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Australian Centre for International Agricultural Research

Final report

Project	**Improving technical and institutional capacity to support development of mariculture based livelihoods and industry in New Ireland, Papua New Guinea**
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prepared by	Paul Southgate Thane Militz
co-authors/ contributors/ collaborators	Cathy Hair, Jacob Wani, Jeff Kinch
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Contents

Acronyms:

ACIAR – Australian Centre for International Agricultural Research

BDM – Bêche-de-Mer

CBFM – Community-based fisheries management

CEPA – Conservation & Environment Protection Authority

CIS – Correctional Services

CMT – Customary Marine Tenure

GBRMPA – Great Barrier Reef Marine Park Authority

FRI – Malaysian Fisheries Research Institute

IATA – International Air Transport Association

LLG – Local Level Government

MMC – Marine Management Committee

NAQIA – National Agriculture and Quarantine Inspection Authority

NIMRF – Nago Island Mariculture and Research Facility

NFA – National Fisheries Authority

NFC – National Fisheries College

OHS – Occupational Health and Safety

OLSH – Our Lady of the Sacred Heart

PAU – Pacific Adventist University

PC – Partner communities

PNG – Papua New Guinea

SPC – The Pacific Community

TVET – Technical and Vocational Education and Training

UNRE – University of Natural Resources and the Environment

UPNG – University of Papua New Guinea

USC – University of the Sunshine Coast

VPC – Village Planning Committee

WCS – Wildlife Conservation Society

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2 Executive summary

Coastal and island communities in Papua New Guinea (PNG) depend primarily on marine resources for their livelihoods. But the collapse of the sea cucumber fishery, and resulting moratorium, extinguished a traditional and significant income source for such communities and development of alternative livelihood options became a priority. This project continued ACIAR support to assess potential for developing mariculture as a livelihood activity in PNG, with emphasis on community-based sea cucumber (sandfish) ranching and production of marine ornamental species. The overall aim of the Project was to provide a sustainable basis for such development and to build further capacity within country partner agencies and coastal communities to support this.

Breakthroughs in land-based production methods supported routine and reliable production of target species for field-based trials and community roll-out. A routine feeding protocol for hatchery production of sandfish, using commercially available micro-algae concentrates, greatly simplified hatchery production. Use of captive sandfish broodstock brought resilience to the production process, while a series experiments allowed refining of early-nursery culture methods and addressed bottlenecks in this phase of production. Experiments to assess the application of micro-algae concentrates for hatchery culture of giant clam (*Tridacna noae*) larvae using epifluoescence microscopy provided new insights supporting more efficient hatchery culture methods and production of novel hybrids with potential in the international aquarium market.

Community-based sandfish culture was established at a number of partner communities and involved community members in all aspects of set-up, monitoring and data collection. At sites with good habitat, sand fish cultured in sea pens achieved commercial size within 12 months. Sea ranches were established at three partner communities, but poaching prevented data collection from two of them. A third successful sea ranch allowed consideration of ‘best practice’ that should include a high level of community engagement and education, frequent oversight by Fisheries staff and production during closure of the sea cucumber fishery to minimise poaching. Two communities were engaged in giant clam farming and another was supported to continue coral culture established during the previous ACIAR project (FIS/2010/054).

Mariculture capacity at NIMRF was built throughout the project via hands-on involvement with production and research activities, formal training by project personnel and visiting scientists, and through development of manuals and other training materials. Hands-on training at partner communities was conducted during all field activities and some community members were selected and trained for on-going engagement in longer-term field-based research activities. Project personnel also contributed to NFC’s formal Aquaculture training programs, to undergraduate and postgraduate training of students from UNRE and to training of local NGO staff.

Opening of the PNG sea cucumber fishery, following a seven-year moratorium, provided opportunity to collect unexpected socio-economic information and detailed information on community impacts. Further information relating to customary marine tenure, and the failure of sea ranches established during this project, informed ‘best practice’, developed to guide future community-based sandfish sea ranching activities in PNG. Much of the economic assessment anticipate from this project was impacted by lack of expected data from sea ranches and, in the case of ornamental species, inability to export ornamental species from PNG.

Outputs from this project have had regional uptake and impacts. For example, NIMRF staff participated in the SPC Regional Exchange on Sandfish Aquaculture where they disseminated project-developed sandfish culture procedures, particularly relating to the use of micro-algae as a larval food source. NIMRF staff have also been engaged directly by SPC to train private sector aquaculture practitioners from the region. There has been broad international uptake of the use of micro-algae concentrates as a hatchery food source for a variety of species. Project outputs include 12 publications in international journals, a book chapter and a variety of manuals and extension materials. The final Project review was conducted in May 2019 and ‘scientific impact’ was among the significant achievements identified by the Project review panel. They noted in particular that the scientific impact of this Project enhanced the profile of ACIAR as a research-in-development funder with technologies developed during the course of the Project having a transformational impact.

3 Background

Although coastal and island communities in PNG depend primarily on marine resources for their livelihoods, the potential economic and livelihood opportunities provided by this environment are not maximised. Collapse of the sea cucumber fishery because of depleted stocks and the resulting nationwide moratorium, extinguished a traditional and significant income source for such communities. As a result, the NFA needed to develop alternatives to the sea cucumber fishery, and to provide livelihood opportunities for coastal and island communities in PNG.

Scoping work conducted in prior ACIAR Projects in PNG (FIS/2006/138[1] and FIS/2010/017[2]) identified marine commodities that may support community-based mariculture activities. This prompted development of FIS/2010/054[3] which supported the NFA in assessing the mariculture potential of three major commodities - sea cucumbers, edible oysters and marine ornamentals. All three are priority commodities within the *PNG National Aquaculture Development Policy* and have established national and international markets. FIS/2010/054 also provided a mechanism for strengthening institutional capacity for mariculture training in PNG and for development of mariculture capacity within NFA, NGOs and local communities as a basis for sustainable mariculture development supporting livelihoods. This was supported by the Nago Island Mariculture and Research Facility (NIMRF) which was established by NFA to support development of mariculture-based livelihood opportunities in PNG and to become a training centre for students from the NFC.

FIS/2010/054 made significant advances in all of its research objectives. A considerable component of the Project focused on fine-tuning the NIMRF facility to support hatchery production of target species. Hatchery production of sea cucumbers and breeding of marine ornamental fish is now routine. Collaborative relationships were developed with local communities supporting establishment of village-based field sites to test ranching of sea cucumbers and collection and culture of oysters with local operational inputs. Strong collaborative links were made between Project partners, local communities and NGOs specialising in technical extension to support these activities. However, full assessment of the local mariculture potential of target species was not possible within the life of FIS/2010/054 and this follow-on Project was required to maximise outputs relating to growth performance, quality and production of priority mariculture commodities, and socio-economic assessment of the compatibility of mariculture with local lifestyles.

While there is no tradition of mariculture in PNG, there are strong traditions in farming and in utilisation of, and familiarity with, marine commodities. Perhaps the biggest question for FIS/2010/054 related to whether these two traditions could be married to support mariculture development. The Project showed, without doubt, that from a technical perspective, the answer to that question is ‘yes’. Community-based sea cucumber ranching was embraced enthusiastically by three partner communities where local people (trained by Project staff) were responsible for day-to-day oversight and maintenance of sea cucumber culture pens that supported excellent growth rates and yields that could potentially generate incomes in the order of A$32,000 per hectare per year. Additionally, trained local NFA staff assumed increasing responsibility for hatchery production at NIMRF during the Project to a point that supported routine production of sea cucumbers and clownfish juveniles sufficient to meet Project research needs. So, while there is no tradition of mariculture in PNG, this is

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[1] *FIS/2006/138: “Developing aquaculture based livelihoods in the Pacific Islands region and tropical Australia”*

[2] *FIS/2010/017: “Building mariculture capacity in Papua New Guinea” (SRA)*

[3] *FIS/2010/054: “Mariculture development in New Ireland, Papua New Guinea”*

not a handicap to mariculture development in the country. From a technical perspective, the outputs from FIS/2010/054 indicated ready uptake of mariculture activities in partner communities and this provided an excellent basis from which these activities could be consolidated and expanded to maximise potential benefits and impacts from the Project.

Building mariculture capacity in PNG and determining the mariculture potential of important marine commodities are key priorities for the NFA. Because of the traditional importance of the sea cucumber fishery for coastal communities in PNG, closure of the fishery and high international demand for dried sea cumbers, developing sea cucumber mariculture in PNG is a particularly high priority for the NFA as outlined in the *PNG National Aquaculture Development Policy*. Research during FIS/2010/054 showed that the environment around Kavieng is appropriate for sea cucumber ranching and supportive of relatively high growth rates. Furthermore, this activity has been successfully introduced to local communities and can be supported by routine hatchery production of sea cucumber juveniles from NIMRF. Further development of community-based culture methods for sea cucumbers, to a point where income generation is possible, is now a major priority for NFA.

An attempt to develop a sustainable, equitable and profitable marine aquarium trade in PNG was pioneered by the NFA through the Seasmart program created in 2008 as a joint venture with US-based consultancy firm EcoEZ Inc. Although the arrangement between the NFA and EcoEZ ended before the start this project, NFA has interest in moving forward with an internally run marine aquarium program with the primary aim of taking the aquarium fishery in PNG from pilot stage to a fully developed and sustainable, privately run industry. The NFA Marine Aquarium Program was supported by FIS/2010/054 which conducted surveys of local coral reef species and developed culture activities for some of them at NIMRF. The "*National Marine Aquarium Fishery Management and Development Plan 2014*" which is yet to be gazetted, identifies aquaculture as a priority for 'sustainable production of marine aquarium organisms' supporting industry development.

Strengthening institutional capacity for mariculture training in PNG, and appropriate training of mariculture graduates, are key priorities for the NFA required to support national mariculture development. Aquaculture training at the NFC has now begun and separate training programmes will focus on mariculture to support sustainable mariculture development in PNG. The NFA was supported in this development by FIS/2010/054 which reviewed current aquaculture/mariculture training opportunities and developed a suggested curriculum and multi-tiered training program for mariculture trainees at the NFC. Mariculture training in PNG can now be supported by a fully functioning NIMRF and related community-based activities which could provide mariculture students with practical training opportunities that will be addressed in this Project. It is further supported by the activities of a recently appointed Aquaculture Instructor at NFC who will oversee implementation of mariculture training at the NFC and the NIMRF.

