spawning trial	Number of batches	Fertilised egg count (millions)	% survival to first stage (<10 mm)	% survival to second stage (10–30 mm)		Release-size juveniles (>30 mm)
				from fertilised egg	from first stage	
Year 1 (May 2007 – April 2008)	8	22.23	0.76	0.11	16.08	12,468
Year 2 (May 2008 – April 2009)	3	10.74	1.14	0.35	32.32	26,331
Year 3 (May 2009 – April 2010)	3	7.10	2.08	0.67	31.44	32,433
TOTAL	**14**					**71,232**

sediment, even with a flow-through system. After the study visit at the Research Institute for Aquaculture No. 3 (RIA3) in Nha Trang, Vietnam, in June 2008, most of the first-stage juveniles (4–10 mm) were reared in hapa nets in a marine pond following Vietnamese methods (Duy 2010). However, a suitable marine pond was about 100 km away from the BML hatchery—a travel time of ~2.5 hours. Thus, manpower resources and costs to transport juveniles were substantial. In addition, while survival was relatively high (60–73%), juvenile growth in the ponds was highly variable. Growth ranged from almost nil up to 6.1 g over 30 days. This variability was probably due to high temperatures (27–31 °C) and extreme fluctuations in salinity (13–29 ppt).

Ocean nursery systems to increase juvenile production and reduce production costs for first-stage juveniles were investigated (Juinio-Meñez et al. 2009). Bottom-set hapa cages, which were used to rear juveniles to >1.0 g during the experimental phase of sandfish culture in earlier trials, were modified to rear first-stage juveniles (4–10 mm). In addition, the use of floating hapas was pilot-tested. Initial trials conducted in high nutrient areas in northern Luzon showed that first-stage juveniles can grow up to ~1.0 g in 49 days in the floating hapas (Edullantes and Juinio-Meñez 2009). Subsequently, an experiment was conducted to compare growth and survival of first-stage juveniles in the three nursery systems—the hapa nets in ponds and the two ocean nursery systems (hapa cages and floating hapa nets). The same type of mesh was used for all set-ups. Stocking density relative to the estimated potential grazing area was 150 juveniles/m^2. The experiment ran for 30 days. Results showed that growth was higher in the hapa nets (0.6 g) in the pond than in the two ocean nursery systems, but average survival was higher in both the hapa net in the pond (57%) and the floating hapa (44%) compared with the bottom-set hapa sea cage (18%) (C. Edullantes, unpublished data). Furthermore, a 60-day juvenile rearing trial using the ocean floating hapa net with a partner community showed survival rates of 12–30%, with juveniles weighing 0.3–7.2 g.

Comparing the three early juvenile nursery systems (Table 2), the high growth and survival of juveniles and ease of retrieval are the advantages of using hapa nets in ponds compared with the other two nursery systems. The hapa cages are the most durable and least prone to extreme changes in salinity, temperature and dissolved oxygen, but they yielded the lowest growth and survival rates. However, while average growth can be lower in the ocean nursery systems, survival rates in the ocean floating hapas are comparable with those in the hapa nets in ponds. The total cost of inputs and maintenance is lowest in the ocean floating hapas and highest for pond hapas. In addition, it was also demonstrated that local community partners were able to maintain the floating hapas and rear the juveniles to release size. Considering all of these factors, the use of ocean floating hapas as a nursery system is the most cost-effective and strategic option for community-based grow-out and sea ranching.

Sand conditioning

Aside from scaling up juvenile production, improving the quality of released juveniles is crucial for successful sea ranching. Hatchery production of environmentally incompetent juveniles jeopardises restocking success (Battaglene and Bell 2004; Purcell

Table 2. Comparison of the different nursery systems (hapa nets in marine ponds, ocean floating hapas and bottom-set sea cages) using different criteria

Criteria	Nursery systems		
	Hapa nets in marine ponds	Ocean floating hapas	Ocean bottom-set cages
Growth	+++	++	++
Survivorship	+++	+++	++
Cost of materials and other inputs	+	+++	++
Maintenance	+	+++	++
Ease of retrieval	+++	++	+
Adaptability (small-scale fishers)	+	+++	++
Other considerations			
Durability of nursery units	++	+	+++
Changes in salinity, temperature, dissolved oxygen	+	++	+++

Rating: +++ = most desirable
++
+ = least desirable

2004; Oliver et al. 2008). In the hatchery, additional conditioning regimes introduce extra expense, but this might be offset by improvements in growth and survival. To improve the quality of juveniles and increase survival in the wild, it has been proposed that hatchery individuals be conditioned to optimise morphological and behavioural traits (Delgado et al. 2002; Davis et al. 2005; Brokordt et al. 2006). While juveniles can be reared to a size of ~3 g in hapa nets in both ponds and ocean nursery systems, they are not exposed to sediment, and graze primarily on biofilm on the nets. Preliminary studies at BML showed that juveniles that were reared in tanks with sediment had thicker body walls and grew faster than those reared in tanks without sediment (Schagerstrom 2003). Subsequent laboratory experiments showed that mean body weights of juveniles were substantially higher in the sand-conditioned treatment than those in treatments without sand. Moreover, up to 60% of juveniles in the sand-conditioned treatment attained a weight of more than 3 g in 30 days, compared with only 23% in the treatment without sand (Dumalan et al. 2009). After 45 days in sea cages, the average weight of sand-conditioned juveniles was higher but, because of the high variability in growth among individuals, it was not substantially different from the average weight of juveniles that were not sand-conditioned in the laboratory prior to release. The average survival rates of sand-conditioned and unconditioned juveniles were also not different. However, post-released juveniles that were not sand-conditioned took a longer time to bury into the sediment (R. Dumalan, unpublished data). This indicates that, even if juveniles can be reared in hapa nets to a release size of >3 g, sand conditioning prior to release may be necessary to improve their survival in the wild.

Proposed production scheme for juvenile sandfish for community-based grow-out

Based on the results of different experiments conducted in the hatchery and the field, as well as experience with local small fishers, production of sandfish from a small hatchery can be made cost-effective and accessible to small-scale fishers for community-based grow-out. The hatchery phase for larval rearing to post-settled stage (4–10 mm) will take 30–45 days. Post-settled juveniles can then be reared in ocean floating hapas (Figure 1) to a size of 2–3 g (25–30 mm) in 30–60 days. To condition juveniles with sediment and grow them to a bigger release size, the juveniles can be reared in bag nets or sea pens and retrieved after 15–30 days at sizes >20 g. This intermediate stage will substantially increase the survival of juveniles during the grow-out phase to marketable size. We recommend the release of these juveniles in suitable and well-managed sea-ranch areas. Based on experience in the pilot sea ranch, sandfish will attain sexual maturity within a year, and the first harvest of animals >320 g can be made after 1 year, with a subsequent harvest after

Figure 1. Ocean floating hapas within the communal sea-ranching site in Masinloc, Zambales

another 6 months. Programmed releases and selective harvesting of sandfish >320 g can maintain a viable reproductive population in the sea ranch, thus optimising both ecological and economic returns (M. Juinio-Meñez, unpublished data).

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Small-scale hatcheries and simple technologies for sandfish (*Holothuria scabra*) production

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Abstract

Sandfish (*Holothuria scabra*) hatchery production is currently being done at various scales across several continents including Australia, Maldives, Vietnam, Pacific island countries, Madagascar and the Philippines. Work in Mindanao in the southern Philippines, through the University of the Philippines Mindanao (UPMin), commenced in 2006. UPMin set up experimental hatcheries, ponds and other facilities by establishing partnerships with two local corporations: Alsons Corporation and JV Ayala Group of Companies. The former facility also has a seawater channel feeding fish ponds, which, through time, has harboured resident populations of sandfish. This channel became a source of broodstock, as well as a 'conditioning area' for sandfish collected from the wild. It also served as the first-stage nursery for juveniles. This paper describes low-cost technology for all stages of culturing *H. scabra* up to production of juveniles ≥10 g for release, and compares the cost-cutting innovations with those of published protocols. Three local modifications made by the UPMin project team are described here: the use of a seawater channel for broodstock and hapa; mono-algal feeding using *Chaetoceros calcitrans*; and the use of recycled or locally made materials. Broodstock can be kept for weeks in the channel with zero mortality, even without maintenance. In the hapas, juveniles can grow to 5–10 g in 1–2 months at an average survival of 84%. *Chaetoceros calcitrans* was bought from Alsons and scaled up using recycled 250-L PVC barrels. It was used as a feed until the early juvenile stage. These innovations yielded a best performance average of 2.2% survival to 3–5-mm juveniles. This paper attests to the progress and innovations made in sea cucumber research in the Philippines since *H. scabra* production was pilot-tested in the country in 2002.

Introduction

Sandfish (*Holothuria scabra*) hatchery production is currently being done at various scales across several continents: Australia, Maldives and Vietnam are doing large-scale for commercial production (Bowman 2012; Duy 2012); the Pacific island countries are trialling small-scale production for community-managed sea ranching (Hair et al. 2011); Madagascar uses in-vitro fertilisation to obtain larvae all year round for their partner communities (Eeckhaut et al. 2008); and in the Philippines, seeds are primarily used in pilot sites for sea ranching and grow-out (Olavides et al. 2011; Juinio-Meñez et al. 2012).

Sandfish production was pilot-tested in the Philippines as early as 2002 (Gamboa and Menez 2003). Work in Mindanao in the southern Philippines, through the University of the Philippines Mindanao (UPMin), commenced in 2006 when UPMin received funding from the Australian Centre for International Agricultural Research (ACIAR). A year later, financial support also came from the Philippine Government through the Department of Science and Technology – Philippine Council for Aquatic and Marine Resource Development. Neither project grant, however, provided any capital outlay, and UPMin did not have a coastal property. Thus began the quest for a research base and a low-cost means of adopting the technology locally.

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The space and facility problems were overcome by establishing partnerships with two local corporations: Alsons Corporation, a large, intensive, commercial milkfish and tilapia industry with aquaculture facilities in Dumoy (Davao City); and JV Ayala Group of Companies, which owns High Ponds Resort, in Toril, Davao City. Alsons' Dumoy facility accommodates one of our two experimental hatcheries. Within the compound is a seawater channel feeding the milkfish and tilapia ponds. This channel became the source as well as the 'conditioning area' for our broodstock, and served as the first-stage nursery for our juveniles. The High Ponds facility of the JV Ayala Group houses our second hatchery and experimental marine pond.

This paper describes a low-cost technology for producing *H. scabra* comprising the following hatchery phases: broodstock collection; broodstock induction (induced spawning); larval rearing and early settlement; nursery, which is divided into first (in the hapa) and second (sand-conditioning) stages; and harvest of ≥10-g juveniles for release. It also describes micro-algal culture.

The seawater channel

In Dumoy, a 300-m-long man-made canal carries sea water from the main pipe to a dyke that feeds all the ponds. Water is pumped five or six times a week, with almost 90% daily exchange efficiency and depths of 2–3 m. Through time, the channel has accumulated a natural sandy–muddy floor with its corresponding flora and fauna, including a population of *H. scabra.* The channel serves two other purposes for our project—as a natural conditioning area for broodstock collected from the wild and as a hapa-nursery system for juveniles.

The hatcheries

Two small-scale hatchery facilities were constructed, one each in Dumoy and High Ponds. The Dumoy hatchery was a 30-m^2 area located between two big holding tanks for tilapia fingerlings. It was basically a nipa-roofed structure with coco-wood posts. Sea water, electricity and space were all provided free by Alsons. At High Ponds, the 80-m^2 hatchery was roofed with corrugated PVC sheets and walled with chicken wire. In addition, a 6,000-m^2 freshwater earthen pond was converted to marine water for experimental use. The space for the hatchery, use of the pond and other selected amenities at High Ponds were free, but the project paid for electricity.

Hatchery protocols

Broodstock collection and conditioning

For each induction, we would use at least 38 sandfish, sized 130–250 g. The broodstock came from either the resident population in the Dumoy channel or our project sites (Davao del Sur and Davao Oriental), located 1 and 5 hours, respectively, from the hatchery. The animals from the sites were purchased through our local People's Organisation groups and were individually packed in oxygen-filled polyethylene bags containing 1 L of sea water (Agudo 2006). The bags were layered inside a styrofoam chest box for transport.

Wild broodstock were brought to Dumoy, where they were acclimatised for 1 hour by allowing the bags to float in a contained area in the water channel. Each animal was then taken out and dropped gently to the bottom. To avoid mixing with the canal residents, the wild broodstock were released at the seaward end of the channel. This conditioning set-up eliminated feeding and maintenance, yet yielded about 99% survival.

We believe that broodstock conditioning played a role in the success of the larval rearing that followed. For example, the collapse of a batch of larvae on one occasion (January 2010) may have been due to short (i.e. 2 days) broodstock conditioning. The successful batches came either from those conditioned longer or from the resident broodstock population.

Induced spawning

In earlier induction attempts, broodstock were brought up from the channel onto a floating cage, 2 × 2 × 2 m and ~2 cm mesh size, where they were allowed to defecate for at least 24 hours. It was observed, however, that smaller individuals could squeeze out of the mesh holes, often incurring injury or lesions. An improved practice involves selecting healthy broodstock from the channel and holding them in a bare, flat-bottomed tank containing UV-treated sea water provided with mild aeration.

After about 1 day, the gut-empty broodstock were rinsed with UV-treated sea water. They were divided into two spawning groups (Pitt and Duy 2004) for induction comprising the following steps (Figure 1):

- *Desiccation.* The animals were transferred with care into a dry tank or bin and kept there for 20 minutes.

- *Conditioning in ambient water.* The 'dry' animals were moved into a 70-L, 45-cm-high bin filled with 10 cm of filtered sea water, and kept there for 15 minutes.
- *Thermal shock.* The water temperature in the tank was raised 3–5 °C above ambient by slowly adding boiled sea water (James et al. 1994). Induction proceeded for 1 hour.
- Spirulina *bath.* Fifteen grams of *Spirulina* were mixed with 1 L of fresh water then blended well and added slowly to the tank. Induction proceeded for 1 hour.
- *Complete water change*. The *Spirulina* was flushed out by using a hose siphon. Ambient sea water was then slowly added up to about 25 cm depth. After several minutes, one or two individuals would stand and exhibit swaying behaviour. These are signs of readiness to spawn—the gonopore on the dorsal surface of the head begins to swell; males release a long thread of milky sperm, while females release yellowish eggs in two to four bursts that usually shoot out of the water.

Gametes were collected using a beaker. Sperm were scooped out of the water and eggs were collected from each spawning individual by following the direction of the swaying female and positioning the beaker accordingly. Since the released eggs usually shoot out of the water, collecting them required some practice. All sperm were mixed together in a 70-L container, and all eggs in a 20-L container.

To estimate the total egg count, the eggs were pooled in 40 L of sea water. Three subsamples of 1 mL each were taken and counted under a microscope. The average of the three counts was computed. The total number of eggs was roughly estimated using equation (1):

$$\text{Total egg count} = \text{average count/mL} \times 40{,}000\ \text{mL} \tag{1}$$

About 0.5 mL of sperm from the mixture was introduced to the 40-L egg stock. Too much sperm can lead to polyspermy. Two-cell stage could be observed within the next few hours.

Figure 1. Induction of *Holothuria scabra*. Upper row: desiccation (left), thermal shock (centre), *Spirulina* bath (right); lower row: spawning male (left) and female (right)

Regardless of the length of conditioning of the broodstock in the water channel, the thermal-*Spirulina* shock (Agudo 2006) proved effective in 9 of our 10 inductions. A summary of the hatchery performance from those successful inductions is shown in Table 1. The single instance when the thermal-*Spirulina* shock did not work was with broodstock that came from the project site and were induced the next day.

Our spawning induction trials were carried out randomly (during any month) based on the available free tanks in the hatcheries. The success of induction alone did not follow any lunar phase, as was also observed by Pitt and Duy (2004). In all nine trials, the males spawned first, which was in keeping with the reports of other authors (Agudo 2006; Duy 2010; Giraspy and Ivy 2010; Pitt et al. 2001).

Larval rearing

Larval density

We used a low density of 0.3 fertilised eggs/mL, calculated as (equation (2)):

$$\text{Number of larvae per tank} = \text{desired volume of water in tank} \times 0.3 \text{ fertilised eggs/mL} \quad (2)$$

The volume of fertilised eggs to be used (equation (3)) was:

$$\text{Volume of fertilised eggs} = \frac{0.3 \text{ eggs/mL} \times \text{total volume of fertilised eggs}}{\text{Average count/mL in the 40 L concentrate}} \quad (3)$$

Rearing tanks

Our 250-L conical-bottom larval rearing tanks were made of marine plywood and custom built to fit the hatchery area. The larval tanks were prepared for stocking by washing them well with chlorine, rinsing with fresh water and then air-drying. Next, each tank was half-filled with 1-µm filtered and UV-treated sea water. The fertilised eggs were then poured in gently and water was brought to the desired volume. Moderate aeration was applied on the first day of rearing.

Rearing tanks were completely covered during the larval stages using thin white cloth overlain with black cellophane bags. This kept the larvae in darkness and also prevented chironomid (bloodworm) infestation. A week after the appearance of pentactula, the black cellophane was removed to allow light to penetrate the tank and encourage moderate algal growth for the juveniles. This differs from Agudo's (2006) protocol, where the tank is covered for only the first 2 days of larval rearing. We noted that algal growth was better on tank walls that were not very smooth.

Water monitoring and larval sampling

Temperature and salinity were monitored daily. Temperatures varied in the range 26–29°C, while salinity was 30–34 ppt. The density of larvae was estimated by counting in a known volume of test tube or glass tubing viewed against the light. Developmental stages of larvae were monitored under the microscope.

Water treatment and water change

Sea water for the larval tanks went through three filtrations: UV light, 10-µm and 1-µm tube filters, and a 1-µm bag filter. Thirty per cent of the water volume was changed daily. To chelate heavy metal residues, we added ethylenediaminetetraacetic acid (EDTA) at 5 g/m^3 per total volume of water changed. When larvae were no longer present in the column, EDTA treatment was halted and water change was done every other day until all juveniles were ready for the hapas. By 2010 we ceased chelating with EDTA and yet our survival rates were improving. During the June and October 2010 batches, the UV light in the Dumoy hatchery broke. We proceeded with the rearing using filtered sea water only. Since survival of juveniles was among the highest in these batches, it appears that UV light and EDTA can be eliminated.

Larval food and feeding regime

Feeding the larvae started on day 2. Our protocol used just one species, *Chaetoceros calcitrans,* throughout—the regime is shown in Table 2. *Chaetoceros* spp. are some of the best algae for larval rearing (Battaglene 1999). We initially adopted a once-a-day feeding regime with *C. calcitrans* until Mr Duy (Vietnam) suggested splitting the ration at 9 am and 3 pm. This strategy improved the survival rate of our June and October 2010 batches (Table 1). Feeding was thereafter done twice a day until the juveniles were moved out into the hapas. In his seed production manual, Duy (2010) prefers a mixture of algae for optimal growth, and recommends the single species only when there is not enough algal supply. We found single feeding with *Chaetoceros*

Table 1. Summary of combined production performance of the Dumoy and High Ponds hatcheries

Days after moon phase Batch date	Total broodstock source, conditioning	Count of spawners		Minutes after the first spawner[a]		Total fertilised eggs (millions)	EDTA[b]	Initial fertilised eggs in tanks	Count and % survival of 3-mm juveniles	Remarks
		M	F	M	F					
1 day after F.Q. 15 October 2010	38, Dumoy channel residents	12	14	40	55	2.4	No	240,000	5,400 (2.2%)	Hapa by day 38
4 days after F.Q. 23 June 2010	38, Dumoy channel residents	9	10	35	53	2.8	No	360,000	6,400 (1.8%)	Hapa by day 38
2 days after F.Q. 23 February 2010	38, Dumoy channel residents	4	5	20	0	1.28	No	180,000	300 (0.2%)	Collapsed by day 34
5 days after L.Q. 11 February 2010	42, Dumoy channel residents	12	14	27	1	1.98	No	300,000	4,425 (1.5%)	Hapa by day 38
6 days after L.Q. 13 January 2010 (High Ponds only)	40 from wild; conditioned in Dumoy channel for 2 days	10	21	30	11	2.6	No	180,000	0	Collapsed by day 6; short (2-day) conditioning period
2 days after F.M. 4 December 2009	47 from wild; conditioned in Dumoy channel for 4 days	12	20	29	15	1.9	Yes	400,000	539 (0.13%)	Collapsed by day 43; heavily infested with bloodworms
6 days after F.Q. 6 October 2009	46 from wild; conditioned in Dumoy channel for 3 days	14	23	25	51	6.8	Yes	300,000	71 (0.02%)	Collapsed by day 39; heavily infested with bloodworms
6 days after F.M. 13 July 2009	40 from wild; conditioned in Dumoy channel for 6 days	12	13	30	12	2.7	No	300,000	0	Collapsed by day 20; heavily infested with bloodworms
4 days after L.Q. 6 May 2009	43 from wild; conditioned in Dumoy channel for more than 1 week	15	16	36	12	4.3	No	300,000	2,500 (0.83%)	Hapa by day 38

[a] Always a male
[b] EDTA = ethylenediaminetetraacetic acid
F.Q. = first quarter; L.Q. = last quarter; F.M. = full moon

was sufficient, simple and cost-effective. Our best performance was 2.2% survival from fertilised eggs to 3-mm juvenile stage.

Settlement plates

Settlement plates were made of corrugated polyethylene roof materials that were cut into pieces about 350 × 200 mm. The long sides of each piece were tied together midway with a nylon string to assume a partial fold that could be stacked randomly at the bottom of the tank.

Each piece was washed with detergent and chlorine and air-dried, making sure to keep off insects that might lay eggs on the plates. The rough side was painted with a thin coat of *Spirulina* paste prepared by diluting the powder with just enough water to create a paste-like consistency (Duy 2010). The plates were added once doliolaria were observed, and were stacked randomly in the tanks up to 50% of the water column. The water was changed 3 hours after adding the plates or until all the *Spirulina* bubbles were eliminated. Strong aeration was provided.

Rearing problems

Infestation of chironomids and copepods, both in the tanks and on settlement plates, was the main cause of low survival or population crashes in our hatcheries. In four of the five crashes, the white cloth tank covers were removed at settlement stage. These tanks showed severe chironomid infestation. We decided to keep the cover on until harvest time at ≥3 mm, and this improved the survival rate. Chironomids at the High Ponds site were more difficult to control, probably due to the shaded location of the hatchery and the presence of more trees in the immediate surroundings. The hatchery in Dumoy, on the other hand, is sandwiched between two concrete structures (Figure 2).

We found that copepods can survive even in UV-treated and filtered seawater systems, as was also reported by Pitt and Duy (2004). They can destroy good batches of settled juveniles within a few days. To address this, proper aseptic procedures were observed, such as chlorination of water pipes and tanks before and after each batch, and covering the

Table 2. Daily feeding concentration of *Chaetoceros calcitrans* used for *Holothuria scabra* production in this protocol

Day from fertilisation	Larval stage	*Chaetoceros* cells/mL	Aeration
2	Early auricularia	20,000	gentle
4	Mid auricularia	20,000–25,000	moderate
6	Mid and late auricularia	25,000–30,000	moderate
8	Late auricularia	30,000–40,000	moderate
10 (till transfer to hapa)	Doliolaria (till 0.5-mm juvenile)	30,000–40,000	strong (once plates are added)

Figure 2. The hatchery at High Ponds, Toril (left) is shaded by trees on one side and at the back, while that in Alsons, Dumoy (right), is more exposed to sunlight.

tanks immediately after water change. Our staff were told to be mindful of being carriers of contaminants. For example, they had to rinse their hands before doing tank water changes, especially if they had come directly from monitoring the hapas in the channel. Agudo (2006) recommends thorough rinsing of all rearing materials with freshwater before and after use, and storing them in containers with chlorinated water.

Nursery

First phase: ≥3-mm juveniles into hapas

In our experience, juveniles do not grow uniformly in the tanks. This is still a difficulty in our optimisation of a low-cost technology, although significant improvement in the rate of survival to 3 mm was obtained when the feeding regime was split into two, tanks were fully covered to prevent chironomid infestation, and rough inner surface tanks and rough settlement plates were used.

By day 38, a good number of juveniles had reached ≥3 mm in size. This group was harvested and moved into the hapas. Harvesting involved using a fine, soft watercolor paintbrush to detach the bigger juveniles from the plates. After harvesting, those plates still with smaller juveniles were dropped back into the tanks without repainting with *Spirulina*. A thin film of algae could regrow on the plates overnight. With this thinning-out process, juveniles were harvested at least three times within a 3–7-day interval.

The hapas, measuring 1 × 2 × 1 m with a mesh size ~1 mm, were made of the same material as that used by local pond operators. Because the water level in the channel changes regularly, floating hapas were designed (Figure 3). The four surface corners of the hapa were tied to bamboo poles fixed to paddle wheel buoys; and the bottom corners and the middle floor were fastened with weights to keep the floor submerged in the water all the time. The hapas were conditioned for 3–5 days to allow a substantial mat of biofilm to grow. Then 400 juveniles (≥3 mm length) were transferred into them (Figure 4). The algal mat served as natural food for the growing juveniles and eliminated the manual task of feeding them. In the channel, growth of biofilm is fast and periodic thinning was done by gently scrubbing the outer sides of the hapa. In Vietnam the hapas are tied to bamboo poles that are fixed on the substrate of the pond. The

Figure 3. The seawater channel at Alsons, Dumoy (left), and the floating hapas (right)

Table 3. Survival of juveniles in the hapas inside the seawater channel at Dumoy

Batch / date	Total count of 3–5-mm juveniles	Total hapas (@ 400 juveniles per hapa)	Mean wet weight (g) after 30 days	Count and % survival after 30 days
15 October 2010	5,400	14	5.45	3,051 (56.5%)
23 June 2010	6,400	16	2.5	2,717 (42%)
11 February 2010	4,000	10	3.5	3,822 (96%)
6 May 2009	2,000	5	2.1	1,453 (73%)

Figure 4. Harvesting ≥3-mm juveniles from a plate (left); releasing the juveniles onto a hapa (centre); 1-month-old juveniles in the hapa (right). A synaptid (foreground) and seahare egg case (tip of caliper) are seen with the juveniles.

water level in their ponds follows the natural high- and low-tide cycle, but growth of biofilm is not as thick as that in the Dumoy water channel.

A summary of the survival rates of juveniles in the hapas is shown in Table 3. Our best record was 96%. Low survival in June and October 2010 occurred when juveniles were kept in hapas longer than 35 days. As in the tanks, juveniles in the hapas do not grow uniformly, and harvesting was also done two to three times. The first harvest was conducted at 30–35 days, and juveniles ≥2.0 g were thinned out. One to two more batches of late shooters would catch up at 2–3-week intervals. Longer time in the hapa and frequent handling seemed unfavourable for the juveniles. This staggered harvesting can be a natural pacing for grow-out or sea-ranching releases. It should be well managed in order to avoid a glut at the nursery and ensure continuous release and, consequently, continuous harvest.

Predators in ocean nurseries include crabs and carnivorous fishes (Dance et al. 2003; Lavitra et al. 2009). Surprisingly, they were not a problem in the water channel. Although synaptids and *Dollabella* (Figure 4) were common invaders, we noted no threats to the growing juveniles. The weights in the bottom corners of the hapas have to be checked regularly—without them the floor rises up to the surface and could expose the juveniles to more direct heat from the sun and warmer water temperature.

Second phase: sand-conditioning of ≥2.0-g juveniles

Juveniles ≥2.0 g were conditioned in the substrate before they were released for grow-out or sea ranching. We conducted several pond experiments using various sized juveniles from the hapas. In one of the trials, three pens (3 × 5 × 0.4 m each, made of PVC screen, with a mesh size of 15 mm) were laid out in one portion of the pond. To each pen, 50 juveniles (3–13 g) were introduced. After the first month, the average wet weight was 21.3 g (i.e. growth rate of 0.77 g/day) (Figure 5). After 4 months, the survival rate was 70–100%, with an average wet weight of 191 g. In another experiment involving smaller juveniles, survival after a month was 58–80% and average growth rate was 0.42 g/day. While growth and survival of juveniles varied, the marine pond proved, at the very least, to be a reliable juvenile sand-conditioning area.

In Vietnam *H. scabra* are commercially grown to ≥500 g in marine ponds. The ponds are converted shrimp ponds and are irrigated by natural rise and fall of the tides. In the Philippines there are also many abandoned shrimp farms, and their potential for sea cucumber grow-out is recommended for further investigation.

Harvest of ≥10-g juveniles for release

We recommend ≥10 g for release size, as the bigger the juvenile, the greater the chances of survival, especially in sea ranches. Juveniles were packed in groups of five in oxygen-filled polyethylene bags containing 1 L of sea water, and transported to the release site in the same way that broodstock are transported. On site, the bags were allowed to float on the water for about 30 minutes to acclimatise the juveniles to the ambient temperature (Figure 6).

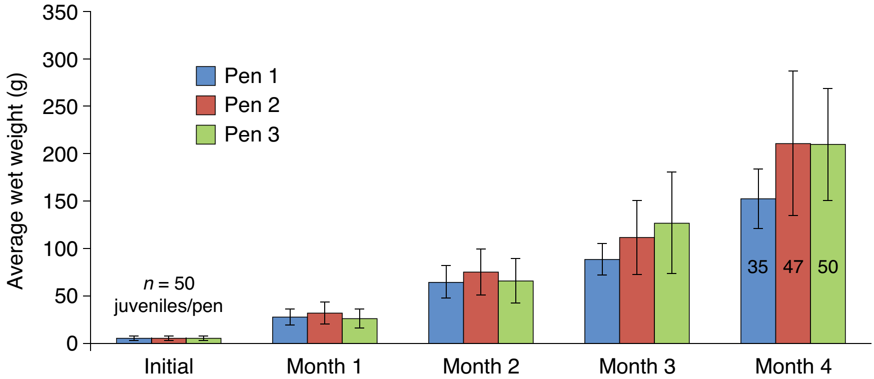

Figure 5. Growth of juveniles in pens within a marine pond in High Ponds. Vertical bars represent standard error while numbers inside bars in month 4 represent the surviving individuals.

Figure 6. Transporting the juveniles to site of release—community partners at work

Chaetoceros culture

A significant reduction in production cost in terms of labour and raw materials was achieved by using a single-species feed, *Chaetoceros calcitrans*, for the larvae. This regime was adopted from practices in Vietnam. Every week, 1 L of stock culture was brought in by Alsons from their algal laboratory in another city. Using the formulation of Agudo (2006), the stock was scaled up to 10 L inside an air-conditioned algal room (Figure 7; refer also to appendix). Sea water for culture passed through UV-sterilisation, microfiltration and chlorination–dechlorination. These 10-L stocks in turn became the seed for outdoor upscaling in 250-L recycled PVC drums. Another suspected source of chironomids was the scaled-up *Chaetoceros* cultures. It was necessary to bring the drums out in the open for exposure to sunlight, but they were tightly covered with thin, white cloth to prevent chironomid infestation.

Conclusions

The cost-cutting innovations in this paper are compared with those of Agudo's (2006) protocol (Figure 8). Protocols to produce sandfish are already established, and *H. scabra* has been found to grow in various systems (James et al. 1994; Battaglene et al. 1999; Gamboa et al. 2004; Pitt and Duy 2004; Agudo 2006; Duy 2010). Three local modifications made by the Mindanao project team have been described here: mono-algal feeding using *Chaetoceros calcitrans*; the

Figure 7. The algal room (left); some *Chaetoceros calcitrans* jugs inside (centre); outdoor upscaling making use of recycled glucose syrup barrels (right)

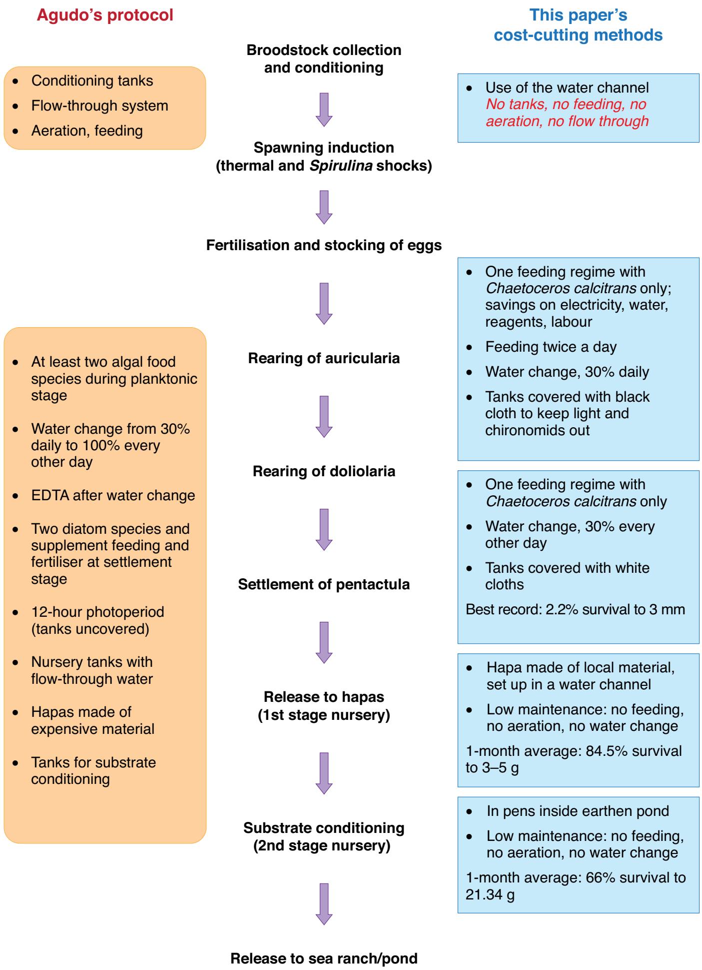

Figure 8. Comparison of cost-cutting innovations in this paper with those of Agudo's (2006) protocol

use of a seawater channel for broodstock conditioning and hapa nursery; and use of recycled or locally made materials. These modifications were made in the context of partnership: the mono-algal feeding was adopted from the system employed by Mr Duy in RIA3, Nha Trang, Vietnam; and the water channel, marine pond and hatchery spaces were provided by two private partners, Alsons Corporation and the JV Ayala Group of companies. This paper attests to the progress and innovations made in sea cucumber research in the Philippines since *H. scabra* production was pilot-tested in Bolinao in 2002 (Gamboa and Juinio-Menez 2003).

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Appendix. Modified *Chaetoceros* upscaling formulation

The technology in this paper does not maintain an algal culture. Instead, a 4 L stock of *Chaetoceros* is purchased from Alsons every other week and scaled up outdoors in the hatchery using recycled polyethylene barrels. The formulation we modified is described here and is not intended for maintaining pure stock cultures.

Chlorination–dechlorination

12.5% chlorine strength stock solution. Usage: 0.2 mL (stock) per litre of culture volume (Agudo 2006). Although chlorine content is not indicated in sodium hypochlorite powder, for calculation purposes we estimated the strength to be around 70%, based on references on the internet about sodium hypochlorite available in the Asian market.

250 g thiosulphate in 1-L solution to make stock solution. Usage: 0.2 mL (stock) per litre of culture volume (Agudo 2006).

Chaetoceros upscaling formulation (modified from Agudo 2006)

1. Fertiliser—Manusol (30:10:10): for 10-L jug culture, 0.25 g is needed; for 200-L culture, 5 g is needed
2. Silicate—sodium metasilicate: for 10-L jug culture, 0.375 g is needed; for 200-L culture, 7.5 g is needed.

Sandfish production and development of sea ranching in northern Australia

William M. Bowman[1]*

Abstract

Sea cucumber harvesting has been carried out in the Northern Territory (NT) since 1700 when Macassans regularly visited the area. Tasmanian Seafoods Pty Ltd currently holds all licences for sea cucumber in the NT, with the main target species being sandfish (*Holothuria scabra*). Tasmanian Seafoods has successfully trialled propagation and juvenile production for wild fishery stock enhancement and land-based grow-out in ponds. Lease of an ex-prawn farm and hatchery facilities at Darwin Aquaculture Centre has progressed its efforts. Tasmanians Seafoods has established working relationships with remote Indigenous communities situated nearby on recognised fishing grounds on Groote Eylandt, to develop the sea-ranching component of the project and establish joint ventures for the harvesting of the 'released' sea cucumbers. Appropriate policies and management arrangements are also being negotiated with the NT Government Department of Resources Fisheries Group.

Introduction

Sea cucumber harvesting has been carried out in the Northern Territory (NT) since 1700, when Macassans from Celeb (Sulawesi island group, Indonesia) visited annually and set up processing sites adjacent to the fishing grounds (Macknight 1976). The industry has evolved and now consists of a series of regulatory controls to manage the fishery, predominantly through input controls. Entry to the fishery is limited to six licences that are restricted by area, species, minimum size and the number of divers on each vessel (Shelley and Puig 2003).

Tasmanian Seafoods Pty Ltd is currently the sole licence owner for sea cucumber fishing in the NT. The fishery's principle target species is the sandfish (*Holothuria scabra*). Since 2004 Tasmanian Seafoods has been investigating the potential of propagation and juvenile production of sandfish, with a view to enhancing the existing wild fishery through sea ranching and exploring land-based grow-out.

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During 2006–08, repeated trials were carried out to assess the potential of land-based grow-out and develop pond-management techniques for *H. scabra.* Promising results led to the expansion of the project by leasing a farm that had previously been used to cultivate prawns. Subsequently, a 'farming' component was added to the sea-ranching project, enabling greater access to, and utilisation of, necessary facilities (e.g. earthen ponds) for the project.

In developing the sea-ranching component of the project, Tasmanians Seafoods has sought to create effective working relationships with remote Indigenous communities situated nearby on recognised fishing grounds, and establish joint ventures for the harvesting of the 'released' sandfish. The development of sea ranching has also required ongoing negotiations with the NT Government Department of Resources Fisheries Group to develop appropriate policies and management arrangements to conform with the NT's *Fisheries Act 1998*.

The fishery

The fishing grounds occur along the Arnhem Land coast, with the major harvest areas being the

Cobourg Peninsula and Groote Eylandt (Figure 1) (Handley 2010). All commercial harvesting of sea cucumber in the NT is conducted by hand, either by walking the shallows, snorkelling or hookah. The fishery operates in waters up to 3 nautical miles seaward of the NT and surrounding islands coast.

The hatchery

In 2004 Tasmanian Seafoods set up a pilot hatchery at the NT Government's Darwin Aquaculture Centre (DAC). Initially, the hatchery was dependent on wild caught broodstock, which proved restrictive due to the logistics of acquiring broodstock from the fishing grounds, with the nearest grounds being on the Cobourg Peninsula about 200 km away with no road access (Figure 1). This led to the development of transport techniques using vessels and aircraft to collect and transfer broodstock to the hatchery with minimal stress, and the lease of ponds at a local aquaculture farm to hold breeding stock.

Successful larval culture of *H. scabra* led to expansion of the hatchery at the DAC. The larval rearing infrastructure is now a recirculating system comprising a 25,000-L sump, 40,000-L larval rearing volume, 36,000-L conditioning system and two 1,500-L experimental larval rearing systems.

All sea water entering the system has a salinity of 30‰ and is filtered to 1 µm. Once in the loop, the water is repeatedly treated with UV sterilisation and foam fractionation. The hatchery is located in a covered outdoor area, and water temperature in the larval rearing tanks is in the range 27–31 °C.

During the larval run, the larval tanks are static with a daily partial water exchange. The larvae are predominantly fed *Chaetoceros muelleri*, beginning at densities of 15,000 cells/mL and increasing to 35,000 cells/mL by the end of the run. Once the larvae have settled, the tanks are put on flow-through at 100% water exchange per day.

The conditioning tanks are used to cover settlement substrates with diatoms, with a good coverage of periphytic diatoms on our settlement substrates generally taking around 5–7 days. Settlement substrates are then put into the larval tanks at the time of settlement, to help induce the larvae to settle and provide food for the post-settlement and early juvenile stages. While larval settlement is consistently achieved, the settlement rate is highly variable between tanks, often ranging from 0.4% to over 20%. The larval tanks are harvested and graded soon after settlement, generally at around day 30.

The ponds

Tasmanian Seafoods secured the lease on a prawn farm in 2009. The facility comprises eight 1-ha ponds, six 0.1-ha ponds, and one 2-ha reservoir. The

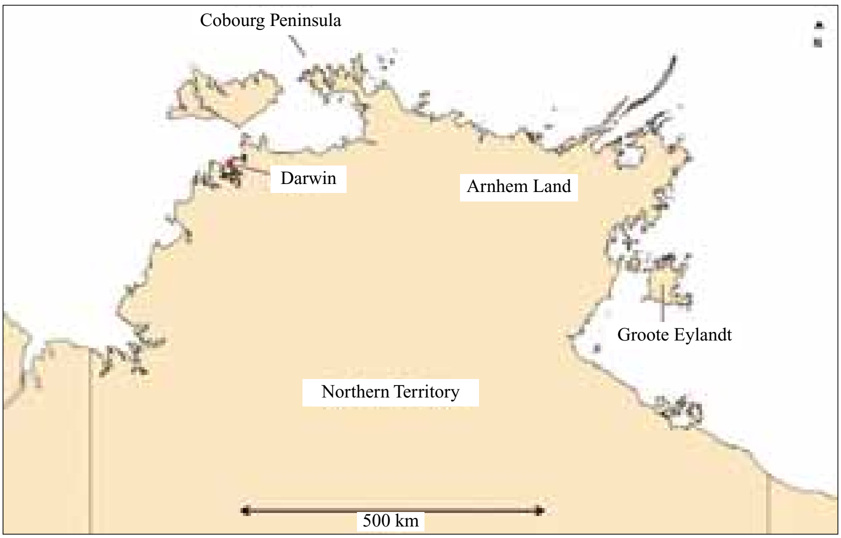

Figure 1. Major harvest areas of the Northern Territory (Australia) sea cucumber fishery

1-ha ponds are used for production, currently yielding 2.0–2.5 tonnes wet weight per hectare. The 0.1-ha ponds are more versatile and easily managed, and are used for broodstock holding and conditioning, and nursery production.

Water is pumped from Darwin Harbour into the reservoir, which then gravity-feeds the rest of the farm. The ponds are on flow-through, and water quality is regularly monitored. Between February 2010 and January 2011, the salinity in the reservoir ranged from 24.6‰ to 38.6‰, and the temperature ranged from 24.7 °C to 35.2 °C. Optimal dissolved oxygen levels are maintained by using air diffusers mounted on the bottom of the ponds connected to air blowers. The diffusers also vertically mix the water column, preventing stratification.

The pond nursery system currently consists of 30 hapa nets (2.5 × 2.5 m, 1-mm mesh), which are stocked with newly settled juveniles (>1 mm). The grow-out ponds are stocked when juveniles reach 25 mm (Figure 2). The growth rates in ponds increase with animal size, and with suitable conditions can exceed 2.5 g/day when animals are nearing harvest (i.e. around 350 g). Freshwater influx into the ponds through the monsoon season is managed by adjusting flow-through rates; and pond depth is maintained using boards or internal standpipes, giving the ability to skim the fresh water off the top.

Sea ranching

In 2006 Tasmanian Seafoods began searching for suitable sites to conduct sea-ranching trials. Little Lagoon on Groote Eylandt (Figure 3) was chosen due to the presence of suitable release habitat for hatchery-produced juveniles. In addition, the local community of Umbakumba expressed an interest in being involved in the project.

Little Lagoon is a shallow basin approximately 2,000 ha in area comprising patches of seagrass, shifting sand bars and mud substrate. The area has long been recognised as a productive fishery and natural nursery area for sandfish (R. Hone, pers. comm., 2009). The lagoon also has favourable geographical characteristics for monitoring the released sandfish, including protection from the weather due to its semi-enclosed nature and a low tidal range, which helps to maintain good water visibility.

Building a successful relationship with the Umbakumba community has been critical for the

Figure 2. Nursery production of sandfish

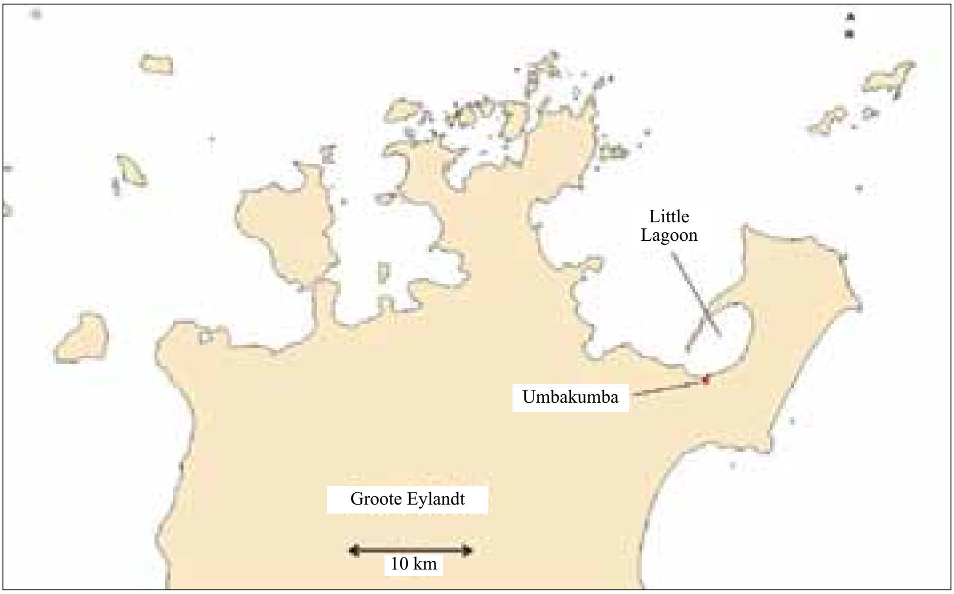

Figure 3. Location of sea-ranching site, Little Lagoon, Groote Eylandt

developmental stage of the sea-ranching project. There are obvious logistical difficulties associated with this site, which is approximately 700 km from the hatchery. However, local community involvement allows for relatively simple management of the project, while regular barge and plane services facilitate transport of equipment to and from the site.

Future direction

The future direction for Tasmanian Seafoods in sea cucumber propagation and sea-ranching research is to increase hatchery and nursery efficiency through improved hatchery protocols and system design; improve pond management to reduce variation and increase yields; and accurately assess the viability of sea-based grow-out of sandfish.

Tasmanian Seafoods aims to promote Indigenous community involvement in sea ranching in the NT, creating opportunities and economic activity in remote areas. Information generated in the research will assist in determining the potential of stock enhancement as a management tool for the future development and sustainable use of the NT's sea cucumber fishery.

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Hatchery experience and useful lessons from *Isostichopus fuscus* in Ecuador and Mexico

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Abstract

This paper summarises lessons learned from captive breeding of the sea cucumber *Isostichopus fuscus* in land-based installations on the coast of Ecuador and Mexico. This species has been intensively fished in Mexico, along mainland Ecuador and around the Galapagos Islands. Management efforts have traditionally been challenged by local economic and social conditions. Populations of *I. fuscus* have thus been severely depleted over the past decades, generating interest in aquaculture and restocking. Spawning, fertilisation, larval rearing, disease control and juvenile growth have been documented in two privately owned hatcheries. Data from trials conducted in Ecuador over several years indicate that, under optimal conditions, juveniles can be grown to a size of ~8 cm in length in 3.5 months and to commercial size in ~18 months. Preliminary tests have shown that growing juvenile sea cucumbers in shrimp ponds is feasible. In Mexico, successful spawnings were restricted to late summer and autumn/fall months, when cultures of larvae and early juveniles yielded growth rates similar to or greater than those recorded in Ecuador. Grow-out of juveniles in shrimp ponds was impeded in both countries by skin infections, leading to high mortality rates, whereas juveniles placed in cages in the ocean (in Mexico) exhibited reasonable growth rates and better survival (to 90%). Overall, studies demonstrate that, with proper disease control, millions of juvenile *I. fuscus* can be reared in captivity annually, thus providing an alternative to fisheries, or a way to maintain sustainable harvests and eventually contribute to restoration of the natural populations.

