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.

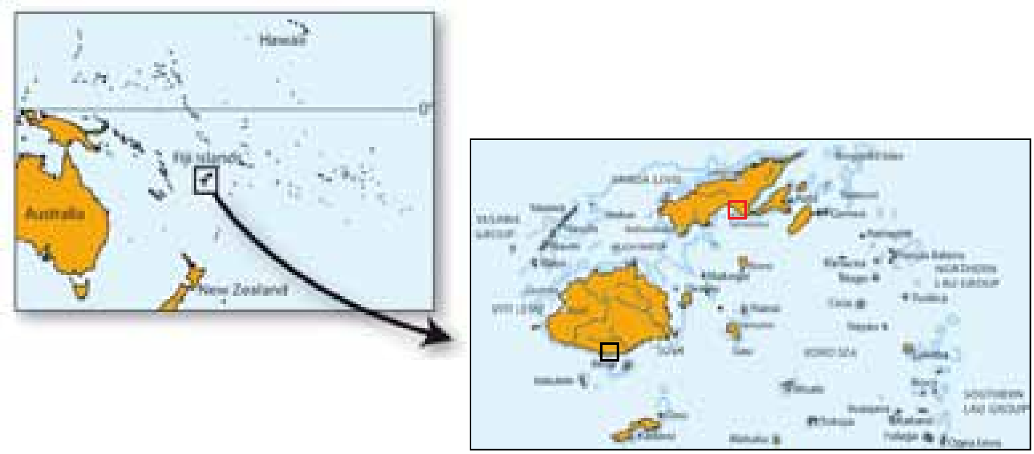

Figure 2. Map of Fiji showing general location of the two study site areas, Savusavu on Vanua Levu (red box) and Galoa on Viti Levu (black box) (map courtesy of Secretariat of the Pacific Community)

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

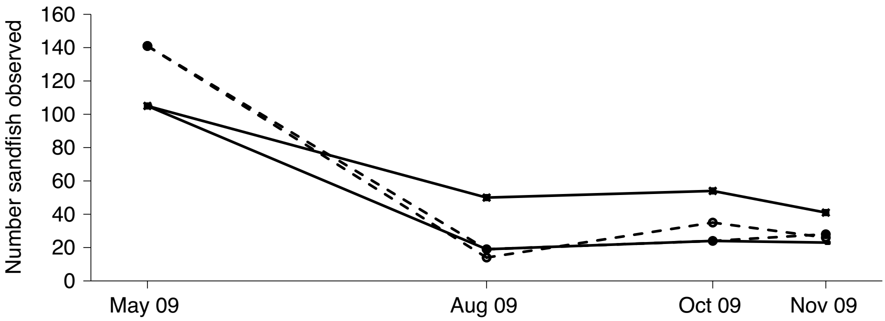

Figure 10. Survival of released sandfish in the four pens after 6 months. Solid lines represent pens stocked with large juveniles (>3–10 g), and broken lines represent pens stocked with small juveniles (1–3 g).

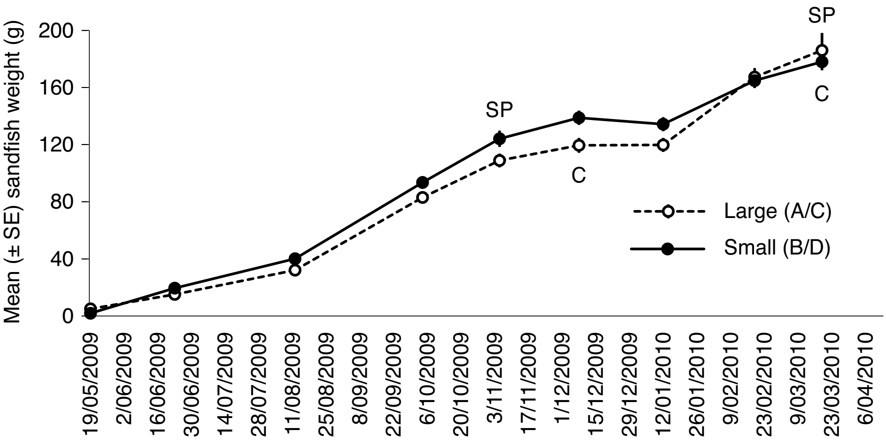

Figure 11. Growth data over 11 months for hatchery-produced sandfish at Natuvu. Solid lines represent large juveniles (both pens combined) and broken lines represent pens of small juveniles (both pens combined). March and April 2010 are subsamples of the sandfish located in pens after cyclone Tomas, 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,

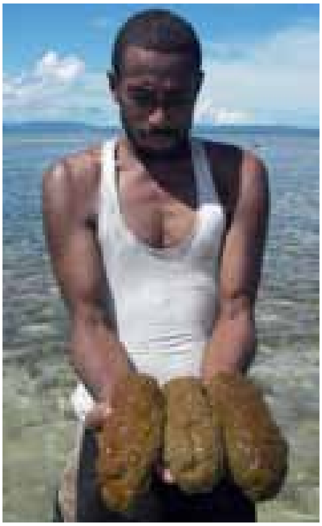

Figure 13. (left) Commercial-size curryfish (*Stichopus hermanni*) and (right) Natuvu women with beche-de-mer

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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