4 Objectives

The overall aim of this Project was to provide a sustainable basis for the further development of a mariculture sector in PNG and to further build capacity within country partner organisations and coastal communities to support this development. The major research questions addressed by the Project were:

- Can the hatchery, nursery and grow-out methods developed for target species during FIS/2010/054 be further developed to support more efficient larger-scale production of juveniles supporting commercial production levels?
- What are the biological, economic and social challenges involved in developing community-based sea cucumber ranching to a level supporting income generation and how transferable is this activity to new communities?
- The outputs of this Project offer potential socio-economic benefits from mariculture – but what are they, how significant are they, how compatible is mariculture with traditional lifestyles, and are there any negative impacts of mariculture development in PNG?

The specific research objectives were:

Objective 1: To further develop culture and husbandry protocols for target species.

1.1 Assess commercial micro-algae concentrate products for large-scale hatchery production of sea cucumbers.

1.2 Refine culture methods to produce large numbers of release-size juvenile sea cucumbers.

1.3 Develop hatchery production and culture of giant clams at NIMRF.

1.4 Develop improved shipping methods for ornamental species.

1.5 Assess the potential for seaweed culture in Kavieng.

Objective 2: To develop community-based sea cucumber culture methodology to a level potentially supporting income generation.

2.1 Determine optimal culture protocol for ranching of sandfish.

2.2 Develop optimised husbandry regime for sandfish under optimal ranching conditions.

2.3 Extend sea ranching to new comm- unities in the Kavieng area.

2.4 Survey the Kavieng region to identify and map areas suitable for sandfish culture.

2.5 Promote sustainable management practices for sandfish ranching through extension and training.

Objective 3: To continue building long-term institutional mariculture capacity in PNG.

3.1 Appoint Project Scientist to be based at NIMRF.

3.2 Support and develop NIMRF hatchery and culture activities in production of target species.

3.3 Continue and expand mariculture training activities at partner communities.

3.4 Continue to train community members to undertake Project activities.

3.5 Conduct targeted training activities for partners organisations, NFA staff, students from NFC and PNG universities.

3.6 Revise and update culture manuals for community and NFA staff training and extension.

Objective 4: To appraise opportunities, risks and impacts associated with sustainable community-based sea cucumber farming.

4.1 Socio-economic baseline surveys in three current partner communities involved in sandfish ranching.

4.2 Ethnographic investigation of customary marine tenure (CMT) systems and existing arrangements in partner communities.

4.3 Socio-economic and CMT surveys in two new partner communities.

4.4 Final socio-economic and CMT surveys in all partner communities.

4.5 Cost-benefit analyses for ornamental commodities from Kavieng.

4.6 Generate economic data for community sea cucumber culture.

5 Methodology

This was a follow-on Project and much of the methodology used in this Project was developed during FIS/2010/054 and further refined in this Project. Development of new methods was also a component of this Project with, for example, remote sensing techniques developed for the identification of suitable habitats for sandfish mariculture and epifluorescence microscopy techniques adapted for assaying micro-algae ingestion and digestion and symbiont uptake and retention in giant clam larvae.

5.1 Objective 1: To further develop culture and husbandry protocols for target species.

5.1.1 Developing culture and husbandry protocols for target species

Hatchery methods (sea cucumbers): Much of the initial hatchery research during FIS/2010/054 focused on teething problems within the newly constructed NIMRF. Methods for routine small-scale hatchery production of sea cucumbers were subsequently developed. They utilised a low larval stocking density and culture of live micro-algae as the larval food source. Culture of live micro-algae was demanding of resources (air-conditioning, lighting, stock cultures sourced from Australia) and labour. Cultured micro-algae was also unreliable as a food source as cultures could unexpectedly 'crash' leaving the hatchery without food. Reliable production of live micro-algae was a major bottleneck in sea cucumber production at the NIMRF, a remote hatchery with limited technical resources.

In other parts of the Pacific, commercially available micro-algae concentrate products have been successfully used in larval culture of pearl oysters (Southgate et al., 2016). Preliminary research undertaken in FIS/2010/54 showed that micro-algae concentrates (Instant Algae®, Reed Mariculture, USA) were readily ingested and digested by all larval stages of sea cucumbers (Duy et al., 2015). This research formed the basis for developing larval culture protocols using micro-algae concentrates as replacement for cultured live microalgae. Experiments intending to support large-scale production of juvenile sandfish determined:

- Optimal microalgae concentrate combinations for different ages of larvae.
- Optimal ration of optimal diet for different ages of larvae.

The major output from this research was a simplified and prescribed larval feeding regime based on commercially available micro-algae concentrates. This simplified feeding regime was subsequently employed in experiments to address production bottlenecks that arose during the Project.

Reopening of the sea cucumber fishery in 2017, after a 7-year moratorium, resulted in population declines of wild adult sandfish (Hair et al., 2018) on which the NIMRF was reliant as a source of broodstock. To address this issue, a captive broodstock population was established in the newly constructed marine pond at the NIMRF. Research in this Project evaluated whether captive broodstock could reliably replace wild broodstock in the hatchery production of sandfish.

Larval experiments were conducted in the newly built climate-controlled hatchery of the NIMRF, using 1-μm filtered lightly aerated sea water in replicate 500 L tanks at 27-29°C. Larvae were stocked at a density of 0.3 mL^{-1} and relative larval performance between treatments was assessed on the basis of survival, rate of development and morphometric parameters including, stomach width, hyaline sphere development and size and larval length (Duy et al., 2016). Statistical analysis of data followed the methods of Duy et al. (2016) developed for similar research during FIS/2010/054.

Nursery methods (sea cucumbers): High numbers of early-juvenile sandfish (i.e., 3-8 mm) were reliably produced using the hatchery methods developed in this Project, but it is common to experience a bottleneck during the second nursery phase when juveniles are transferred out of larval rearing tanks. At the start of this Project, production of large numbers of release-size juveniles (≥ 3 g) would take many months and was both time-consuming and labour intensive. The major constraint may have been inadequate food or insufficient space because juveniles quickly become density limited as they grow (Battaglene et al., 1999). The NIMRF did not, until recently, have a seawater pond or a large number of raceways (employed for nursery stage culture of hatchery produced sea cucumbers in Vietnam and Australia, respectively). During FIS/2010/054 juveniles were held in floating ocean hapa nets under community care but showed slow, highly variable growth rates, similar to that reported in the Philippines (Juinio-Meñez et al. 2012). Construction of the seawater pond at NIMRF was completed in late 2015 and enabled Vietnamese-style hapas (Duy, 2012) to be tested. Survival and growth of hatchery produced juveniles in pond hapas was compared to that in ocean pens and shallow raceways, allowing identification of the optimal technology and husbandry regime to produce large numbers of release-size juveniles in the shortest possible time period. Experiments were established to determine the efficacy of each technology for culture of juvenile sea cucumbers in PNG, including:

- Effect of stocking density (individuals m^{-2}) on survival and growth
- Effect of juvenile age/size on survival and growth
- Effect of supplemental feeding on survival and growth
- Cost-effectiveness of different supplemental feeds
- Effect of sediment grain size on survival and growth
- Potential use of artificial substrates (e.g., shadecloth, polycarbonate structures) in juvenile culture systems

The major output from this research was a staged culture protocol that supported improved hatchery output, minimising the time required for juveniles to reach release-size to address the production bottleneck at NIMRF.

Experiments conducted in the newly completed seawater pond at NIMRF used Vietnamese-style hapa nets (Duy, 2012). The general method used followed the recommendations of Duy (2012) and juvenile performance between treatments was assessed on the basis of survival, growth, and dry weight determination. Some experiments continued after release to the field (such as trialling ocean pens to condition animals prior to liberation in sea ranches) to assess the influence of size/age and behaviour on subsequent growth and survival in the field. Resulting field experiments were conducted in enclosures (i.e., pens) at partner community sites using methods established in FIS/2010/054 (Hair et al., 2016). The results have informed decision making in relation to stocking protocols for sea ranches, such as minimum release size, optimal habitats for release, and optimal timing for release.

Ornamental production: Routine hatchery production of clownfishes and seahorses established during FIS/2010/054 continued in this Project. These programmes were entirely overseen by NIMRF staff. Similarly, asexual propagation of hard corals (Scleractinia) established under FIS/2010/054 was continued by the Nago Island partner-community with support from the Project in sourcing materials and through provision of quality improvement training.

Hatchery production of ornamentals at the NIMRF was broadened in this Project to include four giant clams species (*Tridacna noae, Tridacna maxima, Tridacna squamosa*, and *Hippopus hippopus*) which have considerable demand in the aquarium trade. Giant clams have a relatively short larval life (i.e., short hatchery phase of culture) but unique culture requirements as juveniles (i.e., autotrophy). Culture and production of giant clams at NIMRF therefore broadened the mariculture/husbandry capacity of NIMRF staff and those from partner communities while resulting in a product that has a ready international market and grows to market size in 12-18 months. Growth and survival of juvenile giant clams is affected by factors such as sunlight intensity, nutrient composition of culture water and stocking density. Culture conditions were optimised using culture experiments in land-based culture systems (e.g., Braley et al., 1988). Experiments were established to determine:

- Appropriateness of epifluorescence microscopy to assay micro-algae ingestion/digestion and zooxanthellae uptake by giant clam larvae.
- Potential use of micro-algae concentrates as larvae food source for giant clams.
- Ontogenetic changes in feeding ecology of giant clam larvae.
- Optimal dietary product combinations for different ages of larvae
- Whether established methods for culture of giant clams (Braley et al., 1988) were effective at NIMRF
- Ecological impacts of ocean-based giant clam farming at partner communities

Culture methods and experimental protocols for giant clams are well-established and experimental design in this Project was based on those described by Braley et al. (1988) and Bell et al. (1997). Juvenile performance between treatments was assessed on the basis of survival, growth, and morphometrics.

Transport of ornamental species: Shipping is a major bottleneck in the aquarium trade because the expense of current shipping methods affects the economic feasibility of the industry. Additionally, stress (and often mortality) experienced by culture animals during transportation limits the distance or duration that they can be shipped. Transportation is likely to be a key issue in determining the economic feasibility of exporting live aquarium species from PNG (Kinch, 2008). Developing shipping methods that minimise stress and maximise the duration that animals can be held are, therefore, important.