Introduction

Isostichopus fuscus (Figure 1) is a deposit-feeding sea cucumber that is mainly found on reefs and sandy bottoms along the western coast of the Americas, from northern Peru to Baja California, Mexico (Castro 1993; Toral-Granda 1996; Sonnenholzner 1997; Gutierrez-Garcia 1999). Like many other commercial sea cucumber species, *I. fuscus* has been widely fished over past decades to meet the growing demand for beche-de-mer in the major Asian markets. As the waters along mainland Ecuador became depleted, the fisheries shifted to the Galapagos Islands in the early 1990s, raising international apprehension over the fate of this unique archipelago, which has been recognised as a national park and marine reserve. Since then, attempts by government at regulating sea cucumber harvests, and banning them in some areas, have met strong opposition from local fishers in Ecuador. In fact, illegal fisheries have always been a concern and still occur along the mainland coast, around the Galapagos Islands and elsewhere in the distribution area of *I. fuscus*. In 1994 the Government of Mexico imposed a total closure because this species was considered locally endangered. However, the closure was not obeyed by

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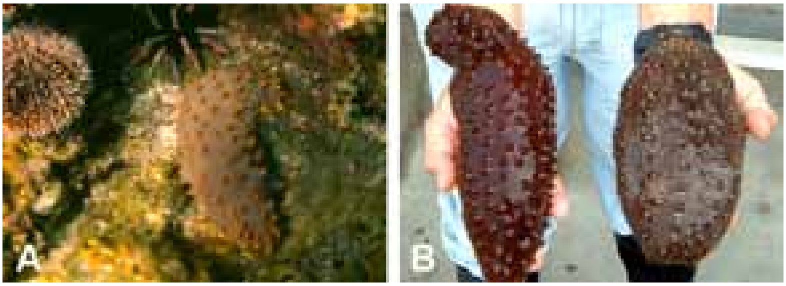

Figure 1. Adults of *Isostichopus fuscus* photographed (**A**) in situ (Galapagos Islands) and (**B**) in land-based installations (mainland Ecuador) showing the main colour morphs

fishers, leading to a decrease in the biomass, which is now only 2% of the original biomass in some regions (Castro 1995; Aguilar-Ibarra and Martinez-Soberon 2002). Currently, the fishery in Mexico is managed under concessions and stricter activity controls (Toral-Granda 2008).

Official information on the fisheries and actual total catches are difficult to obtain and remain sparse (Salgado-Castro 1993; Castro 1997; Sonnenholzner 1997; Gutierrez-Garcia 1999; Jenkins and Mulliken 1999). Nevertheless, recent data and reports on average capture sizes (Sonnenholzner 1997; Martinez 2001) indicate that *I. fuscus* populations have declined substantially and that natural stocks may irreversibly crash in the near future. Stock recovery has yet to be observed in any region (Toral-Granda 2008).

Despite this situation, a very limited number of studies has been conducted on the reproductive biology, spatial distribution, population structure, growth and survival rate of *I. fuscus* (Herrero-Pérezrul 1994; Fajardo-Leon et al. 1995; Toral-Granda 1996; Sonnenholzner 1997; Herrero-Pérezrul et al. 1999; Hamel et al. 2003; Mercier et al. 2004, 2007; Toral-Granda and Martínez 2007; Becker et al. 2009). Some authors have mentioned that aquaculture and restocking should be investigated as possible solutions to the current crisis (Gutierrez-Garcia 1995, 1999; Fajardo-Leon and Velez-Barajas 1996; Jenkins and Mulliken 1999).

Until recently, aquaculture in Ecuador and Mexico was largely focused on shrimp. The emergence of white spot disease in 1999–2000 has severely affected the industry and resulted in the bankruptcy and closure of numerous farms. Consequently, both countries now have abandoned shrimp farm infrastructures that could very well be put to use for the development of other species, such as sea cucumbers.

This paper summarises efforts made to cultivate *I. fuscus*, including methods of larval development and juvenile growth in land-based nursery systems on the coasts of Ecuador and Mexico. Major findings from Ecuador have been outlined previously (Hamel et al. 2003; Mercier et al. 2004, 2007; Becker et al. 2009), whereas data from Mexico are presented here for the first time.

Results show that aquaculture of this species is feasible and that it could potentially be developed as an alternative to fisheries. In addition, it could be used to maintain sustainable harvests and eventually contribute to the restoration of natural populations. Further research to complement the work presented here is being conducted on the feeding, growth and reproductive biology of this highly prized sea cucumber, which is a dominant feature of the Mexican and Ecuadorian marine ecosystems. In time, hatchery production and restocking of *I. fuscus* might provide part of the solution to the current sea cucumber fishery crisis.

Methods and results

Spawning and fertilisation

Adult sea cucumbers were routinely collected from nearby coastal areas in Ecuador or Mexico to serve as broodstock. The adults were adapted to captive conditions in large tanks or raceways for a few days or weeks prior to spawning. Various methods of spawning induction were initially tested. However, close monitoring and spawning experiments later revealed that the species follows a predictable lunar spawning periodicity. Patterns of gamete release were investigated on the coast of Ecuador using several hundred newly collected individuals monitored nearly every month for 4 years. Between 1% and 35% of individuals consistently spawned 1–4 days after the new moon (Figure 2) (Mercier et al. 2007). Most spawnings occurred on the same evening, although some gamete release was often recorded over two to four consecutive evenings. On a spawning night, males typically initiated gamete release around sunset, and females spawned just after the peak male broadcast. The percentage of spawning individuals was higher, and a greater overlap between male and female peak

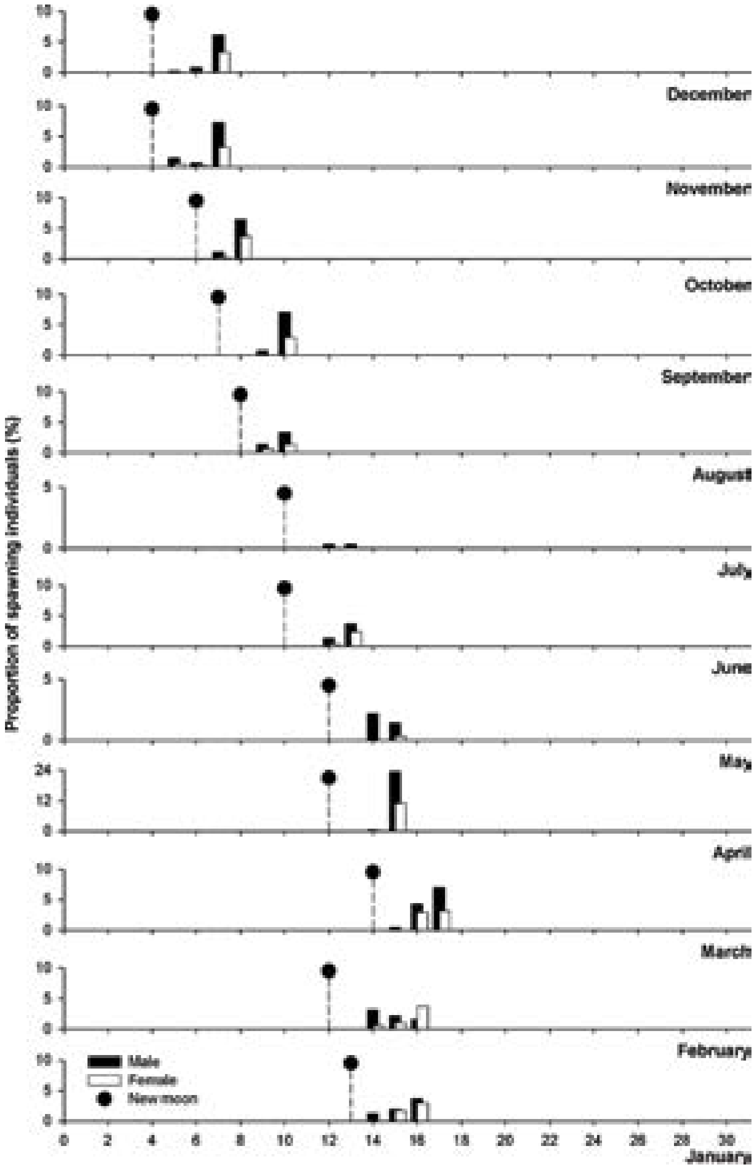

Figure 2. Example of the typical spawning periodicity recorded in captive *Isostichopus fuscus* in Ecuador (from Mercier et al. 2007)

spawning activity was noticed, during clear conditions compared with overcast conditions (Mercier et al. 2007). Preliminary data from Mexico confirmed the same lunar pattern, although individuals mostly started to spawn 2–3 days before the new moon, and continued to do so for 2–4 consecutive days.

In Ecuador, it has thus been possible to obtain male and female gametes on a monthly basis; only a limited number of spawning trials have been unsuccessful, mostly due to poor environmental conditions (e.g. heavy rain). In Mexico, spawning events were recorded solely between June and December of each year, with maximum success in late summer and autumn/fall (August to December).

The broodstock in Ecuador typically consisted of 300–400 adults maintained in large 30-t tanks. Males and females were isolated in buckets as soon as they showed signs of imminent spawning (typical posture with anterior end rising and moving right to left and up and down). Clear morphological distinctions between male and female gonopores at that stage allowed trained personnel to sort them before the actual gamete release. Each female was placed separately in a 300-L spawning tank and maintained there until it had released its oocytes. Once the female had been removed from the tank, dry sperm obtained surgically from three males (sperm extracted from the gonad without adding any sea water until use may be kept at 4 °C for up to 48 hours) was diluted in sea water to allow cell count and prepare the solution required to achieve the desired final concentration of spermatozoa in the tanks. The best fertilisation rates and lowest occurrence of polyspermy were obtained with a concentration of 500–1,000 spermatozoa/mL. Spawning of both males and females occasionally occurred in the broodstock tanks; already fertilised gametes were then transferred to culture vessels. Similar techniques were used in Mexico.

Larval development

After fertilisation, the eggs were rinsed to remove excess sperm. A few hours later, the developing larvae were transferred to the hatchery tanks, where their development was closely monitored (Hamel et al. 2003; Mercier et al. 2004). The routine protocol included daily cleaning of the tanks during the first days, followed by installation of a flow-through system. In Mexico, the flow-through system was used from the very beginning of the culture. The larvae were fed every day using a mix of live microalgae (dominated by *Rhodomonas* and *Dunaliella* in Ecuador, and *Chaetoceros* and *Dunaliella* in Mexico) at a frequency and concentration dictated by the daily observation of digestive tract contents. With improvement of the rearing techniques over the past few years, including the use of running sea water and temperature control (see below), a 30–50% survival rate has regularly been achieved, although the average survivorship remains at 8–30% of juveniles developed from each larval run (Hamel et al. 2003; Mercier et al. 2004).

Isostichopus fuscus possesses planktotrophic larvae that need to feed during their pelagic phase and will undergo a series of transformations to reach the juvenile stage (Figures 3–5; Table 1). In most trials, the development, settlement and growth of the juveniles were asynchronous, and different stages/sizes occurred simultaneously in the cultures. Extreme examples were observed in a few tanks where residual auricularia larvae neighboured 4-mm-long juveniles. Table 1 provides developmental kinetics for both countries based on the bulk of the cultures, discarding extreme asynchronies. Figure 6a shows the different sizes of juveniles that may occur in a typical cohort.

Ovulation occurs in the gonadal tubule as the oocytes are released (Figure 3a). Thus, fully mature oocytes (~120 µm in diameter) are expelled directly in the water column at the metaphase-I of meiosis, after the germinal vesicle breakdown. Embryonic development is initiated with the elevation of the fertilisation envelope, roughly 4 minutes after fertilisation. The expulsion of the first polar body occurs ~3 minutes later (Figure 3b). The second polar body follows rapidly within ~2 minutes. The first cleavage is equal, radial and holoblastic, and divides the cell into two equal hemispheric blastomeres (Figure 3c). The second cleavage again occurs along the animal–vegetal axis, yielding more spherical blastomeres. Embryos hatch from the fertilisation envelope as early gastrulae ~10 hours after fertilisation (Figure 3d). These early gastrulae are ciliated and swim; they elongate into full-size gastrulae after ~14 hours (Figure 3e). Auricularia larvae, which constitute the first feeding stage, begin to appear ~24 hours after fertilisation. Growing auriculariae can be observed during the next 2 weeks of culture (Figure 3f; Table 1). At this stage they begin to accumulate hyaline spheres. The oesophagus, sphincter, intestine, cloaca anus are clearly visible. After 16–18 days the auricularia reaches its maximum size of 1.1–1.3 mm; it has left and right somatocoels, as well as an axohydrocoel (Figure 3g) (Hamel et al. 2003; Mercier et al. 2004).

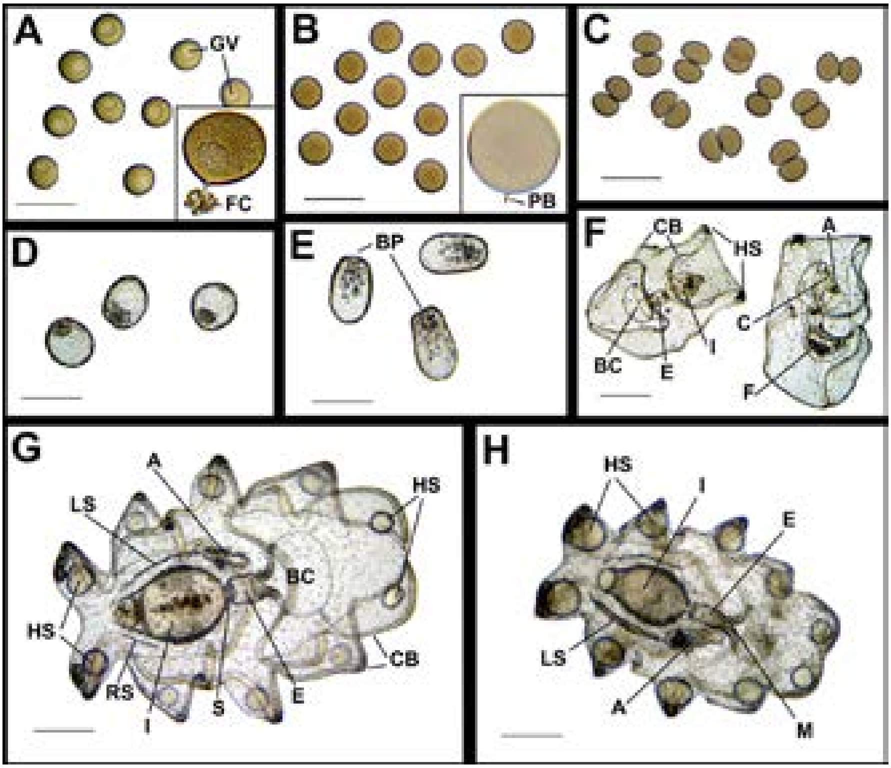

Figure 3. Early development of the sea cucumber *Isostichopus fuscus*; the bars represent 200 µm. **A**: Oocytes collected surgically from a mature gonad; the germinal vesicle (GV) is clearly visible. The insert shows a close-up of an ovulating oocyte with the follicular cells (FC) still attached to it. **B**: Fully mature, newly fertilised eggs with clear germinal vesicle breakdown. The insert shows the expulsion of the two polar bodies (PB). **C**: Two-cell stage. **D**: Newly hatched gastrula. **E**: Elongated gastrula with visible blastopores (BP). **F**: Early auricularia on which the ciliary bands (CB), hyaline spheres (HS), buccal cavity (BC), oesophagus (E), intestine (I), cloaca (C) and anus (A) are identifiable; food items (F) are present in the buccal cavity. **G**: Ventral view of a fully developed auricularia showing the left somatocoel (LS), axohydrocoel (A), hyaline spheres (HS), ciliary bands (CB), buccal cavity (BC), oesophagus (E), sphincter (S), intestine (I) and right somatocoel (RS). **H**: Dorsal view of a metamorphosing auricularia. With a noticeable decrease in size, the buccal cavity disappears and the hyaline spheres (HS) are pulled closer together. The mouth (M), intestine (I), oesophagus (E), left somatocoel (LS) and axohydrocoel (A) are clearly visible.

In the following hours, many auriculariae initiate the transformation that will lead to the doliolaria stage (Figure 3h). During this process, the larvae shrink to nearly 50% of their initial size, the buccal ciliated cavity disappears and the hyaline spheres are pressed closer together (Figure 4a). The doliolaria stage is reached ~19–24 days after fertilisation (Figure 4b; Table 1) as the larvae stop feeding and the cilia are aligned in five distinct crowns along their cylindrical body. At this time, the movement of the primary tentacles can be observed through the translucent body wall. The somatocoel is also visible. A few days later, the doliolaria transforms into an early pentactula possessing five buccal tentacles (Figure 4c). At this stage, the larvae remain close to the substrate, successively going through swimming

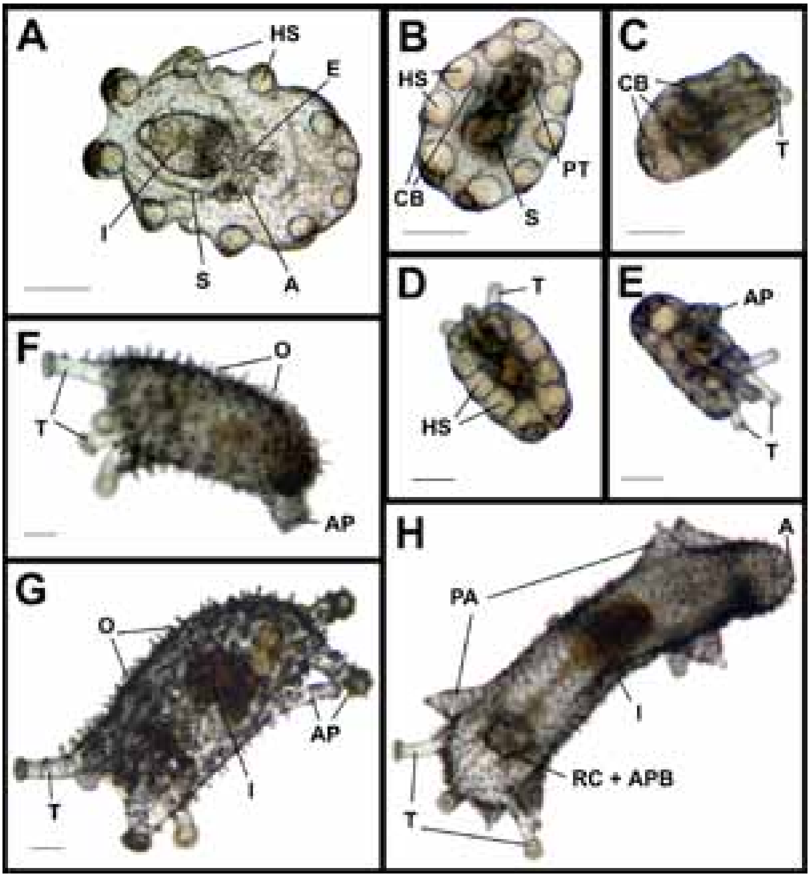

Figure 4. Late development of the sea cucumber *Isostichopus fuscus*; the bars represent 200 µm. **A**: Late metamorphosing auricularia, showing the hyaline spheres (HS), oesophagus (E), intestine (I), somatocoel (S) and axohydrocoel (A). **B**: Fully developed doliolaria with hyaline spheres (HS), primary tentacles (PT), ciliary bands (CB) and somatocoel (S). **C**: Early pentactula with five tentacles (T) and the still-visible ciliary bands (CB). **D**: Dorsal view of newly settled pentactula with tentacles (T) and hyaline spheres (HS). **E**: Ventral view of newly settled pentactula showing the first ambulacral podia (AP) and the five buccal tentacles (T). **F**: Early juvenile, measuring 1.5 mm in length, with tentacles (T), ambulacral podia (AP) and ossicles (O). The hyaline spheres have disappeared. **G**: A 2-mm-long juvenile with five tentacles (T) and three pairs of ambulacral podia (AP). The intestine (I) and ossicles (O) are visible. **H**: A 3-mm-long juvenile showing the tentacles (T), papillae (PA), intestine (I), anus (A) and ring canal and aquapharyngeal bulb (RC + APB)

and settling phases. Definitive settlement, with the complete loss of cilia, completion of metamorphosis and emergence of the two first ambulacral podia, occurs about 22–27 days post-fertilisation in Ecuador and 17–20 days post-fertilisation in Mexico (Table 1; Figure 4d, e). Further details on the development are available (Hamel et al. 2003; Mercier et al. 2004). Hatcheries in Ecuador use corrugated sheets of Plexiglas covered with a rich biofilm to provide settlement substrates and food to settled larvae and

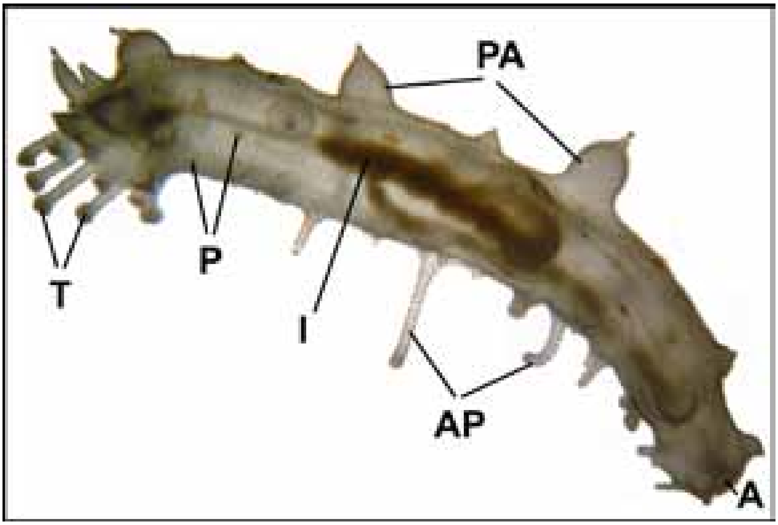

Figure 5. Juvenile sea cucumber *Isostichopus fuscus* measuring 15 mm in length and showing the tentacles (T), early body wall pigments (P), intestine (I), ambulacral podia (AP), anus (A) and papillae (PA)

early juveniles. In Mexico, conditioned, multilayered sheets of locally made fabric mesh are used as settlement substrata and during the early growth phase of juveniles.

Juvenile growth

Although the first settled juveniles can be observed as early as day 17–22, a majority of juveniles measuring 1.0–1.5 mm in length are generally found in the tanks after 21–28 days of culture (Figure 4f; Table 1). They reach ~2–3 mm only a few days later (Figure 4g, h), and 5 mm after ~40–48 days. At this stage, the juveniles start to accumulate some reddish-brown pigments. In 8-mm-long juveniles, the tips of the tentacles become ramified. After 50–65 days of culture, the juveniles are 15–18 mm long and 4 mm wide (Figure 5). They possess several papillae and an elongated intestine that already exhibits strong peristaltic movements. The body wall becomes more opaque as the ossicle density and the tegument thickness increase. When the juveniles reach ~20 mm in length, the whitish colouration that characterises the early stages of life is gradually replaced by a brownish tinge typical of adults (Figure 6a). After 72–85 days of culture, the juveniles are ~35 mm long and 10 mm wide (Hamel et al. 2003; Mercier et al. 2004).

The typical growth of *I. fuscus* larvae and juveniles in Ecuador is shown in Figure 7. The average growth of larvae and juveniles follows the second-order polynomial calculation (equation (1)):

$$f(x) = 1658 - 321(x) + 11(x^2) \qquad (1)$$

where $f(x)$ is the size in µm and x is the time in days ($r^2 = 0.99$)

The latest cultures in Ecuador have yielded significantly faster growth rates, with juveniles measuring 11 mm after 28 days, 31 mm after 56 days and 56 mm after 77 days. Growth rates are slightly slower in Mexico (Table 1).

Grow-out experiments

In Ecuador the juveniles are usually transferred to larger 18-m^2 pre-conditioned flow-through tanks, with or without conditioned plates (the same as those used for larval settlement), when they reach 0.5–1.0 mm in length. Mexico makes similar use of settlement plates for juvenile growth in flow-through tanks. After about 72 days, some of the juveniles have reached sizes up to 34 mm (Figure 7; Table 1). The maximum size of *I. fuscus* grown in aquaculture facilities is ~240 mm in length or ~490 g (Figure 6b).

Juvenile *I. fuscus* were also successfully reared in shrimp ponds in Ecuador. A preliminary experiment was conducted early in the study to determine if small sea cucumbers (~100–150 g) collected from the wild would grow in ponds in different locations. Enclosures

Table 1. Development of *Isostichopus fuscus*, from fertilisation to 35-mm-long juvenile

STAGE	TIME Ecuador	TIME Mexico
Fertilisation	0	0
Elevation of the fertilisation envelope	4 minutes	5 minutes
Expulsion of the first polar body	7 minutes	10–15 minutes
Expulsion of the second polar body	9 minutes	16–20 minutes
2-cell	52 minutes	21 minutes
4-cell	70 minutes	30–40 minutes
8-cell	95 minutes	64 minutes
16-cell	124 minutes	71 minutes
32-cell	140 minutes	80–90 minutes
Blastula	3 hours	2.5–3.0 hours
Early gastrula	6 hours	6 hours
Hatching	10 hours	9 hours
Late gastrula (elongation)	14 hours	11 hours
Early auricularia	1–2 days	20–25 hours
Auricularia	3–15 days	3–10 days
Late auricularia (early metamorphosis)	16–18 days	11–17 days
Doliolaria	19–24 days	13–18 days
Early pentactula	21–26 days	14–19 days
Settlement (metamorphosis completed)	22–27 days	17–20 days
Juvenile, 1 mm	28 days*	21 days
Juvenile, 2 mm	30 days	30 days
Juvenile, 3 mm	32 days	40 days
Juvenile, 4 mm	38 days	45 days
Juvenile, 5 mm	40 days	48 days
Juvenile, 8 mm	44 days	55 days
Juvenile, 10 mm	47 days	61 days
Juvenile, 15 mm	51 days	65 days
Juvenile, 20 mm	56 days	70 days
Juvenile, 25 mm	63 days	74 days
Juvenile, 30 mm	69 days	78 days
Juvenile, 35 mm	72 days	85–90 days

* For the juvenile stages, the time indicated corresponds to the first noteworthy observations of a particular size in the tanks.

of 1 m^2 were used to facilitate recapture. These sea cucumbers grew an average of 17 g/week and exhibited a 98% survival rate, suggesting that shrimp ponds along the coast can provide a good environment to grow *I. fuscus* juveniles to adult size in a reasonable time frame. However, juveniles grown in tanks and shrimp ponds may both develop skin diseases that can cause massive mortality, especially during months with warmer temperatures and heavy rains (see below).

In Mexico in 2009, an experimental shrimp pond was used for the grow-out of hatchery-reared juveniles (starting with 2-month-old seeds of 3–5 mm and 4–7 mg). During the monitoring phase they grew from an average of 1.07 to 42.07 g in 3 months, but survival was low due to outbreaks of skin disease. Using mesh cages at sea (1.8 × 1.8 × 1.8 m) stocked with 3,000 seeds resulted in a more conservative growth rate (from 2.66 to 26.92 g in 3 months) but greater survival (40–90%). The presence of sponges and other fouling organisms on the mesh (500–1,000 µm), and clogging from accumulated sediments, might have prevented the entry of fresh deposits serving as food to the juveniles. The presence of crabs in the cages was also noted, which might have caused stress (slowing growth) and possibly mortalities.

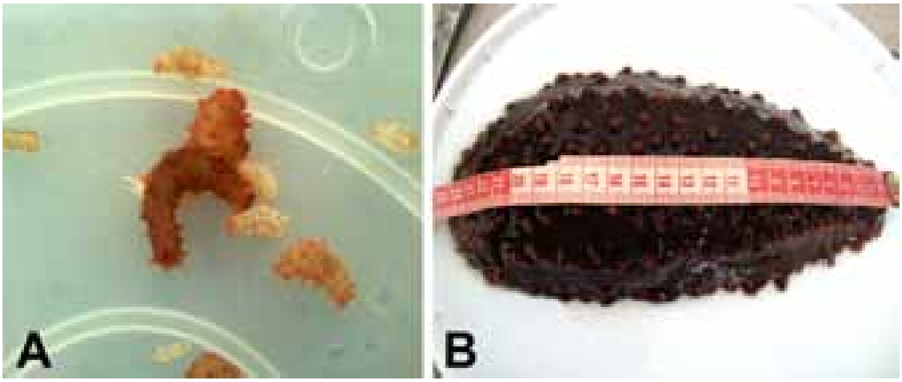

Figure 6. **A**: Juveniles of different sizes, ranging 3–25 mm in length, obtained in the same cohort. **B**: Maximum size of *I. fuscus* obtained through aquaculture (~24 cm long)

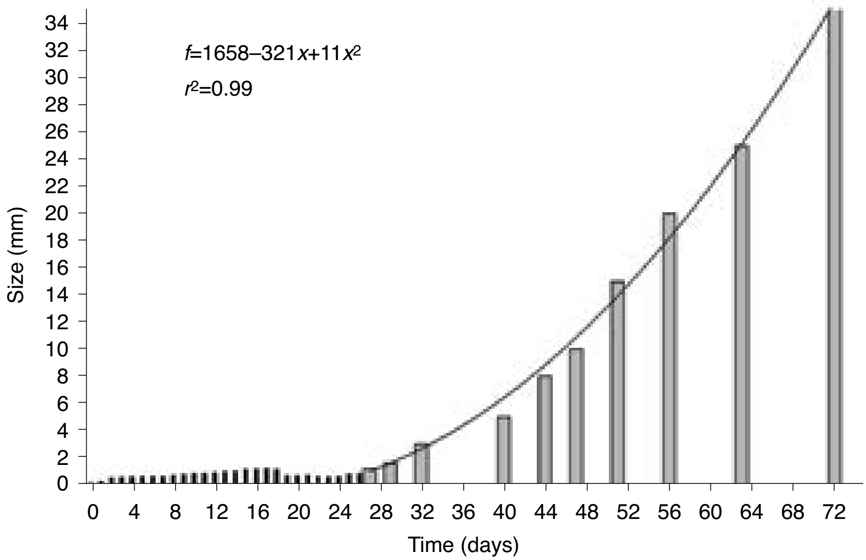

Figure 7. Average growth of larvae (black bars) and juveniles (grey bars) of the sea cucumber *Isostichopus fuscus* in Ecuador

Diseases and other problems

Parasites of the digestive tract in larvae

The most common problem observed during the culture of *I. fuscus* was the development of a disease in the digestive system of early larvae (Figure 8) (Becker et al. 2009). Following the appearance of opaque cells around the digestive tract, the second visible symptom was contraction of the intestine and stomach. In the worst cases, the digestive tract completely shrivelled up and disappeared. Once it became visible, the condition was usually fatal to the larvae.

Upon close examination of the affected larvae under the microscope, the disease was determined to be caused by protozoan parasites (Figure 8a, b). During the first stage of the disease, the parasites can be seen entering through the body wall and the digestive tract, probably inducing the observed contraction. Later in the development of the disease, the

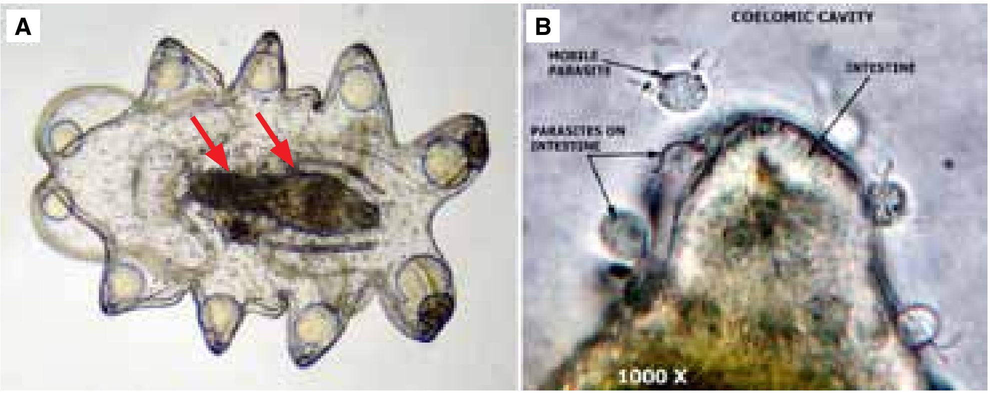

Figure 8. Micrographs of diseased *Isostichopus fuscus*. **A**: Auricularia larva (length 1.2 mm) with digestive tract invaded by parasites (arrows). **B**: Close-up view of the intestine with parasites (parasite diameter 12 µm)

parasites become larger and are present everywhere around the intestine, both inside and outside. The parasites that penetrate the intestine appear to feed on the intestinal contents or tissues, slowly making it shrink, sometimes rupturing the intestinal wall and typically causing the death of the larva within 1–3 days (Becker et al. 2009).

The parasites have never been observed in the larvae before hatching. However, the condition develops rapidly shortly thereafter, suggesting that the causal agents are present in the surrounding environment, and that they enter the larvae at the first opportunity. They seem to remain inactive until the larvae start to feed. Afterwards, they can be seen to develop in different areas of the mouth and, most commonly, the digestive tract (stomach and intestine). A form with thin appendixes can be found attached all over the larvae, but the amoeboid form is mostly observed around the digestive organs; it has the ability to move in and out of what appears to be a trophosoite form (Becker et al. 2009).

We have tried different methods of collecting the gametes to establish whether the parasites were coming from the sea water itself or from the spawning adults. It has proven impossible to develop a culture without the presence of the parasites at one stage or another, even when using artificial sea water from the onset. It would seem that the parasites are either present around the gametes and/or develop spontaneously in the culture (possibly from aerosols).

Close monitoring of the early larval stages allows detection of the first occurrence of the parasites, and enables control of the disease through adjustments of environmental parameters. If the disease is not contained in its earliest phase, the whole culture usually crashes. This problem is especially prevalent during the hottest and rainiest months of the cycle in both countries. Decreasing the temperature to ~24–26 °C and increasing aeration in the cultures mitigates proliferation of this parasite; however, even lower temperatures may slow or interrupt the development of the larvae.

Disease of the body wall (skin) in juveniles and larger individuals

In Ecuador and Mexico, grow-out trials in shrimp ponds or large tanks have so far yielded mixed results, with significant mortality due to a disease affecting the body wall (Figure 9). This condition may cause degeneration, evisceration and eventually death. Some promising treatments were devised in Mexico with daily usage of antibiotics for several weeks, but cured animals could develop the disease again later on. The best way to prevent and cure this condition in Mexico is currently to grow *I. fuscus* directly in the ocean or transfer any affected individual to the field as soon as the skin disease is detected.

Problems related to quality of food and water

Due to variable and often poor environmental conditions along the coast where the water was being pumped, a very complete filtration system, including UV treatment, had to be installed to provide the best possible water quality throughout the trials. The conventional treatment used for prawn culture was not dependable enough to grow sea cucumber larvae with optimum success, especially *I. fuscus*, which requires

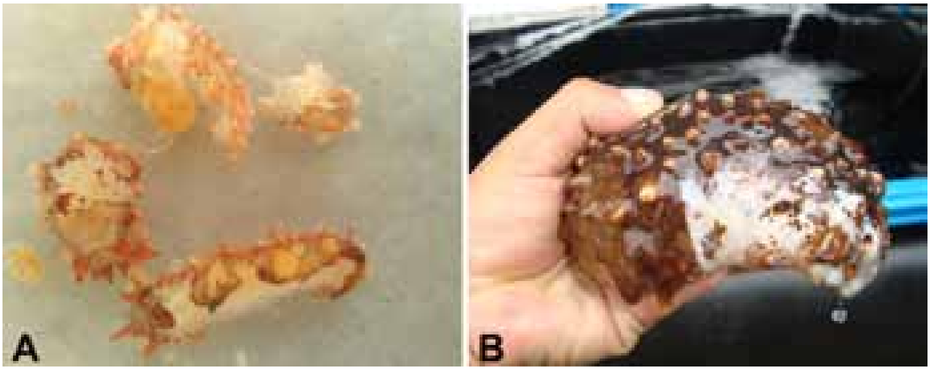

Figure 9. **A**: Juveniles and **B**: adult individuals of *Isostichopus fuscus* affected by body wall (skin) disease; individuals are ~2–3 cm long in A and ~20 cm in B.

high-quality oceanic water. Strict sanitary measures were adopted in the handling of gametes and larvae to maximise survival rates and minimise incidence of infections and diseases. Bacterial counts were routinely made from water samples to monitor the efficiency of the sanitary and filtration procedures.

Bacterial contamination of algal cultures was another common problem that had to be overcome. Growing larvae need large quantities of healthy live algae to develop steadily, especially during the auricularia stage. Inability to provide a healthy mix of algae can significantly delay growth and metamorphosis for extended periods. Thus, it has proven crucial to develop a system of algae production that is reliable and efficient.

As the size of the cultures grew from a few tens of thousands to over 2–3 million larvae per month, rearing conditions had to be maintained and eventually improved to avoid mass mortalities.

Outlook

After 10 years of research and development:

- A good portion of the effort has been placed on adapting shrimp farm equipment and larval rearing conditions to fit the needs of *I. fuscus*.
- The species has been found to follow a predictable lunar spawning cycle, which facilitates the collection of mature gametes (oocytes and spermatozoa).
- A larval rearing protocol has been developed using flow-through systems, an optimal micro-algae diet, water quality management and disease control.
- In successful trials, survival rates from fertilised egg to settlement varied from 2–13% in Mexico to ≥30% in Ecuador.
- Based on the best growth rates, juveniles can reach 8 cm (~25–27 g) in 110 days in shrimp ponds (Ecuador) and 90 days in cages (Mexico), with survival rates of up to 90%.
- While grow-out of sea cucumbers in tanks and shrimp ponds appears to be promising under optimal conditions, cage culture (sea farming) might be a more reliable and simple option because it is free of disease.

Future goals

Future research aims to:

- improve the diets and conditioning of adults to spawn when maintained in tanks to avoid having to continuously collect broodstock from the wild
- finetune hatchery and larval rearing protocols to maximise (scale-up) commercial mass-production
- optimise the control of larval and juvenile parasitic infestations and infections
- experiment with grow-out techniques to determine the best diet, substrates and location to grow the sea cucumbers to commercial size
- determine the commercial and ecological prospects for hatchery-produced *I. fuscus* (e.g. marketing, restocking)
- explore the possibility of culture away from shrimp habitat / installations.

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Sandfish sea ranching and farming

Brushing sea-pen netting to remove biofouling, Ambolimoke, south-western Madagascar (Photo: Georgina Robinson)

Principles and science of stocking marine areas with sea cucumbers

Steven W. Purcell[1]*

Abstract

Clearly stating the goals of stocking builds an essential platform for success. The scales, methodologies, management and time frames of the interventions can then be matched to the original goals. Stock enhancement, restocking and sea ranching will involve different stocking strategies. The genetic risks to wild stocks must be minimised by preventing translocation of juvenile sea cucumbers to different locations than those where broodstock were collected, unless studies show broad genetic homogeneity of the stock. Cultured juveniles are easily marked by immersion in a fluorochrome solution (e.g. tetracycline or calcein), which provides a long-term, unequivocal means of distinguishing hatchery-produced animals from wild conspecifics. Use of open sea pens is an experimental tool that provides better estimates of early stocking success. Juvenile density can be assessed by searching through sand and mud in quadrats by hand, whereas sub-adults and adults can be surveyed visually in transects with a stratified arrangement. Proponents of sea cucumber stocking in the wild should be conservative and realistic about the expected returns; 1 in 5–10 (10–20%) of released juvenile sea cucumbers surviving to market size is a benchmark. Clear goals, use of existing technology, and realistic expectations in sea ranching and restocking of sea cucumbers will provide the foundation for success.

Background

Stocking of marine invertebrates

While fish have been stocked into the sea since long ago, stocking of cultured marine invertebrates is mostly fairly recent (Bell et al. 2005). Notable invertebrates used in marine stocking include scallops and other bivalves, sea urchins, abalone, lobsters, Queen conch, giant clams and trochus. In the past, most stocking programs were unsuccessful in biological and economical terms (Leber et al. 2005; Bell et al. 2006). Poor survival of the released juveniles can be attributed, to a large extent, to inept knowledge about how, when and where to release the animals so that they may survive in high numbers (Liao et al. 2003; Purcell 2004; Lorenzen et al. 2010). Consequently, stocking programs started releasing cultured juveniles before the technology was developed to know how they should be released. This is unfortunate because stocking was thus criticised as a questionable management intervention even before the technology for many species was given the chance to be developed and proven (Hilborn 1998; Molony et al. 2003).

In recent times, criticism about stocking success has fostered a new era for programs to both develop release strategies through research before large-scale releases and conduct stocking in a responsible way (Blankenship and Leber 1995; Lorenzen et al. 2010). Key elements to responsible stocking are: (1) a requirement to demonstrate stocking success using marking of juveniles, (2) precautions to avoid disease transfer from hatchery stocks to the wild and (3) making efforts in the hatchery to produce juvenile cohorts with a wide genetic pool that closely matches the genetic make-up of the wild stocks among which the juveniles are released. As a consequence, greater scientific rigour in stocking programs is now giving back confidence in restocking, sea ranching and stock enhancement as potentially cost-effective management tools (Bell et al. 2006, 2008).

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Stocking of sea cucumbers

Stocking marine areas with sea cucumbers is a relatively nascent intervention (Battaglene and Bell 2004; Bell et al. 2005). Small-scale trials of stocking cultured sandfish (*Holothuria scabra*) in the sea appear to have commenced in the early 1990s in India (James 2004) and the late 1990s in Solomon Islands (Dance et al. 2003).

The Australian Centre for International Agricultural Research (ACIAR) embarked on a long-term program to assess the best tropical candidate species for restocking, develop hatchery technology for producing juveniles en masse, develop optimal release strategies, and apply the technology on a larger scale to test whether tropical sea cucumbers could be restocked or grown economically for village-based sea ranching. The first component, in Solomon Islands, determined that sandfish (*Holothuria scabra*) was the best species for tropical stocking, developed enough hatchery technology to produce them reliably for small-scale releases (Battaglene 1999; Battaglene et al. 1999) and studied the juvenile ecology (Mercier et al. 1999, 2000). The second component, in New Caledonia, adapted the larval culture and grow-out methods (Agudo 2006), developed methods to transport the juveniles (Purcell et al. 2006a) and technology for mark–recapture research (Purcell et al. 2006b; Purcell and Blockmans 2009), assessed release density and size-at-release in long-term release experiments (Purcell and Simutoga 2008), and evaluated restocking design (Purcell and Kirby 2006). The third component, being conducted in the Philippines and the Northern Territory, Australia, aims to determine whether the benefits of stocking sandfish for village-based sea ranching outweigh the costs of stocking (Juinio-Meñez 2012; Fleming 2012).

Purposes of stocking

The goals of stocking interventions will govern the management regulations needed and the spatial context of the releases. It is easy for agencies to develop a keen interest in culturing and stocking sea cucumbers in the wild without a clear description of the ultimate goals of the intervention. Such ambiguity can lead to false expectations of the likely outcomes, ownership or access issues, and the scale of releases and companion measures needed to achieve success. The path to failure in stocking programs is therefore often paved with uncertainty about the ultimate goals.

Stocking is a general term used here to mean the release of sea cucumbers into the sea with the expectation that they will then grow to larger sizes. Bell et al. (2005, 2008) and Bartley and Bell (2008) defined different types of stocking interventions, which are paraphrased, respectively, below.

- *Sea ranching*: *the release of cultured juveniles into open (non-bounded) habitats in the sea for harvesting once they reach market size*. This is a 'put, grow, and take' strategy relying on sole access rights (e.g. via lease of an area) to the proponents, without a main objective of increasing the yield of the overall fishery.
- *Restocking*: *the release of cultured juveniles into natural habitats to build nucleus breeding populations that will subsequently breed and replenish recruitment to repopulate the broader fishery*. This modality is predicated on protection of the released animals from fishing, ideally for their life span.
- *Stock enhancement*: *the release of cultured juveniles into the broader fishery to grow and later improve yields to fishers granted access to fishing grounds.* This modality does not have a main objective of rebuilding egg supply for generational stock rebuilding, and does not rely on sole access to stocked areas within the fishery.

Sea farming is another type of stocking, which is done into impoundments and artificial habitats (e.g. earthen ponds) supplied with sea water, but it is not examined in this paper.

The pathways to impact in restocking interventions are rather long compared with sea ranching (Figure 1). The main reason is because restocking relies not only on the survival of released animals to maturity, but also that they breed in the wild and that their offspring repopulate fishing grounds and survive to maturity (also see Molony et al. (2003)). The success of this latter, vital step of restocking is most difficult to demonstrate scientifically (Battaglene and Bell 2004; Purcell 2004). In contrast, sea ranching requires only that the stocked animals survive in high numbers to a market size.

Proponents should be explicit about whether the aim is to release animals that will be harvested by a particular group of people, or to rebuild depleted wild populations, or to enhance fishery yields for all fishers.

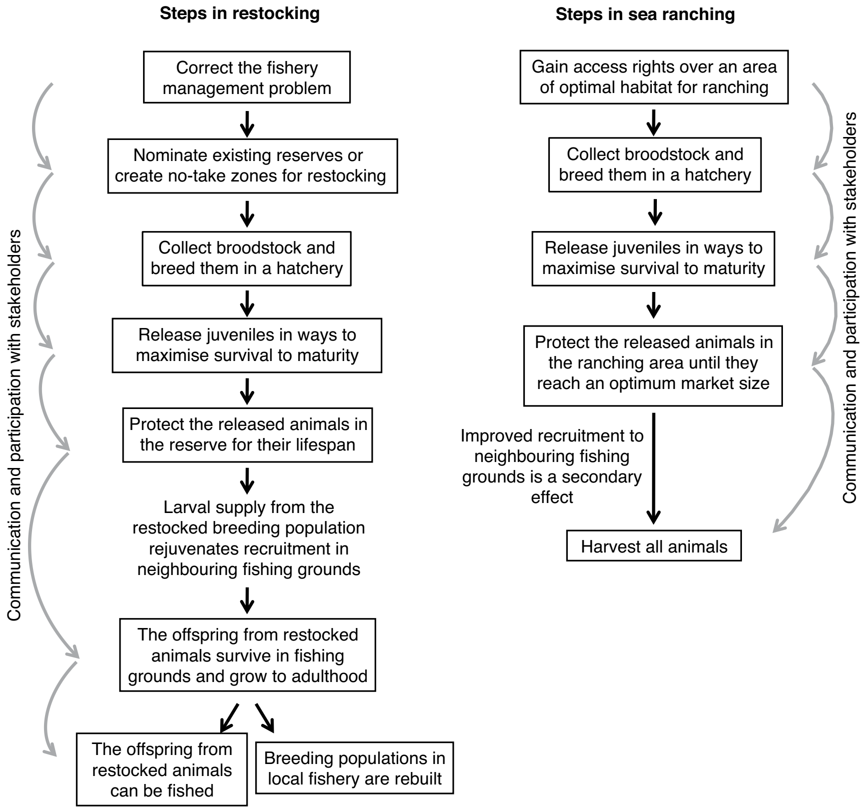

Figure 1. Important steps in restocking and sea ranching. Restocking relies on survival of the restocked animals to maturity and survival of their offspring to maturity. Also important through the steps of both interventions is frequent communication and participation of stakeholders.

Preserving the integrity of wild stocks

Risks of translocation

The ability to produce juveniles in the hatchery often spurs the desire to release them at various sites for various purposes. However, the genetic identity of local stocks, even those suppressed to low levels by fishing, should be maintained (Hindar et al. 1991; Utter and Epifanio 2002; Lorenzen et al. 2010). Some sea cucumbers such as black teatfish (*Holothuria whitmaei*) have high gene flow among populations, suggesting that larvae travel long distances and maintain genetic mixing among populations (Uthicke and Benzie 2000, 2003). In contrast, species such as the sandfish (*Holothuria scabra*) have restricted gene flow, causing certain populations to be relatively isolated from others, even within a country, and leading to unique genetic differences between populations at scales of less than 100 km (Uthicke and Benzie 2001; Uthicke and Purcell 2004). Native stocks may have particular genes that predispose them to cope much better with local environmental stresses that may occur periodically (Templeton 1986; Waples 1995).

Stock translocation may lead to reduced fitness of resident populations through *outbreeding depression* and *introgression* (Utter 1998; Uthicke and Purcell 2004). That is, introduced stock can outcompete with local stock (both ecologically and reproductively) or can interbreed with local stocks, leading to a loss in the genetic differentiation between populations. It is possible that introgression of foreign stocks could reduce the fitness of the population to deal with occasional environmental stresses (Figure 2). Such effects are not just theoretical; studies show that translocation of fish can negatively affect local populations, and the introduction of foreign genes can lead to long-lasting effects that are usually irreversible (Hindar et al. 1991; Waples 1995; Utter 1998).

Are there some instances when translocation of foreign stock could be responsible? In some cases, populations have been depleted to extinction such that teams of divers could not find even a small number to serve as hatchery broodstock for restocking, and years have passed without successful natural recruitment (Bell et al. 2005). If proponents can produce rigorous data to convincingly show this to be the case, foreign translocation of new stock may be the only practical solution to restoring populations, but such interventions should not be swayed by private economic interests. Additionally, responsible restocking in such cases would use broodstock of the closest populations from which broodstock can be collected.

Population viability relies on genetic variability among individuals (Waples 1995). Using a large number of spawning animals in each spawning event in the hatchery, and taking care with using different sperm from different males to fertilise different groups of eggs (to avoid sperm dominance), will help to produce genetically diverse juveniles for stocking in the wild (see Utter 1998).

