Sea cucumber farming experiences in south-western Madagascar

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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

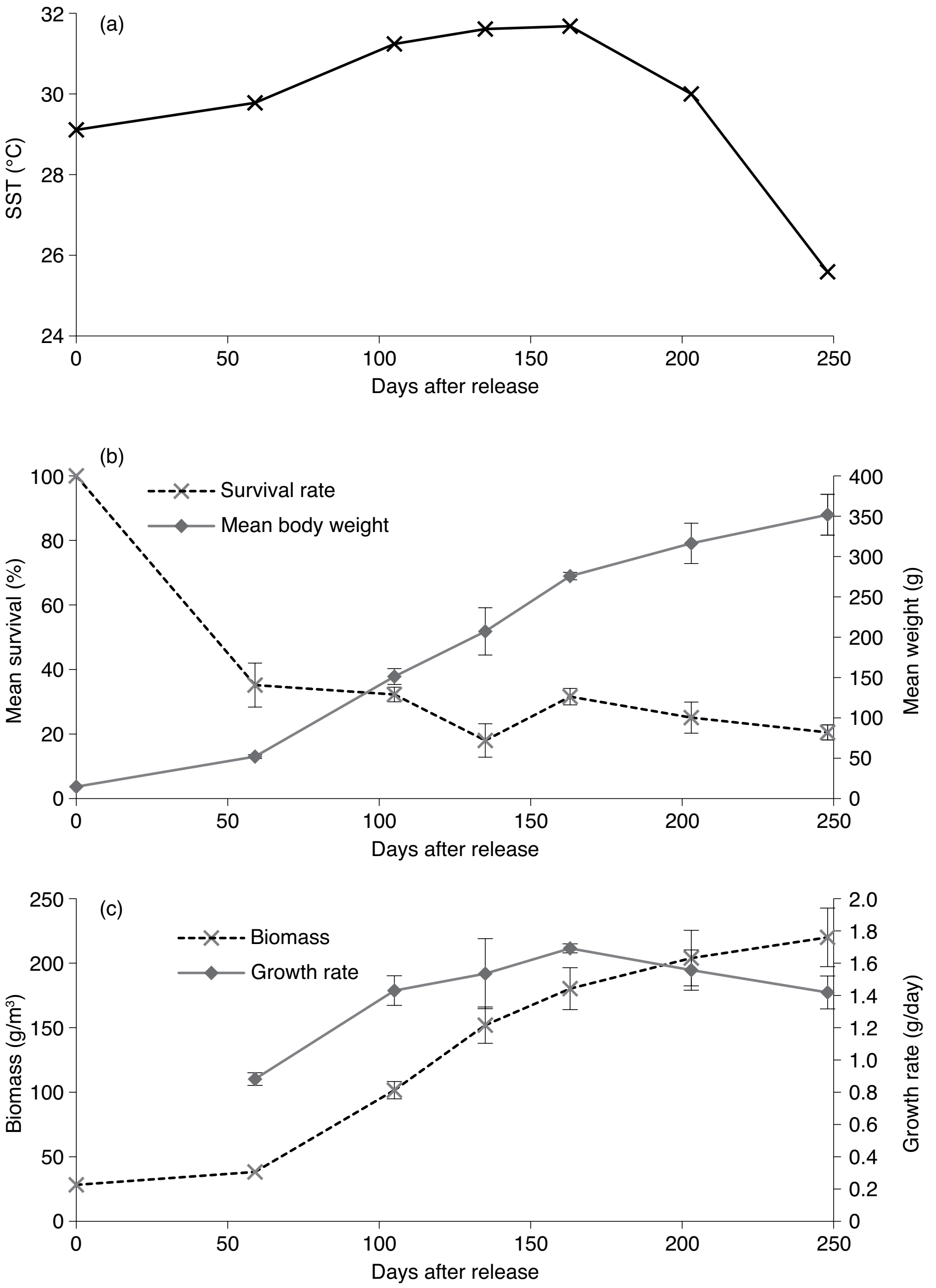

Figure 5. Biological responses of sandfish in the second release in Ambolimoke on 1 October 2008 into four 12.5 ×12.5 m sea pens: (a) sea surface temperature (SST); (b) mean survival and weight of released sandfish; (c) biomass and growth rates of released sandfish. NB: There was high mortaility within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