This Project had proposed to develop links with private-sector importers based in Australia and private-sector exporters based in PNG. However, these collaborations did not occur because of governance barriers to exporting/importing ornamental species that arose during the Project. These barriers, dependent on actors external to the Project team, could not be rectified within the timeframe of the Project. This prevented export and transportation trials of ornamental species produced at the NIMRF.

In lieu of exports, domestic shipping trials were undertaken. Separate shipping trials of giant clams, clownfishes, and sandfish to St Barbara Ltd. (Simberi Island) were completed successfully by adoption of IATA standard industry protocols for aquarium fishes. The success of shipments was evaluated in terms of survival during transport and at 7-days post-transport. These protocols were deemed sufficient for inter-provincial shipping of ornamental species and sandfish.

Seaweed culture trial: Seaweeds are relatively simple to culture in appropriate environments and culture methods for *Caulerpa* spp. have been well established in prior ACIAR projects. For example, simple cage culture technology developed for *Caulerpa lentillifera* in Australia (Paul et al., 2014) was adapted for research that assessed the feasibility of *Caulerpa* sp. culture in coastal villages in Samoa (a ‘mini-Project’ run within FIS/2006/138). A concurrent ACIAR Project (FIS/2010/098) was focused on further developing production and post-harvest processing of *Caulerpa* spp. in the Pacific islands and the same methods developed in FIS/2010/098 were applied to research in Kavieng during this Project.

Seaweed culture trials were conducted using plastic trays to hold the seaweed during culture. Yield was measured as change in seaweed wet weight over a six-week growth cycle with fortnightly sampling. Culture trials were established at multiple sites near the partner community already involved in ornamentals production. This allowed assessment of environmental conditions best suited to *Caulerpa* sp. production in Kavieng. The experiences ('lessons learned') from *Caulerpa* spp. culture research in other ACIAR projects were incorporated into the experimental design used in this Project. This was assured by the direct involvement of Ian Tuart (Project Scientist for FIS/2010/098[4]).

5.1.2 Objective 2: To develop community-based sea cucumber culture methodology to a level potentially supporting income generation.

Community sea cucumber culture: Research during FIS/2010/054 provided an excellent basis for further development towards community-based sea cucumber culture in PNG. Three field sites were established and strong community partnerships were developed. Several experiments were conducted to determine the influence of environmental conditions/characteristics and culture methodology on juvenile sandfish survival and growth.

Further development of sea cucumber culture methods suitable to New Ireland related to identifying appropriate substrate types, enclosure types and husbandry, and stocking density relative to sea cucumber age/size. Various approaches to sandfish mariculture have been applied in other parts of the world, including free-range ranches and individually owned enclosures (Juinio-Meñez et al. 2013, Purcell et al. 2012). The optimal method for coastal communities in New Ireland was developed through monitoring of juveniles reared in sea pens under varying conditions.

Necessary community inputs and actions for sea ranch operation were then identified (i.e., site selection, stocking, protection). This activity was undertaken to ensure that the mariculture intervention was technically realistic and socially and culturally appropriate. Social acceptability was assessed and additional trouble-shooting undertaken where required. For example, socio-economic problems resulting from poaching were experienced at the first two trial sea ranches established in New Ireland. Research to identify the resulting impacts (both positive and negative) and their significance was conducted. Socio-economic research was led by Associate Professor Simon Foale of James Cook University (see Section 5.1.4) who was involved in socio-economic components of three other ACIAR Fisheries Projects.

An important part of projecting the potential economic impacts of a new mariculture activity, and developing policy for it, is to assess the potentially suitable areas for that activity. GIS software was used to build a map of sites in the Kavieng area where sea cucumber mariculture was likely to be most successful. Data inputs included satellite imagery, sea cucumber survey data, local knowledge, and ground truthing. Survey data provided vital information on the potential carrying capacity and productivity of different habitats and allowed identification of sites likely to support optimal survival and growth of cultured sea cucumbers. Results of sediment analyses from FIS/2010/054 and the literature (e.g., Plotieau, 2014) were used to fine-tune habitat selection. Resulting data and the refined GIS protocol for site selection will be valuable in future policy development.

Commercial-sized sandfish were produced during the life of this Project. Sea pen experiments demonstrated that, in good habitat, commercial size could be attained in 12 months. However, commercial size cultured sandfish in sea ranch were poached during sea cucumber fishing seasons following the lifting of the moratorium in 2017, and marketed through the same supply chain as wild-caught sea cucumber. The results of the sea cucumber component of the Project are being used by NFA to guide future sea cucumber management policies to which Project staff will contribute, if requested.

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[4] *FIS/2010/098: "Diversification of seaweed industries in Pacific island countries"*

5.1.3 Objective 3: To continue building long-term institutional mariculture capacity in PNG.

Institutional mariculture capacity in PNG: This Project involved NFA staff, Provincial Fisheries staff, local NGOs, communities, Project staff and students. Productive collaborative relationships between all stakeholders in FIS/2010/054 were consolidated and provided a basis for continued regular interaction and communication. Regular Project meetings provided focus for review and future planning of Project activities with opportunity for inputs from all stakeholders. Dr Thane Militz was employed as Project Scientist, based at NIMRF, from the start of the Project (March 2016) until COVID-19 travel restrictions came into force in March 2020.

With support from Project staff, NIMRF staff maintained the NIMRF facility, produced live foods for hatchery culture activities (i.e., rotifers, *Artemia*, and micro-algae), produced ornamental fishes, sea cucumbers, and giant clams, undertook land-based nursery culture of target species and produced sufficient sea cucumber juveniles for distribution to partner communities. They received on-going training relating to these activities from Project staff and post-graduate students and this was facilitated by the presence of the Project Scientist at the NIMRF, regular Project staff and commodity specialist visits, and hands-on training from targeted workshops and dedicated extension materials. They also gained experience in experimental design and sampling methods, data collection and management, reporting and Project management during this Project. NFA personnel had an important role in guiding Project strategy and activities.

Regular meetings with project staff and NFA/NIMRF staff provided Provincial Fisheries officers with opportunity for input to Project strategy and activities. They were invited to participate in Project workshops, were provided with training materials produced during the Project, and played a role in guiding and delivering Project extension activities including the transfer of sea cucumber culture to new communities. Ailan Awareness and Wildlife Conservation Society (WCS) were the main NGO partners in this Project. They both have strong relationships with community groups and undertake active extension and awareness programs in a variety of marine conservation and community-based fisheries management topics. They developed a strong collaborative relationship with the Project team and the NFA during FIS/2010/054 and played a particularly important role in assisting the Project with initial and ongoing engagement with partner communities. They also have well established collaborative links with Provincial Fisheries and the NFA. Their roles in this Project included assistance with facilitating training workshops and liaison with village leaders and Project workers to maximise Project benefits to communities.

In partner communities, mariculture trainees (appointed by village leaders) were the primary point of contact for the Project. They were kept up to date with Project outputs through regular meetings. For day-to-day running of the Project, at least three people in each participating village were trained and paid a negotiated fee to assist with data collection and maintenance, and security of experimental set ups. These mariculture trainees received training and were included in other Project training activities. Communication was encouraged through regular and frequent support visits to participating villages by Project staff and personnel from the NFA, Provincial Fisheries and local NGOs. Capacity was further strengthened by community participation in workshops relating to specific aspects of Project research (e.g., establishing enclosures for sea cucumber juveniles). Workshops were supported by extension materials (e.g., basic culture pamphlets/leaflets or posters). It is anticipated that the key community workers obtained sufficient skills to enable them, with the support of NGOs and Provincial Fisheries officers, to manage the village grow-out aspects of mariculture activities beyond the life of the Project.

Pamphlets/leaflets and posters on village sea cucumber ranching were produced to facilitate training and dissemination. They explained the processes in easily understandable terms and, where possible, were translated into *Tokpisin* or *Tokples* (local language). These could be used to extend the techniques to other provinces or sites. Project sites were used to support training and extension activities throughout the Project (workshops and practical demonstrations). They were supported by follow-up extension activities at each Project site. The NFA, Provincial Fisheries and NGOs took increasingly important leadership roles relating to the organisation and running of workshops with support from Project staff. Where appropriate, non-Project community members and interested students from the NFC and other institutions were invited to attend Project training activities following approval by the Project reference committee. Project staff encouraged the use of Project sites for training and engaging NFC, UNRE, and PAU students in Project activities

Targeted training activities were conducted regularly during the Project for partner organisations and NFC staff. These included: (1) small workshops run by Project staff and post-graduate students relating to their work; (2) small workshops run by Project staff relating to specific components of NIMRF operations; (3) counter-part training between NFC staff and NFA staff at NIMRF (e.g., hatchery culture methods); (4) involving NFC staff in field-work/research undertaken by Project staff and post-graduate students; and (5) setting up small research Projects (i.e., practicums) for UNRE and PAU students overseen by Project staff and post-graduate students.

An Aquaculture Competency Training package was developed for NFC during FIS/2010/054. The package met the requirements of the National Training Council (NTC) and was endorsed by the Fisheries Training and Advisory Committee (FTAC). Specific lesson plans were developed during this Project, with Certificate courses 2, 3, and 4 being delivered for the first time. An aquaculture instructor (Philomena Sinkau), trained to Master's level in Aquaculture at JCU, was appointed by the NFA to begin implementing and delivering the Aquaculture Competency Training package through the NFC and NIMRF. The Aquaculture instructor worked closely with Project staff to coordinate planned training activities.

5.1.4 Objective 4: To appraise opportunities, risks and impacts associated with community-based sea cucumber farming.

Socio-economic components of the Project: Socio-economic elements of this Project were led by Associate Professor Simon Foale of JCU who oversaw similar components of the prior Project (FIS/2010/054) relating to current socio-economic status of partner communities, past wild fishery practices, community-based fishery management, and attitudes towards mariculture. The data generated by these prior activities provided a basis for further investigation of socio-economic impacts in this Project.

The impacts of re-opening the sea cucumber fishery were monitored opportunistically and closely in partner communities to determine how people used the income from sea cucumber sales, and to what extent the income was improving human development indicators among families in partner communities. Household surveys, and CMT interviews and participant-observation investigations were conducted before (during Moratorium), during (open-fishery) and after (closed-fishery) the 2017 fishing season seasons in partner communities. Household surveys generated data on household occupancy, assets, existing livelihood strategies and income levels. Interviews about CMT investigated in detail the contemporary social protocols by which rights to land and marine territory were reckoned by community residents. Participant observation focused on the extent to which household survey and CMT interview responses reflected actual practice. Questions on the level of female control over income flows, and questions on spending patterns by male and female household heads examined gender-specific impacts arising from sea cucumber sales. Results of this investigation were taken to provide an indication of the potential economic benefits that could result from farming, along with possible social and economic disruptions generated by access to prime fishing/farming territory and/or revenue flows from sea cucumber sales.