Technology for stocking

Use of markers

In a 'responsible approach' to stocking (Blankenship and Leber 1995; Lorenzen et al. 2010), cultured animals stocked in the wild are first tagged or marked. Marking the juveniles allows them to be distinguished from wild conspecifics, and provides a means to evaluate the effectiveness of the intervention (Figure 3). The ability of sea cucumbers to shed tags inserted in their body wall or coelomic cavity prevents the retention of most tags used in fisheries biology, including streamer tags, T-bar tags, coded-wire tags, visible implant elastomer tags and passive induced transponders (Conand 1990; Kirshenbaum et al. 2006; Purcell et al. 2006b, 2008).

Genetic 'fingerprinting' of individual sea cucumbers provides an accurate marking method (Uthicke and Benzie 2002; Uthicke et al. 2004), but the method is relatively costly. This method has not been applied yet to cultured sea cucumbers. Alternatively, sea cucumbers can be marked with fluorochromes, which fluorescently marks the ossicles (spicules) in the outer body wall of the animals. This procedure can be as cheap as 2 cents (US) to mark a 5-g juvenile (Purcell et al. 2006b). Fluorochromes such as tetracycline and calcein have been shown to be

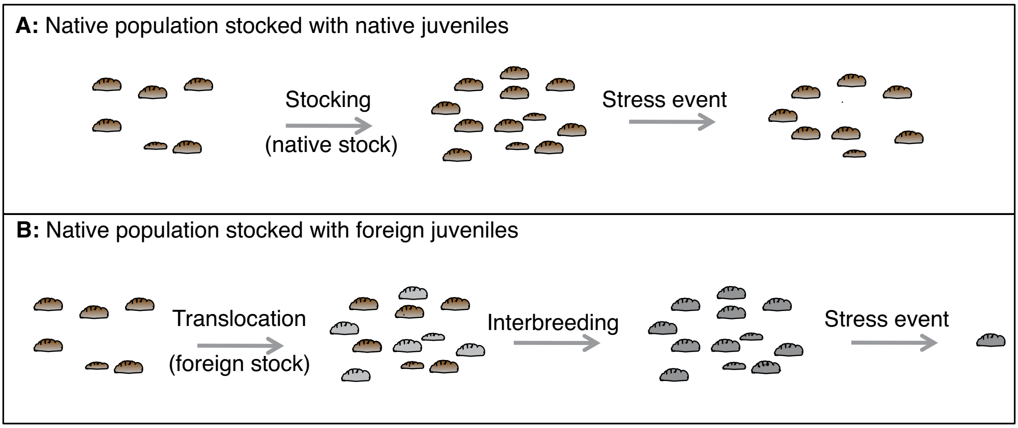

Figure 2. Illustration of one risk of translocation of foreign stock. **A**: Hatchery-produced juveniles from local (native) broodstock are stocked into the local population, the genetic identity of the stock is preserved, and the population is able to cope well with a stress event. **B**: Hatchery-produced juveniles from foreign broodstock (from a genetically different population) are translocated into the local population, the genetic identity of the stock is greatly reduced through introgression, and the interbred population no longer has the previous tolerance to cope with certain stress events.

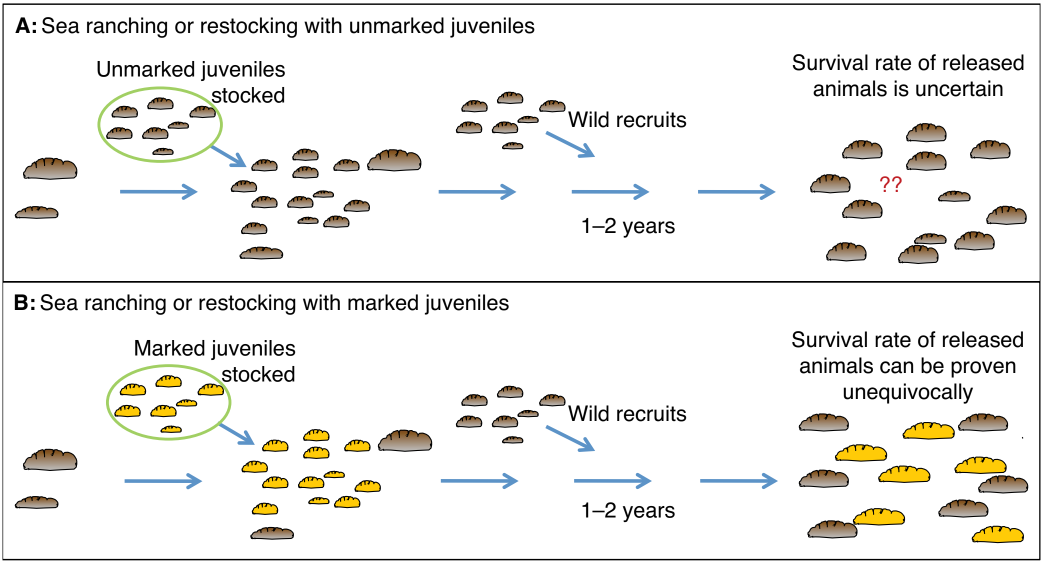

Figure 3. Diagrammatic illustration of pitfalls in releasing unmarked sea cucumbers in the wild. **A**: Unmarked cultured juveniles are released into an area that receives some natural recruitment of wild juveniles—it is impossible to validate how many, or what percentage, of the cultured animals survived over time. **B**: Marked cultured juveniles are released into an area that receives some natural recruitment of wild juveniles—the markers allow the cultured animals to be later distinguished from wild conspecifics mixed in the population to validate how many, or what percentage, survived over time.

suitable for up to about 2 years (Purcell and Simutoga 2008) (Figure 4), and 2-month trials with calcein blue and xylenol orange have shown long-term promise (Purcell and Blockmans 2009).

Cultured juveniles can be immersed in a marker solution in mass numbers in the hatchery within completely shaded flat-bottom tanks (Figure 5). The animals must be in a growth phase for the ossicles in their body wall to take up the fluorochromes (Purcell and Blockmans 2009). Fluorochromes are combined into the carbonate structure of ossicles during the process of calcification, and only that portion (e.g. 10–50%) of their ossicles being developed will be marked (Purcell et al. 2006b; Purcell and Blockmans 2009). Some juveniles may be slightly yellowish for a short time after immersion, but afterwards they are

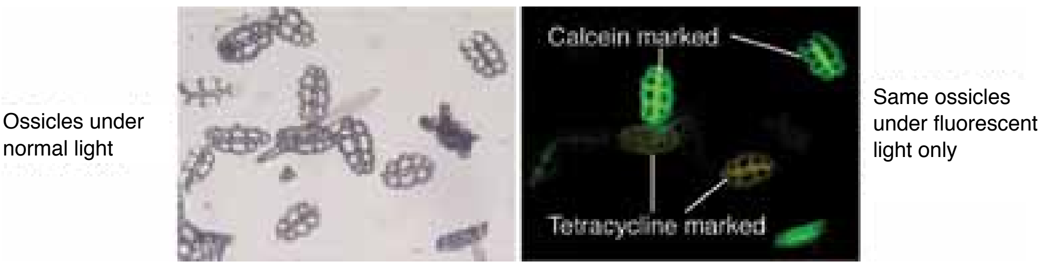

Figure 4. Ossicles (spicules) of *Holothuria scabra* individuals that had previously been marked sequentially by tetracycline then calcein (2 weeks later). Left: a field of view of ossicles under the microscope with normal light; right: the same field of view of the same ossicles under fluorescent light in an epifluorescence microscope. Note that about half of the ossicles have been marked—some that were fully formed were not marked during the immersion treatment.

Figure 5. Fluorochrome stock solution is added to a large tank with aerated sea water and a heater to maintain water conditions. The animals are left for 12–24 hours in the solution to enable effective marking of the ossicles within their outer body wall.

indistinguishable in outer appearance from unmarked animals. If ossicles are unmarked, or weakly marked, after an immersion treatment, it may be that (1) the animals were not growing well before the treatment (i.e. they were 'stunted'), so their ossicles were not being developed; (2) the conditions, such as the temperature of the immersion solution, were not well maintained; or (3) the fluorochrome chemicals were inactive—e.g. tetracycline can be damaged by light and heat.

The materials needed for verification of fluorochrome markers are surprisingly basic, and the methods are cheap and simple (Figure 6). Small tissue samples can be taken from the ventral surface of the sea cucumbers in the field. Most ossicles are about 50–100 µm long and there are thousands of ossicles in each cubic millimetre sample of outer body wall of sandfish (Purcell et al. 2006b). Once in the laboratory, the samples are simply soaked for 30 minutes in household bleach to digest the soft tissue, which leaves the ossicles in the sample container. The ossicles are rinsed with fresh water to remove the bleach, then dried and observed under an epifluorescence microscope.

Use of sea pens

In some situations, sea pens may be used for farming sea cucumbers to market size. For instance, it may be important to separate sea cucumbers from other animals or to keep them from moving into other areas where they can be fished (e.g. Robinson and Pascal 2009, 2012). However, sea pens can be costly (materials and set-up), require regular maintenance and do not allow sufficient space for large numbers of animals unless the pens are very large. Sea ranching of large numbers of sea cucumbers would involve an area (e.g. a sheltered bay) of good habitat in which the ranching proponents have exclusive access to the animals, and where the animals could be released into that area without sea pens. So long as the habitat is optimal or good for the species, the sea cucumbers will not be likely to move far in the years before they are harvested (Mercier et al. 2000; Purcell and Kirby 2006). Sea pens are, therefore, mostly advantageous as experimental tools to help the researcher better estimate survival and growth of released sea cucumbers.

Up to a size of about 50–100 g, juvenile sandfish can crawl up the walls of sea pens made of plastic mesh. Escape then causes an underestimation in survival rates. We conducted short trials in a hatchery tank with sand to test different designs of small (0.1 m^2) prototype sea pens in an attempt to find a design that would prevent 2–10-g juveniles from escaping. Copper wire sewn to the upper edge of the mesh deterred animals from moving over it and escaping, but was toxic. In a weakly replicated ($n = 2$) test over 24 hours, fewer juveniles escaped (climbed over) pens with mesh skirting (mean = 25% escape) compared with pens with the upper edges folded inwards (mean = 60% escape) or pens with simple straight edges (mean = 70% escape). Juveniles were observed to crawl up the mesh wall, but fell back into pens when they crawled to the edge of the net skirts. We therefore used small sea pens of 1 m^2 with mesh skirts for small experiments on release strategies (Figure 7). Later, we tested escape rates of similar sized juveniles from prototype pens in the hatchery that had a strip of antifouling painted on the upper edge, and found that escape rates over 24 hours were comparable with those using the mesh skirts. As mesh skirts were difficult to make, we used an antifouling strip on the upper 10-cm surface of the pen walls for large pens (e.g. 500 m^2). Note that the risk of escape is much higher with smaller pens because the animals are in close proximity to the pen walls; hence, escape rates from small pens are not indicative of those from large pens.

Surveys

Surveys for juvenile sandfish <100 g need to be done by hand because the animals often bury in the sediment during part of the day at this small size. This makes large transects impractical for surveying

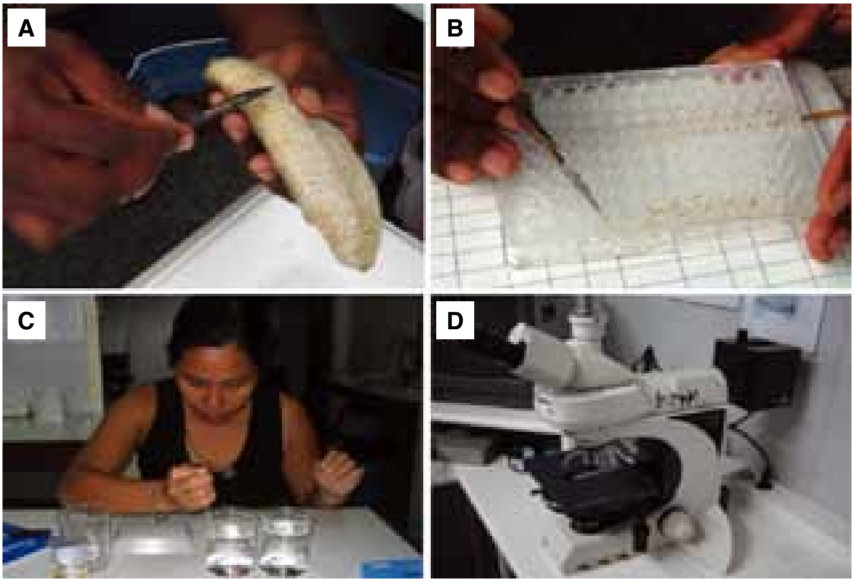

Figure 6. Steps in collecting and processing tissue samples of sea cucumbers to distinguish marked animals from unmarked (wild) ones. **A**: A tiny sample (a few mm^2) of the outer body wall is taken from the ventral surface of the animal, which is returned to the sea. **B**: The tissue sample is placed into a cell of a tray and buffered alcohol is added to preserve it. **C**: The alcohol is removed, bleach is added for 30 minutes to digest the soft tissue, then the bleach is removed and the ossicles are rinsed five times with freshwater. **D**: Once dry, the tray is placed under an epifluorescence microscope to look for fluorescently marked ossicles.

Figure 7. A small sea pen of 1 m^2 set into a seagrass bed. A mesh skirt on the upper edge of the pen mesh helps to prevent juveniles from escaping by climbing over the sea pen wall.

juvenile sandfish. The solution is to assess densities of juveniles within randomly placed quadrats of 1–2 m^2 by laying the quadrat and manually searching through the upper 5 cm of sediment by hand.

It is useful to estimate the survival rate in the initial months after release, when the animals are still juveniles. Within sea pens, quadrat surveys for sandfish should be stratified—some should be placed against the inner wall of the sea pen and some in the centre area of the pen (Figure 8). This is necessary because sea cucumbers will tend to gather near the edge of the sea pen through random movements (Jeanson et al. 2003), so this zone should be surveyed separately (Purcell and Simutoga 2008).

Once the animals in a sea pen are large enough to count reliably using visual census, the sea pen may be removed to allow the animals to displace over a larger area and avoid crowding. Conversely, the sea-ranching program may have simply released animals into the open and waited 6–12 months before doing visual surveys. In most sea-ranching situations, the animals

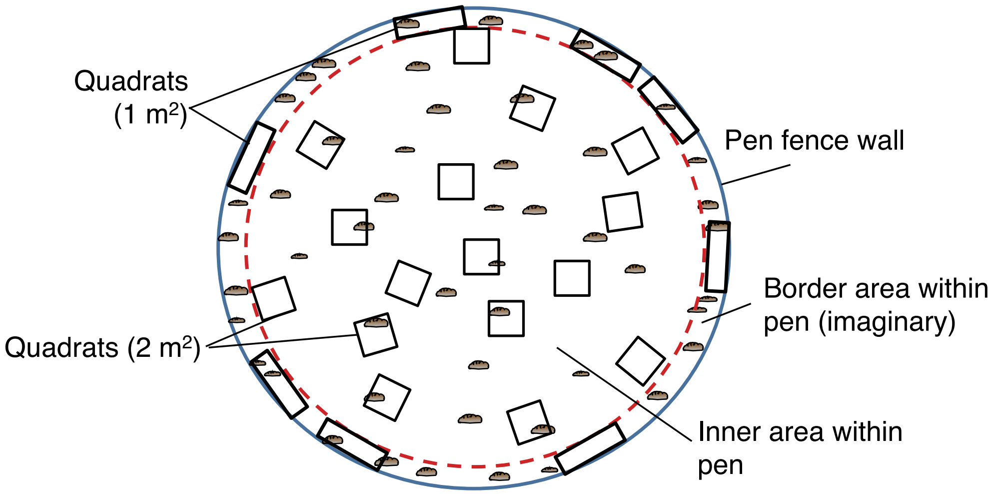

Figure 8. Potential placement of random quadrats within experimental sea pens. The number of animals within the border area—50 cm inside the inner wall of the pen mesh—can be sampled with rectangular 1-m^2 quadrats (2 × 0.5 m). Animals within the inner area can be sampled with square 2-m^2 quadrats (1.41 × 1.41 m).

would be released near the middle of the managed area at moderate density (e.g. 1/m^2). Through random displacement over long time intervals (see Purcell and Kirby 2006), some of the animals will move relatively large distances from the release area (e.g. 100 m), many would move short distances from the release area (e.g. up to 50 m) and many would stay in the release area. The uneven density of released animals calls for a stratified survey design (Figure 9). Zones can be marked out—for example, using buoys at the corners—to delineate the release zone (central zone), a middle zone and the outer zone. Transects can then be laid randomly in each zone, increasing replication in zones successively further from the release area to account for greater variability in counts within the replicate transects from increasing patchiness and sparseness of sea cucumbers.

Where to release?

Nature should be a useful guide to choosing good sites for stocking sea cucumbers. For example, sandfish (*Holothuria scabra*) larvae appear to settle on seagrass blades, and juveniles are known to inhabit shallow seagrass beds (Mercier et al. 2000). Sites with a current or previous history of hosting the species should be a sensible start. It may be that some sites never really were home to the species of sea cucumber but could serve as good stocking sites; however, this will generally be rare. Avoid sites with widely varying environmental conditions; for example, areas periodically subject to freshwater deluges. Likewise, avoid areas that may be vulnerable to pollutants (see Purcell and Simutoga 2008).

In an experiment in New Caledonia, we set up 30 replicate 1-m^2 experimental sea pens with net skirts 15 cm into sediments within various locations in a bay such that each pen had a different undisturbed habitat composition (S.W. Purcell, unpublished data). A group of 25 juveniles (2–10 g) was weighed and released into each sea pen. After 1 week, the juveniles surviving in each enclosure were collected by hand and an air-uplift suction device, and re-weighed. Preliminary analyses suggest that microhabitats for optimal growth and survival of the juveniles would have the following traits to ensure their protection from predators and allow them to bury easily:

- shallow—0.2 m to about 2–3 m depth
- a low proportion of coral or coral rubble in the sediments
- moderate penetrability of sediments; muddy-sand appeared best and should allow a hand to be forced easily to a few centimetres depth
- moderately high seagrass coverage, preferably in the genera *Cymodocea*, *Thalassia* and *Syringodium*.

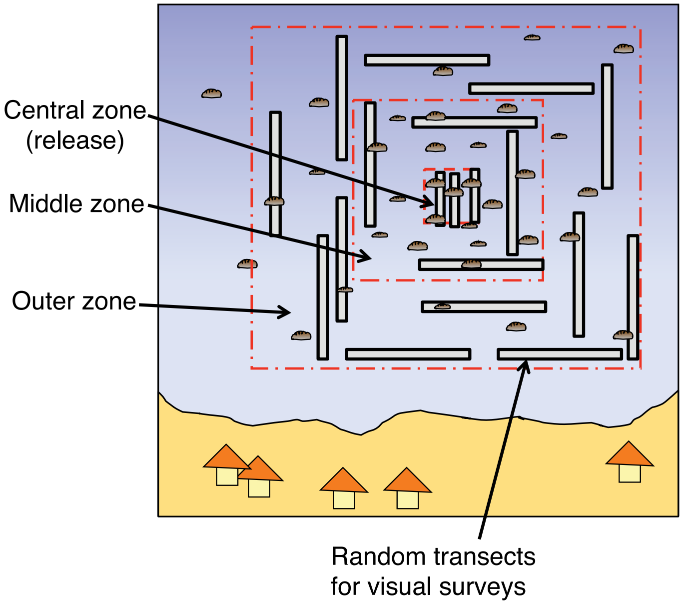

Figure 9. Potential design for transect surveys within a coastal seagrass bed in which cultured sea cucumbers (small oval figures) have been previously released for sea ranching, and have moved out of the central release zone. Bars are belt transects (e.g. 2 × 50 m) laid randomly within three zones (red dashed lines), which are defined at the site by buoys or other permanent markers at the corners of each zone. Stratified sampling is used; that is, the number of transects increases from the central zone to the outer zone because the sea cucumbers are expected to become sparser.

Expected returns

Unfortunately, but quite predictably, most of the small juvenile sea cucumbers released in the wild will not survive. Predation is the biggest hurdle in stocking a wide variety of invertebrates, and most of the released juveniles die or are eaten by predators shortly after being released (Bell et al. 2005). Many different animals eat sea cucumbers, particularly when they are young. Known predators of tropical sea cucumbers include a wide variety of crabs, predatory gastropods, sea stars, sea birds, and fishes including pufferfishes (Tetraodontidae), emperor fishes (Lethrinidae), triggerfishes (Balistidae) and wrasses (Labridae) (Dance et al. 2003; Francour 1997). Personal experience with various release experiments in New Caledonia suggests that invertebrate predators, especially crabs and sea stars, are especially voracious predators of juvenile sea cucumbers. These observations correspond closely with reports of crab predation in Madagascar (Lavitra et al. 2009; Robinson and Pascal 2012).

Modelling of survival rates of 5-g released juveniles showed that 7–20% of sandfish released in New Caledonia could be expected to survive to a good market size of 700 g 2.6 years after being released for sea ranching (Purcell and Simutoga 2008). Therefore, a conservative estimate of survival to this size would be about 1 in 10 (Figure 10). A survival rate of around 20% to this size over roughly 3 years could be achieved if conditions were favourable over the ranching period. This notion corresponds closely with shorter durations of some other recent studies. In Fiji, Hair (2011) determined survival rates of 23–41% for sandfish in sea pens over just 6 months, and the animals had not reached a market size. Similarly, in the Philippines, a survival rate of 39% was reported by Juinio-Menez et al. (2012) for sandfish in a sea ranch;

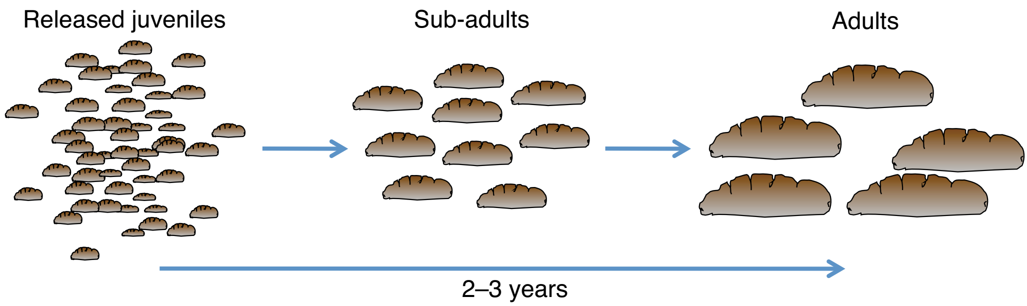

Figure 10. Stylised diagram of changes in size and numbers of sea cucumbers, due to death and predation, from the time of release in the wild to the time at which they reach a good marketable size

however, these comprised juveniles from batches released at various occasions over a 19-month period, and many had been recently released.

Overly optimistic predictions of economic returns from sea ranching will give expectations to villagers that will be difficult to meet, and proponents may benefit more from conservative expectations and praise at exceeding them. Estimates of economic viability of sea ranching can then be made by back-calculating revenue from the harvested animals to the maximum cost of producing juveniles in hatcheries to make a profit (see Leber et al. 2005; Purcell and Simutoga 2008). Two additional points should be considered:

1. As with other mariculture programs, some patience and investment is needed early on because it often takes years to reduce the costs of producing juveniles and to perfect release methods.
2. Benefits to communities extend beyond the economic (Lorenzen et al. 2010); sea ranching and restocking can build technical capacity and foster awareness for better stewardship of the resource by communities, which should be considered a valuable outcome for fishery managers.

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Pond grow-out trials for sandfish (*Holothuria scabra*) in New Caledonia

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Abstract

Sandfish (*Holothuria scabra*) is a high-value tropical sea cucumber widely distributed in the shallow waters of the Indo-Pacific. In New Caledonia, sandfish are locally called 'gris' and have been harvested since the 1840s. The WorldFish Center in New Caledonia grew cultured juvenile sandfish in earthen ponds to assess the potential for farming the species. In this paper, we report on pond culture grow-out of sandfish from small juveniles to market size in a 21-month trial. Sandfish in two ex-shrimp ponds reached mean weights of 390 and 441 g after 19 and 21 months, respectively. The overall average weight gains were estimated to be 0.60 g and 0.77 g per animal per day, and overall survival to be 69% and 41%, respectively. Some mortality occurred in ponds due to high water temperature and salinity. Beche-de-mer produced from the pond-grown sandfish had a darker skin colour and most was classified as grade-A, although cultured animals lost twice as much weight as the wild sandfish during processing. Positive features were the homogeneous sizes of pond-grown animals and the potential for reduced fluctuations in numbers. Recommendations for improving sandfish farming in ponds centre on the management of animal density and the practice of alternating earthen ponds.

Introduction

Sandfish, *Holothuria scabra*, is a tropical sea cucumber widely distributed in the shallow waters of the Indo-Pacific (Conand 1998). This species has a high commercial value on the international market once processed by boiling and drying into beche-de-mer (also called trepang). In New Caledonia, sandfish are locally called 'gris' and have been harvested since the 1840s (Conand 1990). The current fishery is composed mainly of Indigenous artisanal fishers (Purcell et al. 2002). The price for beche-de-mer exports depends on its quality and size, and in 2007 was in the range US$21–47/kg in New Caledonia. Over the past 10 years, exports of beche-de-mer from New Caledonia have ranged from 40 to 80 tonnes annually according to the Institut de la Statistique et des Etudes Economiques de Nouvelle-Calédonie (ISEE).

Pioneering work on sandfish spawning and rearing was done in India in 1988 at the Central Marine Fisheries Research Institute (James et al. 1994). Rearing methods were then developed further by the WorldFish Center (formerly ICLARM) in Solomon Islands (1996–99), Vietnam (2000–04) and New Caledonia (2000–06). The main focus of the research by the WorldFish Center in New Caledonia was the release of juveniles into enclosures in the wild to determine the optimum size and density for restocking and stock enhancement. Additionally, some of the cultured juvenile sandfish produced in New Caledonia were on-grown in earthen ponds to assess the potential for farming the species. Preliminary results were reported by Bell et al. (2007). In this paper, we report more details on pond-culture grow-out of sandfish from small juveniles to market size (400–600 g).

Methods

The grow-out trials for sandfish were conducted over 21 months between June 2005 and March 2007. Two 0.2-ha earthen ponds (A and B) on a private shrimp

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farm at Tontouta, 50 km north of Noumea, were used (Figure 1). All juveniles used for these trials were reared in the WorldFish Center's sea cucumber hatchery at Saint Vincent (Boulouparis, 73 km north of Noumea) using the methods described by Pitt (2001) and Agudo (2006). Pond A was stocked with juveniles that had a mean weight of 0.9 g at a stocking density of 1.6 individuals/m^2. Pond B received larger juveniles (mean weight of 11.7 g) at a density of 0.8 individuals/m^2. The grow-out trials commenced during winter on 6 June 2005, when the average water temperature was 22 ºC.

Both ponds had a maximum depth of 1 m and a muddy substratum. The ponds had previously been used for maintaining shrimp (*Litopenaeus stylirostris*) broodstock, but had been empty since 2002. They were filled with sea water 2 weeks before transferring the sandfish juveniles. No food or fertiliser was added. Daily water exchange usually varied between 30% and 60%, but fell to less than 10% on one occasion due to a broken water pump. Water temperature (ºC), salinity (ppt), dissolved oxygen (ppm) and secchi disk (cm) measurements were taken twice a day, in the morning and in the afternoon.

Figure 1. Earthen pond used for growing out sandfish

To estimate the growth of sandfish, the mean wet weight (g) of 30 individuals from each pond was measured each month. Animals were collected at random, dried in the shade for 5 minutes, then weighed with a digital balance. Survival of sandfish in each pond was determined by counting all animals when the ponds were drained at the conclusion of the trial.

Harvested sandfish were processed by a professional into beche-de-mer by gutting, boiling, soaking in sea water overnight, cleaning, boiling again and drying. A local trader evaluated the beche-de-mer based on skin colour, cleanliness of gut and skin, and resultant product grade.

Results

Water quality parameters

Water temperature was in the range 16.9–33.3 ºC, with mean water temperatures between 27.3 ºC and 27.9 ºC in summer and between 17.5 ºC and 24.1 ºC in winter (Figure 2). Dissolved oxygen variation was 2.9–14.2 ppm, and salinity was mostly between 32 and 36 ppt. Extreme values of salinity such as 25 and 38 ppt were occasionally observed. Secchi measurements averaged 50 cm.

Growth rate

In pond A, sandfish with an initial mean weight of 0.9 g reached a mean weight of 325.4 g after 12 months. Their growth then slowed during the cold season, when mean water temperatures were between 20.4 ºC and 22.7 ºC (Figure 2). Sandfish in pond A reached a final mean weight of 390 g after 21 months (Figure 3). Mean individual growth rate was correlated with water temperature and reached a peak of 1.04 g/day in April 2006, when the mean water temperature was 27.3 ºC (Figure 2).

In pond B, the sandfish with a greater initial weight of 11.7 g reached a mean weight of 395 g after 13 months. Their growth also slowed during the cold season when mean water temperature was in the range 20.7–22.7 ºC. Excessive development of filamentous algae in pond B meant that these animals had to be transferred to another pond in December 2005. At the time of transfer, survival was 73%. The transferred sandfish reached a final mean weight of 441 g after 19 months (Figure 3), and maximum growth rate was 1.3 g/day in March 2006 (Figure 2).

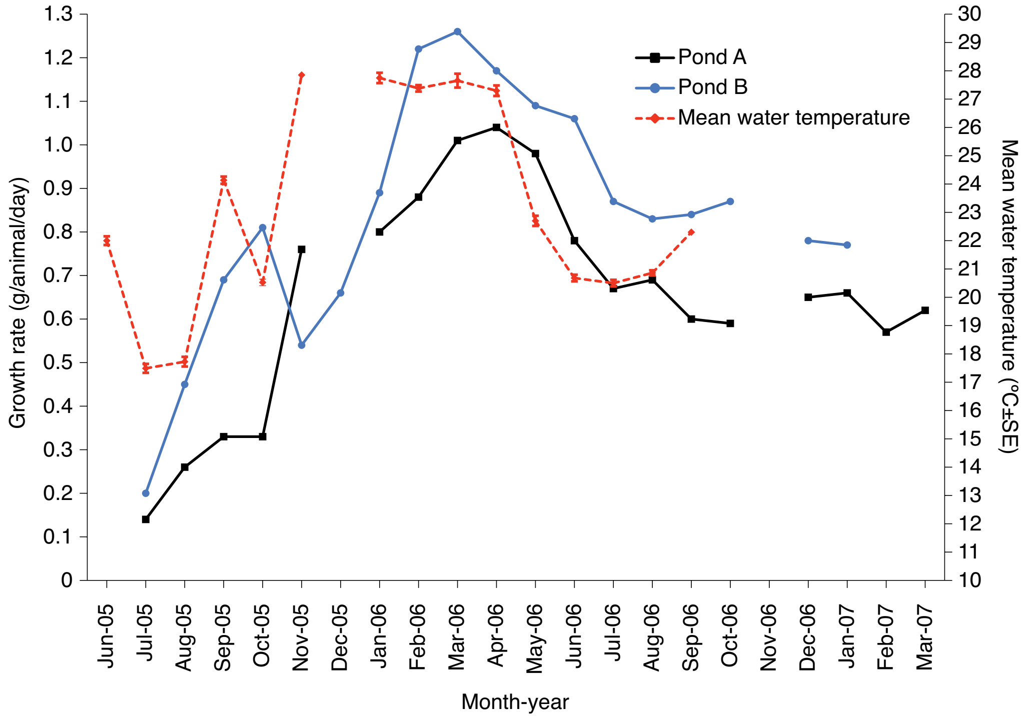

Figure 2. Growth of sandfish and mean water temperature in ponds A and B

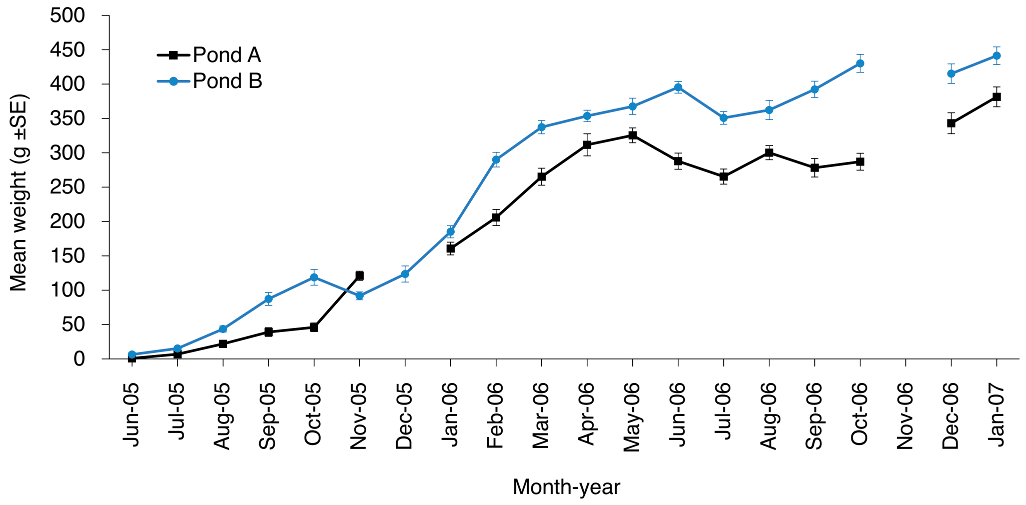

Figure 3. Mean weight of sandfish in ponds A and B

Maximum growth for sandfish in both ponds during these trials was reached after 10–11 months during summer (March–April 2006, Figure 2). Growth then decreased and ranged from 0.6 to 0.8 g/day for pond A, and from 0.7 to 0.9 g/day for pond B (Figure 2). The overall average weight gains were estimated to be 0.60 and 0.77 g/animal/day for ponds A and B, respectively.

The length–weight relationship of the sandfish stocked into ponds A and B (Figure 4) is a power curve, as described by Pitt and Duy (2004a).

Survival and stocking density

In pond A, survival after 21 months was 69%. The final density was 1 animal/m² and biomass was 434 g/m². This was well above the level of ~225 g/m² thought to be the limit of growth rates (Battaglene 1999). Over 3 days in early 2007, 2,222 sandfish were harvested (45, 280 and 1,897 animals harvested on 24 January, 26 January and 15 March, respectively).

In pond B, final survival was 41% after 19 months; high mortalities were observed after the first 6–7 months during the 2005–06 summer due to excessive weed proliferation (Figure 5), which, in turn, induced high water temperature and salinity. At the time of transfer of animals, during that summer, the survival rate reached 73%. The final density was 0.3 animals/m² and biomass was 147 g/m². Over 3 days in early 2007, 668 sandfish were harvested (376, 68 and 224 animals harvested on 10 January, 13 January and 26 January, respectively).

Behaviour of sandfish in ponds

During the full moon in February 2006, when the average water temperature was 27.4ºC, an aggregation of at least 100 sandfish was observed on the edge of pond A (Figure 6). They formed groups of four or five individuals (mean weight of 206 g), reaching a maximum density of 30 animals/m². Pre-spawning behaviour, such as rolling movements, was also observed. In March 2006, in pond B, an adult male (>300 g) spawned in the afternoon. This occurred 1 day after the first quarter of the moon, when the water temperature was 30.7 ºC.

During winter 2006, 70% of the sandfish were buried with a thick layer of mud covering their dorsal surface (Figure 7). The average water temperature in ponds during this period was 20.5 ºC.

Birds and their footprints were often observed around the ponds. Crabs (e.g. *Portunus pelagicus*, *Scylla serrata*), indigenous shrimps (*Penaeus* sp.) and fish (*Apogon* sp., *Siganus* sp.) were also seen in the ponds. During the 21-month grow-out period, 14 sandfish (22–392 g) with skin lesions were observed (Figure 8). The lesions were always on the dorsal surface of the animals, and appeared to have been caused by predators such as large crabs and birds.

Another danger is if the pond water level suddenly drops. Animals buried near the edge of ponds can be trapped, and if they remain out of water for more than a few hours, they will eviscerate and die (Figure 9).

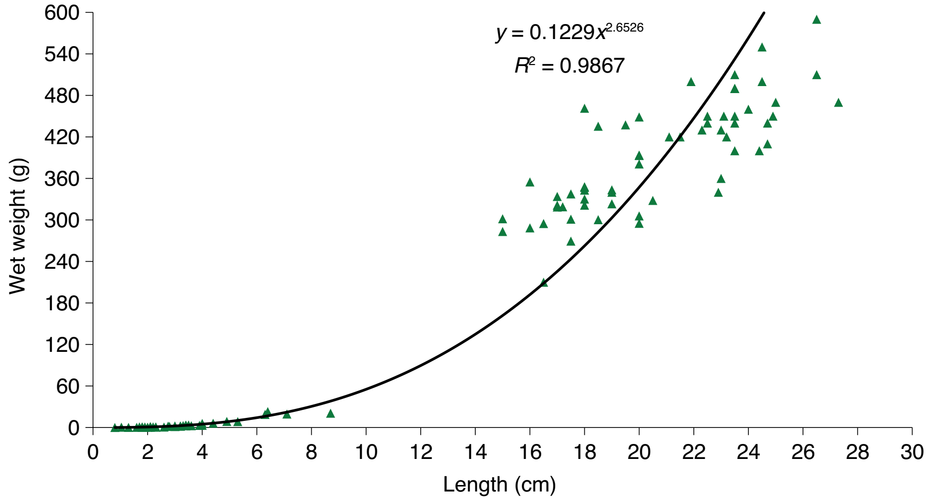

Figure 4. The length–weight relationship for cultured sandfish reared in ponds

Figure 5. Weed proliferation in a grow-out pond

Figure 6. Aggregation of sandfish near pond edge

Figure 7. Buried sandfish

Figure 8. Sandfish with skin lesions

Figure 9. Trapped and eviscerated sandfish

Processing into beche-de-mer

During processing (Figure 10A, B), sandfish were gutted by making a small incision on the ventral surface to remove the viscera. Initial boiling time was about 30 minutes. Drying was done outdoors under the sun for at least 1 week, depending on the weather.

The beche-de-mer from the cultured animals had a darker skin colour than the product processed from wild sandfish. Most of the cultured beche-de-mer was classified as grade A (with some grade Extra-A and grade B) with a free-on-board export value of €75–77/kg (2007 prices). A negative aspect was that cultured animals lost twice as much weight during processing compared with wild sandfish. Hence, for the grade A beche-de-mer, there were 25 pieces/kg instead of 13–15 pieces as found in wild sandfish harvests. In spite of this disadvantage, the consistently large specimens and high final grade were encouraging features for the trader, who normally has to deal with variable sizes and fluctuations in numbers from local wild sandfish fisheries.

Discussion

Although the sandfish in our trials required minimal husbandry, some mortality did occur in pond B due to high water temperature and salinity. Thus, a combination of extreme conditions, such as sudden variation of temperature and salinity, handling and transport may generate harmful stress leading to loss of stock. A key requirement of management is to observe some relatively simple measures to minimise the risks of stress, such as avoiding extreme variations in water temperature, always keeping the animals in water in the shade, and not overcrowding the animals in containers. Nevertheless, the costs of husbandry should be modest because sandfish do not need feeding in ponds at medium densities (1.5–3.0 t/ha) (Pitt and Duy 2003).

Stratification of water in ponds due to heavy rainfall is to be avoided (Pitt et al. 2001) because it can lead to extremely high temperature, low salinity and low dissolved oxygen. Sandfish can survive salinities as low as 20 ppt, but they are vulnerable to anoxic conditions in ponds (Pitt and Duy 2004b). Proliferation of filamentous algae can also cause similar problems.

Figure 10. Sandfish processing showing: freshly harvested sandfish (A) and initial boiling (B)

Provided that suitable water conditions can be maintained in ponds, the growth rates of sandfish are encouraging for farming. Indeed, from grow-out trials in shrimp ponds in Vietnam, individual growth rates of 2 g/day appear to be possible throughout much of the year on a range of substrates (Pitt et al. 2001; Pitt and Duy 2003, 2004b). Growth rates in New Caledonia were also favourable—at 0.6–1.3 g/day—and higher than those in the wild (Hamel et al. 2001). They were lower than those in Vietnam, presumably due to cooler water temperature and lower levels of nutrients in the ponds. It appears that lack of nutrients in the sediment, high biomass and low water exchange resulted in environmental conditions that did not favour growth. Management of density was not attempted during the grow-out trials because of the distance to the site and the fact that a technician was not on site at all times. These results suggest that survival and growth could be improved substantially by regular removal of sandfish to another pond.

The duration of grow-out to 400 or 600 g can possibly be reduced in New Caledonia if juveniles are released in summer into ponds with enriched substrates. Another potentially promising way to reduce the cost of farming sandfish is to find ways to bypass the second nursery phase in hatcheries by releasing newly settled juveniles directly into ponds. For this to succeed, the pond will need to have sediment that allows the growing juveniles to bury, and predators will need to be controlled.

This trial showed that sandfish, *Holothuria scabra*, could be reared in earthen ponds. In nature, these sea cucumbers live mainly on sandy–muddy subtrata. However, the sediment found in shrimp ponds in New Caledonia appears to fit the habitat requirements of sandfish.

In New Caledonia the hot season lasts from November to mid April, and the coldest season from mid May to mid September. In summer, tropical depressions and cyclones can also bring heavy rains that pose a risk to the farming of sandfish. Without any management or intervention, long periods of rain can lead to partial or total loss of animals in earthen ponds. Future studies should focus on the monitoring and management of freshwater influx into ponds during these high-risk periods.

During the hatchery–nursery phase, juveniles of 1 g may be obtained after 2–3 months of culture. But we must consider that 19–20 months of rearing in ponds is necessary for a minimum of 500 g weight, on average, for sea cucumbers. Further research should focus on improving farming conditions for better growth performance and reduced rearing periods.

Finally, the practice and advantages of alternating pond-culture species could also be considered. This practice could actually improve sediment quality and thus the pond environment. Research on the effects of livestock sandfish quality and the structure of the sediment basins would be useful.

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Ability of sandfish (*Holothuria scabra*) to utilise organic matter in black tiger shrimp ponds

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Abstract

Due to frequent viral disease outbreaks, a large proportion of shrimp aquaculture in South-East Asian countries has switched from black tiger shrimp (*Penaeus monodon*) to *P. vannamei,* an exotic species originally imported from Latin America. One of the causes of disease outbreaks is thought to be poor water and sediment conditions in the shrimp ponds, which may aggravate disease symptoms. To obtain basic information for co-culture methods of black tiger shrimp and sandfish (*Holothuria scabra*) for possible mitigation of shrimp-pond eutrophication and prevention of disease outbreaks, basic laboratory experiments were conducted at the Southeast Asian Fisheries Development Center—Aquaculture Department in Iloilo, the Philippines. A feeding trial of juvenile sandfish showed that they do not grow well with fresh shrimp feed on hard substrate. Another trial indicated that sand substrate enhances the growth of juvenile sandfish fed with shrimp feed. A feeding trial using shrimp tank detritus, shrimp faeces and *Navicula ramosissima* (a benthic diatom) as food sources showed that sandfish grew fastest with the faeces, followed by detritus and *N. ramosissima*. Dissolved oxygen consumption and acid-volatile sulfur levels in the shrimp tank detritus were reduced by sandfish feeding. This suggests that sandfish are capable of growing with organic matter in shrimp ponds, and can bioremediate shrimp-pond sediment.

Introduction

The majority of shrimp aquaculture in South-East Asian countries has changed from black tiger shrimp (*Penaeus monodon*) to *P. vannamei*, which is an exotic species originally imported from Latin America. The change in target species has occurred due to frequent viral disease outbreaks, such as white spot syndrome disease, yellow head disease, hepatopancreatic parvovirus disease and monodon baculovirus disease (Flegel 2006). Effective measures for the prevention of the diseases have not been established. Vaccination against these diseases is still under development, and it is extremely difficult to completely prevent viral intrusion via crustaceans and birds that enter outdoor shrimp ponds. In order to avoid risk of economic loss associated with mass mortality, more farmers culture *P. vannamei*, which can be harvested at a smaller size and earlier than *P. monodon*. However, there is a possibility that *P. vannamei* 'escapees' may reproduce in the wild and cause significant problems to the natural environment. With the introduction of *P. vannamei,* Taura syndrome virus and infectious hypodermal and hematopoietic necrosis virus have now become problematic (Flegel 2006). Thus, it is desirable to establish less risky culture methods of *P. monodon* to revive their production.

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While extermination of viruses is difficult, it may be possible to suppress disease outbreaks by maintenance of optimal water and sediment conditions. Anecdotally, it is thought that the disease symptoms do not readily manifest in shrimps reared in good environmental conditions, despite the presence of viruses (Lightner and Redman 1998). As an inexpensive technique of environmental control of shrimp ponds, co-culture with commercially important organisms that have bioremediation capability may be a promising approach, and can also provide additional income to farmers. Mitigation of shrimp-pond eutrophication by co-culture may also help reduce environmental deterioration in areas affected by intensive shrimp aquaculture, which has always been an issue in South-East Asian countries. To this end, the feasibility of co-culture of *P. monodon* and sandfish (*Holothuria scabra*), a high-value tropical sea cucumber, was examined in this study. Since sandfish stocks have been heavily depleted in many parts of South-East Asia (Carpenter and Niem 1998; Hamel et al. 2001; Conand 2004), the co-culture may also be beneficial for sea cucumber conservation.

There are a number of studies on co-culture of sea cucumbers with other organisms, such as teleost fish (Ahlgren 1998), bivalves (Zhou et al. 2006; Slater and Carton 2007, 2009; Paltzat et al. 2008), gastropods (Kang et al. 2003; Maxwell et al. 2009) and shrimps (Pitt et al. 2004; Purcell et al. 2006; Bell et al. 2007). These studies tried to make use of the sea cucumbers' ability to consume particulate organic matter in the sediments. Pitt et al. (2004) studied the effects of size, stocking density and feeding on the feasibility of co-culture of *P. monodon* with *H. scabra*, and reported that co-culture is possible in many situations. However, they encouraged further, more rigorous studies due to statistical uncertainty in their study. In the present study, feeding trials of *H. scabra* using various types of organic matter available in shrimp tanks were conducted in order to ascertain an effective feeding method for *H. scabra* in shrimp ponds. The biomitigating ability of *H. scabra* in tanks was also studied.

Materials and methods

Feeding trial 1: benthic diatoms and shrimp feed

Juveniles for use in the trials were produced at the sea cucumber hatchery of Southeast Asian Fisheries Development Center—Aquaculture Department (SEAFDEC–AQD). In order to compare the relative importance of diatoms and shrimp feed as food sources for juvenile *H. scabra*, feeding trials were conducted using *Navicula ramosissima* (benthic diatom monocultured at SEAFDEC–AQD) and *P. monodon* powdered feed (SEAFDEC–AQD formula). For each treatment described below, five juvenile *H. scabra* were placed in 60-L fibreglass tanks filled with filtered and UV-treated sea water with aeration. Sea water was pumped from offshore, sand filtered, filtered with 10-µm and 1-µm filters, and UV treated before use in the experiments. No substrate was added to the tanks. The juveniles were fed every 2 days with one of the following diets: (1) 1,000 mL *N. ramosissima* (~6.2×10^5 cells/mL); (2) a mixture of 500 mL *N. ramosissima* and 0.5 g powdered shrimp feed; (3) 1 g powdered shrimp feed; or (4) no feed (negative control). Three replicate tanks were used for each treatment, except for the control, where only one tank was used. In order to prevent growth of natural food and accumulation of contaminants, the tanks were cleaned thoroughly and water changed completely prior to feeding every 2 days. To compare the growth rates between treatments after 3 weeks, the juveniles' body length (BL) and weight (BW) were measured to the nearest 0.01 mm and 0.01 g, respectively. To increase size measurement accuracy, the juveniles were anaesthetised with 2% menthol–ethanol solution (Yamana et al. 2005) and blotted dry with paper towels prior to sampling.

Feeding trial 2: effect of sand on sandfish growth

The effects of the presence of sand substrate on the growth of *H. scabra* were studied. Sand collected from the beach in front of SEAFDEC–AQD was sieved through 1-mm mesh, washed with fresh water, bleached with sodium hypochlorite, washed again and sun-dried. The prepared sand was placed in a 60-L fibreglass tank (to approx. 5 cm depth), and filtered (10-µm and 1-µm) and UV-treated sea water was added to the tank. Five *H. scabra* juveniles were placed in the tank and provided with aeration (the with-sand treatment). The same number of juveniles was also placed in another 60-L tank under the same conditions except without sand (the without-sand treatment). The juveniles were fed with powdered shrimp feed (0.5 g/tank) every day. Water in the tanks was changed 100% every 2 days but the sand was not washed during the 2-week trial. Growth in BL and BW over the course of the experiment was compared between treatments.

Feeding trial 3: organic matter from shrimp tanks

Further effects of food types on growth of *H. scabra* juveniles were studied using organic matter that should be available in shrimp ponds: shrimp faeces, shrimp-tank detritus and *N. ramosissima* (*Navicula* species are ubiquitous). Faeces and detritus were collected from *P. monodon* tanks at SEAFDEC–AQD. The tanks were drained to collect the sedimentary detritus, and fresh faeces were manually separated from the total detritus using spoons. Faeces and detritus were stored at –80 °C until used.