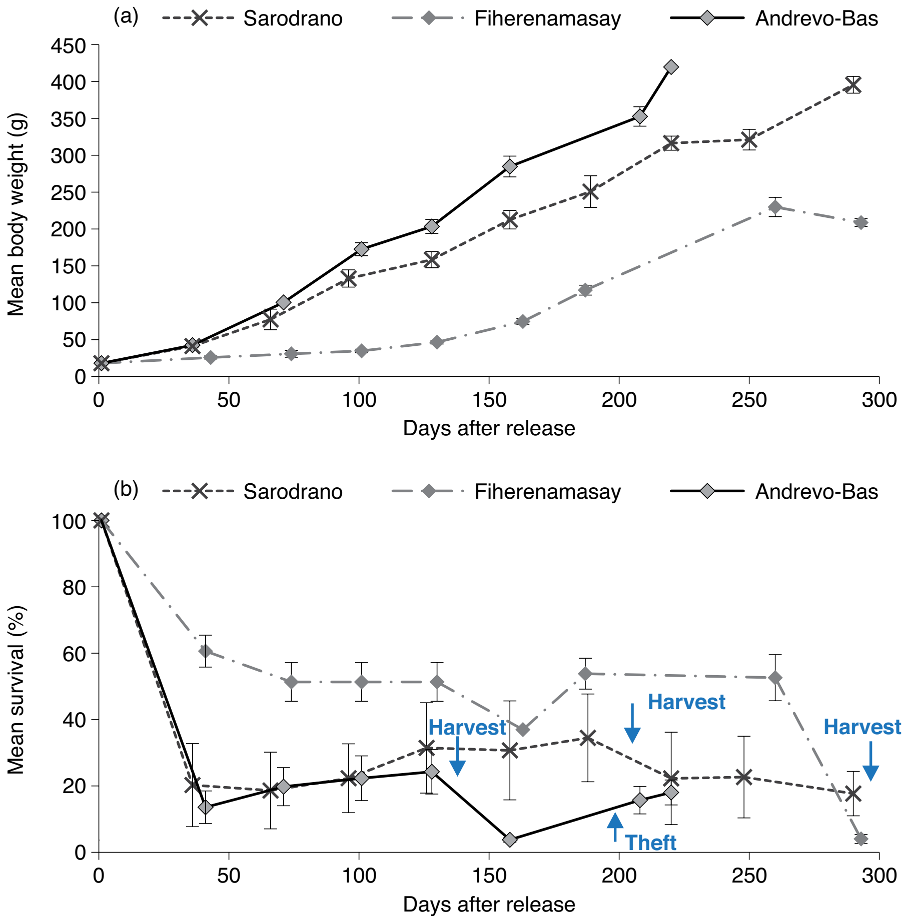

Figure 6. Biological responses of sandfish at the Trans'Mad-Développement farming sites during the first releases of juveniles into five pens in Sarodrano on 1 April 2009 (*n* = 2,250), five pens in Fiherenamsay on 13 May 2009 (*n* = 2,250) and seven pens in Andrevo-Bas on 11 June 2009 (*n* = 3,150)

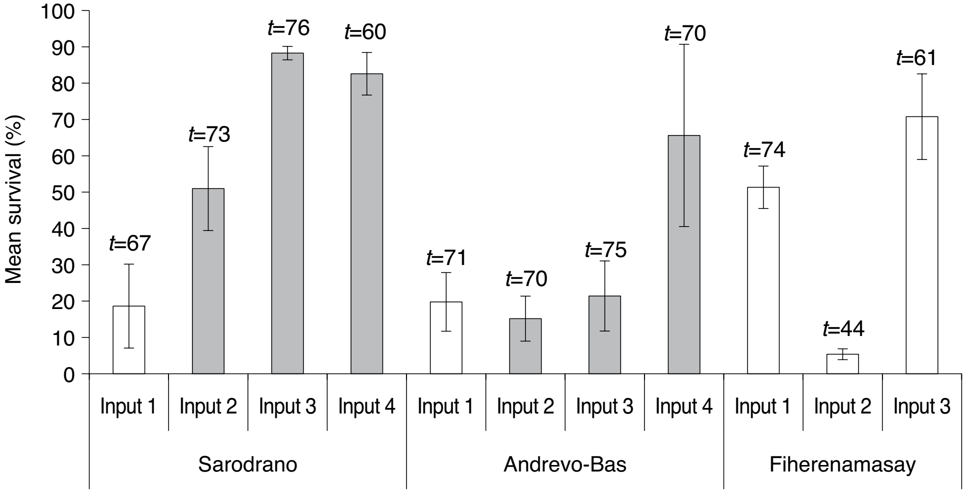

Figure 7. The effect on mean survival of releasing 15-g juveniles into protected nursery enclosures. Unshaded bars denote releases into open 30 × 30 m sea pens; shaded bars indicate release of sandfish into 25-m^2 covered nursery enclosures. The number of days post-release is indicated above each bar.

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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