Later research evaluated the key pre-conditions for successful engagement in sea cucumber ranching and identified the primary risks to sustainable community-scale sea cucumber production. A mixed-methods approach of oral, semi-structured interviews with community members, focus group discussions, and informal conversations with sea cucumber fishers and other community members examined the failure (due to reasons outlined elsewhere in the report) of the trial sea ranch at Ungakum. Questions revolved around the wild sea cucumber fishery season as experienced in the community, events leading to the failure of the ranch, how community members viewed development, and lessons learned related to the role of researchers, government fisheries officers, and community members in the failure of the trial sea ranch. Participant observation during regular field work visits by Project staff also generated substantial knowledge of community attitudes, perceptions, and sea cucumber harvest/processing practices. Results indicate an accurate understanding of the conditions for effective collective management of community-scale sea ranching will require detailed knowledge of culture, history, and politics, in the context of ongoing social and economic change.

The socio-economic components of the Project involved counterpart researchers from PNG institutions (e.g. UNRE graduates and WSC officers) who worked within the Project team and further broadened Project capacity impacts.

6 Achievements against activities and outputs/milestones

Objective 1: To further develop culture and husbandry protocols for target species

no.	activity	outputs/ milestones	comments
1.1	Assess commercial micro-algae concentrate products for large-scale hatchery production of sea cucumbers.	Complete three experiments per year trialling different product combinations in hatchery tanks.	Research undertaken in previous Projects (FIS-2010-042 and FIS-2010-054) evaluated the potential for commercially available micro-algae pastes to replace live micro-algae as a food for sandfish larvae. This Project milestone addresses further development in the use of micro-algae pastes to support large-scale hatchery production of sea cucumber. Six experiments were conducted examining various combinations of micro-algae concentrate products and feeding regimes. Four of these experiments were conducted with the involvement of UNRE and PAU BSc students. Results informed development of a routine feeding protocol which has supported successful production of juvenile sandfish at the NIMRF.
		Develop a routine feeding protocol for sandfish larvae without live micro-algae that accounts for larval density and age.	The routine feeding protocol developed in this Project was published as: Militz, T.A., Leini, E., Duy, N.D.Q., Southgate, P.C. 2018. Successful large-scale hatchery culture of sandfish (*Holothuria scabra*) using micro-algae concentrates as a larval food source. *Aquaculture Reports* 9, 25-30.
1.2	Refine culture methods to produce large numbers of release-size juvenile sea cucumbers.	Complete three experiments per year trialling juvenile culture in raceways and pond-based hapa nets accounting for age, density and food availability.	Research on juvenile culture in raceways focused on maximising survival and biomass yield of early-juvenile sandfish (< 1 g) to better support pond and field-based nursery systems. Five experiments were conducted in raceways systems examining (1) importance of sediment, (2) optimal sediment grain size, (3) optimal juvenile stocking density, (4) benefit of supplemental feeding, and (5) feed selection. Research on juvenile culture in ocean hapas, in marine ponds, and ocean pens focused on maximising survival and biomass yield of juvenile sandfish (≥ 1 g) to improve production of release-sized (3 g) sandfish. The availability of facility space at the NIMRF and stochasticity in juvenile production have emerged as the major barriers preventing scale-out to an industry relevant level. The stochasticity in juvenile production is partly due to juvenile mortality associated with integument degeneration caused by unknown factors.
		Develop a routine husbandry protocol for juvenile sandfish to address current production bottlenecks.	A production bottleneck that arose during the Project was reliable access to wild adult sandfish for use as broodstock. The resumption of the commercial sea cucumber fishery in 2017 quickly depleted wild populations of sandfish (detailed by Hair et al., 2018). To address this bottleneck, preliminary investigations into the appropriateness of utilising a captive broodstock population were undertaken, and published: Militz, T.A., Leini, E., Southgate, P.C. 2019. Evaluation of hatchery production from captive and wild-caught sandfish (*Holothuria scabra* Jaeger, 1833) broodstocks. *Asian Fisheries Science* 32, 64-71. Production of juvenile sandfish is now reliant on a captive broodstock population established at the NIMRF.

<table>
<tr><td rowspan="3">1.3</td><td rowspan="3">Develop hatchery production and culture of giant clams at NIMRF.</td><td>Complete two successful hatchery culture runs per year producing juveniles.</td><td>Nine successful hatchery runs were undertaken:
• 2016 – (1) Tridacna noae
• 2017 – (2) Tridacna noae, (3) Tridacna maxima, (4) Tridacna noae♂ × Tridacna maxima♀, (5) Tridacna maxima♂ × Tridacna. noae♀
• 2018 – (6) Tridacna noae, (7) Tridacna maxima, (8) Tridacna squamosa, (9) Hippopus hippopus</td></tr>
<tr><td>Production of sufficient juveniles to support other research activities.</td><td>Production, resulting from refined giant clam hatchery methods, was sufficient to support research activities. At the conclusion of the Project, production was nearing an industry relevant level with only the availability of facility space at the NIMRF restricting further production.</td></tr>
<tr><td>Complete two experiments with larvae per year to improve hatchery production.

Complete two experiments with postlarvae and juveniles per year to improve nursery and grow-out culture methods.</td><td>Epifluorescence microscopy technique was refined for assaying micro-algae ingestion/digestion and zooxanthellae update by giant clam larvae. This technique provided a basis for further research into the feeding ecology of giant clam larvae and potential for micro-algae concentrate products to replace live micro-algae as a larvae food source.
Braley, R.D., Militz, T.A., Southgate, P.C. 2018. Autofluorescence in embryos and larvae of the giant clam Tridacna noae: challenges and opportunities for epifuorescence microscopy. Journal of Molluscan Studies 84, 463-468.

Experiments showed that commercially availability micro-algae concentrates are ingested and can be digested by giant clam larvae. This greatly simplifies hatchery culture methods. As a result of this work, live micro-algae are no longer cultured or used for hatchery culture of giant clams in PNG.
Southgate, P.C., Braley, R.D., Militz. T.A. 2017. Ingestion and digestion of micro-algae concentrates by veliger larvae of the giant clam, Tridcana noae. Aquaculture 473, 443-448.

Ontogenetic changes in the feeding ecology of giant clam larvae were examined. This has allowed for optimisation of feeding regimes for giant clam larvae.
Militz, T.A., Braley, R.D., Southgate, P.C. 2021. Factor influencing the capacity for pediveliger larvae of the giant clam, Tridacna noae, to ingest and digest cells of microalgae concentrates. Aquaculture 533, 736121.

Novel strains of giant clams of interest to the international aquarium trade were produced through hybridisation. Analysis of larval survival and growth has allowed the most promising strains to be identified.
Militz, T.A., Braley, R.D., Southgate, P.C. 2017. Captive hybridization of the giant clams Tridacna maxima and Tridacna noae. Journal of Shellfish Research 36, 585-591.
Militz, T.A., Braley, R.D., Southgate, P.C. 2019. Larval and early juvenile culture of two giant clam (Tridacninae) hybrids. Aquaculture 500, 500-505.

Appropriateness of established hatchery protocols for giant clams were evaluated for Tridacna noae. Comparison of larval survival and growth allowed the most promising protocol to be identified.
Braley, R.D., Militz, T.A., Southgate, P.C. 2018. Comparison of three hatchery culture methods for the giant clam Tridacna noae. Aquaculture 495, 881-887.

Remote underwater visual video stations were used to examine fish activity at ocean-culture giant clam farms. Fish activity varied over time and among species. Results identify the impact of giant clam farms on resident fish assemblages and identify predators of cultured giant clams. Results have informed husbandry protocols and site selection for ocean-culture of giant clams.</td></tr>
</table>

			Militz, T.A., Southgate, P.C. in prep. Diurnal finfish activity on ocean-culture giant clam farms in Papua New Guinea. Militz, T.A., Southgate, P.C. in prep. Environmental impacts of ocean-culture giant clam farms on substrata and fish assemblages.
		Develop a routine hatchery and nursery protocol for *Tridacna noae* for the first time.	The hatchery protocol developed during the Project for *Tridacna noae* was published as: Southgate, P.C., Braley, R.D., Militz, T.A. 2016. Embryonic and larval development of the giant clam *Tridacna noae*. *Journal of Shellfish Research* 35, 777-783.
1.4	Develop improved shipping methods for ornamental species.	Complete two shipping trial per year for hatchery bred clownfish, giant clams and corals. Develop standard shipping protocols for market-sized individuals of target species.	Resolution of governance barriers to exporting ornamental species that arose during the Project was dependent on actors external to the Project team and could not be rectified within the timeframe of the Project. This prevented the export of ornamental species produced at the NIMRF (seahorses, clownfishes, giant clams, and corals). Through collaboration with CEPA, NFA, and SPC substantial progress was made towards development of a regulatory framework for the export of ornamental species from PNG. This progress resulted in the finalisation of the National Marine Aquarium Fishery Management and Development Plan which is currently before the NFA board for approval. In lieu of exports, domestic shipping trials were undertaken. Separate shipping trials of giant clams, clownfishes, and sandfish to St Barbara Ltd. were successfully completed by adoption of IATA standard industry protocols for aquarium fishes. These protocols were deemed sufficient for inter-provincial shipping of ornamental species and sandfish.
1.5	Assess the potential for seaweed culture in Kavieng.	Establish a small culture trial at a selected partner community.	Seaweed specialist Ian Tuart (Project Scientist from FIS/2010/098) was engaged to train NIMRF staff and establish cultural trials. Two culture trials for *Caulerpa racemosa* var. were established at the Nago Island partner community.
		Complete trials and evaluate production data.	The resulting production data discouraged further seaweed culture activities in the vicinity of Kavieng.