Juvenile *H. scabra* were individually placed in containers made of PVC pipe (10 cm diameter × 5 cm length) with both ends covered with 5-mm mesh. For each treatment described below, 10 containers were placed in each 60-L fibreglass tank with sand and aeration. Each container was partially embedded in the sand. Juveniles were fed every 2 days with the following: (1) 2 g shrimp-tank detritus; (2) 2 g shrimp faeces; (3) 430 mL *N. ramosissima* (~ 6.2×10^5 cells/mL); and no feed (negative control). Two replicate tanks were used for each treatment except for the control, where only one tank was used. Water was changed 100% every 2 days and sand in the tanks was not cleaned. The trial ran for 10 days.

The BL and BW of all juveniles were measured after 10 days. The juveniles were anaesthetised before recording the measurements. Carbohydrate concentration in the coelomic fluid of the juveniles was measured after the size measurements. Coelomic fluid was collected with a micropipette though an incision along the abdomen, and the carbohydrate concentration was measured by a modified phenol – sulfuric acid method (Kushwaha and Kates 1981). A 10-µL aliquot of coelomic fluid was mixed with 40 µL distilled water, 20 µL 5% phenol solution and 100 µL concentrated H_2SO_4 in 2-mL microtubes; vortexed; and incubated in a block heater at 80 °C for 10 minutes. Absorbance was read at 490 nm against a blank, using a microplate reader.

Biomitigation of sediment eutrophication by sandfish

In order to examine the ability of *H. scabra* to mitigate sediment eutrophication, two aspects of sedimentary organic matter were studied: (1) reduction of acid-volatile sulfur (AVS) level in detritus after ingestion and excretion by *H. scabra;* and (2) reduction of dissolved oxygen (DO) consumption by detritus after ingestion and excretion by *H. scabra*.

Holothuria scabra (about 20 cm in BL) were allowed to defecate in a bare tank for 2 days, then were separately placed in bare 60-L fibreglass tanks (n = 3) with aeration, and allowed to feed on shrimp tank detritus for 2 days. Their faeces were then collected with a spatula. AVS levels in both the faeces and the detritus were measured by Hedorotech-S kit (GASTEC Co.)

About 3 g of both the faeces and detritus samples (n = 3 each) were mixed with 330 g filtered sea water, placed in sealed Erlenmeyer flasks, shaded with aluminum foil, and placed in an incubator at 27 °C. A control flask containing filtered sea water was also incubated. DO levels were measured every hour with a DO meter until DO in one of the treatments was depleted. DO consumption rate (mg O_2/g/hour) was determined as the largest difference between two successive readings.

Results and discussion

Feeding trial 1: benthic diatoms and shrimp feed

Diatoms and epiphytic algae are suggested to be important food sources for juvenile *H. scabra* by Battaglene et al. (1999), who hypothesised that reduced light decreased growth in *H. scabra* juveniles through lower algal production. Shrimp starter feed is also reported to be good food for *H. scabra* (Pitt et al. 2004). Results from these trials confirmed that there was no mortality of *H. scabra* in any feed treatment during the 3-week study. However, unlike the previous study (Pitt et al. 2004), negative growth was observed in *H. scabra* fed with powdered shrimp feed (Figure 1; –0.026 to –0.022 g/day, –0.27 to –0.17 mm/day). Positive growth was observed in *H. scabra* fed with a mixture of powdered shrimp feed and *N. ramosissima* (Figure 1), in which the growth rates (0.065 to 0.12 g/day, 0.36 to 0.45 mm/day) were comparable to those of those fed only with *N. ramosissima* (0.036 to 0.12 g/day, 0.30 to 0.52 mm/day). Thus, powdered shrimp feed by itself was found to be ineffective for the growth for *H. scabra* under the rearing conditions used in this trial.

Feeding trial 2: effect of sand on sandfish growth

Battaglene et al. (1999) reported that the growth rate and survival of *H. scabra* juveniles reared on sand was higher than those on a hard substrate when fed with dried powdered algae and natural biofilm. Kihara et al. (2009) observed faster growth and better survival of Japanese sea cucumber juveniles (*Apostichopus japonicus*) with the presence of sand, compared with those provided with no sand, when fed with dried powdered algae. Although the effect of sand on the survival of juveniles is not consistent, sand substrate seems to have a positive effect on the growth of sea cucumbers.

In this study, a similar result was observed. *H. scabra* juveniles provided with powdered shrimp feed showed positive growth (0.068 g/day, 0.25 mm/day) in the presence of sand (Figure 2), whereas juveniles reared without sand showed negative growth (–0.13 g/day, –0.42 mm/day). The growth rate observed in the 'with-sand' treatment was smaller than that reported for similar sized individuals by Pitt et al. (2004), in which shrimp feed and sand substrate were used. Nevertheless, the presence of sand substrate seems important for feeding and/or assimilation of food for *H. scabra*. Kihara et al. (2009) reported that, although *A. japonicus* ingested dried powdered algae, it did not bring about positive growth in the absence of sand. Since faeces were constantly observed in the 'without-sand treatment' during this trial, *H. scabra* seem to ingest powdered shrimp feed without sand. Therefore, sand may assist digestion of food particles in the gut of sea cucumbers. It is also possible that partially decomposed shrimp feed that could not be removed from the sand was more readily digestible or assimilable than fresh feed for sea cucumbers, which have been shown to have low digestive enzyme activity (Yingst 1976).

Feeding trial 3: organic matter from shrimp tanks

H. scabra juveniles showed positive growth when fed with shrimp tank detritus, shrimp faeces and *N. ramosissima*, except in one of the replicates of the detritus treatment (Figure 3). The growth rate was fastest with the faeces (0.018 to 0.052 g/day, 0.18 to 0.38 mm/day), followed by

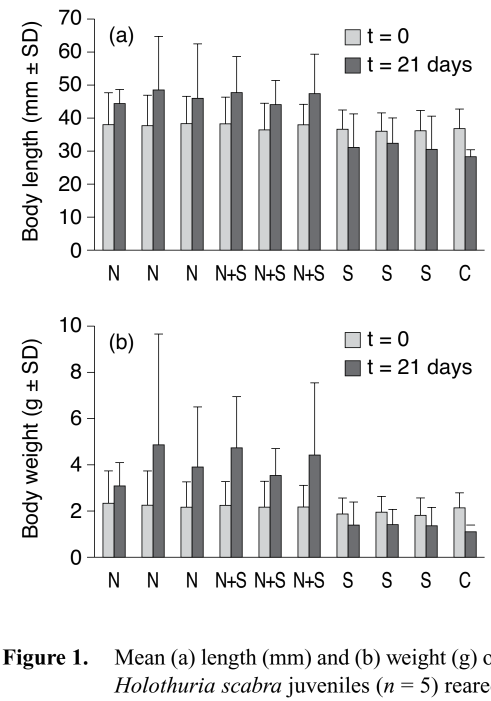

Figure 1. Mean (a) length (mm) and (b) weight (g) of *Holothuria scabra* juveniles (n = 5) reared with: *Navicula ramosissima* (N); a mixture of *N. ramosissima* and powdered shrimp feed (N+S); powdered shrimp feed (S); and no feed (C) for 21 days; error bars represent standard deviation.

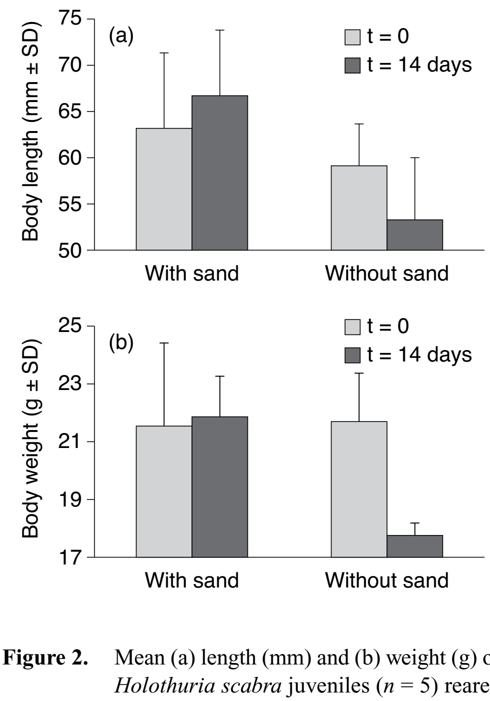

Figure 2. Mean (a) length (mm) and (b) weight (g) of *Holothuria scabra* juveniles (n = 5) reared with and without sand substrate in fibreglass tanks and fed powdered shrimp feed for 14 days; error bars represent standard deviation.

detritus (–0.021 to 0.026 g/day, –0.26 to 0.29 mm/day) and *N. ramosissima* (0.011 to 0.013 g/day, 0.156 to 0.158 mm/day). This, together with the result of feeding trial 2, indicates that *H. scabra* can grow in a *P. monodon* pond without additional feeding. Growth rates obtained in this trial are comparable with those reported by Battaglene et al. (1999), in which diatoms and epiphytic algae were fed to *H. scabra*, but almost an order of magnitude slower than those reported by Pitt et al. (2004). Therefore, shrimp feed in the presence of sand substrate, rather than decomposed leftovers, shrimp faeces or naturally occurring micro-algae, seems to be suitable for the growth of *H. scabra*. Yuan et al. (2006) reported that the mixed diets of bivalve faeces and powered algae showed promising results for cultivation of sub-adult *Apostichopus japonicus*, while the sea cucumber fed with powdered algae or faeces alone could not obtain the best growth. *Holothuria scabra* may be able to consume fresh leftovers by *P. monodon* more efficiently, rather than deteriorated sludge in the shrimp pond.

The carbohydrate concentration in the coelomic fluid had a significant negative correlation with growth in BL (Figure 4; $r = –0.30$, $p < 0.05$) and BW ($r = –0.29$, $p < 0.05$, $n = 70$). Watanabe et al. (2012) found that carbohydrate concentration in the coelomic fluid is positively correlated with starvation period. Therefore, carbohydrate concentration may be correlated with growth rate through nutritional condition, which presumably affects the growth rate of *H. scabra*. However, although the correlations were significant, the correlation coefficient had small values, and carbohydrate concentration values were highly variable, especially at low growth rates. Since feeding condition or nutritional condition is not the only factor affecting growth rate, one should be careful in the interpretation of carbohydrate concentration when analysing it in relation to growth rate.

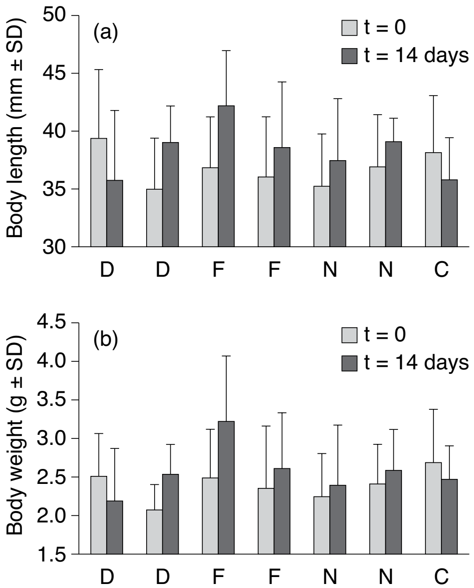

Figure 3. Mean (a) length (mm) and (b) weight (g) of *Holothuria scabra* juveniles (n = 10) reared with detritus collected from *Penaeus monodon* rearing tanks (D); *P. monodon* faeces (F); *Navicula ramosissima* (N); and no feed (C) for 14 days; error bars represent standard deviation.

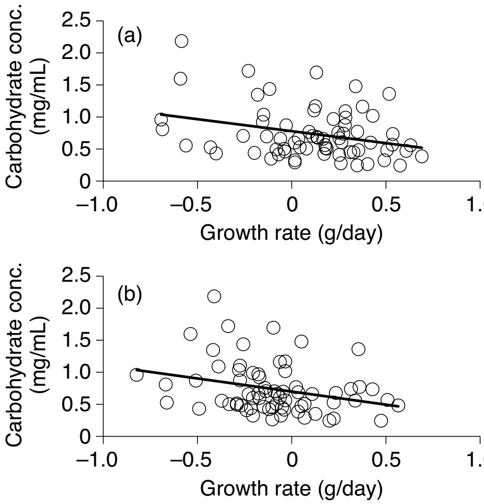

Figure 4. Relationship between growth rate of (a) length (mm/day, and (b) weight (g/day) and carbohydrate concentration (mg/mL) in the coelomic fluid of *Holothuria scabra* juveniles (n = 70) reared with detritus collected from *Penaeus monodon* rearing tanks; *P. monodon* faeces and *Navicula ramosissima*. Linear correlations were significant in both graphs.

Biomitigation of sediment eutrophication by sandfish

Dissolved oxygen consumption by faeces of *H. scabra* fed with shrimp tank detritus was 22% of that consumed by the shrimp tank detritus alone (from 1.0 ± 0.1 SD to 4.5 ± 1.0 SD g O_2/g dry wt/hour, $p < 0.001$, $n = 3$, t-test) (Figure 5). This may be attributable to reduction of organic matter in the detritus through assimilation by *H. scabra* (i.e. less organic matter equals less oxygen consumed by micro-organisms during decomposition of organic matter). Grazing of the brown sea cucumber (*Australostichopus mollis*) reduces total organic carbon, chlorophyll *a* and phaeopigment, as well as the chlorophyll *a* : phaeopigment ratio of sediments impacted by green-lipped mussel depositions (Slater and Carton 2009). Conversely, it is reported that, while *H. scabra* bioturbate sediments and eat organic deposits in tanks with blue shrimp (*Litopenaeus stylirostris*), they did not significantly reduce the organic content of the sand in the tanks (Purcell et al. 2006).

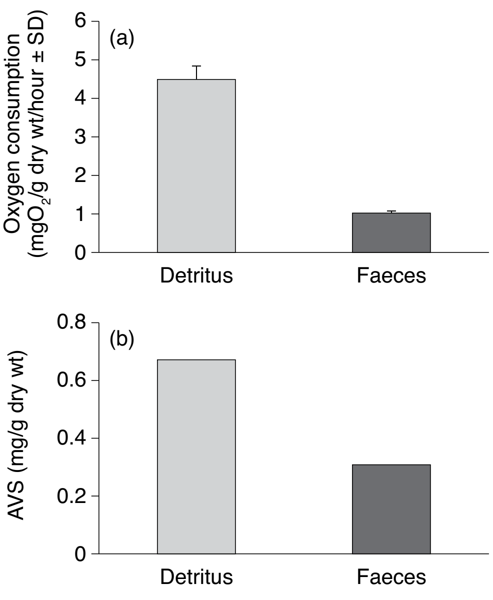

Figure 5. (a) Dissolved oxygen consumption rate and (b) acid-volatile sulfur (AVS) level of detritus collected from *Penaeus monodon* rearing tanks and faeces of *H. scabra* fed with the detritus ($n = 3$ for oxygen consumption rate and $n = 1$ for AVS level); error bars represent standard deviation.

If this also applies to the detritus derived from *P. monodon*, *H. scabra* may somehow change the nature of organic matter in the detritus so that oxygen consumption is reduced. Regardless of the actual mechanism, reduction of oxygen consumption is an important consequence of *H. scabra* feeding since hypoxia in the sediment and bottom water is a major problem in shrimp ponds (Suplee and Cotner 1996; Avnimelech and Ritvo 2003).

AVS level (hydrogen sulfide and iron sulfide ≈ total sulfur) in the shrimp tank detritus (0.67 mg/g dry wt) was reduced by 55% by *H. scabra* (0.31 mg/g dry wt) feeding (Figure 5). Dissimilative sulfate reduction by sulfate-reducing bacteria (Fenchel and Blackburn 1979) results in the release of hydrogen sulfide into the environment, which is very toxic to many aquatic organisms (Bagarinao and Vetter 1992). Sulfide diffused out of sediments into bottom water is quickly oxidised biotically and abiotically (Jorgensen 1977); therefore, high sulfide levels in the sediment can aggravate hypoxia in the bottom water. Thus, AVS reduction in shrimp-tank detritus by *H. scabra* should bring about positive effects to the environment of a shrimp pond. Further quantitative analysis should be carried out to determine the proper stocking density of *H. scabra* for effective biomitigation of a shrimp pond.

Conclusions

The series of experiments conducted in this study showed that, although more quantitative data are needed, *H. scabra* has potential to biomitigate the eutrophication and improve sediment quality in a shrimp pond. Studies on the relationship between stocking density of *H. scabra* and the extent of biomitigation, as well as relationships between the shrimp-pond environment and shrimp disease manifestation, should also be carried out.

Agudo (2006) suggested that, although the availability of cultured juvenile *H. scabra* provides potential for farming *H. scabra* in earthen ponds or sea pens, it should not be reared in ponds together with shrimp because shrimp prey on *H. scabra*. Bell et al. (2007) reported that co-culture of *H. scabra* with blue shrimp (*Litopenaeus stylirostris*) is not viable due to death and morbidity of *H. scabra*. Therefore, in co-culture with *P. monodon*, *H. scabra* should be either protected in cages or reared in a separate pond, to which shrimp-pond effluents are introduced before the water is returned to the shrimp pond. Rotational culture is another possible approach. Further studies to establish practically feasible co-culture methods should be conducted.

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Establishment and management of communal sandfish (*Holothuria scabra*) sea ranching in the Philippines

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Abstract

Sea ranching of sandfish is being piloted as a means to enhance the recovery of depleted natural stocks and provide a supplemental source of income for artisanal fishers. Participatory and adaptive approaches were employed in the establishment and management of sea ranches to ensure that benefits accrue to both the 'rights-holders' and other community members. Three pilot sea-ranching sites have been established in north-western Luzon, the Philippines. The sites are managed by members of a local association of small fishers with the support of the municipal government, which granted limited exclusive-use rights to the sea-ranch managers. Each site was delineated into two major use zones: the 1-ha no-take release and nursery area, and the 4-ha reserve area. Multiple releases of cultured sandfish juveniles produced from local wild broodstock were conducted in the sites. Within 7–10 months, effective spawning populations were established in the sea-ranching sites when the density of reproductively mature (>200 g) individuals (ind) exceeded 100 ind/ha. Growth and survival rates were variable among sites. At the Bolinao sea ranch, the maximum estimated overall density reached 1,119 ind/ha, with an estimated survival rate of 39% after 19 months. Mass spawning of sandfish in the sea ranch further demonstrated that community-based sandfish sea ranching can help rebuild depleted wild populations. Among the major threats to sustainability are periodic poaching and storms, which reduce harvestable biomass and economic returns to the rights-holders. Sea ranching should be integrated within a broader fishery management framework to improve the management of sea cucumber fisheries.

Introduction

Rehabilitation of overexploited and depleted stocks is essential to securing continued production from capture fisheries (Bartley and Bell 2008). This has become imperative for species that are commercially important and heavily exploited, such as sea cucumbers. Sea cucumber collection has been an important part of the multispecies invertebrate fishery in the Indo-Pacific region for over 1,000 years (Conand 1990). Production of cultured species from hatcheries has been undertaken to increase and/or replenish yields through restocking, stock enhancement and sea ranching. However, despite progress in aquaculture, the application of hatchery technologies in fisheries management has yet to overcome many challenges. These include cost-effective production of juveniles; identification of where and when to use such interventions; integration of these initiatives with institutional fisheries management regimes; monitoring the success of interventions; and releasing juveniles into the wild in such a way that they survive in high numbers (Blankenship and Leber 1995; Bell et al. 2005, 2006; Lorenzen 2008). Putting these concepts

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into practice in a developing-country context to harmonise socioeconomic and ecological benefits to small fishers was the primary consideration in the establishment of communal sandfish sea ranching in the Philippines.

Historical overview of Philippine sea cucumber resources and fisheries

The sea cucumber fishery has been and is still an important source of livelihood for many of the coastal communities in the Philippine archipelago (Domantay 1934; Trinidad-Roa 1987; Akamine 2001). One of the earliest commercial sea cucumber fisheries in South-East Asia, dating back over 200 years, was in Sulu. Sea cucumbers were collected by the best pearl divers of the coastal Tausug and *vinta*-dwelling Samal and Badjao communities for the Sulu Sultanate. Licence to fish sea cucumbers was given by the sultan, while the *datus* (the local elites) commonly led or deployed several hundred fishers in fishing fleets (an early sign of fishery management) (Warren 1985).

In the late 18th century, the sea cucumber fishery in the southern Philippines developed rapidly as a result of trade with Spain, China and Britain (Warren 1985; Akamine 2001). From 1805 to 1830, dried sea cucumbers or *trepang* were shipped from Sulu to Manila twice a year in varying amounts up to 50 t (Warren 1985). Manila was also a main trading port between the South Pacific region and China (Ward 1972, cited in Akamine 2001).

Between 1924 and 1932, the Philippines exported an average of 272 t/year of dried sea cucumbers to China, British East Indies, Hong Kong and Japan (Domantay 1934). Post-World War II records show that the Philippines exported only 0.54 t in 1950 (Montilla and Blanco 1952), 5 t in 1958 (Surtida and Buendia 2000) and 12 t in 1970 (Akamine 2002). Export volume rapidly increased to over 600 t in 1978, exceeding pre-war records, and again doubled in 1983. Since then, the Philippines has maintained a total annual export of no less than 1,000 t, making sea cucumbers a major export commodity.

Although the Philippines is the second-largest exporter of tropical sea cucumbers in the world (Conand and Byrne 1993), results of a multisectoral national forum established that there have been no significant efforts to effectively regulate and manage the fishery, either at the national- or local-government level (Casilagan and Juinio-Meñez 2007). The scarcity of useful fishery baseline information in most regions is often cited as an obstacle in the formulation of a management plan (Gamboa et al. 2004). Furthermore, resource managers at the local-government unit level and the national agencies generally know very little about the value and status of the sea cucumber resources.

The status of the sea cucumber resources and fishery in the municipalities where the pilot sea-ranching sites were established is characteristic of overexploited fisheries in many parts of the country. For example, in the Bolinao–Anda reef system, species diversity is high but population densities are very low, and the average sizes of sea cucumber are below reported sizes at sexual maturity per species (Olavides et al. 2010). Fishery-dependent and independent studies in the area found 49 species, 26 of which are being collected and traded (including the very low-value species). The catch per unit effort in the 1970s–1980s was reported to be over 100 kg/day, and had declined to less than 1 kg/day in 2008. Several high-value commercial species such as *Thelenota ananas* and *T. anax* have been fished to local extinction, while the populations of other target species, particularly *Holothuria scabra* and *Stichopus horrens,* are depleted.

Sandfish sea ranch establishment process and management scheme

One of the highest valued sea cucumber species in the Philippines is *Holothuria scabra*, commonly known as sandfish. With the scaled-up juvenile production of sandfish (Juinio-Meñez et al. 2012), sea ranching was piloted in three coastal municipalities in north-western Luzon. The framework, establishment process and management scheme for communal sea ranching of sandfish were developed to ensure that benefits accrue to both the 'rights-holders' and other community members (M.A. Juinio-Meñez, unpublished data). These were also aimed at minimising social conflicts, which are inherent in the open-access and multiple-use nature of nearshore fisheries in the Philippines. The key implementation strategies are: (1) acquisition of exclusive communal-use rights for a 5-ha sea ranch, (2) increases in the production, and improvement in the quality, of hatchery-produced juveniles, and (3) regular monitoring to estimate population growth and survival in the sea-ranching sites.

Biophysical, social and governance criteria were considered in the selection of three sea-ranching sites in the provinces of Pangasinan and Zambales, north-western Luzon (Figure 1). The biophysical requirements included 50–60% seagrass cover, sandy–muddy substrate, minimum exposure to wave action, and presence of sandfish. Even if the biophysical prerequisites had been met, the final site selection was based on the presence of an interested local fisher association (or a group with experience in community-based coastal resource management) and a supportive local government unit willing to grant preferential-use rights to the sea-ranch managers.

Community consultations were conducted in the potential sites and in neighbouring villages that may be affected by restricted access in the sea-ranch area. Upon endorsement of the village council, the local partners applied for preferential-use rights to manage the sea ranch and exclusively harvest all sea cucumbers in the site. This was legitimised by an ordinance passed by the local legislative body, and the issuance of a gratuitous permit by the mayor. The responsibilities of the local sea-ranch managers were to help in conducting information and awareness campaigns, provide manpower in developing and maintaining the site, and guard the sea ranch (Figure 2A, B, C, D).

The sea-ranch rights-holders initially comprised 12–15 families of fishers per site, with an average annual income of US$640–5,600 per household. Each of the 5-ha sites was delineated into two major use and management zones composed of a 1-ha nursery no-take zone located at the centre of the sea ranch, and a 4-ha reserve zone surrounding the nursery zone. Inside the no-take zone is a core release area (50 × 50 m), where cultured sandfish juveniles were released. In addition, 3 × 100 m^2 circular pens were installed in the core release area and stocked with juveniles to facilitate monitoring of growth and survival of a single batch. To minimise disturbance of the released juveniles, entry into the nursery zone is restricted to release and monitoring activities. In the reserve area, boat passage and traditional fishing activities (except for any species of sea cucumbers) are allowed with permission from the sea-ranch managers.

Hatchery-produced juveniles (>3 g) were released in multiple batches, with varying numbers of individuals (ind) per batch. Juveniles were released individually by pressing their bodies lightly into the surface

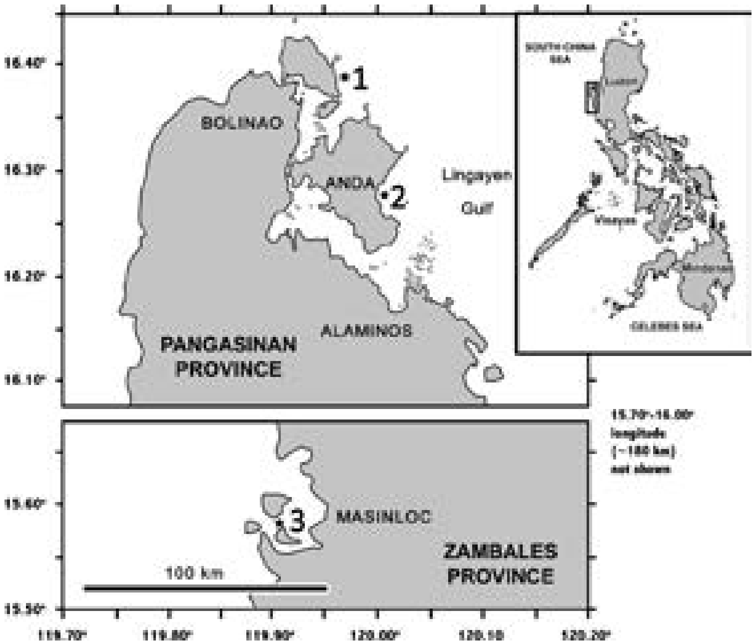

Figure 1. Map of the three sea-ranching sites in north-western Luzon, the Philippines: (1: Barangay Victory, Bolinao, Pangasinan; 2: Barangay Sablig, Anda, Pangasinan; 3: Panglit Island, Masinloc, Zambales)

Figure 2. Regular activities of sea-ranch managers. **A**: Conducting information and education activities for local communities and site visitors. **B**: Site development (e.g. delineation and pen construction). **C**: Release of hatchery-produced sandfish juveniles. **D**: Guarding the sea ranch. **E**: Periodic monitoring. **F**: Mass harvest and processing

of the sediment, partially burying them, to reduce the risk of predation. Stratified belt transect surveys in different areas of the sea ranch were conducted with local partners every 3–4 months to estimate survival and growth. Population densities, abundance and biomass of sandfish were also estimated. The results of the surveys were discussed with the sea-ranch managers to assess the status of the sandfish in the sites and schedule harvests. The managers processed the harvested sandfish themselves (Figure 2E, F), and sold their products to sea cucumber wholesalers or exporters in Manila. A comparison of key information on the management and monitoring surveys in the three pilot sea-ranching sites is presented in Table 1.

Lessons learned and insights

A viable spawning population can be established and maintained in a sea ranch

Growth and survival of sandfish in the sea-ranch sites were widely variable. From an average release size of 5–7 g, sandfish reached an initial size of sexual maturity of about 180 g within 7–10 months. The density of sandfish in the sea ranches increased rapidly in the first year of operation, with maximum densities across the three sites in the range 302–1,119 ind/ha (Table 1). The highest estimated survival was 39% in the Bolinao sea ranch after 19 months, with density reaching 1,119 ind/ha. This is over 400 times the density of the wild population in the Bolinao–Anda reef system, which is only about 6 ind/ha (Olavides et al. 2010). This density approaches that of a relatively unexploited natural population of 2,900 ind/ha reported from Papua New Guinea (Shelley 1985). In contrast, the maximum survival estimate in the two other sites was only 14% (Table 1).

More importantly, within 10 months after the first release of juveniles, the density of reproductively mature (>200 g) individuals exceeded 100 ind/ha. The highest density of reproductively mature sandfish was 499 ind/ha after 19 months, comprising over 40% of the sandfish in the Bolinao sea ranch. Synchronous spontaneous spawning was also observed in the Bolinao and Anda sites on 23 February 2010 (Olavides et al. 2011). Prior to and after this mass spawning event, the sea-ranch managers observed sandfish exhibiting spawning behaviour, clearly demonstrating that a viable spawning population has been established in these sites.

Typhoons and poaching are major threats to economic viability

The modal size (total weight) of sandfish in the Bolinao sea ranch decreased drastically after protracted periods of heavy rainfall and strong waves brought about by two consecutive typhoons during September and October 2009 (Juinio-Meñez, unpublished data). There was a decrease of about 70% in the estimated total biomass in the sea ranch—from 1,100 kg to 347 kg over a 7-month period—after the typhoons (6th to 8th monitoring periods). The estimated harvestable biomass (i.e. sandfish >320 g) prior to the typhoon in July 2009 was about 188 kg. Four months after the typhoon, there was no harvestable biomass. The negative impact of typhoons on the growth of sandfish may be attributed to drastic changes in environmental factors and habitat modification. The heavy rains may have caused significant exposure to suboptimal salinity levels that stressed the sandfish—preliminary laboratory experiments showed that sandfish ceased to feed at around 20 ppt salinity (J.R. Gorospe, unpublished data). Further, it was also observed that, after the typhoon, sediment in the sea-ranching area became coarse, with abundant coral rubble on the surface. The progressive decrease in weight of individual sandfish months later indicates that the strong typhoons decreased sediment quality in the sea ranch.

Table 1. Management and sandfish population data in the three pilot sea-ranching sites in north-western Luzon

	Location of sea-ranching sites		
	Bolinao, Pangasinan	**Anda, Pangasinan**	**Masinloc, Zambales**
Rights-holder	Association of small fishers	Co-managed by representatives of village council and a people's organisation	Members of the marine protected area council
Date of first release	Dec 2007	Dec 2008	May 2009
Total number of juveniles released[a]	14,300 (10 releases)	18,749 (8 releases)	21,272 (6 releases)
Mean weight (g) (size range 3–20 g)	7.0 ± 4.7	5.8 ± 2.8	5.5 ± 1.9
Maximum weight of sandfish harvested (g)	630	560	500
Estimated density (ind/ha) after 16–18 months	1,119	86	90
Highest estimated density of individuals >200 g (ind/ha)	499	224	116
Range of estimated survival of released juveniles (%) during the first six monitoring periods	19–39	2–13	2–14
Highest estimated biomass (kg) in entire sea ranch (5 ha)	1,100	419	292

[a] Excluding juveniles released in the pens inside the sea ranch during the first year

Aside from natural disturbances, poaching reduces the potential economic returns to the sea-ranch rights-holders. All the sites have a round-the-clock rotational guarding scheme agreed upon by the sea-ranch managers to minimise opportunity costs (i.e. 2–3 days a month per household). The income share from the sea ranch was proportional to the time and effort invested by each member household. Consistency and commitment of members to adhere to guarding schedules varied among sites. Even in Bolinao, where the management has been exemplary, incidences of successful poaching have occurred. No major typhoon has affected the two other sites, and yet estimated survival rates in these sites were lower (Table 1). This may be due, in part, to poaching incidences of sandfish within the sea ranch. Poaching is a given socioeconomic constraint in open-access areas with many poor subsistence fishers. Thus, governance mechanisms to mitigate and manage social conflicts are crucial to the success of sea-ranching efforts.

Another factor that affects the harvestable biomass is movement of sandfish outside the sea-ranch area. This is determined by various environmental factors that affect habitat quality (including incidence of natural disturbances such as typhoons), and needs to be investigated more closely in the future.

Sea ranching is part of an integrated fishery management framework

Communal sandfish sea ranching is a model that could be adopted to harmonise the need to rebuild depleted populations and, at the same time, provide economic incentive for rights-holders who invest in managing the areas. The community-managed 5-ha sea ranch demonstrates that release of sandfish in suitable and well-managed sites can establish viable spawning populations that should contribute to rebuilding depleted fishery stocks. An effective spawning population in the sea ranch can be maintained while optimising economic returns through programmed releases of juveniles and selective harvesting of sea cucumbers (e.g. >320 g). Harvesting animals larger than the average size at sexual maturity (~200 g) also increases economic returns since bigger sandfish fetch a higher price in the market.

However, sandfish sea ranching will not be feasible in many situations; for example, where there is no supply of cultured juveniles, in habitats that are not suitable for *H. scabra,* and where risks from natural disturbances and poaching are very high. In the Philippines, where management of nearshore waters is under the jurisdiction of local government units (LGUs), local-level management systems such as partnerships between small-scale fishers and LGUs are important. To promote sustainability of severely exploited and unmanaged multispecies sea cucumber fisheries in the country, the important components of an integrated fishery and sea-ranching management system include: implementation of a registry and permit system for fishers, processors and traders that is consistent with the provisions of national fisheries codes; minimum size limits for harvest and trade; and community-managed reserves such as the communal sandfish sea ranches discussed here.

Acknowledgments

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Maldives sea cucumber farming experience

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Abstract

With recent technological developments and the increasingly intensive interest in tropical sea cucumber farming, it is an opportune time to review the existing strategies of the first successful commercial hatchery in the Republic of Maldives (the Maldives). This may help to understand the success of the hatchery and grow-out operations. This paper analyses the strategies used in the production and grow-out of the commercially important sea cucumber *Holothuria scabra,* and their effects on the local communities and the environment in the Maldives. *Holothuria scabra* has been cultured in the Maldives since 1996. Hatchery production techniques consistently produce high-quality juveniles. When the juveniles reach 2–3 cm in size, they are transferred to nearby company-owned atoll lagoons for further growth. The sea cucumber grow-out period varies between 12 and 18 months in these waters. In addition to the company's own sea cucumber grow-out operation, considerable quantities of juveniles are grown, with similar grow-out periods, by contract growers and villagers from the nearby islands. When the sea cucumbers are fully grown (350–425 g), the local growers sell them back to the company and are paid a management fee according to the duration of care and quantity of the product. The participation of the local community and village groups is one of the reasons for the ongoing success of sea cucumber culture in the Maldives. Sea cucumber hatchery production is a profitable operation in the Maldives, even though the cost of production per juvenile is higher due to the remote location and associated higher energy and transportation costs.

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Sandfish (*Holothuria scabra*) production and sea-ranching trial in Fiji

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Abstract

There is presently enormous interest in the Pacific islands region in restoring depleted sea cucumber fisheries with hatchery-produced juveniles. The Australian Centre for International Agricultural Research funded projects in Fiji to transfer technology for culturing and sea ranching of sandfish (*Holothuria scabra*, known locally as 'dairo'). Two hatcheries that respectively produce blacklip pearl oyster and penaeid shrimp were successfully used to culture sandfish. Government aquaculture officers and private-sector hatchery technicians were trained in sandfish production methods. Successful spawning and rearing to the small juvenile stage were carried out at both hatcheries but, due to factors such as cyclones and equipment failure, only one of the hatchery runs produced about 500 large juveniles for a release trial. An extensive seagrass bed on a shallow sand flat in front of Natuvu village, Vanua Levu, met the criteria for suitable habitat for sea ranching, and the community was committed to the research. The juveniles were released into four 100-m^2 sea pens (two pens each of small and large juveniles, 1–3 g and >3–10 g, respectively). Survival after 6 months was around 28% overall (23% for small and 33% for large sandfish).

The Natuvu community ceased harvest of sandfish from the wild prior to the project starting, and also declared a marine protected area (MPA) around the sea-ranching site. An unanticipated benefit of the project was an increase in other valuable sea cucumber species in their MPA, which were harvested for a one-off community fundraising event.

Introduction

There is enormous interest in the Pacific islands region in the potential for restoring depleted sea cucumber fisheries with hatchery-produced juveniles. This report describes Australian Centre for International Agricultural Research (ACIAR)-funded projects in Fiji to transfer technology for culturing and sea ranching of sandfish (*Holothuria scabra*, known locally as 'dairo'). Sandfish are a traditional food item (Figure 1) and are restricted by legislation to collection for domestic consumption. However, Fisheries regulations are ambiguous—on one hand stating that sandfish are reserved for domestic markets, and on the other setting export limits for them. Hence, export-driven overfishing of sandfish has occurred in recent years.

Sandfish is one of the few high-value sea cucumber species that can be reliably cultured (Battaglene et al. 1999; Raison 2008). Two hatcheries that normally produce other invertebrate species in Fiji were involved in the production of larval and juvenile sandfish: a private-sector blacklip pearl oyster (*Pinctada margaritifera*) hatchery and the government penaeid shrimp hatchery. One of the uses for cultured sandfish juveniles is sea ranching—the release of hatchery-produced juveniles into unenclosed coastal environments where they are allowed to grow to commercial size and later harvested by an individual or group in a 'put-and-take' operation (Bell et al. 2008). However, although hatchery techniques for sandfish are well established, the value of the final product must be weighed up against the cost of producing the juveniles, the subsequent growth rates and the survival of sufficient numbers to commercial size. Unfortunately, there is limited

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Figure 1. Sandfish prepared as a traditional Fijian meal

information on the economic viability of sea ranching using cultured juveniles.

Fiji had several factors in its favour as the location for a Pacific-region sandfish sea-ranching trial. Importantly, the national government, the private sector, non-government organisations (NGOs) and the University of the South Pacific (USP) agreed to cooperate in the trial research. Many coastal communities were also interested in this species. Traditional marine tenure and control in the form of *qoliqolis* (traditional fishing-rights areas) provides good security for cultured sandfish during trials. In addition to longstanding customary management practices, there has been a trend in recent years for the traditional owners of many *qoliqolis* in Fiji to develop management plans in conjunction with the Fiji Fisheries Department and NGOs. Such plans often include the setting aside of a marine protected area (MPA) as a 'no-take' zone within the *qoliqoli*. These managed areas provide the perfect opportunity for trials on the feasibility of sea ranching of sandfish. The village involvement also improves the chances of development of a management framework for sea ranching.

There were two major goals of the project:

1. to transfer technology for sea cucumber production, release techniques and post-release monitoring to government and private-sector technicians
2. to conduct trials of sea ranching of sandfish in a Fijian community *qoliqoli* to obtain information on juvenile sandfish growth and survival; assess social, technical and economic feasibility; and look at the implications for management options for sea ranching as a village livelihood.

Methods

Transfer hatchery and juvenile grow-out technology

Study sites and facilities

The first phase of the technology transfer component was carried out between May 2008 and April 2010 at Savusavu (Figure 2) on Vanua Levu, the second largest Fijian island (Hair et al. 2011a). The second phase was carried out between October 2010 and January 2011 at Galoa on Viti Levu, the largest island of Fiji (Figure 2). Both sites had hatchery facilities but neither was set up for sea cucumber aquaculture, so systems were modified and new gear provided where necessary.

In Savusavu, the pearl oyster hatchery of J. Hunter Pearls was used (Figure 3; Table 1). The hatchery had the essential resources of power, seawater supply and treatment capacity (i.e. UV-sterilisation and filtration to 1 μm) and aeration. Importantly, it also had a micro-algae production facility, since several species are routinely cultured to support pearl oyster spat production. Four 1,600-L conical-based tanks were available for sea cucumber larval rearing. A reliable source of broodstock was available at Natuvu village, about 2 hours' drive (by car or boat). In order to support sandfish aquaculture, we used available tanks and hatchery resources, built temporary raceways, and negotiated the use of a local seawater pond for holding broodstock and for hapa net trials for juvenile grow-out.

In Viti Levu, the Fiji Fisheries Department shrimp hatchery at Galoa (Figure 4; Table 1) was used. This hatchery also had town power with a backup generator, treated sea water and aeration. Five conical-based 300-L tanks and two 1,000-L flat-based tanks were available for larval rearing. Various raceways and large tanks were also made available for holding broodstock, water storage and so on. A spawning tank was created by cutting down a 1,000-L rainwater tank and installing a central standpipe. There was no micro-algae production at the hatchery but carboys of algae were supplied by USP and stored for 2–3 days at a time in an air-conditioned room fitted with lights. There were reports of adult sandfish being available locally, but we used Natuvu broodstock again because we planned to release juveniles back at that location. Galoa also had three saltwater earthen ponds used for shrimp culture, one of which was allocated for sandfish juvenile grow-out.

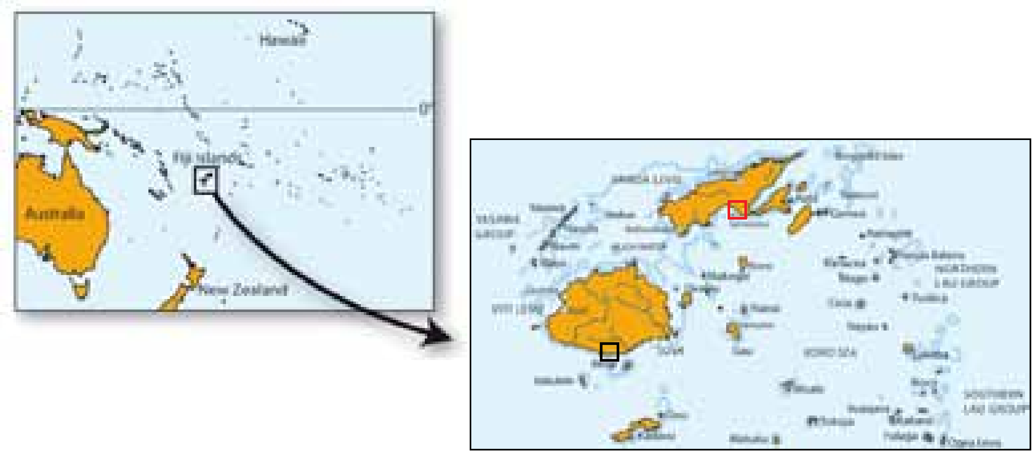

Figure 2. Map of Fiji showing general location of the two study site areas, Savusavu on Vanua Levu (red box) and Galoa on Viti Levu (black box) (map courtesy of Secretariat of the Pacific Community)

Figure 3. The J. Hunter Pearls blacklip pearl oyster hatchery at Savusavu, Vanua Levu

Table 1. Summary of features and resources available at the two hatcheries used to produce sandfish in Fiji

	J. Hunter Pearls	Fisheries Department
Location	Savusavu, Vanua Levu	Galoa, Viti Levu
Core production species	Blacklip pearl oyster (*Pinctada margaritifera*)	Penaeid shrimp (*Penaeus monodon*) and freshwater prawn (*Macrobrachium rosenbergii*)
Water supply	Direct from the sea, filtered to 1 µm, UV-treated	Pumped into large, open storage tank from the sea, filtered to 1 µm, UV-treated
Spawning tank	Modified fish transport box (1 m^3)	Modified circular rainwater tank (0.7 m^3)
Larval rearing tanks	4 × 1,600-L conical-based fibreglass	5 × 300-L conical-based fibreglass, 2 × 1,000-L flat-based plastic
Live micro-algal feed	*Chaetoceros muelleri,* T. ISO[a], *Proteomonas sulcata*. *Nitzschia closterium*: produced on demand on site	Primarily T. ISO[a], with small quantities of *C. muelleri* and *N. closterium*: supplied from Suva by University of the South Pacific in carboys when available
Power	Town power, no backup	Town power, with backup generator
Broodstock source	Natuvu, Vanua Levu (2 hours transport by boat and car)	Natuvu, Vanua Levu (24 hours transport by car and ferry)
Broodstock maintenance	Pond/sea	Large concrete tank (~6,000 L)
Juvenile rearing	2 × 2 m improvised raceways (built of coconut logs and tarpaulins)	Bag nets in earthen pond

[a] T.ISO = Tahitian *Isochrysis* sp.

Figure 4. Fiji Fisheries Department penaeid shrimp hatchery at Galoa, Viti Levu, showing earthen pond in the foreground

Broodstock

All broodstock for hatchery production in both Savusavu and Galoa were collected from the Savusavu area, predominantly around Natuvu. This was important to ensure that juveniles released into the Natuvu *qoliqoli* were the same genetic stock as the existing wild stocks (Purcell 2004). Broodstock were usually collected on a rising tide, the time when local fishers claimed they were less likely to be buried. Depending on the time of collection, broodstock were either left in a holding pen until ready for packing and transport, or packed directly on the boat. They were always transported with one large or two smaller individuals in a plastic bag containing one-third sea water and two-thirds oxygen.

In the initial runs at the J. Hunter Pearls hatchery, broodstock were held in a pond in Savusavu between runs. However, due to poor condition of broodstock and losses of animals, we moved to a system where sandfish were collected for spawning and returned to the sea. At Galoa, a large, indoor cement tank with a 10-cm layer of sand in the bottom was used. The sand was replaced fortnightly, and water exchange and feeding occurred on alternate days.

Larval and juvenile production

Spawning of sandfish generally followed methods developed by the WorldFish Center (WorldFish) (Agudo 2006). Spawning induction employed a combination of stresses including (in order): (1) drying out a group of 30–40 broodstock for half an hour; (2) immersing them in a warm bath for 1 hour (~5 °C above ambient water temperature); (3) immersing them in a bath of *Spirulina* for 1 hour; and (4) placing them in clean water at ambient temperature until spawning occurred. Spawning males were removed from the spawning tank after they had each released sperm for some minutes. Spawning females were left until it was obvious that no more egg releases would occur. After all broodstock were removed, eggs were left in the tank for at least half an hour and were monitored to observe cell division. To minimise the incidence of polyspermy, the spawning tank was put on flow-through after several males had spawned, then eggs were siphoned into an 80-µm egg-washing basket and rinsed further. Larval rearing tanks were stocked at 0.3 viable eggs/mL.

At Savusavu, from day 2 after fertilisation, early auricularia larvae were fed daily with live microalgae (primarily *Chaetoceros muelleri* and T. ISO (Tahitian *Isochrysis* sp.), with small amounts of *Proteomonas sulcata*). Feeding rates ranged from 20,000 cells/mL at day 2 up to 40,000 cells/mL by around day 10 (Agudo 2006). Small amounts of *Nitzschia closterium,* a benthic diatom used for conditioning settlement plates and feeding early juveniles (Agudo 2006), were also produced, but this species was difficult to mass culture and not available routinely.

At Galoa, a varied live micro-algae diet was difficult to obtain: USP provided carboys of T. ISO and occasionally small quantities of *C. muelleri* and *N. closterium*. To make up for the shortfall in live feed, the larvae were fed Reed Mariculture's Instant Algae® (Shellfish Diet 1800®) (Figure 5) at the same ration as for live micro-algae. This commercially available diet is composed of a mixture of *Isochrysis* (30%), *Tetraselmis* (20%), *Pavlova* (20%) and *Thalassiosira weissflogii* (30%), and was used successfully as the primary diet for sandfish larvae for the first time in Fiji (Hair et al. 2011b).

At both hatcheries, one-third of the tank was exchanged with treated sea water daily from day 2 onwards. Larvae were monitored daily through all larval stages (i.e. length measurement, density estimates, observations on condition, activity level and malformation). Once doliolaria larvae were observed, signalling that settlement was imminent, conditioned plates were placed in the tanks. Because we were unable to reliably and consistently condition plates with live diatoms, we employed the technique of Duy (2010) and used perspex plates painted with a *Spirulina* paste (Figure 6). These plates remained in the larval tanks until transfer of juveniles to raceways 4–6 weeks after spawning. Live *C. muelleri* and

Figure 5. Instant Algae—a commercially available diet used to raise sandfish larvae

Figure 6. Plates coated with *Spirulina* being placed in a larval rearing tank at Galoa

T. ISO, with small amounts of Algamac 2000 (Biomarine Inc.) and *Spirulina* were added to the tanks to feed pentactula and early juveniles (Agudo 2006; Duy 2010). At Galoa, where the live algae supply was unreliable, instant algae was also used to supplement the diet of small juveniles (Hair et al. 2011b).

Juveniles at both hatcheries were transferred from the larval rearing tanks 4–5 weeks after spawning. At Savusavu, strong tidal flushing caused low productivity in the only available pond, and juvenile grow-out was unsuccessful in this environment. Therefore, the juveniles were transferred to a bare 4-m^2 raceway inoculated with *N. closterium* at the J. Hunter Pearls hatchery. They were moved later to a second 4-m^2 raceway with sand, and fed with shrimp feed. At Galoa, early juveniles were transferred from larval rearing tanks directly into 2 × 2 × 1 m bag nets in a pond (1-mm mesh), as recommended by Duy (2010).

Trial sea ranching

Study site

The trial sea ranching was carried out in the *qoliqoli* of Natuvu village (Wailevu district), near Savusavu (Figure 1). A *qoliqoli* is a traditionally managed fishing area under communal ownership that is fished for subsistence by the owners, and can also be fished commercially by both owners and non-owners (with the owners' permission). Natuvu village was selected after assessing several potential sites. It fulfilled a number of key criteria, namely:

- It had good physical microhabitat based on criteria developed by Purcell (2004) (Figures 7, 9a). There was an extensive seagrass meadow (approx. 750 m long parallel to shore by 500 m wide), characterised by a diverse invertebrate fauna (several species of sea cucumber, sea stars, urchins, sponges, crabs, ascidians, worms etc.) as well as numerous sandfish of small to medium size. The substratum was sandy–muddy sediment of moderate softness (i.e. it was possible to easily push fingers into the sediment but not the whole hand). At low tide the water depth was 0.2–2.5 m. It had 40–70% seagrass cover (primarily *Syringodium isoetifolium*, with a small amount of *Halodule uninervis*), and we graded the area as good to very good.
- There was minimal freshwater discharge into the area. There was some flood risk, but only likely during extreme events (e.g. heavy rain associated with cyclones). This can be considered a risk anywhere in the tropics.
- There was strong community interest in the research—in fact, sandfish collection was banned in the months leading up to the research team's visit to Natuvu in order to 'attract' research.
- The village is located on the seashore directly in front of and in direct line of sight of the seagrass bed. This meant that good security could be provided for the released juveniles as they grew to commercial size. The site also allowed convenient access to the juveniles for monitoring, cage maintenance and so on.
- There were stocks of adult-sized sandfish in the surrounding *qoliqoli* that were available to be used as broodstock. This meant that any juveniles produced would be released into the same area as their parents, which ensured an environmentally responsible approach resulting in least genetic modification of the wild stocks at the release site (Purcell 2004; SPC 2009).

Figure 7. Natuvu sandfish release habitat with resident wild sandfish

- The village was located about 2 hours by car or by car and boat from the J. Hunter Pearls hatchery. This proximity made it easy to transport animals from Natuvu to the hatchery (i.e. broodstock) or from the hatchery to Natuvu (i.e. broodstock return or juveniles for release).

Once the preferred site was selected, negotiations were conducted with the *qoliqoli* owners on how the research project would proceed. We also made an agreement on who would own any sandfish that reached commercial size during the project.

Pen construction, release and monitoring

Construction of the pens was a community undertaking (Figure 8) and was completed over 2 days prior to the release in May 2009. Four circular 100-m^2 pens were deployed in the seagrass bed. The pens were made of 3-mm black plastic oyster mesh. Each stood 30 cm above and 10–15 cm below the substratum, to reduce the chance of juveniles burying and escaping under the sides. The pen sides were reinforced with metal posts (Figure 8).

Release of juveniles into the seagrass bed at Natuvu was carried out according to the methods recommended by WorldFish and based on studies carried out in New Caledonia (Purcell and Eeckhaut 2005; Purcell et al. 2006a; Purcell and Simutoga 2008; Purcell and Blockmans 2009). Juvenile sandfish were marked by immersing them in a tetracycline solution (100 mg/L) for 24 hours, 1 week prior to release. They were then returned to the sand raceway to recover. At the time of marking, however, the juveniles were stunted, and we suspected that marking would not be successful because spicules must be in the growing phase in order to take up the fluorochrome stain (Purcell et al. 2006b). Prior to packing and transport, individual animals were examined for any lesions or obvious health problems (Purcell and Eeckhaut 2005).

At the hatchery the juveniles were divided into small (1–3 g) and large (>3–10 g) size classes, counted and packed into plastic bags with water and oxygen. Two size classes were used because half of the available juveniles had not reached the optimal release size of >3 g (Purcell and Simutoga 2008). Furthermore, we were releasing into quite different habitat to that used by WorldFish researchers, who determined a 3-g minimum—the Natuvu *Syringodium* seagrass bed presented an opportunity to test the recommendation of ideal release size.

At the release site, two 1 × 1 m hapa nets (~1-mm mesh) were staked out in the seagrass beds near the pens. Small juveniles were placed in one hapa and large juveniles in the other, and left overnight to acclimatise. The next day the project staff, wardens and other community members retrieved the juveniles and individually ‘planted’ the sandfish inside the pens by forming a small trench with a finger and placing the animal inside. Individuals in a subsample of released juveniles were marked with numbered pegs and checked at regular intervals in the 24 hours following release in order to observe behaviour.

Figure 8. Project staff (Fiji Fisheries, University of the South Pacific, James Cook University) and community helpers constructing one of four sea pens in Natuvu *qoliqoli* seagrass bed in May 2009

Monitoring by project staff and community wardens was carried out 3 months after the release (August 2009) and then at approximately 2-monthly intervals until the conclusion of the study (April 2010) (Figure 9). On each occasion, the number of animals in each pen was counted, and their length and width measured. The length–width data were used to calculate weight using a formula developed by Purcell and Simutoga (2008). Prior to release and at the first two monitoring times, skin samples of released sandfish were taken and preserved to check if they were marked. The skin samples were checked using a fluorescent microscope.

Results

Transfer hatchery and juvenile grow-out technology

Broodstock

Wild broodstock were mostly collected from Natuvu, although a small number was collected from other locations near Savusavu (Table 2). Minimum broodstock size was 250 g.

Between spawning runs at the J. Hunter Pearls hatchery, sandfish broodstock were held in a pond near Savusavu, but average size decreased while they were held there. This may have been due to suboptimal pond conditions or poaching of large animals. Consequently, broodstock were not kept in the pond for the last 6 months of the project; instead, wild broodstock were collected for spawning and then returned to the sea afterwards.

Broodstock were kept in tanks at Galoa hatchery but became stressed, diseased and then died after problems with the seawater pump, which meant that water exchange did not occur for more than a week.

Hatchery production to early juvenile stage

Between November 2008 and March 2010, five hatchery runs were undertaken at Savusavu. Each run involved multiple spawning attempts with at least 30 animals. Gamete release from males and females, egg fertilisation and larval production were achieved on every run. However, only two of the runs resulted in settlement, and only one run produced substantial numbers of juveniles: 1,500 small juveniles (from 640,000 stocked eggs) were transferred to raceways for further grow-out in February 2009. Of these, 500 progressed to 1–10-g juveniles, to be used for the sea-ranching trial at Natuvu.

Multiple spawning attempts using 30–40 broodstock individuals were carried out during a single hatchery run at Galoa in November 2010. Spawning occurred, fertilised eggs were produced and larvae were reared successfully to settlement. After 7 weeks, 5,300 small juveniles (from 600,000 stocked eggs) were transferred to three bag nets in the pond for

Figure 9. Sandfish in a pen (left), and project staff and community warden measuring sandfish (right), Natuvu

further grow-out. They reached a mean individual weight of ~0.6 g and ~ 2 cm length at 10 weeks of age. However, breakdown of water pumps, freshwater influx into the pond and insufficient maintenance of the bag nets resulted in total mortality of the juveniles at 11 weeks (4 weeks after transfer to the pond).

Trial sea ranching

Survival and growth of sea-ranched juveniles

The release was carried out on 18 May 2009: 105 large juvenile sandfish were placed into each of two pens (A, C), and 143 small sandfish were placed into each of two pens (B, D). Observations made during 2–24 hours post-release suggest that most juveniles buried relatively quickly and did not show stress behaviour by 'balling' up. Many juveniles commenced feeding within hours, as evidenced by faeces trails.

Survival after 6 months was around 28% overall (23% for small and 33% for large sandfish). The highest overall survival—41%—was recorded from a pen of large sandfish (Figure 10), and the lowest survival was also from a pen of large sandfish at 23%. Losses (due to mortality or escape) were greatest in the first 3 months, and thereafter remained relatively steady (Figure 10). Due to bad weather causing damage to the pens in November 2009, survival is only reported up to this time.

Growth of hatchery-produced sandfish in pens was measured every 1–2 months throughout the trial (Figure 11). Measurements from the trial are considered reliable up until 8 months after release, immediately prior to cyclone Tomas in March 2010. At this time, average sandfish size was 165 ± 5 g and 167 ± 6 g for small and large sandfish, respectively. Additional measurements were taken after the cyclone (Figure 11), but may also have included some wild sandfish because of the damage to pens. Processed skin samples did not show any fluorescent spicules, as we had suspected during the marking process. Therefore, in our case, fluorochrome marking was not useful in distinguishing hatchery-produced juveniles from wild individuals. A data logger indicated that sea temperatures were lower than normal in October–November 2010 and early January 2011, which may have contributed to the slower growth observed during those periods. However, cyclones also occurred around those times.

Community engagement and resource management

Prior to the start of the study (mid 2008), the Natuvu chief banned the harvest of sandfish throughout the entire *qoliqoli*. During 2009, an MPA of almost half the *qoliqoli* area was declared, and this initiative was supported and ratified by Fiji Fisheries (Figure 12). The Natuvu community was closely involved with the

Table 2. Broodstock collection time, hatchery where they were used, collection location, number collected and mean (± SE) weight (g)

Time	Location	Hatchery	Number	Mean weight ± SE (g)
November 2008	Natuvu (2 collections)	Savusavu	70 / 30	301 ± 8 / 321 ± 8
	Nawi Island (Savusavu)		5	857 ± 46
	Yaroi (Savusavu)		10	192 ± 8
December 2009	Natuvu	Savusavu	33	342 ± 15
March 2010	Natuvu	Savusavu	40	453 ± 14
November 2010	Natuvu	Galoa	55	395 ± 17

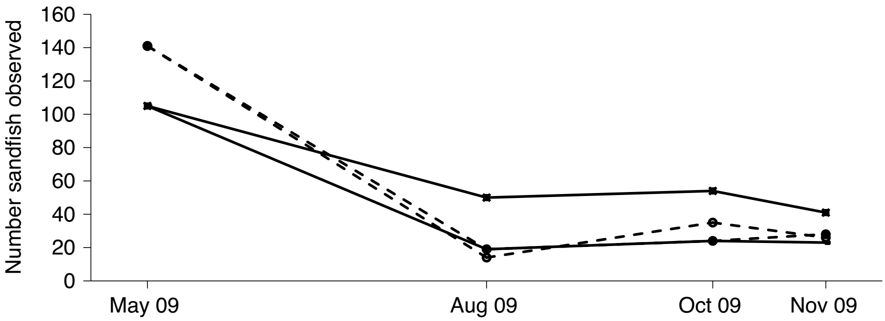

Figure 10. Survival of released sandfish in the four pens after 6 months. Solid lines represent pens stocked with large juveniles (>3–10 g), and broken lines represent pens stocked with small juveniles (1–3 g).

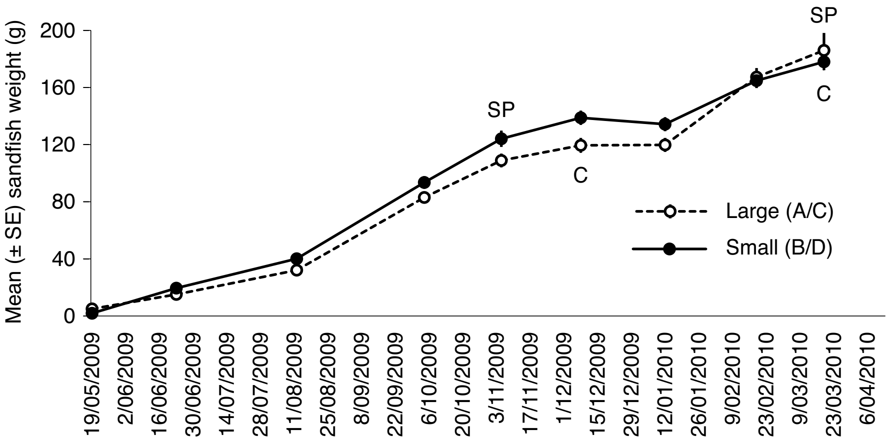

Figure 11. Growth data over 11 months for hatchery-produced sandfish at Natuvu. Solid lines represent large juveniles (both pens combined) and broken lines represent pens of small juveniles (both pens combined). March and April 2010 are subsamples of the sandfish located in pens after cyclone Tomas, and data are to be treated with caution. Cyclones are denoted by **C**, and observed spawning in pens is denoted by **SP**.

Figure 12. Marine protected area (broken line) within the Natuvu village *qoliqoli* (solid line). Sea pens are red circles inside the *qoliqoli.*

research at all stages of the study. They assisted with all project work, such as building pens and releasing the juveniles. Four 'wardens' were assigned to ensure that the hatchery-produced juveniles were protected and not disturbed. They also performed routine maintenance on the pens, assisted with monitoring and carried out other project-related duties.

Observations by the wardens and other project staff suggested that wild sandfish populations improved (e.g. increased in size and abundance) following the introduction of the protective measures This could benefit the seagrass habitat, as sea cucumbers are known to have a beneficial ecological effect on the substratum through their feeding and burying habits. In addition, spawning of hatchery-produced sandfish in pens was observed in November 2009 and March 2010, suggesting that the sea-ranched sandfish may contribute to future stock biomass.

Natuvu locals also stated that other commercial sea cucumber species, such as curryfish (*Stichopus hermanni*, a medium-value species), increased in number and size within the MPA (Figure 13a). In fact, large-size curryfish were observed to be so abundant that the community temporarily opened the MPA to harvest this species in late 2010. The 300 kg of beche-de-mer they processed (Figure 13b) earned the community approximately FJ$24,000 (A$15,000)—enough to fund a community hall (disaster evacuation centre), contribute to church fundraising, support the local school and meet other community needs. The MPA was closed to fishing again after the curryfish harvest. Despite the lack of a large-scale sandfish release in their *qoliqoli*, the community continues to protect sandfish throughout the entire *qoliqoli* and is keen to see ongoing research in this area. They intend to manage their MPA in collaboration with Fiji Fisheries in ways to ensure continued benefits from sandfish and other commercial holothurians.

Discussion

A number of positive outcomes resulted from the ACIAR projects. Private-sector and government staff were trained in sea cucumber production techniques, leaving a core of skilled and experienced technicians in Fiji. Furthermore, national government fisheries officers, students and community members were trained in release and monitoring methods for hatchery-reared juvenile sandfish. During production activities, the relative ease of producing sea cucumber in non-sea-cucumber hatcheries was demonstrated. This suggests that a multispecies hatchery approach to aquaculture production may be a successful and sensible option for small Pacific island nations where there are often shortfalls in resources and trained staff. Some variations were made to accommodate the local conditions and the available hatchery facilities: however, thousands of juveniles were produced with comparatively little modification. The lack of pond or raceway facilities was a constraint in Savusavu,

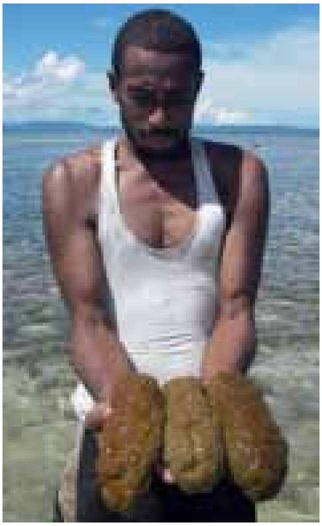

Figure 13. (left) Commercial-size curryfish (*Stichopus hermanni*) and (right) Natuvu women with beche-de-mer

while the availability of earthen ponds at Galoa was an advantage—production at the latter site may have been increased substantially if time and resources had permitted. Equipment breakdown and insufficient staff were major constraints at Galoa. The failure to produce juveniles in subsequent production runs was due to a combination of factors, including unfavourable environmental conditions, the effects of two cyclones and human error. It is noteworthy that the December 2009 hatchery run was carried out successfully by the Fijian hatchery counterparts with no outside assistance, but was cut short by a cyclone. Disruptions from cyclones were as minor as a few days of bad water quality and power loss during larval production, and as severe as months of hatchery down time to repair facilities and destroyed sea pens, and loss of released animals.

Production methods were adapted during the projects. Changes were based on new techniques from Vietnam and the Philippines (e.g. Duy 2010; Gamboa et al. 2012) as well as variations customised for Fiji. For example, perspex settlement plates were painted with a *Spirulina* paste instead of conditioning with *Nitzschia* sp. (Duy 2010). Another major change was applied in the feeding techniques used at Galoa in November 2010. The successful rearing of larval and early juvenile sandfish by feeding predominantly with instant algae was a major breakthrough in terms of simplifying techniques for small hatcheries in the Pacific region (and potentially other developing countries) (Hair et al. 2011b). More research is needed, but the use of an off-the-shelf algal diet may prove a huge boost for small hatcheries with limited resources and staff.

In terms of the success of the trial sea ranching, only one small trial was carried out, due to the difficulty in getting sufficient numbers of juveniles through to release size. However, of those that were released, the survival and growth results were encouraging. Both large and small sandfish from the release at Natuvu grew and survived well. The results compared favourably with similar studies in the Pacific islands region (Purcell and Simutoga 2008). As reported from the Philippines (Olavides et al. 2011), sandfish in pens were observed to spawn on two occasions (at 6 and 11 months post-release). There was a high level of community cooperation and commitment in the project, with community leaders taking the opportunity to apply other management measures around the project that led to environmental and financial benefits.

Technical challenges for Fiji (and many similar small nations) continue to include producing live feed for larval production, collection and maintenance of broodstock, producing sufficient numbers of large-sized juveniles, and risk management of extreme weather events (in particular, cyclones). Management, environmental and socioeconomic challenges will undoubtedly become more important as the technical issues are overcome. A number of sandfish sea-ranching and farming programs in more advanced stages may offer solutions or outline promising approaches to these challenges (e.g. Robinson and Pascal 2009, 2012; Fleming 2012; Juinio-Meñez et al. 2012). However, the hatchery and release activities described here have increased awareness of and interest in the technology. Fiji in now a position to pursue further development of sea cucumber sea ranching if desired.

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Sea cucumber farming experiences in south-western Madagascar

Georgina Robinson[1]* and Benjamin Pascal[2]

Abstract

In south-western Madagascar, anthropogenic and environmental factors are adversely affecting marine resources, and alternatives to fishing for the local Vezo community are limited. In an effort to overcome this problem, a non-government organisation (NGO), Blue Ventures, has been pioneering farming of sandfish (*Holothuria scabra)* in pens as a livelihood strategy for communities. Successful preliminary trials resulted in Blue Ventures and the NGO Trans'Mad-Développement obtaining funding to expand the project to include 40 families in seven villages. The pens, measuring between 625 and 900 m^2, were constructed in nearshore seagrass beds and stocked with batches of 300–450 hatchery-reared juveniles (15 g) at 3–4-month intervals. Sea cucumbers reaching a minimum size of 300 g between 4 and 12 months later were harvested and sold to the commercial partner, Madagascar Holothurie S.A., for processing and export. During the period of the study, a total of 51,500 juveniles were released at seven sites during 21 release events spread over 45 months. Although preliminary trials yielded high survival rates (80%), on scaling up the project a number of factors led to increased mortality rates; these included suboptimal transportation and stocking conditions, and predation. To meet these problems, methodologies were improved and a number of strategies were adopted to improve survival of juveniles following release. Socioeconomic issues remained a challenge throughout the project, as theft of market-size sea cucumbers was prevalent.

Introduction

In south-western Madagascar, anthropogenic and environmental factors, including climate change, population growth and overfishing, are adversely affecting marine resources. Coupled with the aridity of the region, alternatives to fishing for the Vezo community who inhabit the region are limited. As a means to address these issues, a sea cucumber mariculture project was launched in Madagascar in 1999 (Jangoux et al. 2001). In March 2008 the project evolved from its experimental roots into the commercial domain with the creation of Madagascar Holothurie Société Anonyme (MH.SA), the first private company based on sea cucumber aquaculture in Madagascar (Eeckhaut et al. 2008; Robinson and Pascal 2009).

Since January 2007, the local non-government organisation (NGO) Blue Ventures has been pioneering sea cucumber farming as a livelihood strategy for communities. After preliminary trials demonstrated the feasibility of rearing juvenile sandfish (*Holothuria scabra)* in sea pens, funding was obtained from the Regional Coastal Management Programme of the Indian Ocean Countries (ReCoMaP) for Blue Ventures and the NGO Trans'Mad-Développement (TMD) to develop community-based holothurian mariculture in partnership with commercial operator MH.SA. Between September 2008 and September 2010, the project was scaled up to include 40 families in seven villages in south-western Madagascar. A handbook on sea cucumber farming has been developed that contains detailed methodologies used in the project (<recomap-io.org/publications/guidelines_manuals>).

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This paper describes community efforts to farm hatchery-reared juvenile sandfish in sea pens. It examines a series of 21 releases at seven sites between January 2007 and September 2010. Importantly, it discusses a range of technical, biological and ecological factors that affected the survival and growth of the farmed sandfish, and outlines adaptations to farming practices that were implemented in order to address these factors.

Methods

Study sites

The two NGOs operated in geographically distinct areas to ensure maximum spatial coverage for the project (Figure 1). Extensive site surveys were conducted to identify villages with suitable habitat for sandfish, comprising shallow, sheltered areas with high levels of nutrients, such as muddy substrata and seagrass beds (Hamel et al. 2001; Agudo 2006). Additional selection criteria included adequate sediment depth (~50 cm) for pen construction and proximity to the village to facilitate maintenance and surveillance of the pens. Seven villages in total were selected: Blue Ventures continued to work in Andavadoaka, where preliminary trials were conducted and expanded to the villages of Nosy Be, Ambolimoke and Tampolove, situated within the Velondriake Locally Managed Marine Area. TMD worked in the villages of Fiherenamasay, Andrevo-Bas and Sarodrano, close to the regional capital of Toliara (Robinson and Pascal 2009).

Farming methods

Initially, pens were constructed from locally available materials, using wooden stakes and 10–15 mm nylon fishing net. The base of the pens was buried 25 cm into the sediment to prevent escape of the sandfish. Blue Ventures experimented with a variety of pen models and sizes ranging from 60 to 625 m^2. After preliminary trials were completed, pens were designed in order to maximise growth rates, by ensuring that the total biomass in the pens did not exceed the natural carrying capacity of habitats for *Holothuria scabra*, believed to be in the range 225–250 g/m^2 (Battaglene 1999; Purcell and Simutoga 2008). The pens measured 25 × 25 m, with one-quarter of the pen (12.5 × 12.5 m) sectioned off to form a 156.25-m^2 juvenile pen and the remaining 468.75-m^2 as a grow-out pen. The production model was designed to stock batches of 300 juveniles every 3–4 months, with subsequent transfer to the grow-out section 5 months after input. However, problems were experienced after constructing the grow-out section, as the mesh size used (15-mm nylon fishing net) led to fish (Lutjanidae, Gerreidae and Plotosidae) becoming trapped in the nets. This, in turn, attracted crabs, mainly *Thalamita crenata*, which ripped holes in the net, through which sea cucumbers could escape (Robinson 2011). The pens were eventually reconstructed with 6 × 8 mm HDPE plastic mesh; however, the delay in importing materials meant that juveniles delivered between 19 August 2009 and 12 May 2010 were overstocked in the 156-m^2 juvenile section, and it was not possible to fully test the production model.

TMD constructed large, open 30 × 30 m pens from the outset, which were stocked with batches of 450 juveniles every 3–4 months depending on availability from MH.SA. In an effort to reduce losses from predation in Sarodrano and Andrevo-Bas, 25-m^2 protective enclosures were constructed in the centre of the pens. The nursery pens had a 10 mm top net stitched on to prevent the entrance of crabs (Figure 2). Juveniles were held in the protective enclosures for 2–3 months until they reached an average size of 50 g, at which stage they are better able to withstand predatory attacks from crabs (Lavitra 2008) and are well acclimatised to the wild.

Juvenile supply

The commercial operator, MH.SA, was responsible for the supply and transport of large juveniles (approximately 15 g or 6 cm) from the nursery site at Belaza, located approximately 20 km south of Toliara (Figure 1), to the village grow-out sites. MH.SA was given exclusive rights to buy back all market-sized sea cucumbers for processing and export. At the start of the project, production costs were relatively high at US$0.54 per juvenile; thus, project funding was used to subsidise the cost for farmers. Juveniles were supplied to farmers on credit at a cost of US$0.20 per juvenile, advanced by project funds, and the cost of juveniles was reimbursed at set rates when the sea cucumbers were harvested and sold. NGO staff were required to relay the number and weights of market-ready sea cucumbers to MH.SA 2 weeks prior to harvest and sale. In addition, MH.SA imposed a minimum size limit of 300 g and a minimum quantity of 300 market-sized animals before they would travel to the villages for the sale.

Figure 1. Sandfish farming sites of Blue Ventures and Trans'Mad-Développement in south-western Madagascar

Transportation and stocking

Initially, MH.SA used their fishing vessel to transport juveniles from the nursery in Belaza to grow-out sites. A number of protocols were put into place to minimise handling and maintain optimal water quality, such as defecation of juveniles prior to transport and regular partial water changes. Juveniles were loaded into fish transport boxes (100 per box), which were stacked in insulated plastic fish harvest bins filled with sea water (Figure 3). Transportation occurred overnight or in the early morning in order to avoid daytime temperature extremes, and to schedule arrival time for juveniles to be stocked during mid-morning spring low-ebb tides. Transportation times to Andrevo-Bas and Fiherenamasay ranged from 4 to 10 hours (Tsiresy et al. 2011), and journey times to reach grow-out sites in Velondriake (200–250 km to the north), ranged from 14 to 22 hours depending on weather conditions.

In an effort to reduce the level of mortality due to boat transportation, more conventional transportation strategies were adopted later in the project (Purcell et al. 2006). Juveniles were stocked in 5-L plastic bags with 2.5 L of sea water and oxygen, packed into insulated containers and transported directly to the grow-out sites by four-wheel drive vehicle. Motorised boats were used to relay juveniles to villages with no road access. Where delivery was problematic and delayed, contingency plans were implemented. On two occasions, juveniles were released by SCUBA divers at high tide during the day into pens at a water depth of 2.5 m. However, as methodologies used in the development of sea cucumber farming aimed to maximise community participation, it was preferable to keep juveniles ashore in open containers, and carry out partial water changes until they could be stocked at night during the spring low tide. This allowed the juveniles a 6–8-hour period to recover from the stress of transportation and resume normal behaviour. Prior to release, farmers were trained to gradually acclimatise juveniles to ambient water temperatures for 30 minutes before releasing them individually into the pens.

Capacity building and monitoring

The NGOs were responsible for providing training and technical support to farmers throughout the project, including training in pen construction and maintenance, husbandry, conflict resolution and financial management. Log books were issued to each farming group to record details of all husbandry and maintenance activities, together with accounts detailing the number of sea cucumbers delivered and sold, the amount of juvenile credit repaid and the profits generated per group. Participatory monitoring was carried out on a monthly basis at night during spring low tides to provide data on growth and mortality. All sea cucumbers found during monitoring were counted, and a minimum subsample of 25% was weighed using a top-pan electronic balance.

Predator control

Due to high levels of predation experienced at some sites, TMD developed a number of targeted predator control techniques. Two types of traps were designed—a bucket buried in the sand with bait suspended across the entrance, and a baited mesh cage with a circular opening (Figure 4). Traps using locally harvested arc shell meat (*Anadara natalensis)* as bait were deployed around the pens. Farmers were encouraged to regularly hunt for crabs in and around the pens, with an intensification occurring in the month leading up to juvenile deliveries. A variety

Figure 2. Protective nursery enclosures (25 m^2) constructed in the centre of 30 × 30 m sea pens in Sarodrano to protect newly released juveniles from predation

Figure 3. Methods used to transport hatchery-reared juveniles by fishing boat to grow-out sites in Velondriake using fish boxes stacked inside insulated harvest bins

Figure 4. Traps designed by Trans'Mad-Développement to capture predatory crabs

of techniques were used—using a spear or gloves to catch crabs, snorkelling along the sides of the pens to flush crabs towards the traps, or trapping and killing them. All species were targeted; edible crabs such as *Lupa sanguinolenta, Scylla serrata,* and *Lupa pelagica* were sold or used for domestic consumption, and non-edible species (e.g. *Thalamita crenata)* were dried to provide food for pigs and chickens (Ravoto 2010).

Anti-poaching measures

As theft was considered to be one of the main risks facing the project (Robinson and Pascal 2009), a number of proactive measures were put in place, including nightly surveillance programs and the creation of marine reserves governed by social conventions (*dinas*) to regulate access to the mariculture zones, and enable villagers to deal with incidents of theft at a local level. As theft was prevalent throughout the project, a regional meeting, organised by MH.SA and chaired by the Minister of Fisheries, was held in April 2010 in Toliara. The meeting was attended by a wide range of stakeholders, including sea cucumber farmers, NGOs, Department of Fisheries, police, army, middlemen and seafood traders. A number of additional strategies were agreed upon, including establishing a system of traceability for farmed sea cucumbers by issuing certificates of origin; legalising the village *dinas* at the district level; increasing the presence of government officials, including fisheries surveillance and police; and constructing guard platforms adjacent to sea pens to facilitate surveillance.

Results

Farming trials

During the period of the study, 51,500 juveniles were released at seven sites during 21 release events spread over 45 months (Table 1).

Survival of hatchery-reared sandfish

A number of factors were found to affect the survival of hatchery-reared sandfish post release, including transport and handling stress, predation and human factors (poaching), leading to variable survival rates between farming sites (Table 2; Figures 5b, 6b).

During preliminary farming trials, where juveniles were properly transported and acclimatised, survival rates were high after 11 months, with 79% and 80%, respectively, for the first two releases in Andavadoaka and Ambolimoke (Table 2). However, the use of the boat to transport larger quantities of juveniles from October 2008 increased mortality rates. During transportation by boat of the first five batches of juveniles to grow-out sites in Velondriake, a total of 3,061 juveniles (11% of the total number of sandfish delivered) died (Robinson 2011). The journey by sea was frequently complicated and prolonged during periods of rough weather, leading to evisceration of juveniles and mortalities on board. In December 2009 the occurrence of a tropical storm in the afternoon caused the direct mortality of 55% of juveniles destined for Nosy Be (Table 2). During the same month, the delivery boat was stuck in heavy seas behind the barrier reef in Fiherenamasay, resulting in direct mortality of 91% of juveniles. Frequently delayed or prolonged transportation also led to suboptimal stocking conditions early on in the project. During the delivery of 1,200 juveniles to Ambolimoke in October 2008, the late arrival of the boat resulted in releasing the juveniles into pens on a rising spring tide. The animals, which were already stressed after a 16-hour boat journey with no water exchange, were unable to bury or even maintain their position on the sediment, and were observed rolling around on the sediment surface. Some farmers even reported observations of juveniles floating out of the pens as the strong tidal current, wind and waves swept through the shallow area where the pens were located. Survival rates were 35% after 2 months (Table 2; Figure 5b).

During the first releases in Sarodrano and Andrevo-Bas, there was intense predation from crabs, with mortality rates of 80% and 81%, respectively, after 2 months (Table 2; Figure 7). Transportation and acclimatisation of juveniles for Sarodrano was optimal, as juveniles were transported by canoe from the nursery (30 minutes) and released at midnight during the spring low tide. However, within 20 minutes, large numbers of *Thalamita crenata* arrived at the pens, where they succeeded in scaling the pens and ripping holes in the sides (10-mm nylon net) to prey on the newly released juveniles. One month after release, survival estimates between pens varied greatly, ranging from 0% to 71%, with an average survival rate of 20% for the five pens (Table 2; Figure 6b). In an effort to protect newly released juveniles from predation by crabs, nursery enclosures (Figure 2) were constructed after the first release at Sarodrano and Andrevo-Bas. With this new system, the observed survival rates were 79% and 70%, respectively, 15 days after release.

Table 1. Summary of all juvenile sandfish releases, January 2007 – September 2010

Date	Site	NGO	No. juveniles released	Pen size (m^2)	No. pens	Total no. of juveniles	Other factors of importance
24 January 2007	ADV	BV	200	60	1	200	
16 January 2008	ADV	BV	200	100		200	
1 October 2008	ABM/ADV	BV	1,200/200	*156/100	4/1	1400	*Only juvenile section of pen constructed
24 February 2009	ABM/ADV/ NSB/ TMP	BV	1,800/450/ 1,200/1,800	*156/225/ 156 /156	6/1/4/6	5,250	*Only juvenile section of pen constructed
31 March 2009	SAR	TMD	2,250	900	5	2,250	
13 May 2009	FHM	TMD	2,250	900	5	2,250	
11 June 2009	ADR	TMD	3,150	900	7	3,150	
19 August 2009	NSB/ TMP	BV	1,200/2,400	*625/625	4/9	3,600	*Grow-out section constructed with 15-mm nylon net
18 September 2009	SAR	TMD	2,250	900	5	2,250	Juveniles released into 25-m^2 protective enclosures
6 October 2009	ABM/ TMP	BV	2,700/300	*156/156	9/1	3,000	*Grow-out section removed due to damage to nets
20 October 2009	ADR	TMD	3,150	900	7	3,150	Juveniles released into 25-m^2 protective enclosures
2 December 2009	ABM/ NSB/ TMP	BV	2,700/1,200/2,700	156/156/ 156	9/9	6,600	Juveniles released into 25-m^2 protective enclosures
17 December 2009	FHM	TMD	2,250	900	5	2,250	
3 March 2010	ADR	TMD	3,150	900	7	3,150	Juveniles released into 25-m^2 protective enclosures
16 April 2010	SAR	TMD	1,800	900	4	1,800	Juveniles released into 25-m^2 protective enclosures
27 April 2010	TMP	BV	2,700	156	9	2,700	
12 May 2010	ABM/ NSB/	BV	1,500/1,200	*625/625	5/4	2,700	*Grow-out section reconstructed with HDPE mesh
27 May 2010	FHM	TMD	*900	900	2	900	*Quantity reduced due to poor farming efforts
15 June 2010	ADR	TMD	*1,500	900	6	1,500	*Quantity reduced due to poor farming efforts
25 August 2010	SAR	TMD	*1,200	900	4	1,200	*Quantity reduced due to lack of supply from MHSA
22 September 2010	TMP	BV	*2,000	625	9	2,000	*Quantity reduced due to lack of supply from MHSA

Site codes: ADV = Andavadoaka; AMB = Ambolimoke; NSB = Nosy Be; TMP = Tampolove; SAR = Sarodrano; FHM = Fiherenamasay and ADR = Andrevo-Bas
NGOs: BV = Blue Ventures; TMD = Trans'Mad-Développement

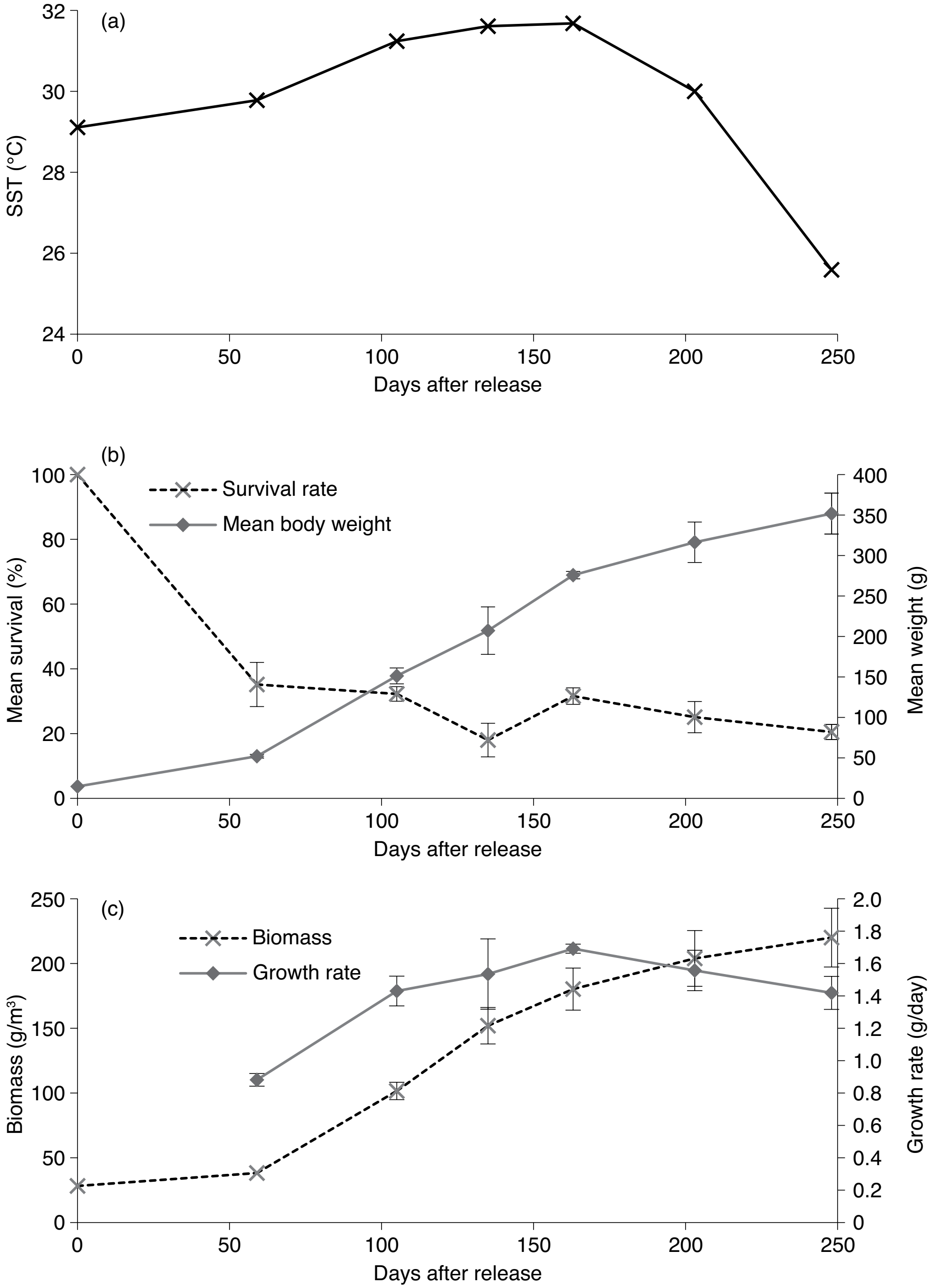

Figure 5. Biological responses of sandfish in the second release in Ambolimoke on 1 October 2008 into four 12.5 ×12.5 m sea pens: (a) sea surface temperature (SST); (b) mean survival and weight of released sandfish; (c) biomass and growth rates of released sandfish. NB: There was high mortaility within 1 month due to poor transport conditions.

Unfortunately, however, these positive results led farmers to neglect crab culling, both in nurseries and the rest of the pens, and survival rates decreased dramatically (Tsiresy et al. 2011) (Table 2; Figure 7). The effect of protective nursery enclosures on the survival rate of newly released juveniles in Andrevo-Bas and Sarodrano is shown in Table 2 and Figure 7. In Sarodrano, the vigilance of farmers in excluding crabs from nursery enclosures prior to and after stocking led to survival rates of 88% (76 days after the third input) and 83% (60 days after the fourth input) (Figure 7).

Theft of market-size sea cucumber was also an important factor affecting survival. Over the course of the study period, eight incidents of poaching were reported, amounting to 2,735 sandfish, 5% of the total number delivered. Seven of the eight reported incidents were directly linked to planned harvests and sales to MH.SA, either in the 2 weeks prior to a sale or following the cancellation of a sale (Table 2). Furthermore, half of the thefts occurred during periods of celebration, including Christmas and New Year in 2007 and 2009 (Figure 6b), and Independence Day in June 2009. Periods of bad weather, which prevented fishers from going to sea, coincided with two of these celebration periods, providing an additional driver for poaching.

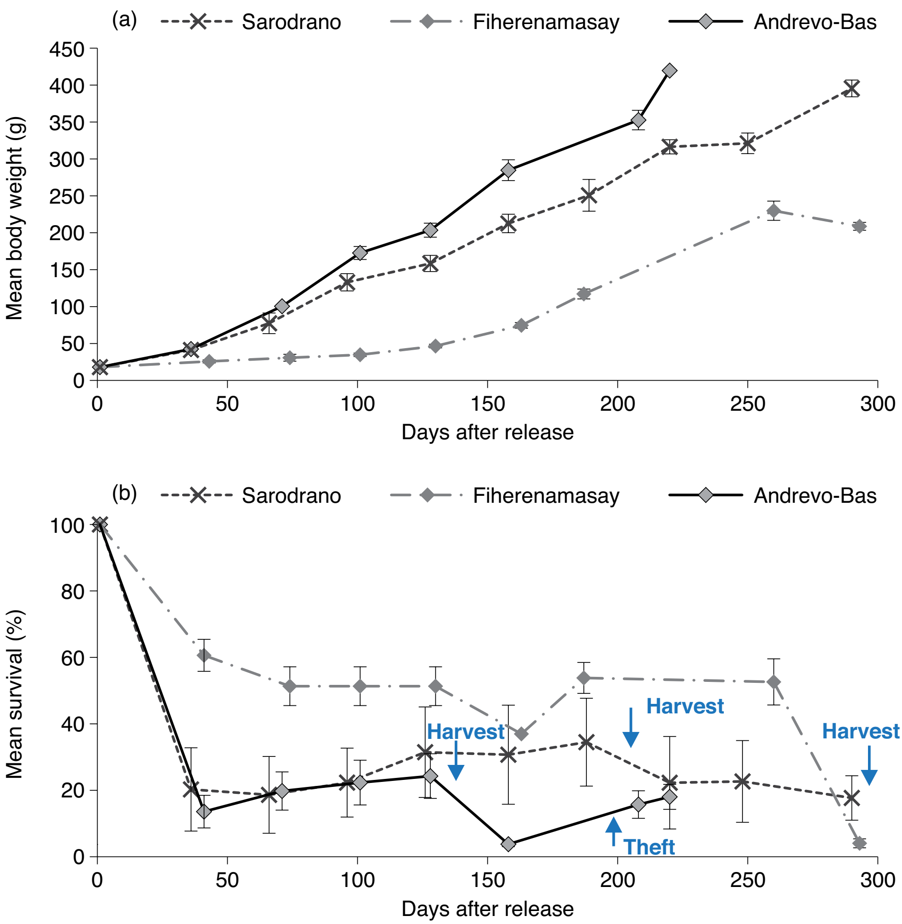

Figure 6. Biological responses of sandfish at the Trans'Mad-Développement farming sites during the first releases of juveniles into five pens in Sarodrano on 1 April 2009 (n = 2,250), five pens in Fiherenamsay on 13 May 2009 (n = 2,250) and seven pens in Andrevo-Bas on 11 June 2009 (n = 3,150)

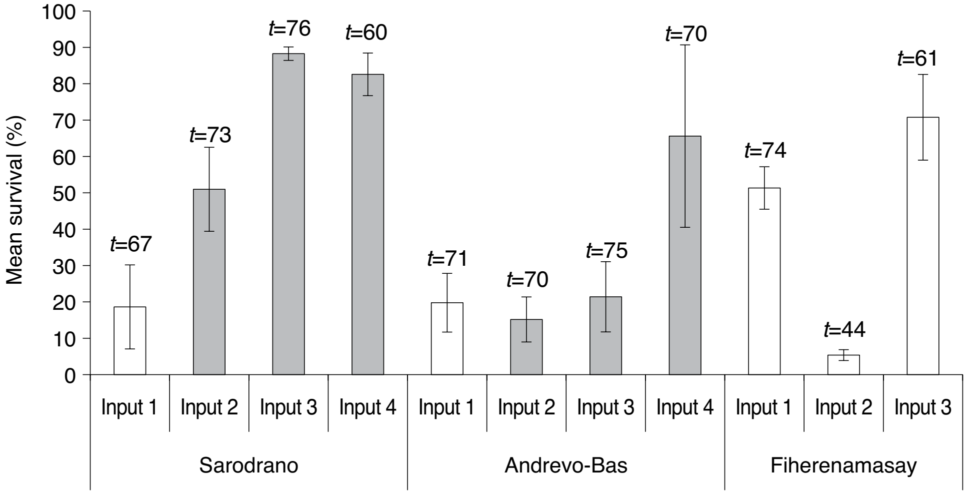

Figure 7. The effect on mean survival of releasing 15-g juveniles into protected nursery enclosures. Unshaded bars denote releases into open 30 × 30 m sea pens; shaded bars indicate release of sandfish into 25-m^2 covered nursery enclosures. The number of days post-release is indicated above each bar.

Growth of hatchery-reared sandfish

A wide range of growth rates was recorded in the farming trials throughout the study period, and time to reach commercial size varied between sites and individual release events (Table 3). A number of factors were found to affect growth, including seasonality (water temperature) and stocking density; density-dependent factors were linked to site-specific carrying capacities.

The minimum time to reach market size was observed in Andrevo-Bas, where 128 animals (16% of the stock remaining following mortalities from predation) were harvested after only 128 days at an average individual weight of 362.4 g. Partial harvests of the fastest growing animals (the 'shooters') were also carried out in Sarodrano, when 206 animals (29%) with an average weight of 363.9 g were harvested after 219 days, and the remaining sea cucumbers (average weight 410.6 g) were harvested after 290 days (Figure 6b).

Conversely, some sites showed poor growth rates throughout the study period, most notably Andavadoaka and Fiherenamasay (Table 3). In Andavadoaka, sandfish from trials in January 2007 and January 2008 failed to reach commercial size within 12–15 months. The carrying capacity for the site was estimated at approximately 100 g/m^2. As it would not have been economically viable to rear sandfish at such low densities, the site was subsequently abandoned in 2009. In Fiherenamasay, poor initial growth rates of 0.23 g/day after 4 months of farming led to experimentation by technicians to rework the sediment by either 'ploughing' or removing the top 5-cm layer. These two techniques resulted in increasing the weight gain of juveniles fivefold and fourfold, respectively, after 38 days, increasing the average growth rate to 1.0 g/day (Tsiresy et al. 2011). Overall, the average growth rate for Fiherenamasay was only 0.65 g/day, and the pens were relocated to a new site prior to the second release.

Growth rates were variable within and between sites due to effects of stocking density and seasonality, indicating that spatio-temporal variation is important. During the first field trial in Ambolimoke (January 2008), 196 juveniles (average weight 14.7 g) were stocked in a 100-m^2 pen at densities of 1.96 juveniles/m^2. Survival rates were high (80%); however, the average growth rate was only 0.55 g/day. When sandfish were harvested experimentally after 11 months, the mean weight was only 185.9 g (± 3.0 SE) (Table 3). During the second release into new pens in October 2008, growth rates were higher and sandfish reached a market size of 351.8 g (± 3.1 SE) after only 8 months. The average growth rate of 1.4 g/day was due to a combination of warm water temperature during the

Table 2. Summary table of mortality and losses recorded from selected releases due to varying factors

Month/year	Site	Time post release	Mortality (%)	Probable cause or mitigating factors
January 2007	Andavadoaka	11 months	21	Optimal transport (car in bags with oxygen)
January 2008	Andavadoaka	11 months	20	Optimal transport (car in bags with oxygen)
January 2008	Ambolimoke	11 months	20	Optimal transport (car in bags with oxygen)
October 2008	Ambolimoke	2 months	65	Various (long boat journey, no water changes, weakened juveniles, rising tide, low pen height)
March 2009	Sarodrano	67 days	81	Predation (crabs)
June 2009	Andrevo-Bas	71 days	80	Predation (crabs)
October 2009 and March 2010	Andrevo-Bas	70 and 75 days	85 and 79	Protective enclosures, with lax crab hunting
December 2009	Nosy Be	Immediate	55	Physical damage due to boat transport during a storm
December 2009	Fiherenamasay	Immediate	91	Physical damage and prolonged transport stress due to boat being stuck in rough seas
February 2010	Tampolove	12 months	99	Theft 2 days prior to a sale to MH.SA (n = 929)
March 2010	Fiherenamasay	10 months	42	Theft after cancellation of a sale to MH.SA (n = 953)
April and August 2010	Sarodrano	60 and 76 days	11 and 17	Protective enclosures, with vigilant crab hunting, well-maintained enclosures
June 2010	Andrevo-Bas	70 days	34	Protective enclosures, with vigilant crab hunting, well-maintained enclosures

Table 3. Summary of growth rates and time to harvest recorded for each farming location. NB: Data presented is restricted to initial releases where there was no mixing of cohorts.