PC = partner country, A = Australia

Objective 2: To develop community-based sea cucumber culture methodology to a level potentially supporting income generation.

no.	activity	outputs/ milestones	comments
2.1	Determine optimal culture protocol for ranching of sandfish.	A standard culture protocol for field-based sandfish culture supporting maximal yield.	A standardised culture protocol was developed with minimal external inputs. Development of the protocol involved evaluating the minimum size at which sandfish should be stocked into sea ranches, identifying potential predators, identifying the most appropriate habitats to release sandfish into during stocking, and understanding the burying behaviour of newly released sandfish. Several of these investigations are reported on in: Hair, C., Militz, T., Daniels, N., Southgate, P.C. 2020. Comparison of survival, growth and burying behaviour of cultured and wild sandfish (*Holothuria scabra*) juveniles: Implications for ocean mariculture. *Aquaculture* 526, 735355.

		A protocol used for extension at partner communities to determine husbandry inputs required (i.e. community and personnel inputs) to run an optimised sea ranch (see 2.2).	The standardised protocol used for extension at partner communities will be explained in: Hair, C., Militz, T.A., Daniels, N., Southgate, P.C. Performance of a trial sea ranch for the commercial sea cucumber, sandfish (*Holothuria scabra*), in Papua New Guinea. Undergoing peer-review; submitted for publication in *Aquaculture* in June 2011.
2.2	Develop optimised husbandry regime for sandfish under optimal ranching conditions (see 2.1).	A standard husbandry regime for sandfish farmers with suitable habitat and marine tenure arrangements.	Two of the three sea ranches established with partner communities were poached before data related to cultured sandfish survival, growth, and movement were obtained. On this basis, active management of the ranch by farmers is essential to: (1) prevent fishing and protect cultured sandfish until the stocked individuals reach commercial size and (2) develop a means of equitable distribution of benefits.
		Establish sandfish sea ranches using best practice at the three partner communities established in FIS/2010/054.	Lessons learnt from the poaching that occurred with the first two sea ranches were applied to the third (successful) sea ranch. Best practice includes a high level of community engagement and education, with frequent and conspicuous presence at the site by NFA staff (made possible by close proximity to the NIMRF). Ranching activities were also timed to coincide with the periodic closure of the sea cucumber fishery, limiting the incentive to poach cultured sandfish before attaining commercial size. The resulting production data will be communicated in: Hair, C., Militz, T.A., Daniels, N., Southgate, P.C. Performance of a trial sea ranch for the commercial sea cucumber, sandfish (*Holothuria scabra*), in Papua New Guinea. Undergoing peer-review; submitted for publication in *Aquaculture* in June 2011.
2.3	Extend sea ranching to new communities in the Kavieng area.	Establish sandfish sea ranches using best practice at two new partner communities in the Kavieng area.	Given potential problems with community-based management of sea cucumber mariculture (see above), discussions at the Annual Project (Review) Meeting in May 2019 focused on developing stronger links with private-sector to further develop community-based culture activities. An MOU was drafted for engagement with private-sector, and NIMRF staff undertook scoping visits to proposed sites and met with potential private-sector partners. A protocol for inter-provincial transfer of juvenile sandfish was also developed in anticipation of establishing sea ranches outside New Ireland. The results from a site selection study conducted at Rugen Harbour and other coastal areas in East New Britain Province are communicated in: Daniels, N., Bitalen, P., Minimulu, P. 2021. Rugen Harbour, Pomio District site selection report (March 2021). Kavieng: National Fisheries College. Further progress against this milestone was impeded by travel restrictions imposed by the COVID-19 pandemic. A number of NFA staff based at NIMRF and trained by the Project were offered employment by private sector entities concerned with establishing alternative livelihood activities following mining activities. Two employees now undertake community-based sea cucumber culture and other aquaculture activities at Simberi.

2.4	Survey the Kavieng region to identify and map areas suitable for sandfish culture.	Identify suitable sea ranch habitat using bio- physical survey techniques developed in FIS/2010/054.	Bio-physical survey techniques developed in FIS/2010/054 (see Hair et al., 2016) were employed to identify suitable sea ranch habitats and validate remote sensing techniques (see below). Data generated were included in broader regional analysis with data from the Philippines and Northern Territory, Australia generated within FIS/2010/042 (see Mills, 2020).
		Trial remote sensing techniques to identify suitable areas for sandfish sea ranching.	Geographic information systems (GIS), satellite imagery and biophysical survey data were applied to the Limellon and Ungakum trial sea ranch sites to develop classification methods to identify suitable sandfish habitat (in collaboration with Dr Peter Wood of GBRMPA). Worldview 3 satellite imagery and field data were used to produce supervised classification of shallow water habitats, then overlaid with sandfish distribution and abundance data. The techniques proved reliable, but ground-truth data was necessary. Therefore, remote sensing is unsuitable as a stand-alone method to predict suitable sandfish sea ranching sites without field data collection. Results provided the basis for a flexible, 3-stage GIS protocol for site selection for sandfish mariculture. This protocol can be found in: Hair, C.A. 2020. Development of community-based mariculture of sandfish, *Holothuria scabra*, in New Ireland Province, Papua New Guinea. PhD thesis. James Cook University. Socio-economic and cultural factors (e.g., traditional knowledge and CBFM capacity) should also be considered. Pilot grow-out of cultured juveniles in any potential farm or sea ranch location is recommended prior to commencing sandfish mariculture.
2.5	Promote sustainable management practices for sandfish ranching through extension and training.	Five partner communities with sustainable sea ranch management strategies.	The target of five communities with operational sea ranches was not obtained due to the poaching of sea ranches at Limellon and Ungakum (see Objective 4) and delays in availability of release-size juveniles, both of which constrained the rate at which partner communities could be engaged to undertake collaborative sea ranching trials. A reorientation of effort towards developing stronger links with private-sector to further develop community-based mariculture activities was pursued following recommendations of the Project Review Panel.

PC = partner country, A = Australia

Objective 3: To continue building long-term institutional mariculture capacity in PNG.

no.	activity	outputs/ milestones	comments
3.1	Appoint a Project Scientist to be based at NIMRF	A qualified person based at NIMRF.	Dr Thane Militz held the position of Project Scientist. Based full-time at NIMRF, he returned to USC in March 2020 because of COVID-19 travel restrictions.
3.2	Support and develop NIMRF hatchery and culture activities in production of target species. (i.e. expert	Project and outside personnel to visit NIMRF regularly to assist in technology transfer and capacity building.	In addition to regular visits by Project personnel, the following outside personnel visited NIMRF to assist in technology transfer and capacity building. Dr Rick Braley (Aquasearch) Giant clam hatchery production (three 1-month visits)

	personnel and technology transfer)	Commodity experts to visit regularly to transfer technology in specific areas.	Assoc. Prof. Simon Foale (JCU) Socioeconomic surveys (two 1-week visits) Ian Tuart (ACIAR Project FIS/2010/098) Seaweed culture trials (one 1-week visit) Ben Parker (Blue Ventures) Sandfish knowledge exchange (one 1-week visit) Juda Nindima and Nicho Gowep (CEPA) Facility inspection for CITES-listed species export approval and knowledge exchange (one 2-day visit) Max Wingfield (USC) Hatchery production of pearl oyster (one 1-month visit) Dr Pranesh Kishore (USC/USP) Mabé pearl seeding (one 1-week visit) Michel Bermudes (SPC) Advisory visit (one 1-week visit) SPC Sandfish Regional Exchange (one 1-week visit) Ellenica Kingal (NAQIA) Giant clam health assessment and biosecurity research (one 2-week visit)
3.3	Continue with (and expand) mariculture training activities at partner communities using local partners as liaison and facilitators	Small regular workshops and training activities as required for selected persons from existing collaborating sea cucumber ranching communities.	Hands-on training was conducted during all field work. In addition to routine maintenance of grow-out and nursery systems, community members assisted with sampling and survey work, either on volunteer or paid basis. Regular contact was made with all trainees to ensure they had adequate equipment to care for the grow-out systems and to address any problems.
		Training activities for selected persons from two new sea cucumber ranching communities established during this Project (see 2.3).	See Objective 2. The target of establishing two new sea cucumber ranching communities was not achieved due to the poaching of sea ranches at Limellon and Ungakum and a reorientation of effort towards developing stronger links with private-sector to further develop community-based culture activities.
		Training of selected persons from a comm-unity selected for seaweed culture trial.	Three persons from the Nago community were engaged with the seaweed culture trails and received training from Ian Tuart.
3.4	Continue to train community members to	In consultation with village leaders, select two suitable	A community liaison, sea ranch warden, and nursery systems carer (3 trainees) were selected within each partner community, and paid for work undertaken in relation to Project activities. Regular contact was made with all trainees to ensure they had adequate equipment to care for the grow-out systems and to address any problems.

	undertake Project activities	trainees from each partner village	
		Facilitate one-on-one training and involvement in other training activities	Seaweed: Three persons from the Nago community were engaged with seaweed culture trails. Giant clams: Four families among two communities were trained to undertake giant clam Project activities. The Nago community leader was trained to oversee husbandry of the ocean-based giant clam broodstock populations utilised by the NIMRF for giant clam production. Coral: The Nago community continued coral culture activities initiated in the previous Project (FIS/2010/054). Two workshops were conducted to facilitate production improvements.
3.5	Conduct targeted training activities for partner organisations	Conduct two training courses per year relating to land- and ocean-based culture methods.	NFC's Aquaculture Competency Training: Project staff provided assistance in delivering the mariculture component of the NFC Aquaculture Certificate programme developed in FIS/2010/054. The program now delivers Certificates 1-4, each with one to five weeks of teaching at the NIMRF. UNRE BSc practicums: The Project provided training to UNRE BSc students undertaking their 3rd year practicum unit at the NIMRF. Nine students received training at the NIMRF during the practicum. Each unit consisted of a three-month minor research Project supervised by Project and NIMRF staff (see Activity 1.1). PAU BSc practicums: The Project provided training to PAU BSc students undertaking their 3rd year practicum unit at the NIMRF. Two students undertook sandfish hatchery and research methods training under Project and NIMRF staff. Malaysian Fisheries Research Institute: An FRI aquaculture technician undertook sandfish hatchery training under NIMRF hatchery manager Esther Leini. OLSH International School: Year 12 students undertook an annual one-week work experience placement at NIMRF and engaged in Project activities. A total of 15 students participated during the course of the Project. Independent volunteers: The Project has supported one PAU student and one UNRE student wishing to gain experience in marine science as volunteers at the NIMRF. WCS: Two officers received hands-on training from Project staff in conducting socio-economic household surveys and enumerating sea cucumber harvests as part of Project activities. UNRE Graduates: Three UNRE graduates received hands-on training from Project staff in conducting socio-economic household surveys and enumerating sea cucumber harvests as part of Project activities.
3.6	Revise and update culture manuals for community and NFA staff training and extension.	'Best-practice' extension materials to support workshops and other training activities.	A manual "Seed production of sandfish (*Holothuria scabra*) using micro-algae concentrate products" has been produced based on the refined hatchery protocol developed in Objective 1.1. A draft version of the hatchery manual was field-tested in Kiribati (Atoll Beauties) by Esther Leini, as part of an SPC sponsored regional technical exchange program, resulting in successful hatchery production of sandfish.

			A manual detailing hatchery, nursery, and grow-out production of giant clams was produced, and since published as a book chapter: Militz, T.A., Southgate, P.C. 2021. Culture of giant clams. In: Shumway, S. (Ed.), Molluscan Shellfish Aquaculture: A Practical Guide. Sheffield: 5m Publishing Posters and pamphlets/leaflets produced in Tok Pisin were used as a visually engaging media for training community members in mariculture of target species.

Objective 4: To appraise opportunities, risks and impacts associated with sustainable community-based sea cucumber farming.

no.	activity	outputs/ milestones	comments
4.1	Socio-economic baseline surveys in three current partner communities involved in sandfish ranching.	Overview of household income and assets, and subsistence and livelihood profiles of three partner communities.	Associate Professor Simon Foale of JCU was to undertake this research but there was a delay to his engagement with the Project because of negotiations relating to JCU's commitment to the research and the amount of research that could be performed relative to available budget. Agreement was eventually reached for his engagement at a lesser than anticipated level. This milestone was further impacted by the re-opening of the PNG sea cucumber fishery in 2017, which provided opportunity for socio-economic research that was unforeseen at the start of the Project. Socio-economic data on livelihood activities, income, spending patterns and diet were collected during the moratorium, the 2017 sea cucumber open season, and the subsequent closed season. The results were published as: Hair, C., Foale, S., Kinch, J., Frijlink, S., Lindsay, D., Southgate, P.C. 2019. Socioeconomic impacts of a sea cucumber fishery in Papua New Guinea: Is there an opportunity for mariculture? *Ocean & Coastal Management* 179, 104826
4.2	Ethnographic investigation of customary marine tenure (CMT) systems and existing arrangements in partner communities	Overview of stability of marine tenure arrangements in the context of increased income from sea cucumber farming.	Interview data from the moratorium and the open season periods provided insights into CMT systems in the study area. All communities were found to have similar tenure arrangements, and these were typical of the Tigak Islands. Generally, there is whole-of-community access to well-defined traditional fishing grounds. Outsiders can generally come to fish for food if permission is granted but harvest of cash-earning commodities (e.g. trochus, lobster, sea cucumber) is restricted to community members. However, capacity to enforce the rules and the level of outsider fishing pressure varies between communities due to a range of factors including proximity to town, degree of inter-clan marriage, and strength of the village leaders. The stability of marine tenure relationships in the context of sea ranching and sea cucumber fisheries management were evaluated in a case-study of the Ungakum community. The results of this investigation were published as: Hair, C., Foale, S., Daniels, N., Minimulu, P., Aini, J., Southgate, P.C. 2020. Social and economic challenges to community-based sea cucumber mariculture development in New Ireland Province, Papua New Guinea. Marine Policy 117, 103940
4.3	Socio-economic and CMT surveys in two new partner communities.	Baseline socio-economic and CMT data prior to establishing trial sea cucumber farming.	See Objective 2. The target of establishing two new sea cucumber ranching communities was not obtained due to the failure of sea ranches at Limellon and Ungakum and a reorientation of effort towards developing stronger links with private-sector to further develop community-based culture activities.

4.4	Final socio-economic and CMT surveys in all partner communities.	Information on both benefits and costs (including social) of sea cucumber farming	Data on sea ranch productivity and potential socio-economic benefits were obtained from the sea ranch established at Enuk and the results were submitted to *Aquaculture* for publication in June 2021 as: Hair, C., Militz, T.A., Daniels, N., Southgate, P.C. Performance of a trial sea ranch for the commercial sea cucumber, sandfish (*Holothuria scabra*), in Papua New Guinea. Information on benefits and costs of sea cucumber farming could not be obtained for the sea ranches established at Limellon and Ungakum because poaching occurred.
4.5	Cost-benefit analyses for ornamental commodities from Kavieng	Cost benefit analysis complete Recommendations relating to the feasibility of ornamental production in Kavieng including require scale of production, product type and appropriate markets.	Completion of milestone was not possible due to inability to export ornamental species from PNG (see Objective 1.4)
4.6	Generate economic data for community sea cucumber culture	Economic production model for sea cucumber culture (inc. hatchery and grow-out to market size) Economic models for various levels of community-based sea cucumber and beche-de-mer production	Completion of milestone was not possible because data on large scale sea ranch productivity were not obtained from two of the three sea ranches established due to poaching. Data obtained from the only successful sea ranch were informative but inadequate to provide reliable input data for economic modelling.

7 Key results and discussion

7.1 To further develop culture and husbandry protocols for target species

A routine feeding protocol for sandfish larvae without live micro-algae: The Project further developed hatchery culture protocols for large-scale hatchery culture of sandfish, *Holothuria scabra*, in the absence of live, cultured micro-algae. Micro-algae concentrates supported comparable hatchery production of sandfish to that of live, cultured micro-algae traditionally used in large-scale hatchery culture. The hatchery protocol developed has allowed a single technician to achieve production of more than 18,800 juvenile sandfish at 40 days post-fertilisation in a remote, low resource hatchery (NIMRF) in Papua New Guinea. Growth of auricularia larvae fed micro-algae concentrates was represented by the equation *length* (µm) =307.8 × ln(*day*) + 209.2 (R^2 = 0.93) while survival over the entire 40-day hatchery cycle was described by the equation *survival* = 2 × $day^{-1.06}$ (R^2 = 0.74). These results show that micro-algae concentrates have great potential for simplifying hatchery culture of sea cucumbers by reducing infrastructural and technical resources required for live micro-algae culture. The hatchery protocol developed during the Project is likely to have applicability to low-resource hatcheries throughout the Indo-Pacific and could support regional expansion of sandfish hatchery production. Regional extension of this protocol has already begun (see Section 8.1).

For further information please see:

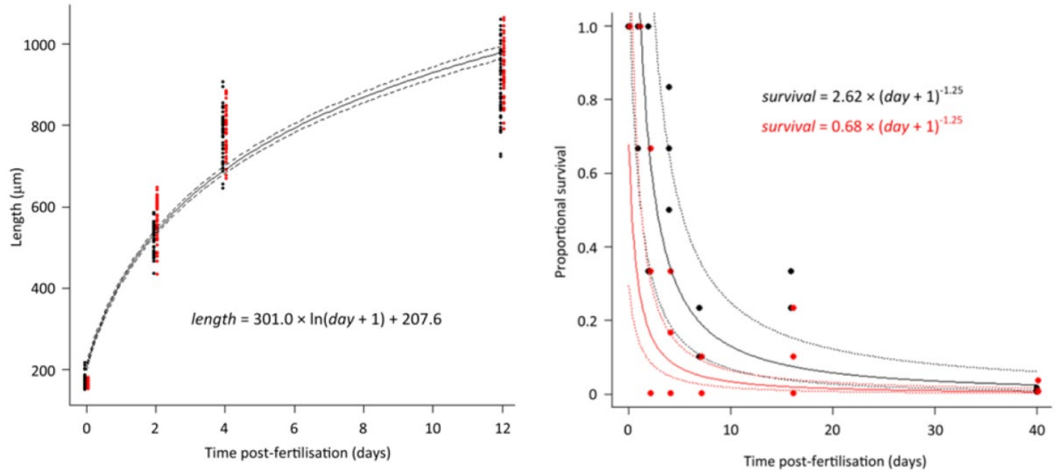
Militz, T.A., Leini, E., Duy, N.D.Q., Southgate, P.C. 2018. Successful large-scale hatchery culture of sandfish (*Holothuria scabra*) using micro-algae concentrates as a larval food source. *Aquaculture Reports* 9, 25-30.

The NIMRF hatchery manager Esther Leini with juvenile sandfish, *Holothuria scabra*, cultured using micro-algae concentrates.

Addressing current production bottlenecks - broodstock: The over-exploitation of natural populations of sea cucumbers is a threat to the sustainability of sea cucumber aquaculture operations reliant on wild-caught broodstock. Maintaining wild-caught broodstock in captivity ensures continuous availability of suitable broodstock. However, at the start of the Project it was unclear if captive broodstock were suitable for use in hatchery production. The Project evaluated hatchery production of sandfish (*Holothuria scabra*) using captive broodstock, maintained in a pond for 1 year, compared to newly wild-caught broodstock. At the end of the 40-day hatchery cycle, lengths of juvenile sandfish resulting from the wild-caught (3.26 ± 0.13 mm) and captive (3.28 ± 0.16 mm) broodstock were comparable ($P = 0.92$). Survival curves of larval and juvenile sandfish differed between the two broodstock sources ($P < 0.01$), owing to differences in the onset of exponential mortality. However, survival was comparable for juvenile sandfish derived from the wild-caught (1.23 ± 0.27 %) and captive (1.34 ± 0.73 %) broodstock ($P = 0.89$) at the end of the hatchery cycle (40-days post-fertilisation). The results demonstrate that captive sandfish broodstock supported hatchery production comparable to that of wild-caught broodstock. Through a reliance on a captive broodstock population, the NIMRF has been able to continue producing sandfish juveniles despite resumption of wild sandfish harvest when the sea cucumber fishery reopened in 2017. Further research is needed to reliably assess broodstock quality and develop protocols for longer term (> 1 year) maintenance in captivity.

For further information please see:

Militz, T.A., Leini, E., Southgate, P.C. 2019. Evaluation of hatchery production from captive and wild-caught sandfish (Holothuria scabra Jaeger, 1833) broodstocks. *Asian Fisheries Science* 32, 64-71



(**Left**) Temporal change in length and (**right**) proportional survival of larval sandfish derived from captive (red) and wild (black) broodstock spawnings.