Site	Release date	Average growth rate (g/day)	Time to harvest (days)	Size at harvest (g)	Other comments
Andavadoaka	January 2007	0.5	333—no harvest	150—not achieved	Poor site—abandoned 2009
Ambolimoke	January 2008	0.55	340	185.9	Experimental harvest/processing
Ambolimoke	October 2008	1.4	248	351.8	New pens constructed, low stocking density due to high mortalities
Nosy Be	February 2008	0.82	163	Not achieved	Periodic internal theft of large sea cucumbers
Tampolove	February 2008	1.19	282	349 (n = 223)	Partial harvest, followed by theft prior to sale in February 2009
Sarodrano	March 2009	1.6 1.36	219 290	363.9 (n = 206) 410.6 (n = 277)	Partial harvests, low stocking density due to high mortalities
Fiherenamasay	May 2009	0.65	293—no harvest	208—not achieved	Poor site—abandoned and new site selected
Andrevo	June 2009	1.45 1.8	128 220	362.4 (n = 128) 420 (n = 568)	Partial harvests, low stocking density

summer months and low densities resulting from post-release mortality. The growth rate increased from 0.88 g/day to a peak rate of 1.69 g/day during February and March 2009, when water temperatures were ~32 °C. The growth rate then decreased as water temperatures fell to 25.6 °C and as the biomass approached 220 g/m^2 (Figure 5a, b, c).

In the farming villages of TMD, for the first releases of 450 juveniles per pen, stocking densities were low, at 0.5 $juveniles/m^2$. Medium to high levels of mortality were experienced at all three villages during the first month (Figures 5, 7b); thus, stocking densities were further reduced, and throughout the production cycle the biomass never exceeded 45 g/m^2. At these sites, average daily growth rates over the first 5 months for Sarodrano, Andrevo-Bas and Fiherenamasay were 1.3, 1.8 and 0.23 g/day, respectively (Tsiresy et al. 2011).

Discussion

Factors affecting survival

The following factors have the potential to affect the survival of released sandfish: method of transport to the release site, size at release, type of substrate, time of release (both within the diurnal cycle and seasonal), stocking density, abundance of predators and availability of food (Battaglene and Bell 2004). The impact that some of these factors can have on the survival rate of juveniles released into sea pens in the wild was highlighted in the results of the study. In addition, the effect of techniques developed to improve survival during various release events in south-western Madagascar was also demonstrated.

Size at release has a significant effect on survival of sandfish (Purcell and Simutoga 2008). In comparison with other studies, the high survival rates (~80%) obtained when juveniles were properly transported and acclimatised was largely due to the large size of juveniles released (15 g). During transport and release, juvenile sandfish are subjected to a wide range of stresses, including physical shocks and prolonged agitation, periods out of water, temperature shocks, buffeting by tidal currents and wave action, and predators (Dance et al. 2003; Purcell 2004). Therefore, optimal transportation and acclimatisation strategies should be employed to maximise survival of hatchery-reared sandfish released into the wild.

Predators constitute one of the main risks to be considered for sea cucumber aquaculture using pens (Lavitra et al. 2009). High mortality due to predation was a major obstacle to the economic viability of some of the aquaculture ventures (Tsiresy et al. 2011). Purcell (2010) postulated that minimal handling of juveniles in transporting them into the wild should promote longer periods of burial for the first days after release, which may improve post-release survival by enhancing their avoidance of predators. However, our results indicate that, at some sites that were subject to high predation pressure, behavioural modifications post release were not sufficient to prevent predation. The results of this study demonstrate the positive effect that providing a physical barrier to predators can have on increasing survival of hatchery-reared sandfish. However, a two-pronged approach is needed; the combination of using protective nursery enclosures in conjunction with targeted predator control proved extremely effective in increasing survival rates of newly released hatchery-reared sandfish, as demonstrated by the success of farmers in Sarodrano who remained vigilant in crab hunting and maintaining enclosures.

After a number of biological and technical hurdles affecting survival of sandfish were overcome, and once market-sized sea cucumbers started to be reliably produced in sea pens, a new set of socio-economic problems came into play as theft became prevalent. The issue of theft was exacerbated by a number of weaknesses in the business model. First, the fact that credit was extended to farmers to obtain juveniles eliminated any risk on their part, and therefore did not engender responsibility among farmers. Second, the low prices paid by MH.SA of approximately US$1.00–1.39 per piece, from which juveniles' costs were also deducted, often meant that it was more profitable for farmers to sell their sea cucumbers to traders in the neighbouring villages. Finally, the 2-week time delay, enforced by MH.SA, between NGO staff communicating the number and weights of market-ready sea cucumbers to MH.SA, and MH.SA staff travelling to Velondriake to buy them, increased the risk of theft in the interim period, when the majority of thefts occurred.

Factors affecting growth

Density-dependent factors were not found to directly affect survival of sandfish, but they were important in regulating growth rates. During this study, lower stocking densities appeared to lead to higher growth rates, and high growth rates were recorded in periods of high water temperatures. Battaglene (1999) observed that growth of *Holothuria scabra* ceased when densities reached approximately 225 g/m^2, and that even juveniles held at this density lost weight. A study by Purcell and Simutoga (2008) on the long-term growth of sandfish in the wild also indicated a natural carrying capacity for sandfish of around 2.5 t/ha for farming programs. Our results also indicated that carrying capacities for sandfish exist and affect their growth rate. However, we found there was considerable variation between sites. In Ambolimoke, growth rates slowed as the biomass reached ~220 g/m^2 although water temperature was also a contributing factor. In Andavadoaka, the low carrying capacity of the site (~100 g/m^2) prevented sandfish from reaching market size after 12–15 months. In addition, when sandfish were released temporarily at this site at biomass of 360 g/m^2, the effects of overcrowding were evident as sandfish were observed squeezing through the mesh in an effort to disperse.

Density-dependent effects on growth rate are likely to be linked to food availability; however, it appears that some sites are capable of supporting higher stocking densities than others. For example, the sea pens opposite the MH.SA nursery in Belaza are capable of supporting a biomass of ~700 g/m^2, and it is therefore possible for sandfish to reach market size at a density of 2 individuals/m^2 (Lavitra 2008). As the carrying capacity of the site will strongly affect the economic viability of farming sandfish, a simple method was developed during the project to assist with optimal site selection and to assess the carrying capacity of potential sites. Small 4-m^2 test plots were stocked with juveniles, and weekly growth was monitored until the sea cucumbers stopped growing due to density-dependent effects, at which point the total biomass per unit area was calculated (Pascal and Robinson 2011).

Highly variable growth rates within specific cohorts lead to heterogeneous sizes of sandfish (Purcell and Kirby 2006), which was confirmed by this study. In some echinoderm species, the presence of larger individuals can suppress the growth of smaller ones (Grosjean et al. 1996; Dong et al. 2010); therefore, grading is often used in aquaculture to produce uniform size classes. In some cases the removal of 'shooters' (fast-growing individuals) can allow the smaller ones to catch up, as seen in the successful partial harvests at villages near Toliara. In-situ partial processing of sea cucumbers at the community level is now being investigated. In addition to alleviating incidents of theft, as sea cucumbers can be harvested and processed on a regular basis as they reach market size, it may also lead to the production of more uniform batches of sandfish, and reduce the time to reach harvest size.

Conclusions

Over recent years, research has led to the development of reliable techniques to produce hatchery-reared sandfish (James et al. 1994; Battaglene 1999; Agudo 2006; Duy 2010). Studies on the release of hatchery-reared juveniles commonly report high levels of mortality during the first few months after release into the wild (Dance et al. 2006; Purcell and Simutoga 2008; Hair et al. 2011), yet the probable cause of mortality remains unidentified or unreported. It is perhaps timely then for future research priorities to focus on improving survival of hatchery-reared juveniles in the wild. By gaining a better understanding of the factors that affect their survival in the natural environment, acclimatisation and release strategies can be improved. Enclosures or cages acting as an intermediate 'halfway home' to acclimatise juveniles during the first days or weeks of release have been suggested (Dance et al. 2003; Purcell 2004). In Vietnam and the Philippines, new technologies such as floating and fixed bottom hapa nets in ponds and the sea are currently being used (Duy 2010; R. Gamboa, pers. comm.) to extend the nursery phase into the marine environment, in order to increase production capacity and reduce production costs. It is likely that such techniques, in addition to being more cost-effective, will also produce hardier juveniles more capable of withstanding the broad range of abiotic and biotic conditions of the marine environment.

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Sea ranching of sandfish in an Indigenous community within a well-regulated fishery (Northern Territory, Australia)

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Abstract

The Northern Territory is in a unique position to support sandfish (*Holothuria scabra*) ranching as it has an intact wild fishery and low poaching pressure. Indigenous people own 85% of the coastline, and are keen to develop economic opportunities through their natural resources. The commercial wild-caught sector has well-established markets, and has expressed a willingness to partner with Indigenous coastal communities. Research currently underway is focused on the biological and economic feasibility of sea cucumber ranching as well as developing effective facilitation and evaluation approaches to ensure that Indigenous people drive enterprise development themselves.

Introduction

A wild sea cucumber fishery operates across northern Australia, extending from the tropical regions of Western Australia, across the Northern Territory (NT), to tropical Queensland in the east. This paper reports on the fishery within the NT, which comes under the management and regulation of the Northern Territory Government (2009).

Compared with countries also working to develop sea cucumber ranching, the NT is in a unique position. It has an intact and sustainable wild-catch fishery with well-established supply chains and markets. This is largely due to a strong management regime and the efforts of the commercial sector, which consists of a single operator who owns all six available licences. In addition, the NT has a large population of coastal Indigenous Australians who own 85% of the coastline, and who aspire to pursue economic development through the use of their natural marine resources. The recent recognition of Aboriginal people's legal ownership of the intertidal zone within the NT offers further opportunities for marine-based economic activities. The commercial wild-catch operator has demonstrated a willingness to partner with Indigenous communities to establish sea-ranching enterprises, and is currently operating a commercial hatchery in the NT, and conducting pond-based grow-out and sea-ranching trials, the latter with a community on Groote Eylandt (Bowman 2012).

Another unusual factor that exists within the NT is the absence of significant sea cucumber poaching activity. This is largely because local people, both Indigenous and non-Indigenous, do not eat sea cucumbers, and because illegal take by Indonesian fishers has been drastically curtailed in recent years due to enhanced surveillance and apprehension operations.

The implications of this unique set of factors in the NT will be discussed in this paper in the context of opportunities for sea cucumber aquaculture by Indigenous people living in remote communities.

The wild fishery context

A modern wild fishery, targeting the high-value sea cucumber, sandfish (*Holothuria scabra*), has operated in the NT since the 1980s. It continues

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to be sustainable today due to the precautionary management approach by the NT Government and a unique set of circumstances around the nature of the commercial sector and the characteristics of the operating environment.

The fishery is divided into two zones, three licences per zone, with six licenses in total. The government's conservative approach includes a limit on the number of licences and the area of the fishery (within 3 nautical miles of the coast to preserve deeper sea breeding stocks considered important for recruitment). Collection of sandfish is by diving from vessels, using hand methods only.

Fishery management aims to ensure intergenerational equity of stocks, and it does this by having a range of performance indicators, any one of which can trigger a management response. The performance indicators are:

- a breach of a total catch of 300 t/year (wet weight)
- a variation in the rolling 3-year average catch per unit effort by a factor of 30% from the current year value
- a decrease in the average weight by more than 20%
- a change in species composition to over 30% of total catch
- a change in licence ownership.

The government takes this precautionary management approach due to the limited knowledge of the biology and ecology of sandfish. Consequently, there is a push, initiated by the Australian Government, towards addressing key research priorities to fill the knowledge gaps and develop meaningful yield estimates**.**

The second set of factors that contribute to sustainability are around the nature of the commercial sector and the characteristics of the operating environment:

- There is only one licencee, so there is no 'gold rush' mentality around fully harvesting the good stocks.
- The company has the ability to rotate harvests.
- Crocodiles, poor visibility, monsoon season and extreme tidal range restrict access to many fishing grounds, and limit the ability of divers to pick up all harvestable stocks.
- There is relatively low poaching activity (at least in recent years).

In the past, the incidence of illegal fishing in northern Australian waters, predominately by Indonesian sea cucumber vessels, has been considerable. However, recently, there has been a significant increase in the apprehension of illegal vessels, from 60 in 1999 to 210 in 2005.

In 2006, the Australian Fisheries Management Authority (AFMA) set in place an extensive surveillance and apprehension program within the Australian Fishing Zone using aircraft and sea vessels, together with extensive data gathering**.** As a result of this concerted effort, by 2009 the apprehension rate was down to nine vessels in the first 5 months (AFMA, pers. comm.). Clearly, the message had filtered back to illegal fishermen in Indonesia that surveillance had increased and apprehension was likely.

It is interesting to consider this illegal activity by Indonesian fishers in the context of the long history of sea cucumber (or 'trepang' as they are traditionally known) fishing in northern Australian waters by the Macassans from Sulawesi. They came each year in the monsoonal months and fished for trepang, often working in collaboration and mutually beneficial trade with the coastal Aboriginal people (Macknight 1976). They had been doing this since around the mid 1700s until Europeans put a stop to it in 1907 to allow local white people to take over the trade. As a result of this historical sustained contact with Indonesians, Northern Territory Aboriginal people have a cultural affiliation with trepang and with the fishing activity, even though they do not eat sea cucumber.

In addition to the unique factors around the wild sector, there are also some quite unusual characteristics around current sea-ranching aspirations, by both Indigenous people and the commercial sector. In 2008 the High Court of Australia gave legal recognition to Indigenous Australians' ownership of the intertidal zone within the NT (Altman 2008). Negotiations are currently underway to determine access to marine resources in that zone. Irrespective of the final outcome of negotiations, there are opportunities for Indigenous people to conduct sea ranching and on-sell to the commercial sector, which has demonstrated a willingness to partner with Indigenous people in this enterprise, committing to buy all postharvest or first-process product.

The sea-ranching trials

In 2009 the NT Government began working with the commercial operator on two trials to assist Indigenous communities to establish sea-ranching enterprises. One is in partnership with the Warruwi community of Goulburn Island and the other with the Umbakumba community on Groote Eylandt. The former is an Australian Centre for International Agricultural Research (ACIAR) project in partnership with a broader project involving Vietnam and the Philippines that is led by the WorldFish Center.

On Goulburn Island an 18-ha research site has been established and four research pens set up to monitor growth and survival according to the methods developed by Purcell (2004, 2012) and Purcell and Simutoga (2008). The site is a perched reef, accessible only at low tides when water levels are 10–30 cm deep. Suitable daytime low tides occur only between August and March. The danger of crocodile attack precludes diving or snorkelling. Surveys have shown that standing stocks of wild sandfish are healthy in the trial area. These will be removed prior to release of juveniles produced by the private sector in collaboration with government staff. Releases of approximately 10,000 fluorochrome-stained 5-g juveniles are planned using a cage release method developed by the private sector. The release cages are designed to exclude most predators, and protect animals from extreme water currents resulting from the 5-m tide difference. Animals are expected to move out of the cage as they become acclimatised. The logistics of working at the site make the research very difficult, primarily due to extreme currents, crocodiles, infrequent daytime low tides and the cost of flights to these remote areas. Data from the sea-ranching trials will be used to assess economic and biological viability. Assuming the trials demonstrate that sandfish sea ranching is viable, future work is likely to see expansion of trials to other sites within the West Arnhem region.

Strategic approach to Indigenous engagement

The NT Government's Aquaculture Branch seeks to identify aquaculture enterprises that meet a set of social and economic criteria that increase the likelihood of Indigenous enterprise success. The focus is on selecting species and farming activities that:

- have low capital requirement and low, infrequent management/operational demands
- meet social and cultural criteria suitable for Indigenous engagement and job participation (e.g. culturally relevant species, culturally familiar and engaging operational activities, flexible weekly working hours, work that enables people to attend to cultural activities and obligations for extended periods of time)
- have high market value and strong to medium market demand, with existing supply chains and/or clear commercialisation pathways. However, it is recognised that a staged approach where people develop familiarisation with farming through first engaging in more culturally aligned activities and outcomes is more likely to achieve success. Thus, target species, and the products and uses of those products, may be developed for purely social and cultural outcomes as a staged approach to longer term economic outcomes
- have a commercial partner and/or project enterprise champion and facilitator.

Sandfish sea ranching meets the criteria for suitable Indigenous development projects in terms of these social, technical and economic assessments. Nevertheless, capacity to engage in western-style commerce and participate in the mainstream workforce is low for most communities. To overcome these barriers, the Aquaculture Branch is partnering with social scientists and trained Indigenous research practitioners to ensure that people define their vision for their community and their work style aspirations (in their first language), conduct research to develop successful engagement and governance models, gauge effectiveness in meeting community aspirations, and measure both community and individual social and economic outcomes. Such evidence is critical to identifying success and failure points, thus ensuring that a culture of continual learning is embedded in current activities to inform future ones.

Community-based organisations and agencies play an important facilitation role in this 'bottom-up', community-driven approach, particularly in assisting people to develop appropriate governance arrangements and capabilities, and providing job-specific training. However, enterprise facilitators must ensure that they do not influence enterprise development choices, but allow the community to decide what the outcomes for aquaculture enterprises will be in the short term. In this way external non-Indigenous people are less likely to unwittingly impose culturally inappropriate development choices on people.

Another important aspect of facilitating community enterprise development is to work with the children. The Aquaculture Branch has worked with the Warruwi school on Goulburn Island to enhance awareness of the current trepang trials on their lands, as well as the history of trepanging with Macassans by their grandparents and distant ancestors on the island. The education program also seeks to communicate the potential future opportunities and benefits of aquaculture enterprises if the trials prove

Warruwi community members inspecting sandfish holding pens on Goulburn Island, Northern Territory, Australia (Photo: Wayne Tupper)

successful. In this way the community's youth will foster aspirations to take advantage of such opportunities when they become young adults. Job-specific training will be developed for current participants if the trials prove successful, enabling them to readily progress to paid work when enterprises become profitable.

The above approach requires the Aquaculture Branch to form effective working partnerships between agencies to facilitate enterprise development. The Branch is therefore developing a policy on Indigenous aquaculture development that identifies the key guiding partnerships, activities and principles to underpin Indigenous aquaculture development in communities. This policy will guide the activities of the Aquaculture Branch and its partners when facilitating aquaculture enterprises and activities in communities.

Summary

The unique context in the NT—where Indigenous communities own most of the coastline (now including the intertidal zone), the commercial sector has well established markets and is keen to partner with Indigenous communities, and there is largely no poaching—offers culturally and socially suitable natural resource-based opportunities for Indigenous people living in remote coastal communities. In relation to pursuing sea-ranching enterprise development, facilitators must recognise the following:

- Social disadvantage and cultural differences require facilitators to take a whole-of-community perspective of physical and human resource development. They must commit to a long-term course of facilitation, and must install processes to ensure that Indigenous people drive the visioning, planning and implementation process. Thus, partnerships between agencies must be formed to bring together the broad range of skills necessary to facilitate enterprise development.
- Selection of species and sea-ranching methods must meet social and cultural criteria suitable for Indigenous engagement and capacity.
- The terms of collaboration between the commercial sector and Indigenous communities must allow for a win–win outcome to work in the long term.
- Evidence must be gathered to identify success and failure points, thus ensuring that a culture of continual learning is embedded in current activities to inform future ones.

Further, in relation to sea cucumber ranching, facilitators must recognise that time frames must be appropriate (i.e. long) to ensure gradual development, because:

- technologies are not yet established
- many logistical factors have to be addressed
- the capacity to identify suitable sites is not certain
- economic returns are yet to be determined
- Indigenous engagement for many communities is not yet adequate for effective participation.

The government is keen to take a cautious approach to facilitating development so that expectations can be managed. Indigenous people are accustomed to waves of failed ventures coming and going through their community. The government wants to see this enterprise develop in a way that maximises the chances of success, both socially and economically. Past evidence from successful natural resource based enterprises point to a gradual, measured, community-controlled approach as the way to achieve this.

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Resource tenure issues

Sea cucumber processing by a Fijian exporter (Photo: Cathy Hair)

Marine tenure and the role of marine protected areas for sea cucumber grow-out in the Pacific region

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Abstract

Many Pacific island countries are reviving longstanding customary marine resource management systems and traditional tenure through the locally managed marine area (LMMA) approach. The customary tenure systems vary: some are formally recognised in national laws, while for others the recognition is informal. These practices include seasonal bans on harvesting, temporarily closed (no-take) areas, and restrictions placed on certain times, places, species or classes of persons. The LMMA demonstrates the shared vision of stakeholders that promotes the success of adaptive management, as evidenced by healthy ecosystems and communities, abundant marine and fish stocks, sustainable fisheries utilisation, protected marine biodiversity, sustainable development in coastal communities, an understanding of what communities are doing and can do in managing marine areas, and an understanding of ecological and socioeconomic responses to LMMA and coastal management implementation. The LMMA approach helps to ensure that benefits from marine conservation efforts will accrue to the local community, generally in an equitable manner, benefiting them spiritually, culturally, communally, socially and economically. A Fijian site in Verata district revealed that, since 1997, there has been a 20-fold increase in clam density in the *tabu* areas, a 200−300% increase in harvest in adjacent areas, a tripling of fish catches, and a 35−45% increase in household income. Similar trends have also been observed in the other *tabu* areas across Fiji in a range of potential marine commodities, such as giant clam, seaweed and coral transplanting. Currently, there are more than 200 traditionally imposed LMMAs, including *tabu* areas, and numbers continue to grow.

In Fiji, application of the LMMA approach at Natuvu village on the island of Vanua Levu has demonstrated how a customary tenure system can be integrated with sea ranching of sandfish in a closed area. The entire process can be governed by Fijian customary institutions and laws that incorporate local socioeconomic considerations, and provide more diverse and culturally appropriate approaches to enforcement, compliance, monitoring and restitution. The effectiveness of traditional practices is a reflection of the strength and viability of the customary law regime. There may also be issues regarding enforcement, the viability of a closed area in the long term, and the roles taken by governments, communities and traditional leaders. Traditional practices are generally accompanied by strategies and resources to support sustainable use, viable livelihoods and equitable sharing of benefits.

Introduction

Customary tenure in the Pacific region has been well documented by Hickey (2006), and a comprehensive compilation of the different types of tenure system and their implications is set out in case studies for Pacific island countries by Vierros et al. (2010). In summary, the tenure systems are diverse and unique to the traditions and cultures across the island nations. However, a few of these countries are either beginning to lose or are phasing out fundamental elements of their traditions in modern times (Vierros et al. 2010). Although some of the Pacific island nations still hold onto strong traditional tenure, there are variations in management influenced by modern practices and efficient technology. The locally managed marine

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area (LMMA) approach is one that seeks to retain and revive traditional approaches in marine tenure, and facilitate their use as a means to provide solutions for modern-day marine resources management issues confronting coastal communities.

This paper provides an overview of the tenure systems across the Pacific region, the associated initiative of LMMA and the opportunities it presents, and suggestions for how the grow-out process of cultured sea cucumber could be carried out successfully. The geographical areas under LMMA across the region are highlighted. Further, the ability of *tabu* areas to protect sedentary marine organisms sharing the same habitats and ecosystem as sea cucumbers is discussed, based upon qualitative and anecdotal information collected. *Tabu* areas are portions of traditional fishing grounds that have been consensually approved by the community owners to be closed to fishing or harvesting. The paper also provides an account of how the traditional marine tenure system in one Fijian community could be mobilised, via the LMMA approach, to integrate the management of sea ranching of sea cucumbers.

Customary tenure systems

Customary marine resource management practices have long been used in some Pacific island communities in accordance with traditional spiritual beliefs. These practices include seasonal bans on harvesting, temporarily closed (no-take) areas, and restrictions placed on certain times, places, species or classes of persons. Closed areas include the *tabu* areas of Fiji, Vanuatu and Kiribati, the *ra'ui* in the Cook Islands, the *kapu* in Hawaii, the *tambu* in Papua New Guinea, the *bul* in Palau, the *mo* in the Marshall Islands, the *tapu* in Tonga and the *rahui* in New Zealand.

In Palau, the *bul* can be put in place to close an area of reef to harvesting on a short-term basis, such as during periods of fish spawning. Vanuatu also has networks of spatial–temporal refugia created as part of a range of customary practices, such as the ordination or death of a traditional leader, the death of a clan member, grade-taking rituals, and agricultural and ritualised exchange cycles (Hickey 2006). Such area closures may be off limits to fishing for as long as 7 years. Historically, Hawaiians also used a variety of traditional marine resource management practices, which included *kapu* (fishery closures). These closures were often imposed to ensure catches for special events, or as caches for when resources in the regular fishing grounds ran low.

In Fiji, traditional marine practices still exist, even though they have been eroded to some degree over the years. For example, when a high chief dies, certain marine areas are restricted for approximately 100 nights. Moratoriums are also put in place for traditional ceremonies or funerals; once the restriction period has ended, the area is reopened for public use. Bans also exist for seasonal harvesting; for example, the yellowing of the traditional Fijian beach trumpet tree (*Cordia subcordata*) indicates the octopus mating and spawning season, at which time a temporary ban on catching octopus is put in place. Recently, such practices have been strengthened through the codification of traditional ownership of rights to harvest fish in coastal areas of Fiji.

During the past decade, many Pacific island countries have experienced a revitalisation of traditional management systems and tenure (Johannes 1998; Govan et al. 2008). In some cases, customary tenure systems are recognised in national law, while recognition of others is informal. Fiji is one of the few countries that have demarcated boundaries, to legally recognise a total of 410 fishing-rights areas or *I qoliqoli*—pronounced 'ng-go-lee, ng-go-lee'—which are communally owned fishing grounds passed down through generations (Figure 1). These records of the ownership of fishing areas are one of the strengths of the traditional marine management system in Fiji. The demarcation process took approximately 20 years (1974–94) and has been applied to the customary fishing areas, which are generally inshore (from the high-water mark to the reef outer edges).

Interestingly, in the context of the current debate in the United Nations relating to governance of the high seas, the traditional fishing grounds in Fiji extended as far offshore as one could go, which could be a considerable distance in a fishing boat. The present-day *I qoliqoli* can range from 0.5 to more than 10 km out to sea from the high-water mark. Beyond the *I qoliqoli* boundaries are Fiji's archipelagic waters, over which the government has legal control. Every Indigenous Fijian must be registered to a clan to have the right to fish in the *I qoliqoli*. As a token of respect, permission from the chief must be sought to fish in another *I qoliqoli*, even if the individual has an ancestral connection to that area. While demarcation of boundaries is perceived to be positive, it can also create conflict: if an area is overfished, people tend to move out to other *I qoliqoli* (Aalbersberg et al. 2005).

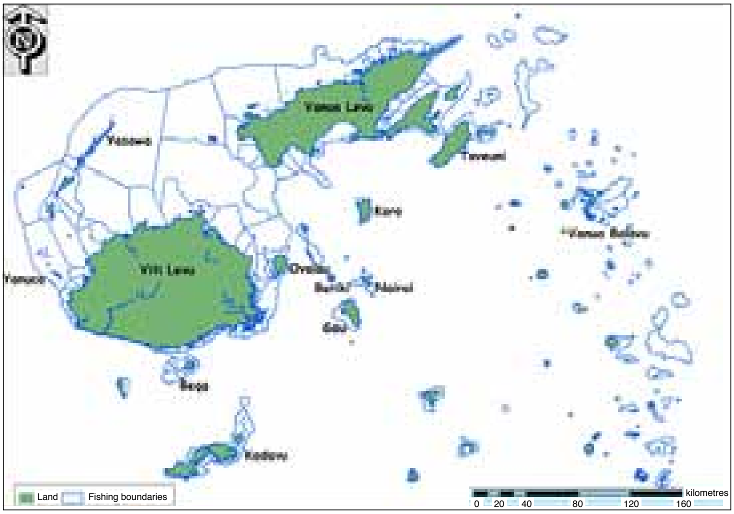

Figure 1. Map of the *I qoliqoli* or traditional fishing areas in Fiji

Locally managed marine areas (LMMA) network

The LMMA network is a group of marine conservation practitioners who have joined together to learn more about and increase the success of their implementation efforts. The network trains practitioners and community members how to collect comparable monitoring data from their project sites, and assists these groups in sharing and systematically learning from one another about LMMA project implementation across the region. It is active in eight Asia–Pacific countries, including the Philippines, Indonesia, Papua New Guinea, Solomon Islands, Vanuatu and Fiji. There are more than 400 active conservation sites and the level of interest in the network is growing. The LMMA network envisions providing an enabling environment for its respective member-country networks and its various stakeholders to facilitate community-based adaptive management in their own countries.

Fiji's LMMA (FLMMA) network, consisting of over 200 communities, protects about 30% of Fiji's nearshore reefs. The FLMMA network, in collaboration with other national stakeholders, is working towards establishing community resource management action plans in the 410 *I qoliqolis* around the country and, at the same time, achieving national goals of effectively managed areas in its jurisdiction's fishing areas. Noticeable declines in coastal resources have prompted communities in Fiji to take action to protect their valuable natural and cultural coral reef resources, specifically to replenish fish stocks. The FLMMA network has established 149 LMMAs (*I qoliqoli*) with about 216 *tabu* areas covering 17,726 km^2 of inshore area. The community benefits of LMMAs and corresponding *tabu* areas are far-reaching, and explain why the LMMA community has expanded across the region. The success of LMMAs is linked with fisheries, coastal protection, waste assimilation, research and education, as well as bequest values (IUCN 2009), and is attributed more or less to ecological, socioeconomic, political and traditional culture advancements.

Intertidal sedentary marine species in *tabu* areas

Ecological benefits from LMMAs and associated *tabu* areas for species associated with inshore intertidal areas have been described in the literature. In the Verata district, Tawake (2004) recorded an approximately 20-fold increase in *Anadara* clam density in *tabu* areas, and about 200−300% increase in harvest in adjacent fished areas. Other flow-on effects were attributed to the tripling of fish catches, and a subsequent 35−45% increase in household income. Aalbersberg et al. (2005) detail how, in one LMMA, mangrove lobster (*Thalassina anomala*) increased by approximately 250% annually, with a spillover effect of roughly 120% outside the protected area. Perhaps more importantly, the study describes how weekly household income in three Fijian communities with LMMAs increased by an average 43% from 2000 to 2003. The study authors noted that 'a successful locally managed marine area is, in effect, an alternative income source. The increase in fishery resources not only improves nutrition but also raises household income through market sales'. Tawake et al. (2001) noted that results such as these in other places have led communities to establish no-take areas in the mangroves and coral reefs to encourage lobsters and coral fish production. Sedentary marine species such as trochus, giant clam, seaweed and sandfish have been the focus of other LMMAs and *tabu* areas in the Pacific islands region.

Social and economic studies in LMMA communities reveal that the social cohesion among the community members, the perceived condition of the fishery resources, the condition of the terrestrial and village environment, the community's understanding of the values of their marine environment, and the amount of marine resources have all greatly improved (Fong 2006). They also conclude that the average catch per unit of effort and the income level of fishers have increased significantly compared with non-LMMA communities.

Monitoring capacity in LMMA sites

LMMA communities, in the process of collecting data, gain skills and experience in simple underwater reef monitoring, measuring key indicator species that indicate the effect of their management actions. Communities with *tabu* areas in intertidal zones often select sea cucumber as an indicator of change, and carry out monitoring of their abundance. Sandfish (*Holothuria scabra*) were monitored twice in a *tabu* area and an adjacent harvest area in Navakavu in Fiji within a 6-month period (Meo and Mosley 2003). Community monitors took the lead to carry out surveys, analyse data and present results to be used for adaptive management (Figure 2).

The *tabu* area had higher numbers of sandfish than an adjacent harvested area during both times of the survey. An LMMA site with its associated *tabu* area may provide the enabling environment and the opportunity for a cultured sea cucumber grow-out phase; however, there needs to be careful consideration of the *tabu* habitat type and characteristics. It strongly suggests that the criteria for selecting

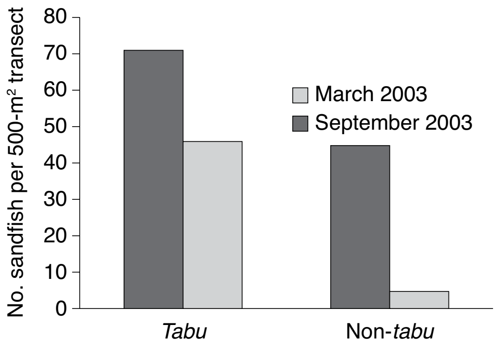

Figure 2. Survey results of sandfish abundance (no. individuals/500 m^2) in a *tabu* locally managed marine area versus an adjacent non-*tabu* harvest area

suitable habitats are extremely important in ensuring that the environment supports each life-cycle stage. The community of Natuvu, through the technical and advisory support of the FLMMA network and the Australian Centre for International and Agricultural Research researchers, has taken an advanced step in applying aquaculture techniques combined with the LMMA approach (Hair et. al. 2011). The initiative demonstrates how restocked sandfish can be managed, and how the restocking was, in itself, a trigger to initiate such management via traditional means. On the other hand, it also narrows a gap in knowledge about how the necessary link or partnership can be established between the community and the investing partner in producing cultured organisms.

The marine tenure system in the Pacific region is dynamic and contemporary. It is essential that the principles of good governance, including a participatory and inclusive approach, are upheld. The community-based management system provides flexibility to integrate traditional and science-based knowledge systems harmoniously.

Resource governance in LMMA communities is quite pronounced compared with non-LMMA communities (Fong and Aalbersberg 2011). Hence, these communities are able to use existing arrangements to organise and orientate them to take the lead in any resource-related project such as grow-out of hatchery-produced sea cucumber (e.g. restocking or sea-ranching activities). However, input from technical resource organisations is essential, as most communities will not have the capacity to undertake such a project alone.

Natuvu village case study

In Fiji, application of the LMMA approach at Natuvu village on the island of Vanua Levu has demonstrated how a customary tenure system can be integrated with the sea ranching of sandfish in a *tabu* area (Hair et al. 2011). In this case, a number of advantageous factors coincided—overseas aid funding and technical support, the availability of cultured juvenile sandfish, suitable physical conditions on the ground and the will of the community—to provide the trigger to institute such management via traditional means. The FLMMA network, local Fisheries officers, Natuvu community leaders, outside technical experts and local private-sector partners collaborated to carry out a trial sea-ranching project within the Natuvu *tabu* area.

The project's aim was to transfer sandfish-hatchery technology to local government and private hatcheries, increase juvenile production, and conduct sea-ranching trials within a local coastal community. The initiative collectively engaged a range of stakeholders from national and local government, community-based resource management advocates, the private sector and the community. The partnership was perceived as deliberate and essential in achieving the goal of the initiative. The juveniles produced in a privately owned hatchery were sea ranched in the *tabu* area in Natuvu and the communities were engaged in various components of the rearing processes from pen deployment, monitoring and enforcement. The community had a very strong sense of its ownership in the use of their *I qoliqoli,* and felt obliged to be engaged and to drive the initiative forward. The community-based adaptive management knowledge and skills of the FLMMA network engaging the Natuvu community over the past years was quite fitting, and prepared them for this aquaculture initiative.

Although the sea cucumbers did not reach commercial size (due to the destructive effects of a cyclone), the trial demonstrated that there is potential for this approach to succeed. The application of the LMMA approach at Natuvu demonstrated how a customary tenure system can be integrated with the sea ranching of sandfish in a closed area.

Discussion and recommendations

Aquaculture skill and technique is still new to most Pacific island communities; however, a community in Fiji has been exposed to this activity with positive outcomes. Although it is a relatively new activity, one important issue in the process is the transfer of knowledge and technology at different levels. The aquaculture stages of sea cucumber culture are interdependent. One stage that relies on local knowledge is the location of broodstock animals (i.e. suitably sized adults) in their fishing ground. The hatchery phase requires specialised technical expertise to conduct successful spawning and larval rearing. All stakeholders should have a sound understanding about the importance of each stage in the entire process. In doing so, assessment of any capacity gaps in acquired skills can be carried out, and knowledge of different stages can be established. Appropriate training can then be arranged. Outside technical assistance must be accessible when needed.

The grow-out (or sea ranching) stage requires the cooperation of community members (and their neighbours) to allow the animals to survive and grow, and to resist poaching. This stage has been shown to be technically feasible in certain suitable areas, but needs to be proven economically feasible before proceeding. The *tabu* LMMA provides suitable habitat for culture of sandfish and, with other supporting evidence, these areas would be prioritised for this purpose. After successful research work at this stage, a checklist can be prepared of the conditions required for optimal productivity and maximum benefits for the sandfish in *tabu* sites. Technical expertise is required to further research these conditions.

Community-based initiatives are often unsustainable in the Pacific region. This is a major issue, as managers and practitioners unwittingly fail to include community goals and aspirations in the project. Communities must be collectively involved, and their daily lives need to be influenced by the initiative in order to get their active participation and engagement. LMMAs become active sites as communities work their way towards setting their resource management governance, and establishing new management units in committees and corresponding provincial networks, the operation of which ensures the sustainability of projects at the local level. The main reason that communities engage in sea cucumber culture projects is for alternatives to secure their livelihood and food security. The communities' expectations are raised once they get involved in sea cucumber aquaculture, and this imposes a risk if it fails to succeed. These factors should be studied further.

At the moment, sandfish is commonly used because it is a well-established culture species (see papers in these proceedings). However, expanding the list of culture species would be useful, given that most *tabu* areas comprise reefs and lagoon ecosystems. In Kiribati, the culture of white teatfish (*Holothuria fuscogliva*) in the hatchery has been achieved, but it is not known about its survival rate after release into the wild, since monitoring has been problematic. Further research into the culture and grow-out of this and other sea cucumber species would assist communities and ecosystems of the Pacific islands region, where *tabu* areas could be used to optimise management and provide maximum benefits.

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Sandfish (*Holothuria scabra*) fisheries in the Pacific region: present status, management overview and outlook for rehabilitation

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Abstract

A regional comparative assessment of reef resources and socioeconomic activities of fisheries in 17 Pacific island countries and territories (PICTs) conducted by the Secretariat of the Pacific Community (SPC) over an 8-year period (2002–09) reveals useful resource status information. Here we review the status of sandfish (*Holothuria scabra*) stocks from a range of PICTs, some of which have had a moratorium on commercial exports for many years. *Holothuria scabra* was present in 41% of countries and 23% of sites assessed, although sites with sandfish were mostly at low density, with 81% below the mean density of 1,200 individuals/ha, and the majority of sandfish were small (<23 cm body length).

Progress in community-based marine resources management in the past decade has done little to reverse the declining trend in sea cucumber fisheries for the production of the export commodity, beche-de-mer. Both customary marine tenure and fisheries regulations are used to manage sandfish resources across the Pacific region, but have limitations. Community-based management controls were often outside the traditional boundaries of subsistence fishing when trying to control commercial harvests, while fisheries agencies were limited in the resources available to devise and implement regulations. While there are some well-managed fisheries as well as prospects for recovery in fisheries that are under pressure, difficulties in enforcing commercial fishing and export controls, and unlimited exemptions on subsistence and domestic sales, are challenging the sustainability of this fragile resource.

Continued extraction of sandfish for export and subsistence use is causing local extinctions and depletion of broodstock, threatening the potential development of sandfish aquaculture. PICTs therefore face a big challenge to reverse current trends to ensure continued use and commercial return from sandfish resources. At present, aquaculture offers both a hope and, in some cases, further pressure on a stressed legal, social and ecological system. While aquaculture is being trialled in the region with some success, the introduction of relatively new technology is also resulting in direct (broodstock losses) and indirect (trial harvests and clearing to prepare ground for seed) depletion of wild stocks. Many fishers and managers in PICTs lack basic knowledge of sea cucumber biology and aquaculture technology. In the face of big promises from aquaculture investors in the region, SPC has provided advice to assist decision-makers in making the best choices for sea cucumber aquaculture development in their countries.

Introduction

Sea cucumber resources are being overfished worldwide (Conand 2004; Uthicke 2004). For many Pacific island countries and territories (PICTs), this is a major concern for fishers and coastal communities for whom the resource is a source of livelihood.

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There is also concern by fisheries managers and governments, because these easily accessible, inshore resources are often no longer able to return economic benefits to remote and rural communities that have few other options for income generation. Sea cucumbers, which are generally exported in their dried form (beche-de-mer) to Asian markets, are one of the oldest commercial export commodities for many PICTs. Some sea cucumber species are also a local source of protein for the Pacific island communities. Where subsistence fishing was important, domestic commercial activities have often developed to support demand of this local delicacy. These domestic sales fit the definition of commercial fisheries, but are normally not classified in standard recordings of commercial activity. Instead, they are classed as subsistence fishing, which is normally exempted from formal legislation and controls.

Production of sea cucumbers in the region varies depending on the size and nature of the island and the coastal systems of each country. The high island lagoon systems found in Melanesia dominate production, with Papua New Guinea (PNG) (600 t), Solomon Islands (400 t), Fiji (200 t) and New Caledonia (Kinch et al. 2006, 2008) producing the bulk of commercial products. PNG, the single most important producer, was supplying approximately 10% of world production before a moratorium on its fishery was declared in late 2009. Due to unregulated take and degradation of stocks, other countries have taken similar actions: Palau in 1994 (>10 years), Samoa (1994 to present), Tonga (2007 for 10 years), Vanuatu (2008) and Solomon Islands (2005). Historical time-series show that sea cucumber fisheries in the Pacific region have been characterised by boom and bust cycles (Uthicke 2004). High production since the 1990s to early 2000 represents the latest fishery 'boom' across the Pacific, and now the region is going through the 'bust' cycle, which has resulted in a number of moratorium declarations in the past few years.

A regional comparative assessment of reef resources and socioeconomic activities of fisheries from 17 PICTs conducted by the Secretariat of the Pacific Community (SPC) over an 8-year period (2002–09) reveals useful resource status information not readily available in the past (Friedman et al. 2010). Here we review the stock and management status of sandfish stocks from a range of PICTs. We use snapshot data to compare spatial distribution, abundance and size distribution of sandfish (*Holothuria scabra*) stocks across multiple sites in five of the seven countries studied between 2002 and 2009. In addition, we look at the status of golden sandfish (*H. lessoni*) in Tonga, where sandfish is naturally absent and golden sandfish is a species of potential interest for aquaculture development.

Regional, national and state legislative control

At present there is no regional agreement about the management of sea cucumber fisheries in the Pacific region (Friedman and Chapman 2008). National regulations control the species harvested, and the amount and size of sandfish exported (Table 1), although subsistence fishing and fishing for the local market are not well monitored or controlled.

Community-based management

Community-based management via customary marine tenure (CMT) in the Pacific islands region is an effective framework for sustainable management of marine resources. Reef invertebrate resources such as sea cucumbers can be managed effectively by CMT systems; however, progress in community-based marine resources management in recent years has done little to reverse the declining trend in sea cucumber fisheries. Customary resource tenure gives villages, clans or communities the right of ownership to the land or coastal areas where they live, or over which they have ancestral claims. These rights were in place prior to colonisation and are often recognised in national legislation (Table 2). A lot of attention and financial support have been given to community-based management in the past decade to strengthen local governance of resources (see Meo 2012). The goal is to delegate and empower some management responsibility to resource custodians, thereby relieving pressure on government, especially on the difficult roles of surveillance and enforcement. Customary management is promoted also as a means of preserving local traditions and cultural practices by recognising and supporting local governance structures.

Survey results

Here we review the survey data for sandfish stocks from a range of PICTs, some of which have had moratoriums on exports for up to 10 years. Snapshot data across sites in 17 SPC member island countries and territories were used to compare spatial

Table 1. Government regulation of sandfish stocks in Pacific island countries

Country	Commercial/subsistence extraction	Individual species controls	Size/weight controls	Export licence required
Palau	Subsistence/commercial	Commercial export ban	None	–
Fiji	Subsistence/commercial	Commercial export ban	76 mm dry length	–
Vanuatu	Commercial	None	None	Yes–no limit
New Caledonia	Commercial	None	None	Yes–no limit
Tonga	Commercial (golden sandfish)	Commercial export ban	70 mm dry length	–
Federated States of Micronesia	Commercial	None	None	Yes–no limit
Solomon Islands	Commercial	None	100 mm dry length	Yes–no limit
Papua New Guinea	Subsistence/commercial	None	100 mm dry length	Yes–no limit

Table 2. Status of customary resource tenure in selected Pacific island countries in relation to sandfish stocks

Country	Commercial / subsistence extraction	Strength of village management[a]	Customary marine tenure (CMT)	CMT supported in national legislation
Palau	Subsistence domestic sale	Strong	Strong	Weak
Fiji	Subsistence domestic sale	Moderate	Strong	Weak
Vanuatu	Commercial	Variable	Strong	Weak
New Caledonia	Commercial	Moderate	No	?
Tonga	Commercial (golden sandfish only)	Absent	No	No
Federated States of Micronesia	Commercial	Low	Yap state	Yes–Yap state
Solomon Islands	Commercial	Low	Moderate	?
Papua New Guinea	Domestic/ commercial	Low	Moderate	?

[a] perception of survey personnel

distribution (presence), abundance (density) and size distribution of stocks over an 8-year period, 2002–09. Sandfish stock status was assessed by shallow water, soft-benthos transect surveys. General fishery information was collected through discussions with fisheries officers, processors, exporters and fishers during visits. All data were entered into the Reef Fisheries Integrated Database at SPC in Noumea. Survey data are analysed and presented as 'presence' (percentage of total replicate transects) as a measure of spatial coverage; density (individuals (ind)/ha) as a measure of abundance; and total length (cm) as a measure of size.

Sandfish was present in seven PICTs, where the species is endemic, and golden sandfish was present only in Tonga. Of all the sites where sandfish and golden sandfish occurred, 44% had suitable habitat for sandfish (soft bottom substratum with seagrass, often with mangrove influence). The best sites where sandfish were present were Ngatpang, Ngarchelong and Airai (Palau), Maskelynes (Vanuatu), Riiken (Federated States of Micronesia), Dromuna, Muaivuso and Lakeba (Fiji), Oundjo (New Caledonia), Tsoilaunung and Andra (PNG), and Nggela (Solomon Islands), while golden sandfish was present in Ha'atafu and Nukunuku (Tonga). Density results for these sites (Figure 1) reveal that most sites held densities that were characteristic of an impacted stock (71% of sites had a mean density of below 942 ±156 SE ind/ha), and

60% of the sites recorded a mean of <500 ind/ha (i.e. 1 sandfish every 20 m^2). Considering that the natural population of sandfish can easily reach densities in the range 8,500–9,500 ind/ha, as was recorded in Abu Rhamadan Island in the Red Sea (Hasan 2005), and up to 4,000 ind/ha in Mahout Bay, Sultanate of Oman (Al-Rashdi et al. 2007), the majority of sites in the Pacific region are considered depleted for this species.

Further analysis of site-specific management data reveals useful information on the causative factors behind stock status findings. In Palau, commercial export of dried *H. scabra* was banned for 12 years prior to the survey presented here. However, sea cucumbers are an important component in the diet of both the Palauan people and visitors to Palau; sandfish is the most sought-after species for its meat and polian vesicles, and the largest specimens receive a premium when collected (Pakoa et al. 2009). Exploitation of *H. scabra* and other edible species for subsistence, as well as 'domestic sales', are both exempted from existing commercial beche-de-mer management policies and regulations.

The densities of *H. scabra* at the northern sites of Ngatpang and Ngarchelong were much higher (mean of 2,972 ± 482 SE ind/ha and 1,479 ± 176 SE ind/ha, respectively) than at the southern site of Airai (~208 ind/ha), which is closest to the capital of Koror and supplies most of the invertebrate products to the urban centre. Length distribution data reveal a relatively small-sized population of sandfish (mean length (cm) of 16.5 ± 0.4 SE) with reduced maximum length (Lmax) of 23 cm, compared with less impacted stocks in the Pacific region, which had a mean length of approximately 23 cm (Lmax 32 cm). The missing section of the population (>23 cm size) is highly likely to be lost due to continuous exploitation by the subsistence and domestic-market sectors, and there is also significant export of raw sea cucumber to Palauans living overseas. Distance from the market, presence of marine protected areas (MPAs) and lower fishing pressure contributed to the more healthy stocks in the northern states. However, fishing controls of the domestic-market sector are still needed to prevent further depletion of the resource.