Addressing current production bottlenecks – early nursery culture: High numbers of early-juvenile sandfish (i.e., 3-8 mm) were reliably produced using the hatchery methods developed during the Project. However, a bottleneck remained during the first nursery phase when juveniles were transferred out of larval rearing tanks. The Project evaluated a number of culture protocols to increase survival and growth rate of early-juvenile sandfish in tank-based early nursery systems between six and ten weeks post-fertilisation.

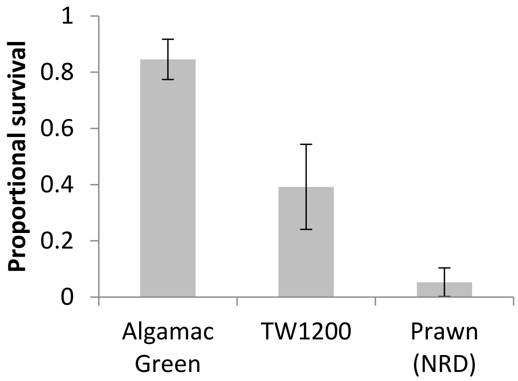
The first experiment evaluated the importance of fine (≤ 200 µm) sediment on the survival and growth of early-juvenile sandfish during the 4-weeks immediately following transfer out of the hatchery and into fibreglass raceways. In the absence of sediment juvenile survival was 30.2 ± 6.4%, which increased to 39.5 ± 9.4% when fine sediment was added to tanks ($t_{2,6} = 0.88$, P = 0.41). Growth increased significantly with the addition of sediment ($t_{2,6} = 6.62$, P < 0.001), with a final size of 7.6 ± 0.4 mm in tanks without sediment compared to 12.3 ± 0.5 mm in tanks with fine sediment.

A second experiment examined the effect of stocking density on survival and growth, comparing these metrics for juveniles stocked at 440 m^{-2} with those stocked at 100 m^{-2} in raceways with fine sediment. Survival improved dramatically, increasing from 39.5 ± 9.4% at 440 m^{-2} to 65.1 ± 8.6% at 100 m^{-2}, but final sizes were similar (12.3 ± 0.5 vs 12.5 ± 0.3 mm).

The next experiment evaluated whether supplemental feeding was necessary. Micro-algae concentrate (TW 1200®) was added to raceways with fine sediment and resulting growth and survival of early-juvenile sandfish was compared to those reared in raceways without supplemental feeding. The addition of micro-algae concentrates did not impact survival, but improved biomass yield by 38% and increased the number of ≥ 1g sandfish (i.e., those ready for transfer to pond sand hapas) from 13 to 18% of the population. While the biomass gain attributed to TW 1200® converts to a food-conversion-ratio of 0.75, the cost was prohibitive (A$2.26 g^{-1} on dry weight basis).

Alternative supplemental feeds were then trialled, comparing Algamac Green, TW1200®, and NRD prawn diet (similar to what is commercially used in Vietnam). Supplemental feeding with Algamac Green at 0.25 g m^{-2} achieved superior survival and growth compared to TW1200 and NRD prawn diet. Compared to TW1200, Algamac Green improved biomass yield by 147% with a food-conversion-ratio of 1.43. Feed cost was also substantially less, A$0.17 g^{-1}. Surprisingly, the prawn diet performed poorly with near total mortality, associated with the development of cyanobacteria films on the tank bottom.

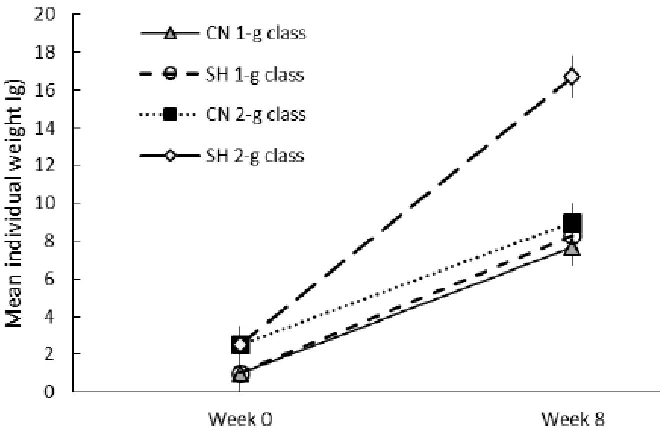
These series of experiments led to refinement of early-nursery culture methods at the NIMRF. The current protocol is to stock 6-week old sandfish from the hatchery system into raceways filled with fine sediment (200 g m^{-2}), with continued additions of fine sediment (100 g m^{-2} $week^{-1}$) as the sandfish age, at a density of 100 juveniles m^{-2}. Algamac Green is provided as a supplementary feed with a ration of 0.25 g m^{-2} day^{-1}. This protocol has improved early-juvenile sandfish production at NIMRF, however further research is needed to address the stochasticity among production runs. Possible sources of variability include undocumented seasonal effects related to water temperature/quality or sunlight and incidences of disease.



Impact of three supplementary feeds on early-juvenile (6-10 weeks post-fertilisation) sandfish survival in raceway nursery systems.

Juvenile sandfish afflicted with integument disintegration – a fatal condition. Future research should examine sources of mortality during early-nursery culture to improve reliability of production.

Addressing current production bottlenecks – nursery culture: The available land-based rearing systems at the NIMRF were inadequate to permit production of large numbers of release-sized (3 g) juvenile sandfish. Community-based nursery systems were explored as a possible alternative. If acceptable survival and growth at community nursery systems could be achieved, this would allow NFA to increase production and increase the engagement of communities in sandfish mariculture. The Project evaluated the growth of pre-release (1 and 2 g) sandfish in sand hapas maintained in the NIMRF pond in comparison to ocean-based pens maintained at the Limanak partner-community. Six 2 m^2 pens were dug 15 cm into the sediment and covered with predator exclusion mesh, and six sand hapas were installed in a similar manner in the NIMRF pond. The partner-community mariculture trainees were tasked with providing appropriate husbandry and pen maintenance at Liminak, while NIMRF staff maintained the sand hapas in the pond. Three pens were stocked with 0.8 g voided juveniles and three pens were stocked with 2.2 g voided juveniles at each site. An identical stocking was undertaken with the NIMRF sand hapas. Survival and growth of sandfish juveniles was assessed two months after stocking. Survival at both size classes was superior in the sand hapas maintained in the NIMRF pond, and very high for the 2.2 g juveniles (94% survival). Growth was slow for all groups, except the 2.2 g juveniles in pond hapas. The poor survival of juveniles in community-based nursery systems suggests a reliance on land-based rearing systems (e.g., marine ponds) is necessitated until juveniles are greater than at least 2.2 g in size. Further production increases of release-sized juvenile sandfish at the NIMRF remains contingent on increasing the available nursery systems.



Growth of two size classes (0.8 and 2.2 g) of juvenile sandfish in community nursery pens (CN) and pond sand hapas (SH).

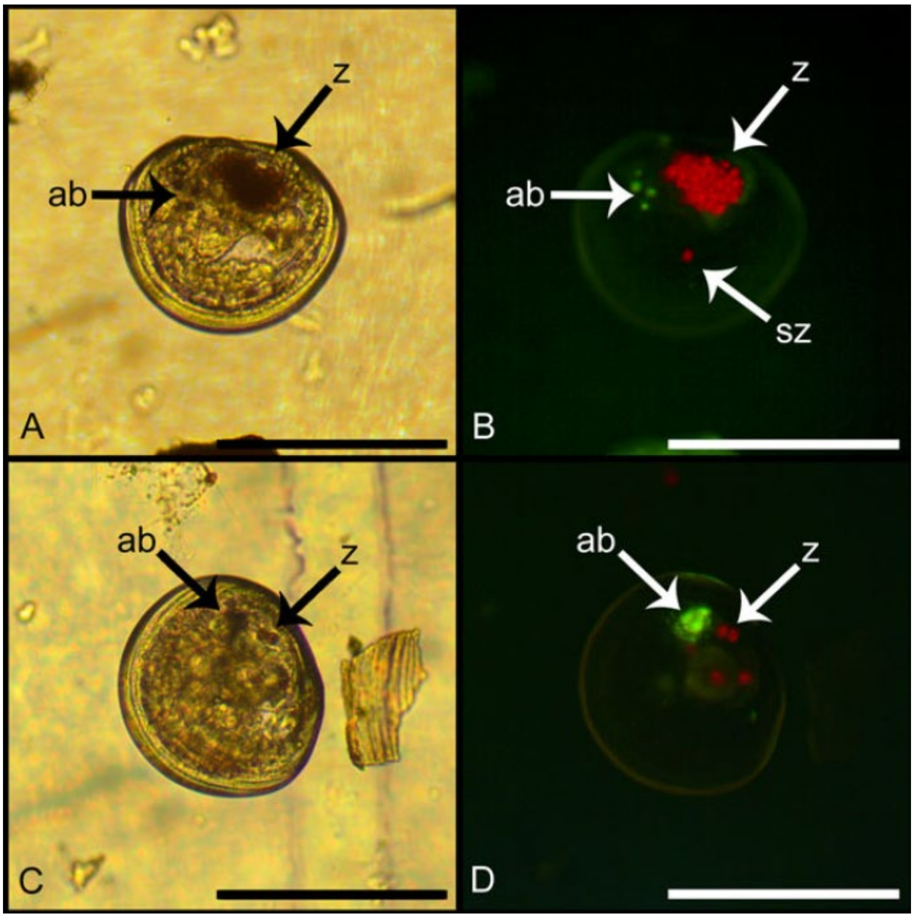
Survival (%) of two size classes of juvenile sandfish in community nursery pens and pond sand hapas.

Size class	community nursery	Pond sand hapa
0.8 g	21.3%	66.7%
2.2 g	75.0%	94.4%

Novel techniques to assay micro-algae ingestion and digestion by giant clam larvae: Epifluorescence microscopy has numerous applications in molluscan research. Methods rely on distinguishing target fluorescent signals from natural fluorescence, termed autofluorescence, of a specimen. Limited research has been conducted on the autofluorescence of marine bivalves, which hinders development of epifluorescence microscopy techniques in this sector. The Project examined autofluorescence in larvae of the giant clam *Tridacna noae* to identify challenges and opportunities in applying epifluorescence microscopy to the study of giant clams. Under blue-light excitation (λ_{ex} = 460–490 nm) three sources of autofluorescence were identified in larvae of *T. noae*: (1) green autofluorescence of the gut region; (2) green autofluorescence of the ‘dark bodies’ anatomical structure; and (3) red autofluorescence of ingested zooxanthellae, *Symbiodinium* species. Each of these sources of autofluorescence varied in prevalence and relative intensity over the course of larval development. The multiple sources and varied wavelengths of the observed autofluorescence presents challenges for applying fluorescent labelling techniques. However, this research identified epifluorescence microscopy as a novel means of examining larval ontogeny, micro-algae ingestion and digestion, and the uptake of zooxanthellae in giant clams.