Holothuria scabra or 'dairo' is a local delicacy in Fiji. Three sites that had sandfish—Muaivuso, Lakeba and Dromuna—assessed twice in this study, provided valuable insight into resource status over two time

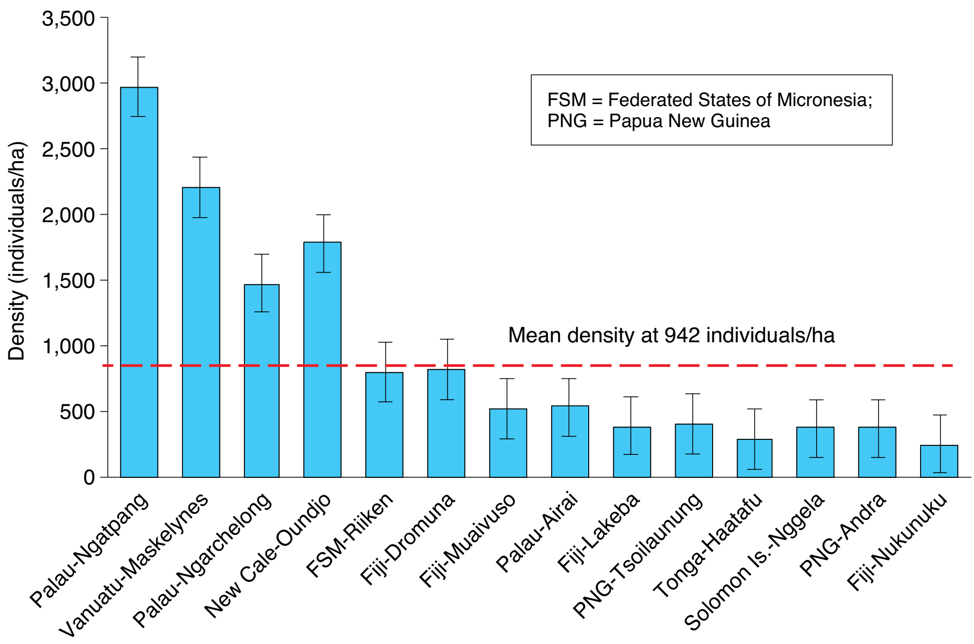

Figure 1. Density of sandfish (individuals/ha) in the 14 best sandfish sites in the Pacific region

periods. As in Palau, commercial export of dried *H. scabra* is banned in Fiji (since 1988), but harvesting for subsistence use, which includes domestic sales, is exempted from this regulation. Two of the three sites assessed in Fiji that had *H. scabra* (Lakeba and Muaivuso) had MPAs established, but they do not cover sandfish habitats. The density of *H. scabra* decreased across all sites between 2003 and 2009 by 54%, 51% and 36% for Dromuna, Muaivuso and Lakeba, respectively (Figure 2).

In the Northern province of New Caledonia, sandfish density was high, with a mean density of 1,784 ± 203 SE ind/ha. Interestingly, the area surveyed was split by the size of individuals recorded between an area within an MPA and an area that had more open access. The larger and older individuals (mean length 22 cm) were found in the MPA, while the smaller and younger individuals (mean length 14 cm) were recorded in the open access area.

In Vanuatu, customary management is widely used to protect inshore resources. In the Maskelyne Islands, South Malekula, *H. scabra* fishing had been banned for some years prior to the surveys, and there is no subsistence use of sandfish. The study revealed the presence of good stock densities (2,202 ± 296 SE ind/ha) and a relatively healthy population, with sizes in the range 6–32 cm length. There is no subsistence exploitation of sandfish, which is an advantage in that the community have to manage only the commercial aspect of the fishery. In addition, Maskelyne Islands is remote to the main island of Efate, where there are greater commercial pressure and incentives.

In Tonga, sandfish is naturally absent and golden sandfish is featured strongly as a local delicacy. The golden sandfish is exploited for subsistence but, more importantly, in domestic commercial sales of processed meat and guts, which are sold at the local market. Resource surveys conducted by SPC (K.J. Friedman, unpublished data; Friedman et al. 2008) revealed the presence of golden sandfish in the three island groups of Tongatapu, Ha'apai and Va'vau; however, densities are patchy, suggesting that stocks may have been overharvested. Anecdotal reports (Charly Valentine, pers. comm.) indicate that this species was one of the main products exploited in the 1990s. The golden sandfish stock of Tonga is struggling to recover after this exploitation and the continued additional pressure from subsistence and domestic commercial fishing activities.

Resource management status

From this stock status information and existing management measures, we are able to suggest improvements in current PICT management systems to ensure that there is sustainable management or rehabilitation of sandfish resources.

Where sandfish is not important in the local diet, subsistence and domestic commercial pressures don't exist, simplifying the issue of management for legislators. However, the trend of resource depletion being experienced at sites surveyed in this study shows that both subsistence and domestic commercial sales are depleting sandfish resources across the Pacific region. Existing national and local management regimes are not reversing the trend of declining spatial availability, abundance and size in the sea cucumber fishery. For most island countries, the existing national and local (province or state) sea cucumber management regimes are not well aligned to ensure maximum

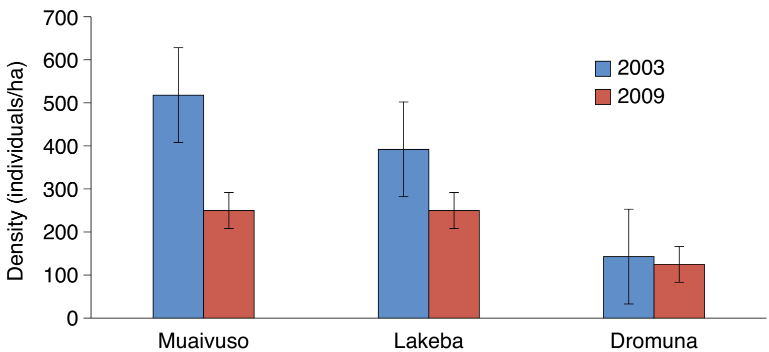

Figure 2. Density of sandfish (individuals/ha) in three sites assessed in Fiji between 2003 and 2009

protection of resources, the socioeconomic needs of the population and the customary practices of managing resources. We believe that having comprehensive enforceable fishery management plans, and accompanying regulatory frameworks, for each country can provide managers and community leaders with a good basis for management.

The 12-year moratorium on harvest of *H. scabra* in Palau has been successful in controlling commercial export of the species; however, the policy is not working effectively to improve the status of the resource, as larger sandfish with greater reproductive capacity are being removed by the domestic commercial fishery. Continuous depletion of the population through fishing could result in stocks of predominantly young animals (i.e. less breeding capacity), possibly leading to poor or erratic recruitment. Domestic commercial sale is proving to be the major contributor to the depletion of *H. scabra* in Palau, and development of regulations and policies are a matter of priority to control the fishery.

In Fiji, where sandfish is a local delicacy, both subsistence and domestic commercial activity exist. In a similar situation to Palau, Fiji has banned commercial export of sandfish (Fiji Fisheries Act 1991), while subsistence and domestic commercial sales remain unregulated. Domestic commercial selling is classed under subsistence activity and thus is exempted from fisheries regulations. MPAs established by communities do not usually include *H. scabra* habitat (i.e. shallow, soft-bottom substratum) or, if they do, community enforcement of the MPAs is not working effectively in the sites assessed by this study. It is recommended that the national and provincial fisheries authorities take action to regulate domestic commercial exploitation of *H. scabra*, which is currently contributing significantly to the pressure on the resource.

In New Caledonia, national and provincial control on the sea cucumber fishery is working relatively well, with control systems partially protecting resources and controlling fishing pressure. Sandfish continue to be fished commercially for export, and it is the third-most important species fished in terms of quantity (Purcell et al. 2009). Putting limits on export licences is an effective tool to control exploitation and encourage responsible fishing. Moreover, this does not stop communities from setting aside parts of their lagoon area as MPAs. Therefore, as shown in this study, having an effective national control of the fishery provides a healthy environment for MPAs to operate. Where an MPA is not effective in improving recruitment, stricter harvesting conditions on size and quality may be needed in addition to a national closed season.

In Vanuatu, a moratorium was enforced in 2008 as a result of concerns about unsustainable harvesting. Community-based management was the principle form of control used by rural communities, while the Fisheries Department controlled the exit point of export. Customary management of *tabu* areas, as used in the Maskelyne Islands, was previously effective in managing the *H. scabra* resource. However, the lack of a national sea cucumber fishery management policy, monitoring protocol and associated regulations are existing weaknesses that make it difficult for authorities to control the industry. In one particular case, a community was lured by a foreign 'trader' into giving up their resource in exchange for a promise to reseed their reefs with juvenile cultured *H. scabra* (imported seed stock). This venture cost the community most of their wild stock, and did not result in the successful grow-out of seeded juvenile sandfish. Customary marine tenure is an effective management tool, but there are limitations to the scope of social law in the context of controlling fishing of sea cucumbers. In the case of social law, as experienced in the Maskelynes, the commercial nature of the fishery is changing rapidly, and is therefore relatively difficult to control. Lack of knowledge of the fishery, and introductions of new aquaculture opportunities with no proven track record, combined with weak national and provincial fishery control systems, were some of the factors contributing to management failure. A national fishery policy and additional regulations are needed to strengthen control and limit exposure of communities and their management systems to these external market pressures.

In Tonga, where sea cucumbers are a local delicacy, several species are exploited for subsistence and domestic sale. Among the locally exploited species is golden sandfish, a high-value species of great importance to Tonga. The species was also important in the commercial export trade in the 1990s, with Tongatapu yielding most of Tonga's golden sandfish production (according to anecdotal reports from export agents) prior to the 1997 moratorium. While the moratorium on golden sandfish was extended in recent harvest seasons, lack of control on domestic sale activities continue to impede the recovery of its stocks in Tonga.

Aquaculture and the management of sea cucumbers

Sea cucumber aquaculture may provide options for restocking, stock enhancement and sea ranching to restore depleted populations and rebuild stocks to commercially viable levels (Bell and Nash 2004; Bell et al. 2008). However, while these technologies are being developed and refined to determine the best strategies, wild harvesting continues unabated, and there is significant anticipation and expectation by communities that aquaculture will save the fishery. The promise of aquaculture development in the Pacific region has been used as a tool to access and further exploit wild resources. The effects have been both direct—through the fishing of broodstock—and indirect—through 'trial harvesting and clearing, to prepare the ground for seed', which speeds up adult decline and habitat degradation.

Many fishers and managers in PICTs lack basic knowledge of sea cucumber biology and aquaculture technology. Sea cucumber fishers, resource owners and fisheries managers have been exposed to promises of huge profits from sea cucumber aquaculture via restocking of imported hatchery-reared juveniles (e.g. Vanuatu, Figure 3a); artificial splitting and sea ranching of sea cucumbers (e.g. Marshall Islands, Figure 3b); hatchery development and reseeding; and aggregation of broodstock to aid spawning as a form of stockpiling of sea cucumbers before the next harvest season (Figure 3c).

One main concern is that traders promote such ideas in order to obtain access to wild stocks through both the upper levels of management and the community. Following such experiences, advice was disseminated by SPC to assist decision-makers in making the best choices for sea cucumber aquaculture development in their countries (e.g. SPC 2009):

1. Under no circumstance should investors in a hatchery, and sea ranching or restocking, be permitted to engage in fishing of the wild stock.
2. Sea-ranching projects must be governed by robust partnership arrangements with resource owners.
3. Investors must employ qualified hatchery staff to conduct the breeding and sea-ranching activities.
4. Hatchery-reared animals must be released into defined areas, and harvesting operations must NOT involve collection from areas outside these defined areas.
5. The harvest size of sea-ranched animals should be above the size at first maturity, to allow spawning before harvest.
6. Sea-ranched sea cucumber should be clearly distinguished from wild sea cucumber.
7. Broodstock should be sourced from local stocks.
8. Importation of broodstock and juveniles should NOT be permitted.
9. Investors for sea cucumber hatcheries should bear the cost of proving the social and commercial viability of their operations.
10. Investors should provide evidence of their capital commitment to do the research.
11. Cutting up of animals for sea ranching is not a recommended aquaculture technology, and should never be promoted.
12. Aggregation of broodstock to encourage spawning should not be used as a means to stockpile resources for harvest in the next open season.

Discussion

Although both customary marine tenure and fisheries regulations seek to manage the sandfish resource, there are limitations to the scope of both social and government law in the context of controlling fishing of sea cucumbers. In the case of social law, the commercial nature of these fisheries is relatively difficult to control, as witnessed by the differing range and level of adherence to social controls across the Pacific region. Equally, fisheries regulations are only effective when fisheries agencies have the resources to implement comprehensive controls. These are difficult to implement across the scales at which the fishery operates, and inoperable for subsistence fishing. To be effective, managers need baseline information on the status of resources and fishery levels, coupled with ongoing monitoring.

Sea cucumber is one of the oldest fisheries in the Asia–Pacific region, yet it is one of the least well managed. Many island countries do not have proper national, provincial or state sea cucumber fishery management policies or plans. Where such policies exist, regulations to enforce them are not developed, making enforcement difficult. Most PICT legislation is not reviewed regularly to adjust to changes and new developments of the fishery; for example, aquaculture and sea-ranching developments are relatively new initiatives, and are unlikely to be included in legislation. Aquaculture, restocking and sea ranching are management options that require further refinement

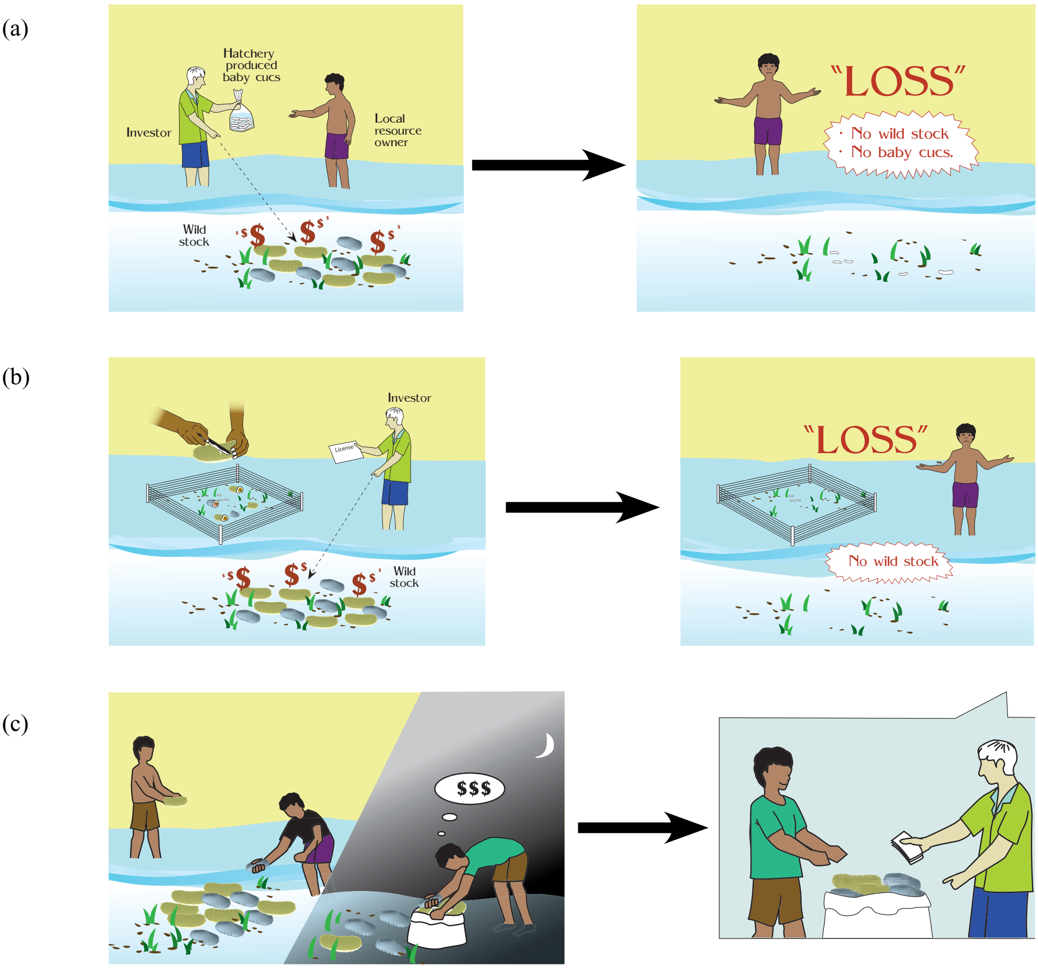

Figure 3. SPC educational material warning PICT fisheries and aquaculture managers of the risks associated with (a) restocking of imported hatchery-reared juveniles in exchange for harvest of wild stocks; (b) artificial splitting and sea ranching of sea cucumbers and (c) aggregation of broodstock to aid spawning as a form of stockpiling (illustrations by Youngmi Choi, SPC)

before they are given wide-scale promotion in the region. Additional research is needed to fully test techniques. Private-sector aquaculture activities must be monitored to ensure environmental and social responsibility at all times.

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Market potential and challenges for expanding the production of sea cucumber in South-East Asia

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Abstract

Sea cucumbers are fished worldwide, with more than 50 species commercially exploited. In South-East Asia, important sources of sea cucumber are Indonesia, the Philippines, Vietnam, Thailand and Malaysia, with Singapore and Hong Kong being major export destinations. The product is popular among oriental consumers due to its alleged ability to improve vigour and cure a number of ailments. Supply in South-East Asia is declining due to overfishing. While significant volume is being produced from sea ranching and pond culture, this is not enough to offset rapidly declining collection from the wild. This and the increasing demand for the product have kept prices at attractive levels. Nevertheless, high prices do not translate to improved income for coastal households as individual catch size remains small and the cost per unit of fishing effort high. The market offers high premiums for well-dried, good-quality sea cucumber. However, primary processing, which is the sole determinant of product quality, remains mostly at the village level, which employs traditional practices. The nature of the fishery itself, which is characterised by small catch volumes per day, leads to diseconomies of size, constraining large processing facilities that are compliant with 'good manufacturing practice' (GMP) and 'hazard analysis critical control point' (HACCP) standards from engaging in the business. The market also operates in the absence of officially formulated grades and standards that would guide transactions along the value chain.

The marketing system for sea cucumber in South-East Asia is generally inefficient, and marketing channels are multilayered. Information asymmetry encourages proliferation of redundant players in the distribution system, while high transaction costs keep the overall marketing margin high but the price received by collectors low. Unlocking the full potential of the sea cucumber industry calls for a set of well-conceived strategies that would sustain supply from the wild, increase the supply from aquaculture, improve primary processing and remove the inefficiencies in the distribution system. Emerging systems for more-efficient processing of the product should also be explored to address issues of economies of scale and improve returns on investment for GMP- and HACCP-compliant facilities, as well as the incomes of fishers and farmers.

Introduction

Marketing systems cover supply, demand and prices. Simple as it may seem, the complication becomes apparent when one considers that analysis of supply includes a range of concerns, from collection of the product to processing and distribution. In addition, supply is not only about quantity, but quality as well. Similarly, analysis of demand covers a wide array of interests. Of particular importance are the geographical characteristics of demand, the nature of products demanded, specific product requirements and the trend in volume resulting from changes in taste and preference. Price may be viewed as the result of interaction between demand and supply. In a capitalist economy, the price system determines what, how and how much of a given commodity to

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produce. Price trends provide a snapshot picture of overall industry trends.

Since the marketing system covers supply, demand and prices, consideration of attendant issues crucial to each component is inevitable. In the case of sea cucumber, overexploitation is a crucial supply issue, as are inefficiencies in processing and distribution. Also important are issues on grades and standards, such as the application of 'good manufacturing practices' (GMP) and 'hazard analysis critical control point' (HACCP) methods. On the demand side, globalisation of demand and the increasing number of new sea cucumber products are interesting developments. Of course, supply and demand issues cannot be viewed in isolation. Understanding how one affects the other is at the core of a good marketing system analysis.

This paper is limited to establishing the major features of the marketing system for sea cucumber in South-East Asia. The opportunities and challenges associated with this system, especially in relation to expanding production in response to a growing demand, is the primary focus. The potential for aquaculture is also explored. The paper uses secondary data on production and marketing, as well as information/data generated from relevant studies conducted in the Philippines, Vietnam and Hong Kong. The paper also provides a synthesis of results and discussion from available literature on the subject. The first section outlines the marketing system, particularly in terms of features common to countries in South-East Asia. The second section discusses the marketing opportunities and challenges to expanding sea cucumber production in the region. The third section provides a synthesis of common marketing issues, and offers a set of recommendations on how to explore the opportunities, overcome the challenges, and deal with the various issues plaguing the sea cucumber industry in the region.

Major characteristics of the marketing system for sea cucumber in South-East Asia

The marketing system for sea cucumber in South-East Asia can be characterised in terms of the three fundamental components: supply, demand and price. Supply includes collection from the wild and production from ponds, but is not limited to these. All activities related to processing and distribution of the sea cucumber products available to consumers are also viewed in this paper as part of supply. Demand is assessed in terms of the utility derived in consumption as well as in terms of its spatial and temporal nature. Characterisation of the marketing system in terms of price is limited to analysis of premium price for quality, price spreads and price trends.

Supply-related marketing system characteristics

There are a number of common threads that run across countries in South-East Asia when it comes to supply-related marketing system characteristics for sea cucumber. Most countries in the region are major sources of sea cucumber products, and the species profiles are more or less the same since the countries have a similar tropical environment. Collection from the wild is generally marginal, and carried out mostly by low-income households in coastal villages. Primary processing remains traditional, and processing techniques are generally the same across the region. Overexploitation of high-value species is a common problem, with each country pursuing specific initiatives to address the problem. Finally, almost all countries are exploring aquaculture as a significant supply source to improve the incomes of coastal households and lessen the pressure of overfishing in the wild.

South-East Asia is a major source of sea cucumber, with Indonesia, the Philippines and Malaysia among the top producers in the region. Despite the increasing demand and high price for the product, sea cucumber fisheries are mostly artisanal, with sea cucumber just an incidental catch to finfish. However, fishing activities where sea cucumber are targeted appear to have significantly grown during the past few years.

Recent reviews of the state of sea cucumber fisheries in South-East Asia showed alarming increases in fishing pressure. Overexploitation has led to local extinction of high-value species in some localities, and prompted closure of many national fisheries to allow stocks to recover, and to allow more sustainable management plans to be established (Purcell 2010). In the Philippines, the Bureau of Fisheries and Aquatic Resources (BFAR) considers sea cucumber to be a heavily exploited resource, and acknowledges that localised depletion has occurred in many fishing grounds. But BFAR possesses no quantitative census to support this claim (Gamboa et al. 2007).

In response to overfishing and declining catches, and spurred by high international prices, aquaculture, sea ranching and restocking have been attempted in a number of countries (Macfadyen et al. 2009). The Australian Centre for International Agricultural Research (ACIAR) and the Worldfish Center are among the international organisations leading the development of sea cucumber aquaculture in South-East Asia. Hatchery and nursery protocols for high-value species, particularly *Holothuria scabra* (sandfish) are fairly well developed in the Philippines, Vietnam, Malaysia and Indonesia. Existing methods for sandfish grow-out include pond and pen culture as well as sea ranching.

Primary processing

In the Philippines, village assemblers are the ones who typically carry out primary processing. It is tedious and time consuming, and generally involves gutting, boiling, brushing, smoking and sun-drying (Brown et al. 2010). However, the processing steps depend on the species being processed, and techniques vary from place to place. Most collectors sell their collection fresh to assemblers or processors, while some process the sea cucumbers themselves before selling them to assemblers, processors or other traders. In southern Thailand, processing of sea cucumber involves gutting and boiling the animal in sea water for 1 hour. The fishermen then bury them in the sand overnight, before removing them and stepping upon them for 10–20 minutes to squeeze out their colour. The sea cucumbers are boiled again in water for 1 hour, then brushed to remove the spicules, before they are ready for consumption or dried for storage.

Primary processing of sea cucumbers in South-East Asia will likely remain traditional, small scale and limited at the village level. The nature of the fishery, which is widely dispersed and where daily collection volume from source villages is small, would not warrant economies of scale in processing. In Vietnam, a large processing company dropped sea cucumber from its processed product line because insufficient volume to achieve economies of scale could be sourced locally. A detailed example of the processing method employed in the Philippines, as well as the associated costs, is shown in Table 1. Total cost is PhP248 (about US$6) for 12 kg of product.

Distribution system

Sea cucumber production in South-East Asia is for both domestic consumption and the export market (SEAFDEC 2009). However, the significance of the local compared with the export market varies significantly by country. Countries with small local demand include the Philippines, Indonesia and Cambodia (see Labe 2009; Sereywath 2009; Wiadnyana 2009), where the bulk of production is exported and other consumption is limited to local Chinese residents. Significant local markets exist only in Vietnam and Malaysia.

The general product flow for sea cucumber involves fishers, village assemblers and processors, other local traders in the source areas, and exporters generally located in big cities (Figure 1). Fishermen sell the product to the collector or buyer either fresh or dried. Buyers also directly collect dried sea cucumber from fishers who opt to dry the products themselves. In the Philippines, though, village-level assemblers and processors do exist. They either wait at the landing sites to buy fresh sea cucumber, or the fishers themselves bring the catch to them. A village assembler carries out the primary processing, and stores the dried product until sufficient volume is accumulated for sale to exporters in the capital, Manila, and other big cities (Figure 2).

In Malaysia, sea cucumbers are sent to both domestic and international markets, although a small portion of fresh product is sold at fish markets for consumption by the local Chinese population. The domestic market also includes sales to processors for producing traditional medicines and other health-related products (Ibrahim 2009). However, a major proportion of sea cucumber in Malaysia is exported. In Vietnam, sea cucumber markets include dried and frozen product, although the volume of the latter is relatively small. Dried sea cucumbers are distributed to either domestic or overseas markets.

There are at least 635 firms involved in supplying sea cucumber products all over the world (Table 2). Typically, sea cucumber is one line in a variety of fishery and other agricultural products supplied. In the Philippines, supplier firms are engaged with a long list of high-value marine and agricultural products, including abalone and shark fin. Among South-East Asian countries, Indonesia has the largest number of firms (81) supplying sea cucumber products, followed by Malaysia (61) and the Philippines (50). There are 21 supplier firms in Vietnam, while Thailand has 9. Along the sea cucumber supply chain, supplier firms are among the downstream players responsible for bringing the products to both local and international consumers.

There are limited studies on the efficiency of the sea cucumber distribution system in South-East Asia. However, a recent study conducted in the Philippines

Table 1. Steps involved in processing sea cucumber, the corresponding resources needed, and the associated costs (Palawan processors, the Philippines, 2010)

STEPS	RESOURCES NEEDED	COSTS (PhP/day)		
		Average	Minimum	Maximum
1. Gutting at the mouth	Petromax or lamp Flashlight Gasoline or kerosene Knife (good for 3 years)	2.17 0.28 44.00 0.03	1.85 0.28 33.00 0.06	2.78 0.28 54.00 0.06
2. Boiling for 5 minutes – 2 hours	Aluminium basin or big pan (good for 1–3 years) Scoop made of net (good for 7 months)	0.63 0.29	0.32 0.29	1.11 0.29
3. Mixing with papaya leaves for 1 hour	Pail (good for 1 year) Papaya leaves (can ask children to collect)	0.23 1.00	0.19 1.00	0.28 1.00
4. Boiling with salt for 1 hour	Match Salt Water	1.00 7.50 5.00	1.00 5.00 5.00	1.00 10.00 5.00
5. Brushing to remove outer layer (spicules)	Used laundry brush or toothbrush	-	-	-
6. Smoking for 1–24 hours	Wood (for both boiling and smoking) Screen	7.50 0.33	5.00 0.33	10.00 0.33
7. Sun-drying for 3–5 days until 'stone dry'	Galvanised iron	0.06	0.06	0.06
8. Packing in plastic bag (holding until desired volume is attained, 2.5–5.0 kg)	Plastic cellophane (100 pc × PhP0.5–2.0/pc)	125.00	50.00	200.00
9. Transporting (tricycle)	Fare (to buying station and back)	44.00	44.00	44.00
TOTAL		**239.02**	**147.39**	**330.19**

Source: Brown et al. (2010)

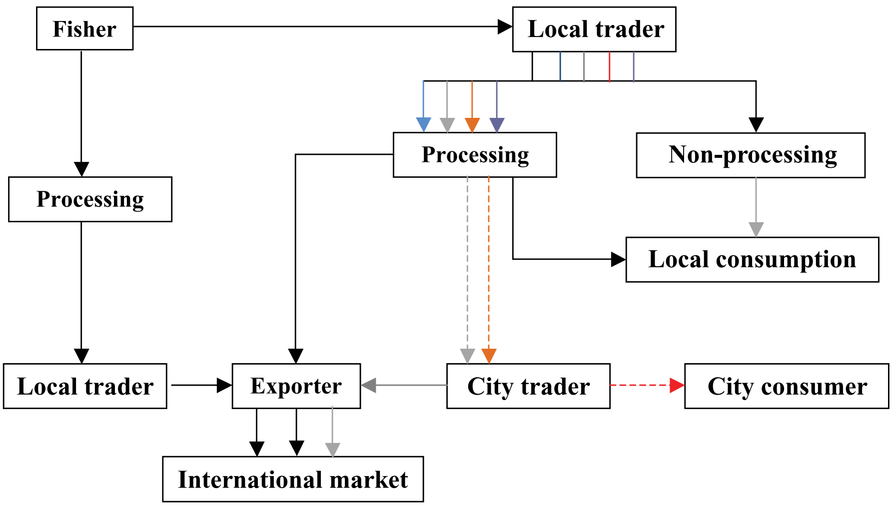

Figure 1. Typical product flow of sea cucumber in South-East Asian countries. Source: SEAFDEC (2009)

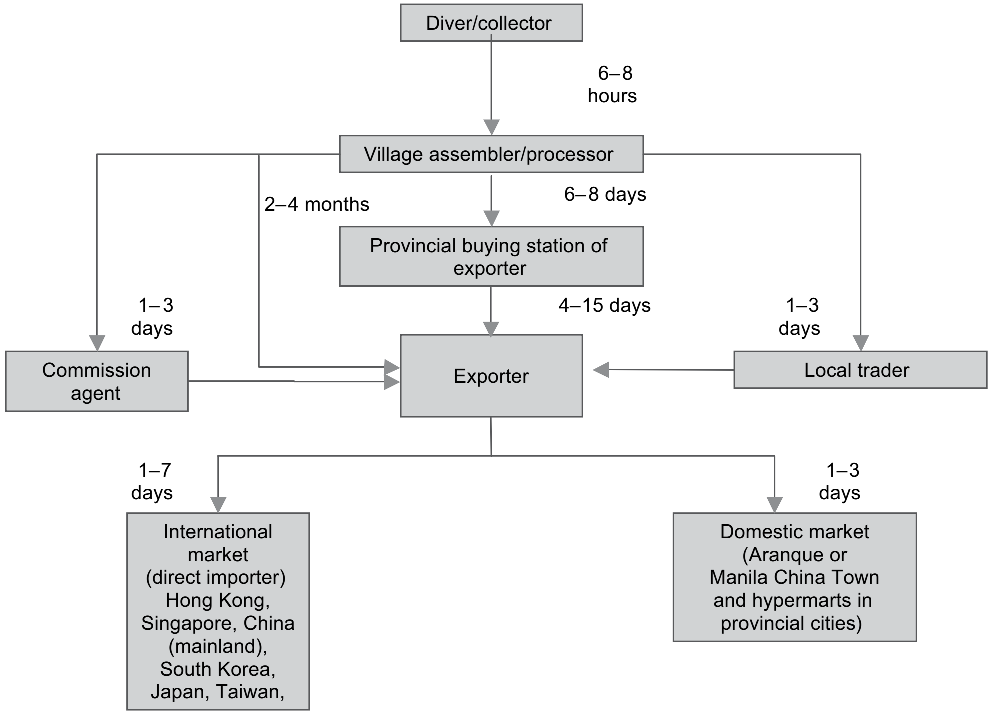

Figure 2. Product flow of sea cucumber in the Philippines. Source: Brown et al. (2010)

(Brown et al. 2010) showed that it appears to be multilayered and characterised by information asymmetry. Redundant market players such as agents proliferate, and are engaged in pure arbitrage (i.e. taking advantage of a price difference between multiple markets). Collectors, the most upstream players in the chain, are generally not aware of the price of sea cucumber at the downstream end, leading to inefficient pricing mechanisms and inequitable distribution of profits along the chain.

The sea cucumber industry is like an hourglass—large at each end and narrow in the middle. The number of upstream players is very large because collection takes place in so many coastal areas in the country. In contrast, the number of downstream players is fairly small. In the Philippines, there are only 45–50 firms involved in sea cucumber trade, four of which are very large and account for the bulk of the products moving along the value chain. The situation in the Philippines is similar to other countries in South-East Asia, particularly Indonesia and Vietnam. Interviews with traders in Vietnam indicate that two or three large buyers typically account for the bulk of sea cucumber outputs in districts where a large volume is collected. However, the number of key Chinese customers catered to by existing supply chains is very large.

This suggests that industry control is in the hands of a few large exporters, who capture much of the value generated by the industry. In the Philippines, the net income of an exporter from a kilogram of *H. scabra* could reach more than PhP1,000 (Table 3). This becomes even more significant considering the volume that passes through each exporter's business. Their power and influence along the entire chain becomes apparent on closer examination. Large exporters have established a vast network of buying stations, agents and relational marketing with assemblers and processors.

Value-chain mapping of sea cucumber in the Philippines showed the specific activities, associated costs and income received, as well as the opportunities and constraints faced by the upstream and downstream players along the chain (Brown et al. 2010) (Figure 3). Although similar studies are unavailable for other South-East Asian countries, the situation is

Table 2. Number and percentage of sea cucumber supplier firms by country

Country	No. of supplier firms	%	Country	No. of supplier firms	%
Indonesia	81	12.76	Australia	7	1.10
Malaysia	61	9.61	Cameroon	7	1.10
United States	55	8.66	Taiwan	7	1.10
Philippines	50	7.87	United Arab Emirates	7	1.10
China (Mainland)	42	6.61	Mauritania	5	0.79
Peru	32	5.04	Mauritius	5	0.79
Singapore	32	5.04	Morocco	4	0.63
Vietnam	26	4.09	Pakistan	4	0.63
Japan	25	3.94	Russian Federation	4	0.63
Sri Lanka	21	3.31	Spain	4	0.63
Egypt	19	2.99	New Zealand	3	0.47
Canada	18	2.83	Colombia	1	0.16
Mexico	18	2.83	Fiji	1	0.16
Maldives	17	2.68	Iceland	1	0.16
South Korea	17	2.68	Italy	1	0.16
Turkey	14	2.20	Mozambique	1	0.16
Hong Kong	13	2.05	United Kingdom	1	0.16
India	12	1.89	Uruguay	1	0.16
Thailand	9	1.42	**Total no. supplier firms**	**635**	

Source: Brown et al. (2010)

Table 3. Cost and return, per kg of high-quality *H. scabra*, to various sectors of the Philippine supply chain

Item	Collector (fresh product)	Assembler/processor (dried product)	Exporter (dried product)
Price received	300.00	4,200.00	5,364.00 [a]
Cost of product	0.00	3,000.00 [b]	4,200.00
Other costs [c]	15.07	58.21	61.67[d]
Total costs	15.07	3,058.21	4,261.67
Net return	284.93	1,142.00[e]	1,102.33

[a] Based on US$120/kg @ PhP44.7/US$
[b] Based on PhP300/kg fresh (10% dry-equivalent weight)
[c] Based on Tables 14, 17 and 18 in Brown et al. (2010) (note: for exporter, Aquamarine cost was used)
[d] Includes PhP8.47/kg cost (see Table 18 in Brown et al. (2010)) plus PhP0.70/kg shipment cost to Hong Kong (i.e. PhP7,000/10,000 kg) and opportunity cost of procurement capital of PhP52.50 (i.e. PhP4,200 × 1.25%/month)
[e] Includes all costs in Table 17 in Brown et al. (2010) plus opportunity cost of procurement capital of PhP37.50 (i.e. PhP3,000 × 1.25%/month)

probably true also for Indonesia, which has a similar distribution system. A quick survey conducted by the authors also confirmed similarities with Vietnam, where a more detailed value-chain analysis is currently being prepared.

The Philippine study showed that collectors receive the lowest net income from every kilogram of sea cucumber, particularly *H. scabra*, while the net incomes of village-level assemblers, processors and exporters are considerably higher. The study also confirmed that various players along the distribution system are already facing the problem of declining volume and increasingly smaller catch size. Increasing price and vibrant demand for the product remain as the most important opportunities available to these players. Aquaculture appears to be the most viable solution to halting the declining supply.

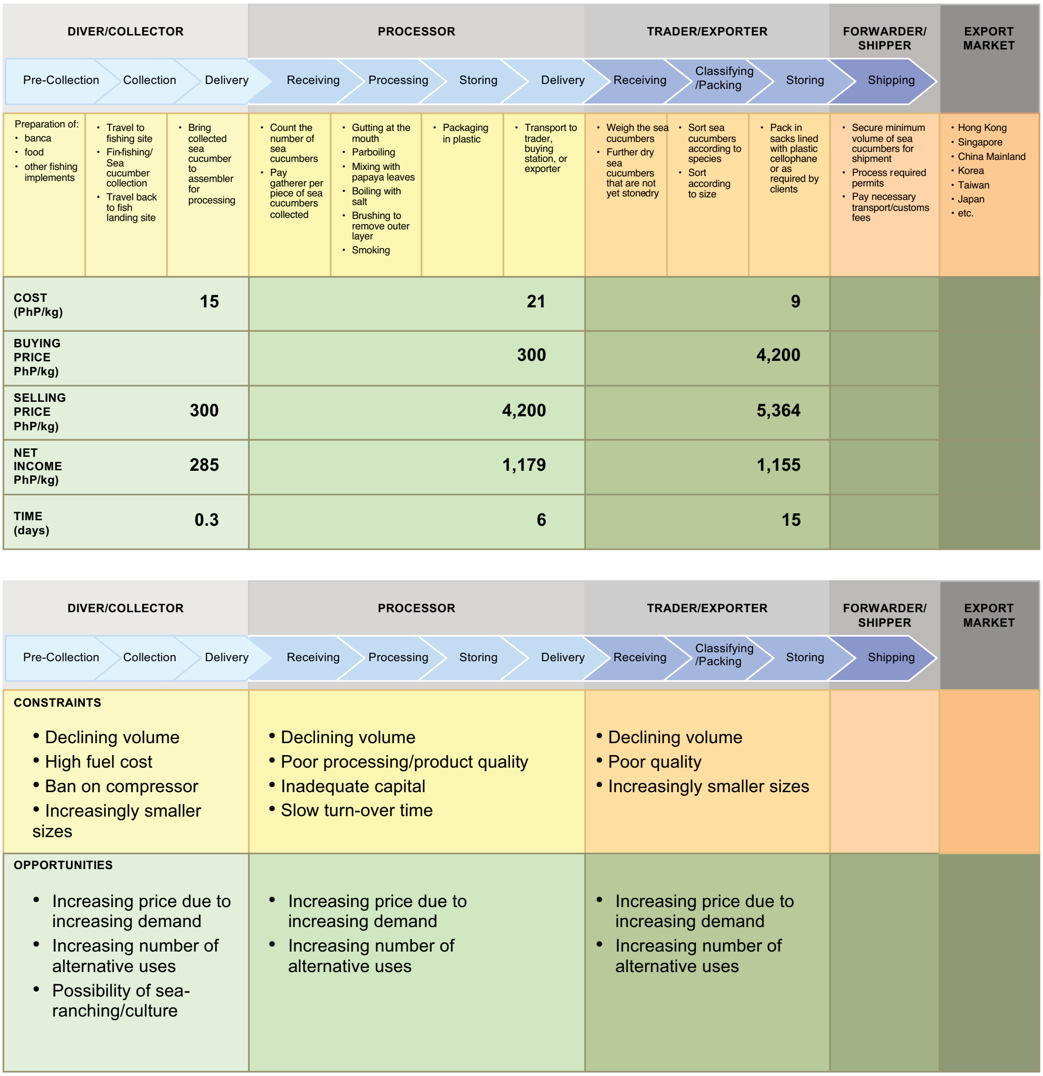

Figure 3. Value-chain mapping of exported sea cucumber, the Philippines. Source: Brown et al. (2010)

Demand-related marketing system characteristics

Demand for sea cucumber comes mainly from the middle and upper classes in Asia, especially in China and Japan. International trade is dominated by the Chinese, whose preference for sea cucumber stems from its high nutritional content and health-giving properties. Traditional knowledge on sea cucumber as medicine exists; for example, the Cuvierian tubules used as crude plaster for minor wounds. Extracts from the muscular body are used for tumours, fungal infections, high blood pressure, arthritis and muscular disorders (Trinidad-Roa 1987).

Hong Kong is still the major world market, followed by Singapore. However, Hong Kong generally re-exports products to mainland China. The product type, volume and value of global trade in sea cucumber are shown Table 4. World trade for sea cucumber continues to increase as the price for the product increases over time, with the Chinese population remaining the major consumers.

Table 4. Global trade in sea cucumber

PRODUCT FORM	YEAR		
	2005	2006	2007
Live, fresh, chilled			
Volume (million t)	56	34	67
Value (US$'000)	375	392	424
Dried, salted in brine			
Volume (million t)	6,463	4,883	5,734
Value (US$'000)	46,342	42,021	55,852

Source: Brown et al. (2010)

One notable characteristic of the Hong Kong market is the proliferation of herbs and medicine stores, which sell sea cucumber displayed in large glass jars (Figures 4, 5). A number of high-value tropical species can be found in these stores, including *H. scabra*, *H. fuscogilva*, *Thelenota ananas*, *H. whitmaei* and *Actinopyga lecanora*. Prices vary considerably from HK$1,200 to HK$1,500/kg, with reported sales of 6–7 kg/day.

In general, the Hong Kong market can be characterised as having:

- a high preference for particular species. *Apostichopus japonicus* is the most popular species (also called *meihua* or *wuxing*), and is sold for up to HK$8,000 per 600 g in the herb and medicine stores. *Holothuria scabra*, *H. fuscogilva*, *T. ananas* and *H. whitmaei* are also highly valued
- an apparent preference for product origin, with the general indication that all the sea cucumber being sold in the stores are from Japan, hardly acknowledging the huge importation of produce from South-East Asia
- a distinct preference for product quality and size, resulting in a wide price range, even within a single species (Table 5).

Figure 4. Herb and medicine store in Hong Kong

Figure 5. Sea cucumbers on display in a herb and medicine store, Hong Kong

Price-related marketing system characteristics

As mentioned, price behaviour provides a snapshot of the overall industry status. Two important characteristics of the sea cucumber marketing system that can be discerned based on price behaviour are stability and viability. Unlike most other agricultural or fishery product prices, which exhibit high seasonal variability, the price of sea cucumber has been stable for the past 5 years. This is remarkable considering that sea cucumber collection is somewhat seasonal. However, the product can be stored for very long periods when properly dried, which probably smooths out the seasonality effect.

Sea cucumber is still considered a minor commodity in official commodity statistics of countries in South-East Asia, and reliable time-series data on price by country are not available. In addition, prices vary by species, size and quality. Time series of average price data (i.e. average of the various species) would therefore have practically no analytical value. Price behaviour over time can be assessed only for the same species belonging to the same size and quality classification.

A useful set of data on sea cucumber prices covering the price range of several species traded in the Philippines during 2000–07 is provided by Labe (2009). For most commercially exploited species, the buying price (i.e. received by fishers) was three to four times higher in 2007 than in 2000. This phenomenal increase in sea cucumber price has been identified as the primary factor that induced overfishing, especially of the high-value species, in many countries. However, it is also possible that the increase in price was due to overfishing itself, as this would cause the supply curve to shift upward with increasing fishing effort (fishing cost) per unit catch. The sea cucumber industry appears to have been caught in a vicious cycle of high price leading to overfishing, which, in turn, leads to decrease in stock and total catch (supply), pushing the price even higher, and the cycle starts again. The depletion of wild sea cucumber stock may have the effect of low-value species becoming medium value, and medium-value species becoming high value, until many of the species have become depleted (Pe 2009).

Such high prices reflect the lucrative nature of sea cucumber production and trade. More importantly, high prices almost warrant the profitability of expanded production through aquaculture.

Table 5. Range of retail prices for dominant sea cucumber species in South-East Asia

Sea cucumber species	Value range (US$)
Stichopus hermanni	62.50
Stichopus chloronotus	21.25–65.00
Holothuria (Microthele) nobilis	20.00–78.95
Bohadschia argus	20.00–30.00
Apostichopus japonicus	17.50–112.50
Holothuria fuscogilva	15.50–95.00
Thelenota ananas	12.50–67.50
Holothuria scabra	9.00–112.50
Actinopyga lecanora	8.00–71.25
Actinopyga miliaris	8.00-–44.00
Holothuria edulis	8.00–22.50
Stichopus variegatus	6.75–62.50
Actinopyga mauritiana	5.00–15.00
Holothuria sp.	4.75–44.00
Actinopyga echinites	4.50–57.50
Thelenota anax	3.68–60.00
Holothuria rigida	3.00–59.00
Holothuria impatiens	2.50
Holothuria atra	1.75–22.50
Pearsonothuria graeffei	1.75–5.00
Bohadschia marmorata	1.40–23.75

Source: SEAFDEC (2009)

Marketing opportunities for expanding production

The current state of sea cucumber fisheries completely discounts any possibility of expanding production through increased collection from the wild. The resource is already overfished in South-East Asia. Regulating harvest and other conservation measures are being contemplated in various countries to encourage stock recovery. Obviously, aquaculture is the only means to expand production of sea cucumber in the region. The technical viability of hatchery, nursery and grow-out (pond, pen and sea ranches) has already been established for certain species such as *H. scabra*. The financial viability of *H. scabra* culture seems very positive considering its high value. However, there are marketing opportunities and challenges associated with expanded production, and these must be clearly understood if South-East Asian countries are to benefit fully from aquaculture programs.

The demand for sea cucumber is the most important opportunity for expanded production. Consumers use sea cucumber not only as food, but also as medicine. Demand will probably be limited to Chinese consumers, at least in the near future; however, considering the increasing global trend towards health foods and alternative medicines, its popularity with other ethnic groups may increase.

Even assuming that demand will be limited to Chinese markets, the future of sea cucumber trade remains vibrant. China is the fastest growing economy in the world, with increasing gross domestic product, per-capita income and population growth—one in every five people in the world is Chinese. The distribution system for sea cucumber is well established in China, with numerous herb and medicine stores ensuring that consumer access to these products is very high. Another marketing opportunity is the increasing Chinese population in almost all countries in the world. Import demand from other countries can be expected to rise as Chinese residents increase.

The sea cucumber trade is well established in South-East Asia. In each country, local traders are present to move the product from fishers to exporters or city-based buyers. Additional volume from expanded production through aquaculture can easily be absorbed by existing market chains. Exporters are the key players in the sea cucumber trade, since most countries in South-East Asia export the product and only a small amount is consumed locally. However, the transaction cost involved in the export business is high, as coastal villages are widely dispersed. In the Philippines, exporters have to establish buying stations in many parts of the country or engage the services of procurement agents to be able to secure bigger volume. One opportunity that may be explored is direct market linkage between the sea cucumber farmers and exporters. Unlike collection from the wild, where daily volume is small and geographically dispersed, production from aquaculture comes in larger volumes from identified locations during predetermined periods. This could lower the search cost, and even transport and other costs normally incurred by exporters, and may entice them to transact directly with producers.

Marketing challenges

While market prospects are generally bright, there are a number of challenges that have to be addressed if countries in South-East Asia are to benefit fully from expanded sea cucumber production due to aquaculture. The absence of reliable market and trade information is a huge challenge. Updated price data, which could serve as the basis for formulating sound production and marketing decisions, do not exist. In the Philippines, information asymmetry persists—certain market players have greater access to information, giving them undue advantage, especially in price bargaining. Distribution systems become multilayered, since those who have the latest information (especially on prices) can embark on pure arbitrage. While there are cases where product moves only along three layers (collector→processor→exporter), there are also instances where the product moves along two or three additional layers involving local traders and commission agents. These appear redundant and contribute to marketing inefficiency rather than adding real value to the product.

Another important challenge relates to primary processing, the single most important determinant of product quality and one for which the market pays a very high price. Primary processing methods currently in use are highly variable; no standard protocol is being followed, resulting in highly variable product quality. The methods employed are very traditional, without knowledge and consideration of existing standards for processed food products (e.g. GMP and HACCP).

A large processing firm in Vietnam that employs global standards has ceased to include sea cucumber in its product lines, since the volume of raw material (i.e. fresh sea cucumber) was too small for the firm to achieve economies of scale. This problem is perhaps true for other South-East Asian countries. As mentioned, sea cucumber collection is widely dispersed, and the volume from individual locations is small. Village-level processing, primarily carried out through traditional methods, will likely remain as a distinct feature of the industry in the region. Whether expanded production through aquaculture can change this is uncertain. Supply from aquaculture should be large enough and available on a continuous basis to encourage large processing firms to engage in processing the product.

The absence of officially formulated and well-implemented grades and standards for sea cucumber is another challenge. This is crucial since such measures could guide transactions along the value chain. Fishers and village-level processors may not find the incentive to improve primary processing if they know that exporters would end up classifying good-quality product as lower grade based on arbitrary standards developed by the exporters themselves.

Finally, the structure of the sea cucumber market may be characterised as oligopsonistic (i.e. a market condition in which there are few buyers), resulting in market inefficiencies exacerbated by lack of adequate information along the chain.

Recommendations

South-East Asia is a major source of sea cucumber supplied to the world market. However, the fishery is mostly artisanal, carried out by low-income households. Sea cucumber is generally an incidental catch in finfish fishing, although fishery activities where it is targeted are becoming more significant. Given declining catch from the wild, a number of possibilities can be explored to meet the ever-increasing demand. For example:

- promoting aquaculture involving technically established protocols that can be explored to address demand and supply gaps
- expanding research to develop culture protocols for other high-value species
- improving support for efforts designed to generate new products from sea cucumber
- exploring new export destinations, especially in countries with significant Chinese populations
- establishing direct market linkage between producers and exporters to reduce market inefficiencies
- establishing regularly updated statistics and information systems for sea cucumber
- formulating and implementing official grades and standards
- improving village-level small-scale primary processing
- exploring strategies that could lead to the achievement of economies of scale in large-scale modern processing methods/facilities that observe international standards for processed food products.

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Understanding the sea cucumber (beche-de-mer) value chain in Fiji and Tonga

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Abstract

As reported in other Pacific island communities and many countries around the world, wild stocks of sea cucumber in Fiji and Tonga are declining because of unsustainable levels of fishing. The Pacific Agribusiness Research for Development Initiative (PARDI) is a partnership involving the Secretariat of Pacific Community, the University of the South Pacific and a consortium of Australian universities, funded by the Australian Centre for International Agricultural Research. PARDI seeks to create sustainable livelihoods by identifying constraints to economic development in the Pacific islands region, and by developing appropriate technologies or products to resolve these constraints. It is currently evaluating the sea cucumber industry and its contribution to community livelihoods in Tonga and Fiji. This paper presents preliminary literature search findings of the PARDI study into sea cucumber market chains in these two Pacific island countries. Although an initial literature review revealed a scarcity of reliable information, interim maps of the current supply chains of both Fiji and Tonga have been developed and are discussed here. Research outcomes may lead to improvements in processing, value-adding to beche-de-mer and identification of new niche markets, and may facilitate investment in sea ranching and aquaculture.

Introduction

Sea cucumber is a valuable resource for income generation for many remote coastal dwellers in Fiji and Tonga, but the fisheries have exhibited boom–bust cycles since the early 1800s (Kinch et al. 2008). Fresh harvested sea cucumbers undergo a series of cooking and drying processes to produce a dried, shelf-stable product (beche-de-mer) that can be shipped in ambient dry conditions to markets in Asia, where it is highly prized by Chinese consumers (Ferdouse 2004). There are many species exploited, with some commanding high prices, but there is significant variability in quality and grade of beche-de-mer (Choo 2008; Kinch et al. 2008).

As reported in other Pacific island communities and many countries around the world, wild stocks of sea cucumber in Fiji and Tonga are declining because of unsustainable levels of fishing (Kinch et al. 2008). Consequently, sea cucumber (particularly sandfish, *Holothuria scabra*) is becoming a priority group for development in the aquaculture plans of a number of countries, although, in reality, more development is needed before it can become a commercially viable alternative.

A new development initiative related to sea cucumber has been funded by the Australian Centre for International Agricultural Research (ACIAR): the Pacific Agribusiness Research for Development Initiative (PARDI). The partnership includes the Secretariat of the Pacific Community (SPC); the University of the South Pacific (USP); a consortium of Australian universities, including the Adelaide University Value Chain group, James Cook University and researchers from Southern

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Cross University; as well as industry representatives and government agencies in selected Pacific island countries (PICs).

PARDI seeks to create sustainable livelihoods by identifying constraints to economic development in the Pacific islands region, and undertaking research to develop appropriate technologies or products to resolve these constraints. Therefore, it is currently evaluating the sea cucumber industry and its contribution to community livelihoods in Tonga and Fiji. This paper presents preliminary literature search findings of the PARDI study into the sea cucumber market chains in these two PICs.

Methodology

In order to identify potential constraints to the sea cucumber industry in Fiji and Tonga, PARDI has adopted the following approach:

1. Review research and literature that have been undertaken in the Asia–Pacific region to identify gaps in our understanding of the whole value chain.
2. Analyse and map the existing value chain from harvesting → processing → export → distribution → consumption.
3. Identify key partners and stakeholders (public and private) willing to co-invest and contribute to the research process, and who are also willing to participate in implementing change and improvements.
4. Conduct research into constraints that limit the ability of these market chains to be more market responsive, equitable and, ultimately, more sustainable.

Results and discussion

Literature review

An examination of existing literature (currently in progress) has highlighted significant gaps in knowledge about the current status and long-term sustainability of the beche-de-mer value chains in both Fiji and Tonga. It indicates that there is a lack of coordination between participants dependent on financial returns from fishing, processing and export, and that the issue of overfishing will need to be addressed by participants. There are also some issues relating to the impacts of harvesting and processing methods (Ram 2008).

Industry structure

There are a large number of operational steps and participants involved in the industry, particularly once the beche-de-mer is exported. PARDI investigations have identified some key knowledge gaps in both the supply and demand sides of the industry in both countries, and a picture of the flow of value in transactions from fishing to consumption is emerging. Interim maps identifying key components of the current supply chains in both Fiji and Tonga have been developed (Figures 1, 2).

While there are purported to be up to 19 buyers and processors listed in Fiji, the industry appears to be consolidating, and a number of operators have left the industry. The estimated harvest volume and value presented here is based on data provided by Fiji Fisheries (FITIB 2009). In Tonga, sea cucumber harvest volume and value are estimated from Fisheries Department data. However, the economic returns and importance to the three island regions participating in this industry require further substantiation. The amount of sea cucumber collected live (fresh:dried = 12:1) (Skewes et al. 2004; Purcell et al. 2009) has been used to estimate beche-de-mer export volumes across all species; however, drying conversion ratios vary between species and may require further validation.

Preliminary estimates indicate that the value of the raw commodity when consumed by restaurant patrons in China and other markets in Asia is increased in value many times. Further research interviewing participants in target markets will be undertaken.

Chain orientation

Both Fiji and Tonga beche-de-mer industries are very much ‘supply driven’, where fishers, processors and exporters push product down to the next part of the chain. There are no industry development plans, and the literature search found little evidence of collaboration or flow of information between the fishing community, processors, exporters, customers and consumers of beche-de-mer in international markets.

Flow of value and information

Well-processed and dried beche-de-mer is an internationally traded commodity in high demand, but the flow of commercial value (cash income) from value-adding and marketing is tightly held by a few operators, and value returns to fishers from the resource are limited. Remote communities, whose

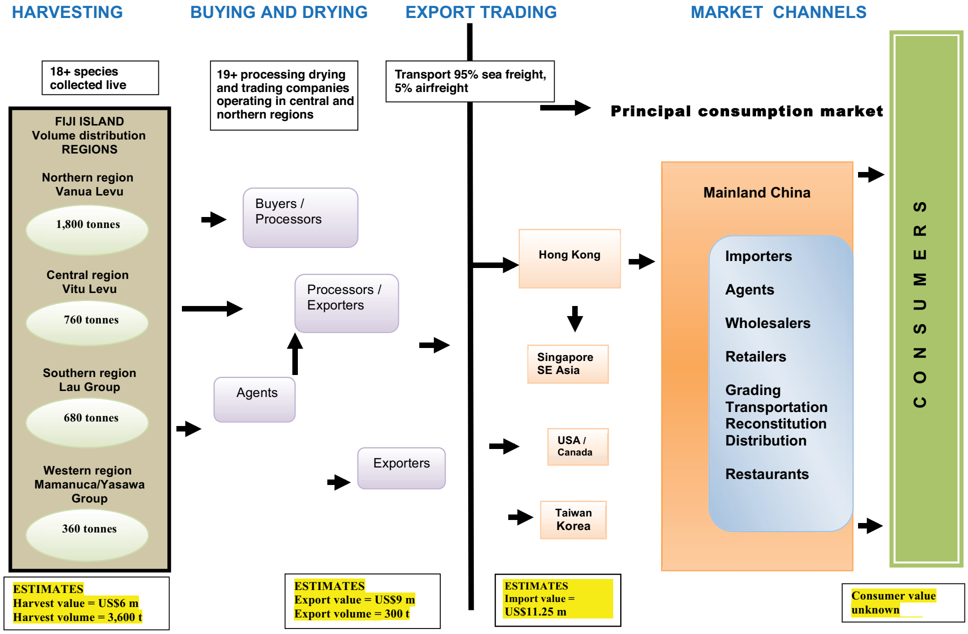

Figure 1. Proposed Fiji beche-de-mer value-chain map based on information gathered by PARDI to date, and supply-chain information from Brown et al. (2010)

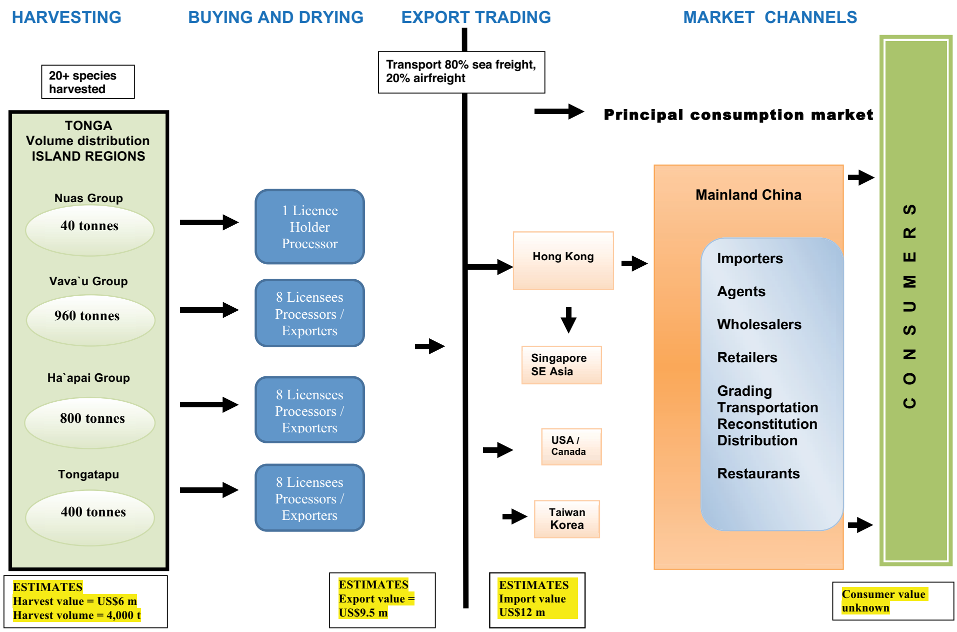

Figure 2. Proposed Tonga beche-de-mer value-chain map based on information gathered by PARDI to date, and supply-chain information from Brown et al. (2010)

livelihoods depend on the harvesting and processing of sea cucumber, have little understanding of export customer and consumer requirements, and are at the mercy of local middlemen and traders.

Beche-de-mer is generally not consumed locally but exported, mainly to destinations with large Chinese populations (Akamine 2009). However, the lack of publicly available knowledge around the structure of the distribution channels in Asia makes it difficult to collect information that will encourage changes to practices, and improvements in returns to participating communities. There was no public information available about assessing the economic impact of the decline in the wild resource, and it is difficult to determine what livelihood returns are generated to flow back to communities.

Processing and export

From the supply side, researchers have identified that there is some waste of the resource that occurs during the harvesting and processing stages of beche-de-mer (Ram et al. 2008). Production losses, due to undersized product, low-value species, postharvest damage and poor processing, may require intervention if deemed significant. PARDI has commissioned a new scoping study (to commence in 2011) on processing improvements, which will attempt to address these issues.

In Fiji, some processors have raised concerns about the viability of the industry as catches decline, and they fear that declining stocks in Tonga may lead to a flood of new traders setting up new harvesting and processing arrangements in what is already a diminishing resource. Fiji and Tonga fisheries agencies have a history of regulating the exploitation of the fishery (Adams 1993).

There are many markets around the world that import beche-de-mer, particularly in Asia (Choo 2008). Little is known about the structure and role of agents, processors, licensees and exporters in these markets. Export volumes, species, quality and grades, sizes and value (Figures 1, 2) are estimated, and it is unclear which destination markets are exploited when, why and by whom? The market that has the most influence is mainland China, which traditionally has used Hong Kong (duty free *entrepôt)* to access sea cucumber and other dried marine products from all parts of the world. These markets are principally located in the southern province of Guangzhou, with product traded to many markets throughout China. The growing affluence and opening up of China is changing these trading patterns, and may provide opportunities to identify new market channels and consumer segments.

Markets and consumers

No reliable information on beche-de-mer exists that identifies the current structure and performance of market channels and participants in the export trade. Further research is required to identify data collected on the volume, value and destination of product exported from Tonga and Fiji. The preliminary value-chain maps (Figures 1, 2) describe the elements of each market chain. These are based on beche-de-mer research from Asia and the trading structures of other commodities exported to these markets (Brown et al. 2010).

Consequently, little baseline information about wholesale and retail market channels, and the purchase behaviour and consumption of beche-de-mer by consumers, can be presented. Potential improvements in returns based on innovative product packaging or other specifications are therefore difficult to estimate. However, there is an expectation that, with growing expansion of the economy, the demand for beche-de-mer among Chinese consumers will continue to grow in both volume and value terms in the future.

Once beche-de-mer is exported from the Pacific region, it undergoes many changes in handling, and passes through many destinations before it ends up in a restaurant on a plate. Further grading and reconstitution is undertaken and, in some cases, the product is sold in forms other than for food consumption. The product's uses are diverse, and the value of the resource in these applications may need to be further understood.

The lack of information on consumer preferences for the end product means that there are very few options for resource owners to exploit.

Recommendations for further research

In order to better understand the value chain and complete its mapping, the following research is recommended:

1. conducting a supply-side study to understand the collection and harvesting of sea cucumber at the village scale
2. conducting a supply-side study to understand the economic value and the income to communities,

and to develop 'what-if' scenarios where new options of restructuring the processing distribution and marketing can be evaluated

3. investigating the collection, purchasing, value-adding and processing industry status. Operators in the sea cucumber industry need to be involved, and their role and contribution towards the future of the industry better defined
4. conducting a demand-side study on market research to identify and understand current market destinations, channels, channel players, tax structures, pricing and profit margins
5. investigating the demand-side of the export industry as it currently operates, including export destinations, market values, desirable species and grades, and packaging. These insights may help to establish clearer product knowledge, and enable better industry development plans to be initiated
6. conducting consumer research in key markets (e.g. China, Hong Kong, Singapore) to better understand purchasing and consumption behaviour, perceived product benefits, and the many ways the product is presented, prepared and consumed. Consumer insights can then be used to improve existing product and packaging standards, and food safety and product handling procedures. Aspects such as place of origin, nutritional aspects, ethical marketing and sustainable environmental practices can be leveraged for the development of superior marketing and selling campaigns. New niche-market channels may be identified in markets willing to pay more for elaborately processed or partially processed products, packaged and labelled in non-traditional ways that can be unique and highly differentiated
7. reviewing new technologies to match consumer requirements (new processing, preservation, packaging, transportation–distribution channels, and buying techniques) for the development of products that are unique and that capture product benefits.

Other research topics that would be useful include:

1. developing new models to enable fishers and key stakeholders to work together, create value-driven organisational structures and develop new market niches
2. facilitating customs, finance and treasury agencies in developing new policy settings for investment attraction
3. collecting, analysing and disseminating industry data that can be used to develop sustainable industry plans.

Conclusions

Further analysis in unlocking the true state and economic benefits of the beche-de-mer value chains in Fiji and Tonga will be important in determining appropriate future interventions. PARDI will seek to engage fishing communities, processors, exporters and other industry stakeholders. They can play an important role in identifying ways to draw the attention of different stakeholders to opportunities for improvement at different stages in the value chain. Research outcomes may lead to improvements in processing, value-adding to beche-de-mer and identification of new niche markets, and may facilitate investment in sea ranching and aquaculture.

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Processing cultured tropical sea cucumbers into export product: issues and opportunities

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Abstract

Sea cucumbers cultured in ponds or in the sea are potentially lucrative commodities, but their export value can be gained or lost through the processing used. The gutting, water temperature, cooking times, handling and drying techniques should all be carefully controlled in order to achieve the highest grade possible for export. Farmed sea cucumbers may have thinner body walls than wild animals, but have the advantage of being of consistent size, can be processed immediately after being removed from the water, and can be processed in bulk. Processors must understand the preferences of overseas importers, as desired processing approaches may vary. The use of fuel for boiling sea cucumber to make beche-de-mer can be an ecological concern. Body organs and muscle bands may offer new products for value-adding of cultured sea cucumbers. Likewise, markets are more open to fresh and canned product. Training and providing guides in the best methodologies and new market opportunities to processors present fruitful scope for improving the cost-effectiveness of farming and sea ranching tropical sea cucumbers.

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Sandfish (*Holothuria scabra*) farming in a social–ecological context: conclusions from Zanzibar

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Abstract

Sandfish (*Holothuria scabra*) farming is being promoted as a potential economic activity for coastal communities, and especially for those currently involved in fishing for sea cucumbers—an unsustainable fishery. With the collapse of many tropical sea cucumber stocks, and with agendas to find new income alternatives for coastal populations, the interest in aquaculture, particularly in sandfish, will most probably increase. However, in-depth analysis of the social and ecological consequences from introduction of sandfish farming is lacking. In Zanzibar, Tanzania, 74 sea cucumber fishers were asked if they would like to farm sea cucumbers. About 64% of the respondents were positive to farming. Their comments highlighted that they perceived farming as an addition, not a replacement, to catch from the fishery, and that they were concerned about the personal risks involved in an investment. The responses illustrate that aquaculture may have a negligible or negative effect on the fishery. There are also potential ecological impacts, which, of course, will depend on the scale of the activity, but for which there is currently little knowledge. The risk-awareness poses the question on what business model a sandfish enterprise should operate to reduce risk for communities with few income alternatives. The results from the interviews indicate that it is essential to learn from past sandfish farming initiatives and other aquaculture ventures that have resulted in the development of standards. It is also apparent that it is important to apply a social–ecological systems approach to sandfish farming development.

Introduction

Many sea cucumber fisheries around the world are suffering from overfishing (Purcell 2010). This can generally be attributed to insufficient capacity to manage the fishery (Muthiga et al. 2010), lack of ecological knowledge from which to form management (Uthicke et al. 2004), stochastic recruitment (Uthicke et al. 2009), strong market demand (Anderson et al. 2011), illegal fishing (Price et al. 2010) and limited presence of institutions (Eriksson et al. 2010). While local fisheries are becoming depleted, resulting in moratoriums being placed on exports in numerous locations (Purcell 2010), there is still a need to maintain income opportunities in communities and nations. In this context, tropical sea cucumber aquaculture is currently gaining momentum.

The only suitable tropical sea cucumber varieties for farming, using hatchery-produced animals, are those in the sandfish species complex (Agudo 2006; SPC 2009). There is currently some uncertainty regarding species nomenclature across the Indo–Pacific region, where the taxon *Holothuria scabra* may contain varieties in need of species recognition (Massin et al. 2009). This text will therefore use the common name 'sandfish'. Sandfish is a high-value species in strong demand on the international market, which makes it a promising candidate for aquaculture. Properties indicating its suitability for farming are, for example, that it feeds low in the food chain and occurs naturally in dense populations in many tropical coastal waters (Hamel et al. 2001).

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A number of scenarios exist for sandfish aquaculture. Commonly, emphasis is on farming hatchery-produced animals in enclosures or no-take zones, with the aims of rebuilding depleted stocks and enhancing livelihoods for coastal communities in areas with few income alternatives. The potential of aquaculture as a source of income in coastal communities is illustrated by the prospective suitability of sea ranching, or farming hatchery-produced animals in pens in coastal waters (Bell et al. 2008; Robinson and Pascal 2009), in particular where there is a need to reduce effort in the fishery to prevent stock demise and maintain income opportunities.

Fishers from poorer households are less likely to exit a declining fishery (Cinner et al. 2008), emphasising both how poverty traps communities in declining fisheries, and how important is the generation of income opportunities to support communities to reduce fishing effort. In addition, subsistence or artisanal fishers often support themselves from a diverse range of livelihoods (Allison and Ellis 2001), which raises a paradoxical question of whether profits from sandfish aquaculture will replace those of fishing, or if it will be perceived as an addition to fishing, with fishing effort continuing at similar levels. Subsistence or artisanal fishers are also generally exposed to high degrees of risk and uncertainty in terms of personal safety and income (Andersson and Ngazi 1998). This can prompt an increased emphasis on a cooperative behaviour to reduce risks, but, in a poverty situation, also reluctance to engage in activities that might further increase risk (Barrett et al. 2006). In Madagascar, where community-based sandfish farming from hatchery-produced animals has been introduced, sandfish juveniles are bought by families on credit and sold when harvestable (Robinson and Pascal 2009). Risk is thus to some extent borne by families. This risk raises concern with regard to how farming should operate to minimise risk in poor households.

Zanzibar Island, in the western Indian Ocean, has an active fishery targeting sea cucumbers for export as beche-de-mer (Figure 1). The fishery in Zanzibar is institutionally marginalised, lacking management and control; as a result, easy-access stocks are widely depleted, and exports are maintained with the aid of sequential exploitation and trade (Eriksson et al. 2010). In this study, information collected through interviewing fishers participating in the sea cucumber fishery in Zanzibar was used to explore how they perceive the potential activity of farming sea cucumbers. The fishers had not been exposed to sea cucumber aquaculture previously, and no hatcheries were operating in Zanzibar. The results were analysed in the context of how farming would fit into a coastal setting where the fishery is active and income alternatives are few. The focus of the analysis was the potential effect on the sea cucumber fishery, and the potential risks involved for communities.

Methods

As part of a study to map and assess the local sea cucumber fishery in Zanzibar, fishers were interviewed regarding their perceptions of the fishery and its management (Eriksson et al. 2010). Here, answers from the categorised yes-or-no question, 'Are you interested to farm sea cucumbers', and the open-ended follow-up question, 'If so, why/why not', were used to analyse perceptions and attitudes. Interviews were conducted in eight villages (Nungwi, Mkokotoni, Uroa, Chwaka, Mazizini, Fumba, Unguja Ukuu and Mtende) (Figure 2), which were chosen because they had an active sea cucumber fishery. The interviewees were chosen randomly, and included men and women gleaning in nearshore areas, and men that breath-hold and scuba dive in nearshore and offshore areas. The interviews were semi-structured (Denscombe 1998) and conducted in Swahili with the assistance of a translator.

Results

Seventy-four fishers (51 men and 23 women) were interviewed. There was interest to farm sea cucumbers among both men and women; however, men showed a higher interest than women (69% and 52% positive answers, respectively) (Figure 3).

Almost one-third of the interviewed fishers indicated that they perceived farming as an addition to catch from the fishery, rather than a replacement (Table 1). For example, fishing was highlighted as a continuous activity while having to wait for harvest. Some fishers also expressed concerns about the personal risks involved in a farming enterprise, and one fisher highlighted that this could be avoided through employment. The perceptions of risk were illustrated by, for example, an emphasis on the current lack of knowledge, the weak management of the sea cucumber fishery in Zanzibar and the likelihood of catch being stolen. Ten percent of interviewees highlighted their reluctance due to the risk of animals

Figure 1. **A**: Middleman gutting and boiling recently caught curryfish in Mkokotoni village, Zanzibar. **B**: 'Pentard' teatfish product held in hand over brown sandfish products at an exporter's location in Stone Town, Zanzibar

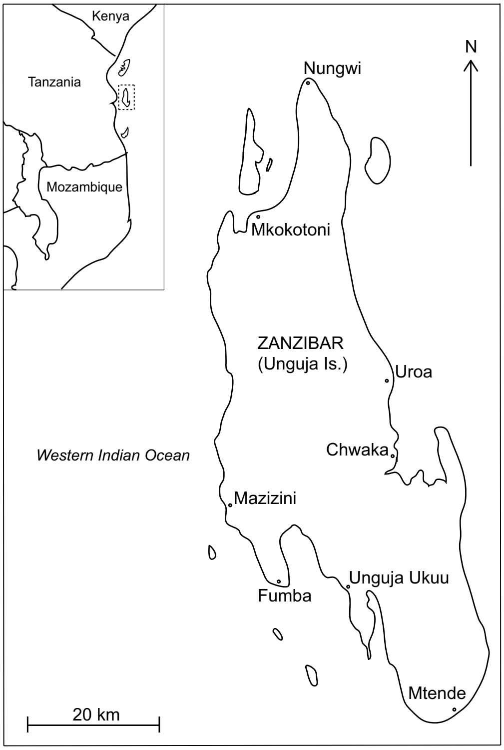

Figure 2. Map of Zanzibar (Unguja Island) showing locations of villages where interviews with fishers were conducted

Table 1. Perceptions of sea cucumber farming among interviewed fishers in Zanzibar, Tanzania

Issue	Comment/concern
Effect on fishery	'I can still fish while I farm' 'Can develop more catch' 'Too long to wait for harvest' 'More to sell' / 'More income'
Risk for communities	'Some could steal' 'Need training on how to do it' 'Cannot afford to wait for harvest' 'Only if employed'

being poached. In relation to knowledge, four fishers (female) said they had no interest because they did not know how to do it, while three fishers (men) indicated an interest if taught how to farm. One fisher highlighted that it might be an activity for the whole village to get involved in.

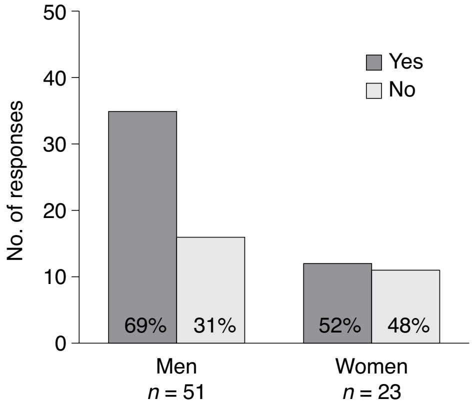

Figure 3. Distribution of answers among men and women in Zanzibar, Tanzania, regarding their interest in farming sea cucumbers

Discussion

Effect on fishery

The responses by sea cucumber fishers in this study illustrate that there is an interest to farm sea cucumber, but that it cannot be taken for granted that farming will reduce fishing pressure or improve the health of wild stocks. In many developing countries, a diversified palette of livelihoods (e.g. fishing, farming, trading or casual work) is common (Allison and Ellis 2001), arguing that it is unlikely that aquaculture will replace any one fishing activity; rather, it will diversify alternatives, thereby providing a potentially important source of social resilience. Whether it will alleviate fishing pressure on other marine resources, however, is a complex question. As experienced in seaweed farming, aquaculture can have a negligible effect, or even a negative effect, on use of other marine resources, for example through increased capital required for fishery improvement (Sievanen et al. 2005). In Zanzibar, a majority of both fishers and trade middlemen make it clear that they want access to more capital to invest in the fishery (Eriksson et al. 2010), and it is therefore probable that profits from farming may be used for investing in the already depleted fishery. To what extent this scenario can be generalised is difficult to gauge. However, in most tropical sea cucumber fisheries, it is likely that fishing will continue or increase as long as the trade is profitable and the governance weak.

There are also potential ecological systems effects with sandfish farming that have not been properly evaluated or studied. Seaweed farming, which was introduced into Zanzibar during the 1990s, is today widespread, and may perhaps provide some reference for sandfish farming. It is also a low-intensive (i.e. does not require additional nutrient input) cash crop, grown in the same coastal communities where sea cucumbers are fished, and serves the international market. When seaweed farming was introduced, it was endorsed with minimal environmental concerns. Today, however, ecological studies have shown that it reduces the abundance of seagrass and macrofauna (Eklöf et al. 2005), reduces aboveground biomass up to 40% (Eklöf et al. 2006), and alters community structure (Bergman et al. 2001). These effects obviously depend on the scale of the activity. It is likely that sandfish farming will have ecological effects not yet studied, which may compromise ecosystem integrity (e.g. translocation of broodstock) or deteriorate ecological goods and services already providing subsistence to coastal communities. Therefore, it is equally important to set aside resources for studying the ecological systems effects of farming as it is to technically develop the hatchery and marketing aspects.

Risk for communities

Although a majority of fishers that were interviewed showed an interest in farming, some were reluctant to engage in the activity due to the perceived financial risk and lack of knowledge. This raises the issue of which business model an enterprise should operate under. In Zanzibar, use of coastal marine resources is characterised by cooperative and conflicting institutions that both cushion and exaggerate resource-use conflicts and sustainability (de la Torre-Castro and Lindström 2010). This can be attributed to many similar fishing situations elsewhere, and highlights the institutional complexity that often affects resource use and ability to implement management. The risks of farming will therefore be dependent on the context in which it is introduced, highlighting the importance of a proper feasibility study before initiation. There are no universal blueprints.

Fishers in Zanzibar also expressed concerns about the risk of poaching, a problem experienced in Madagascar (Robinson and Pascal 2009). This highlights a governance issue that is difficult to circumvent, but certainly compromises the activity and constitutes risk for investors. In Madagascar, some communities that bought subsidised juveniles for grow-out in 2008 are still in debt from lost stock (G. Robinson, pers. comm.). This was obviously not the objective for any of the participants in this operation, but it pinpoints that the full production chain is not foolproof, and that there are monetary risks involved. In addition to risks of crop losses, it is costly to operate a hatchery, and profits are 'far from certain' (Hair et al. 2011). Some interviewed fishers consequently indicated that they would prefer employment, limiting their personal investment to labour. That women are being exploited for profits, as evidenced by an astounding discrepancy in catch value between fishing men and women (i.e. approximately US$2.40/kg versus US$0.10/kg paid to men and women, respectively, for similar catch (Eriksson et al. 2010)), is probably the reason why they are more reluctant to engage in farming than men are. This situation illustrates that fishing communities are already vulnerable and not resilient to cope with change. If the ambition is to create independence and economic opportunities for fishing communities, risk in farming enterprises should consequently not be borne at the community level.

Outlook

The reasons for sea cucumber overfishing and stock degradation are complex. In some cases, however, weak governance and absence of capacity to implement control appears to be a central problem (Muthiga et al. 2010; Eriksson et al. 2010). In this context it is important to underscore that new technology cannot replace governance, nor can it produce the same number of species (sometimes reaching 35) that are targeted in the fishery (Purcell 2010). Successful introduction of hatchery enterprises to restock depleted populations or alleviate pressure from fishing is therefore not guaranteed with the current level of knowledge, and the level of management participation in fisheries where governance is weak. That expectations from sandfish aquaculture need to be balanced was illustrated in a brief questionnaire sent out to five scientists with leading insight and experience in the topic of sandfish farming, asking them to rank on a 1–5 scale how likely some considerations are to be realised (Eriksson 2009). The highest scoring concern was that farming would be introduced on inflated promises. This is very unfortunate—not living up to unreasonable initial expectations may undermine the future potential success of sandfish farming. Moreover, it may lead communities into taking unnecessary risks.

The future of sandfish farming lies in understanding and managing the fishery and beche-de-mer trade (e.g. Friedman et al. 2008), and in the critical evaluation of experiences and development of research in relation to successes and failures of farming; for example, filling the knowledge gap regarding business models that benefit fishers and communities. Therefore, it is very important to share knowledge and experience so that successes are replicated and mistakes not repeated. In this sense, developing new, or strengthening existing institutions, requires that learning mechanisms are implemented, and that a social–ecological systems perspective is applied. This whole process would be made easier by adopting a benchmark approach to developing standards for responsible sandfish farming, on which managers and political decision-makers can base decisions, as has been done for other aquaculture organisms (e.g. WWF 2010).

Conclusion

There is an interest among communities to farm sea cucumbers. However, the current fishery situation in Zanzibar is a result of weak governance, in that actors in the trade operate with minimal ambition to allow fishers to capture profits, and this raises questions regarding the feasibility of farming. The lack of governance mechanisms that would allow for a sustainable and functioning fishery cannot be substituted with new technology (hatcheries). Therefore, unless governance issues are addressed and improved, it is very likely that a farming enterprise will go down the same road as the fishery—impoverished and with marginal social equity.

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World sea cucumber markets: Hong Kong, Guangzhou and New York

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Abstract

Hong Kong, Guangzhou and New York are the most important markets in the sea cucumber industry. Dried sea cucumbers are brought from all over the world to be bought and sold in Hong Kong. Traders and wholesalers are located along Nam Pak Hong Street in the Sheung Wan area in the north-west of Hong Kong Island. Hong Kong and Guangzhou in Guangdong province, China, have been tightly connected since the birth of Hong Kong in the 19th century. Through this channel, most of the dried marine products imported into Hong Kong are re-exported to Guangdong, from where they are traded throughout China. Wholesalers gather along Yat Tak Lou (Yi De Lu) Street in Guangzhou. This paper will explore the historical development of the sea cucumber market in China, with special reference to regional differences. A recent development in the New York market is also explained in relation to trade of the Galapagos sea cucumber, *Isostichopus fuscus*. The characteristics of these three intertwined markets indicate that resource management plans should take market preference into consideration.

Trade in dried sea cucumber

In 2007 Hong Kong imported 5,296 tonnes (t) of dried sea cucumber: Papua New Guinea exported the most to Hong Kong (704 t of dried sea cucumber), Indonesia (653 t) second, and Japan (585 t) third. According to the Monthly Statistics of Hong Kong, it re-exported 4,149 t of dried sea cucumber to 13 countries and regions in 2007. Among them, China imported 3,576 t (86% of the total re-export volume from Hong Kong).

Sea cucumber species

About 50 species out of a total of 1,200 are currently commercially traded in the world. Sea cucumber can be classified by its form in two categories: *ci-shen* (‘spiky’) and *guang-shen* (‘shiny). The spikes actually refer to the parapodia on a sea cucumber’s back and sides that harden when dried.

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The most common *ci-shen* species is *Stichopus japonicus*, which can be found in the Bohai Sea and along the Korean, Japanese and Russian maritime coasts. The species shows regional variation in sharpness of its spikes, with the Hokkaido variety demonstrating the sharpest spikes. Several of the internationally traded *ci-shen* sea cucumber species have temperate seas as their natural habitat, while *guang-shen* sea cucumbers, the rest of the commercially traded species, are typically found in tropical marine environments. Some types of tropical sea cucumber found in the Pacific Ocean and around South-East Asia, such as *Thelenota ananas* and *Stichopus chloronotus*, are also classified as *ci-shen*. *Isostichopus fuscus*, a species harvested around the Galapagos Islands and in other locations, is also considered *ci-shen*.

The differences in the form of sea cucumber species also play an important role in sea cucumber food preparation. Chinese cooking is largely divided into Beijing, Shanghai, Sichuan and Cantonese cuisine, and regional differences are most pronounced between Beijing and Cantonese cuisine. Traditionally, in Beijing cuisine, *ci-shen* sea cucumbers are preferred, while the Cantonese prefer *guang-shen* species. While geographic location plays a part in the preference for the temperate *S. japonicus* in the north and the tropical *Holothuria fuscogilva* or *H. scabra* in the south, cooking styles also explain the difference. Pekinese prefer to serve food in small dishes, while the Cantonese use a large serving dish placed in the centre of a round table, which explains the higher demand for small *ci-shen* species in Pekinese, and large *guang-shen* species in Cantonese, cuisine.

Conclusion

To my understanding, the New York market prefers *ci-shen*, especially *I. fuscus*. The species began to be commercially harvested in the late 1980s, and became very particular in symbolising globalisation of the sea cucumber industry, as well as sea cucumber conservation (e.g. the Convention on International Trade in Endangered Species of Wild Fauna and Flora). This paper presumes that the New York market would have played an important role in the exploitation of *I. fuscus* in Central and South American countries such as Mexico and Ecuador. This is another reason why it is necessary to investigate market preference, and feed the results back into resource management planning.

Applying economic decision tools to improve management and profitability of sandfish industries in the Asia–Pacific region

Bill L. Johnston[1]

Abstract

A component of the recent Australian Centre for International and Agricultural Research-funded sandfish project in the Philippines, Vietnam and Australia has been to build and refine economic decision tools for both sea ranching and pond-based culture of sandfish. Presented here is the background to these models and some basic theory required to understand model outputs. Models take a discounted cash flow approach to predicting returns over a given life cycle. Output includes the expected annual returns when the farm is paid off, and the maximum interest rate at which funds can be borrowed to invest in the project. A risk module allows the user to incorporate anticipated risk to return from a range of sources. Access to these models is open, and a web address is provided.

Introduction

Sea cucumber farming presents a novel economic proposition as it differs in a number of ways from other aquaculture ventures. When compared with more traditional culture systems, sea ranching presents a unique set of parameters regarding survival, transport and release issues; social and management issues; and exposure to natural system variability. Similarly, pond-based farming differs markedly from culture of other species, most notably in the absence of feeding costs, which is offset in part by low stocking densities. Developing tools based on empirical experience gained through pilot-scale sea ranching and pond-culture projects provides a valuable tool to enable potential industry entrants to assess viability under their particular circumstances.

Economic decision tools are a conceptual framework that allows users to make informed decisions underpinned by sound economic methodology. In this project, cost–benefit analysis was used as the conceptual framework for the economic evaluation of sandfish production. The customised economic tools (industry- or situation-specific) aim to assist producers and potential investors understand the economic requirements, costs and benefits, and risks involved in production.

More specifically, economic decision tools allow producers to assess impacts such as disease, climate and market prices (known as externalities) that may influence profitability. They can also assess changes in profitability caused by changes in the cost of feed, labour, electricity, packaging and transport. Additionally, the decision tools can evaluate the economic effects of improvement in yield, future development plans or a change in production efficiency.

Without rigorous economic decision frameworks, the resulting actions can be based on unsound, incomplete or misleading information. Equipping clients with decision tools provides improved capacity for increased profitability and sound economic development, and reduces the risk of failure.

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Developing an effective, sustainable and profitable aquaculture enterprise requires a lot of time and capital input. Prevailing market conditions make it very important to thoroughly research and identify markets for products before venturing into production. This applies to almost all industries, particularly aquaculture. Little or no information is available to farmers and interested investors about the establishment costs or the profitability of operating many currently existing sandfish enterprises. By making an economic analysis tool available for farmers, we aim to provide the knowledge and information necessary so that they are fully prepared and understand the capital required, operating costs involved, labour input and profit margins they might expect to receive given an identified level of risk (e.g. the likelihood of losses by cyclones, or fluctuations in market price).

Culture or sea ranching of sandfish is a relatively new income-generating activity (compared with traditional wild harvest) now being practised in a range of countries as an alternative to other income sources. Many people are interested in moving toward more sustainable methods of sandfish production, but do not have enough information to decide whether they are worth doing. They need a way of comparing these new activities with the other, more-familiar activities.

The income, expenditure and investment levels for any business will be different from place to place. Once an economic decision tool framework has been developed for each income-generating activity, it can be distributed relatively easily (electronically) for rural development trainers or extension agents to use with people in an interactive way. Working with farmers to develop data inputs for models relevant to their particular situation will allow comparisons and decisions to be made regarding different income-generating activities.

Project objectives

The economic tools discussed here were developed or modified as a component of the current Australian Centre for International and Agricultural Research (ACIAR) – WorldFish Center project in the Philippines, Vietnam and Australia. The broad economic objectives of the project include:

- diversified livelihoods based on sea ranching of sandfish
- improved livelihood resilience for small-scale pond farmers due to diversification
- increased earnings for fishers from
  - restored stocks of sandfish
  - production of A-grade beche-de-mer through increased size limits and improved processing methods.

The tools discussed are specifically targeted at providing potential industry participants with a window into the economic realities of this type of enterprise. The primary focus has been to look at the possibility of sandfish culture and sea-ranching operations as alternatives to more traditional pursuits. Aquaculture enterprises are usually capital intensive, requiring substantial investment with extended payback periods. The ability of these enterprises to source investment, establish capital infrastructure and weather financial and operating expenses during inception has, in the past, been a major stumbling block for sustainable aquaculture industries. Variability in market prices and income flows also poses major hazards to establishing early profits and ensuring viability in the long term.

The objectives of the modelling component of the project were to:

1. develop three focused economic decision tools, based upon cost–benefit analysis, that people can use to assess the viability of the proposed sandfish enterprise, as follows
   - hatchery–nursery
   - pond-based production
   - sea-ranching production
2. consult with people who are experts in these income-generating activities, and obtain the necessary information to develop representative business frameworks for each enterprise
3. apply and interpret risk analysis profiles for the associated enterprises.

Explanation of the models

The economic models were developed using the Microsoft Excel spreadsheet program and based upon the cost–benefit analysis technique. Cost–benefit analysis is a conceptual framework for the economic evaluation of projects, with an aim to assist the user to make a decision regarding the allocation of resources. In particular, it helps the user to make decisions about whether or not to invest in an enterprise.

Discounted cash-flow analysis was used to determine the annual cost structure and the likely profitability for each of the commodities. Discounting reduces future costs or benefits to an equivalent amount in today's dollars. People generally prefer to receive a given amount of money now rather than the same amount in the future, because money has an opportunity cost. For example, if asked an amount of money they would prefer to receive in 12 months time in preference to $100 now, most people would nominate a figure around the $110 mark—to them, money has an opportunity cost of around 10%. A dollar tomorrow is not worth the same as a dollar today. Therefore, the timing and duration of these projects has an influence on the annualised costs and revenues of the project. The single amount calculated using the compound interest method is known as the 'present value' (PV) of the future stream of costs and benefits. The rate used to calculate PV is known as the discount rate (opportunity cost of funds).

All the models developed assume a project life of 20 years, and use a real discount rate (equivalent to the current long-term bond rate, which is normally in the range 4–10%) to calculate the net present value (NPV). The budgets also incorporate the initial capital and establishment costs.

Data input into the spreadsheet-based models is simple, and is guided by two simple rules—red colour denotes a calculation cell and yellow colour an input cell. Values (size of ponds, cost of labour etc.) can be entered into the yellow cells, while the values in the red cells are calculated from the data entered by the user. The summary statistics provide a breakdown of costs on a per unit basis.

Once the data are entered into the model, the user can apply it to determine the impact of various management decisions. For example, the farmer may wish to know how a change in wages will affect his profit, or how introducing new management techniques will affect production.

All the statistics are explained in the next section. The output includes the expected annual returns when the farm is paid off, and the maximum interest rate at which funds can be borrowed to invest in the project. Once an economic analysis has been done, this maximum interest rate figure should be taken into consideration when negotiating finance for a project.

Definition of terms

Net present value (NPV) and equivalent annual return

The NPV is the difference between the present value of cash inflows and the present value of cash outflows over the life of the project. If the NPV is positive, the project is likely to be profitable. When the NPV is converted to a yearly figure, it becomes annualised; in this report, it is called the equivalent annual return. It is a measure of equivalent annual returns generated over the life of the project expressed in today's dollars.

Discount rate

The discount rate is the interest rate used in discounted cash-flow analysis to determine the present value of future cash flows. It takes into account the time value of money (the idea that money available now is worth more than the same amount of money available in the future because it could be earning interest), and the risk or uncertainty of anticipated future cash flows (which might be less than expected).

Internal rate of return (IRR)

The discount rate at which the project has an NPV of zero is called the internal rate of return (IRR). It represents the maximum rate of interest that could be paid on all capital invested in the project. In other words, if all funds were borrowed from a bank, and interest charged at the IRR, the borrower would break even; that is, recover the capital invested in the project at the end.

Payback period

A graph representing the cumulative cash flow is displayed in the models. The year in which the cash flow rises above zero is considered the payback period, and is a measure of the attractiveness of a project from the viewpoint of financial risk. Other things being equal, the project with the shortest payback period would be preferred. It is the period required for the cumulative NPV to become greater than zero, and remain greater than zero over the life of the project.

Benefit:cost ratio

The benefit:cost ratio (b:c) is simply a measure of the total flow of benefits over the life of the project compared with the flow of costs. If the ratio is greater than one, the project is deemed acceptable. In other words, the ratio describes the return per dollar invested; for example, if the b:c is 1.6, it can be said that, for every $1.00 invested in the project or enterprise a return of $1.60 is made.

Risk analysis

Risk and uncertainty are features of most business and government activities, and need to be understood to ensure rational investment decisions are made. The process involves the following steps:

1. defining the model—modelling the business operations
2. defining the uncertain variables—price and yield
3. assigning probability distributions for each of our uncertain variables—allocating probabilities to the categories of minimum, poor, average, good and maximum
4. running the simulation and analysing the results—for this risk analysis, the results are displayed using a cumulative probability distribution.

The best way to demonstrate how to input information for the risk analysis and interpret the results is with an example (Table 1). The user needs to first specify the likelihood of various risk factors (cyclone, theft etc.) affecting production (or yield). In Table 1, 'Risk factors' are listed and then the probability of each of these is stated in the 'Probability' column, with reference to the description in the 'Occurs' column.

As seen in Table 1, data are entered in the 'Probability' column, resulting in the cumulative percentages shown in the 'Cumulative' column. The user then enters the expected production or yield (as in Table 2). It is not necessary to enter the minimum or maximum probabilities, nor their associated production.

This example table indicates that there is a:

- 10% chance of producing 0–20,000 kg (minimum to poor)
- 20% chance of producing 20,000–25,000 kg (poor to average)
- 40% chance of producing 25,000–27,500 kg (average to good)
- 30% chance of producing 27,500–30,000 kg (good to maximum)

The same process is followed for the price risk, except that the minimum and maximum prices are entered by the user. The minimum price cannot be zero; it may be a subsidised price set by the government or a historical market low.

Once all the data have been entered, the simulation is run. The simulation produces a set of results that is graphically shown as a cumulative probability distribution (Figure 1), indicating the entire range of outcomes possible, based on the user's inputs, for the enterprise.

The annual return is represented along the x-axis and the probabilities on the y-axis (Figure 1). In this example, with the costs and prices as specified in the input (yellow) cells, the cumulative probability curve crosses the $0 return point at approximately 0.2. This can be interpreted as meaning that a 20% chance exists of making an annual return of less than $0

Table 1. Expected risks for sandfish farm example

Expected production	Risk factors	Occurs	Probability	Cumulative
Zero–poor	Cyclone, severe disease and flood	1 in 10 years	0.1 (10%)	**0.1**
Poor–average	Theft, some disease, lack of stock supplies	2 in 10 years	0.2 (20%)	**0.3**
Average–good	Good conditions, minimal disease, good feed	4 in 10 years	0.4 (40%)	**0.7**
Good–maximum	Excellent growing conditions, no disease	3 in 10 years	0.3 (30%)	**1.0**

Table 2. Risk input proforma for sandfish farm example

Expected production	Kilograms of sandfish	Cumulative probability
Minimum	0	0.00
Poor	20,000	0.10
Average	25,000	0.30
Good	27,500	0.70
Maximum	30,000	1.00

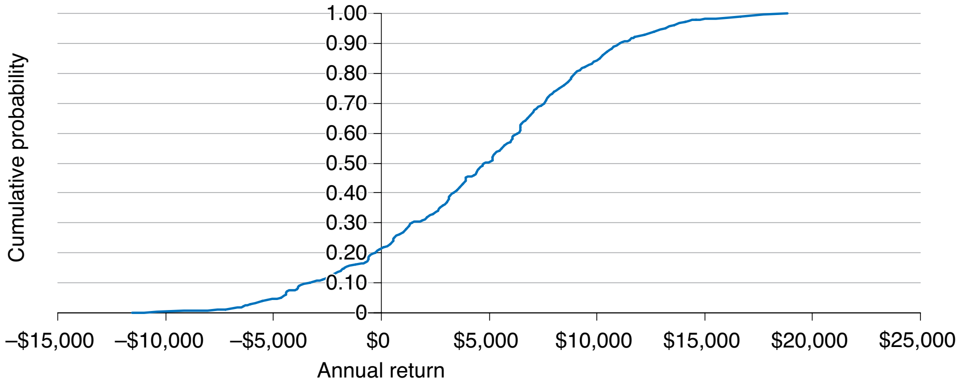

Figure 1. Cumulative probability distribution for sandfish farm example

(i.e. making a loss for the year). Alternatively, a line drawn vertically from the $10,000 mark on the horizontal axis meets the curve at about 0.8 (projecting across to the vertical axis), indicating that there is an 80% chance of earning less than $10,000, and so on.

Should business owners 'pay' themselves?

While identifying costs for inclusion in the economic model framework, there is a tendency for users not to place any value on the time contributed by the owner of the business or the owner's immediate family. Rather, this time and labour is treated as a non-valued good. It is generally assumed that the return to owner labour and management is realised only when the business generates sufficient profit.

The fundamental problem with this way of thinking is that it distorts the decision to undertake that particular enterprise by underestimating the true cost of labour. If the business is able to generate sufficient revenues to compensate owner or family labour, plus all other operating (fixed and variable) and capital expenses, the enterprise would be deemed profitable. If the enterprise returns a profit based solely on unpaid labour, the decision to undertake that enterprise would be based on false economies.

There is a basic requirement to supply food and shelter (subsistence). If the enterprise selected does not meet this need, it should not be undertaken unless it provides a direct food supply to the family.

Consideration must be given to the opportunity cost of labour. An economic value needs to be placed upon the time the business owner and his family devote to the enterprise, so that they can assess whether they are better off to be engaged in that business or in some other economic pursuit. Anybody using these economic models should estimate the cost of that labour, regardless of whether or not actual monies are to be drawn from the business to the owner or their family.

Tool availability and access

These tools have been developed as an open access utility, and are available for download from: <http://agbiz.business.qld.gov.au/>. The tools continue to be refined based on updated empirical information, and new versions may be uploaded periodically.