For further information please see:

Braley, R.D., Militz, T.A., Southgate, P.C. 2018. Autofluorescence in embryos and larvae of the giant clam *Tridacna noae*: challenges and opportunities for epifluorescence microscopy. *Journal of Molluscan Studies* 84, 463-468.

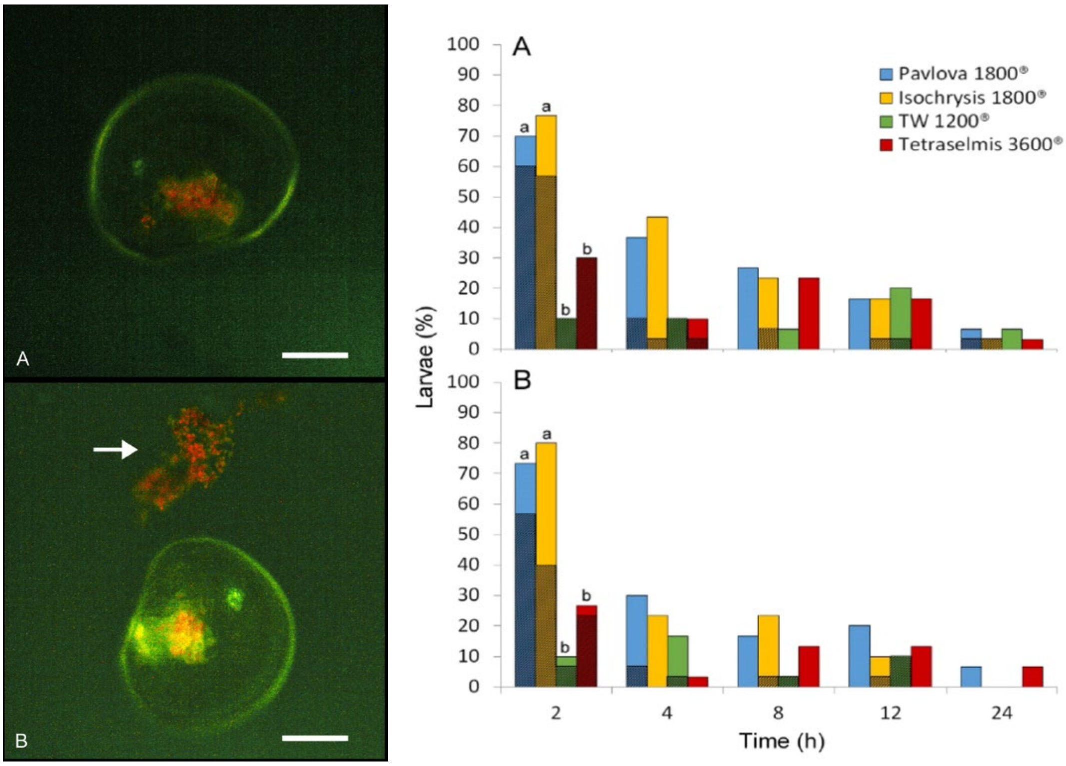


Individual larvae of *Tridacna noae* examined using both bright-field microscopy (**A,C**) and under blue-light (λ_{ex} 460-490 nm) excitation (**B,D**). Red autofluorescence in larvae was attributed to micro-algae (here zooxanthellae), blue-light excitation improving clarity and enumeration of the micro-alga. Scale bars: 200 µm.

Ingestion and digestion of micro-algae concentrates by giant clam larvae: Knowledge of ingestion and digestion of micro-algae by bivalve larvae is critical for provision of appropriate larval nutrition supporting maximal growth and survival. However, little is known about the ingestion and digestion of micro-algae by giant clam larvae. The Project determined the rates of ingestion and digestion of commercially available micro-algae concentrates by *Tridacna noae* larvae of different ages using epifluorescence microscopy. The micro-algae used were *Isochrysis* sp. (Isochrysis 1800®), *Pavlova* sp. (Pavlova 1800®), *Tetraselmis* sp. (Tetraselmis 3600®) and *Thalassiosira weissflogii* (TW 1200®). None of the four micro-algal concentrates were ingested by *T. noae* larvae at 24 h post-fertilisation, but all were ingested at 48 h and 72 h post-fertilisation, at different frequencies. At 48 h post-fertilisation, *Isochrysis* sp. and *Pavlova* sp. were ingested by 77% and 70% of veligers, respectively, while *T. weissflogii* and *Tetraselmis* sp. were ingested by 10% and 30% of veligers, respectively. Similar rates of ingestion were observed for each micro-alga by larvae at 72 h post-fertilisation. Larvae capable of ingesting micro-algae concentrates were significantly larger than those that were empty and the minimum antero-posterior shell length of *T. noae* larvae capable of ingesting *Pavlova* sp. and *Isochrysis* sp. was 141 µm and 132 µm, respectively. Digestion of micro-algae by 48 h-veligers was observed 2 h after the start of feeding in 26.1% and 14.3% of larvae that had ingested *Isochrysis* sp. and *Pavlova* sp., respectively, but digestion of *Tetraselmis* sp. and *T. weissflogii* was not observed until 4 h and 8 h after the start of feeding, respectively. Complete digestion of *Pavlova* sp. and *Isochrysis* sp. took up to 12 h in larvae at both 48 h and 72 h post-fertilisation. These results provide a basis for developing a more nutritionally informed approach to hatchery culture of *T. noae*.

For further information please see:

Southgate, P.C., Braley, R.D., Militz, T.A. 2017. Ingestion and digestion of micro-algae concentrates by veliger larvae of the giant clam, *Tridacna noae*. *Aquaculture* 473, 443-448.

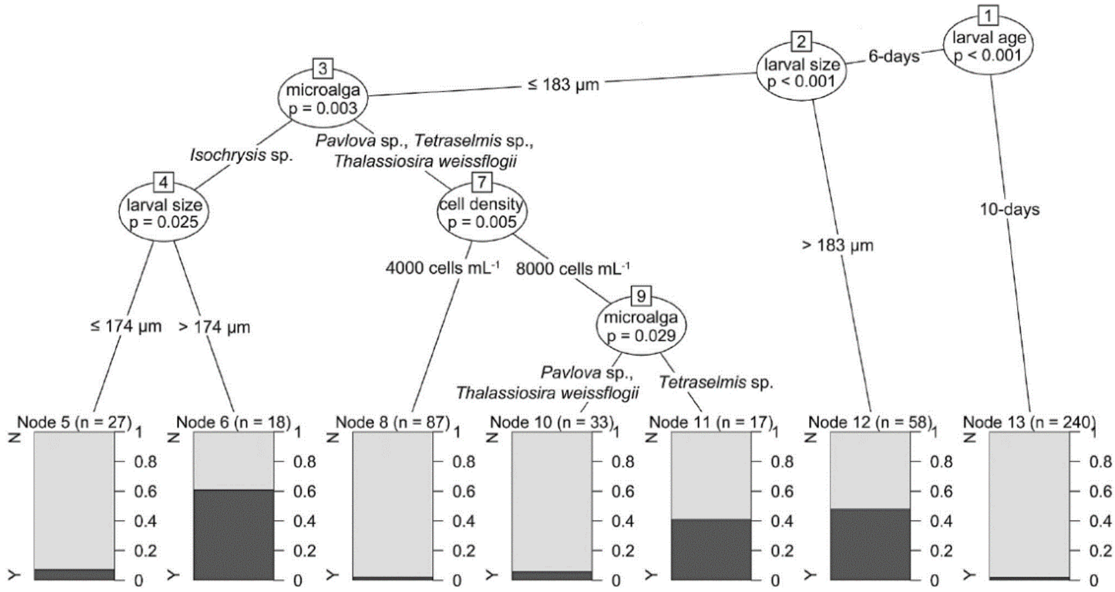


(**Left**) Photosynthesizing pigments of micro-algae cells in the stomach of *Tridacna noae* veligers fluorescing under blue-light excitation; (**A**) red fluorescence of ingested, but not digested, whole micro-algae cells in stomach; (**B**) pink and orange fluorescence of lysed micro-algae cells in the stomach indicating digestion. (**Right**) Percentage of *Tridacna noae* larvae at (**A**) 48-h post-fertilisation and (**B**) 72-h post-fertilisation observed ingesting, but not yet digesting, micro-algae (shaded) and those currently digesting ingested microalgae (unshaded).

Ontogenetic change in the feeding ecology of giant clam larvae: Veliger larvae of giant clams are demonstrable planktotrophs and provision of a particulate food source is generally accepted to improve hatchery production. However, the appropriateness of continuing to administer particulate food after larvae settle and develop as pediveligers is unclear. The Project evaluated whether larval (age and size) and microalgal (species and cell density) factors influenced the capacity for pediveligers of *Tridacna noae* to ingest and digest cells from commercially available microalgae concentrates. Pediveligers at 6 and 10-days post-fertilisation were offered one of four microalgae species (*Isochrysis* sp., *Pavlova* sp., *Tetraselmis* sp., *Thalassiosira weissflogii*) at two cell densities (4000 and 8000 cells mL^{-1}) and subsequently examined using epifluorescence microscopy. The appropriateness of continuing to administer microalgae as a food source was found to diminish as pediveligers approached metamorphosis, with negligible ingestion occurring at 10-days post-fertilisation. Earlier in development, at 6-days post-fertilisation, ingestion was significantly influenced by larval size, microalgae species, and microalgae cell density. Considering capacity for both ingestion and digestion, the *Isochrysis* sp. and *Tetraselmis* sp. microalgae concentrates had the greatest potential as a particulate food source for pediveligers of *T. noae.* The results of this research provide a basis for further refinement of giant clam hatchery procedures utilising microalgae concentrates as a larval food source.

For further information please see:

Militz, T.A., Braley, R.D., Southgate, P.C. 2021. Factors influencing the capacity for pediveliger larvae of the giant clam, *Tridacna noae*, to ingest and digest cells of microalgae concentrates. *Aquaculture* 533, 736121



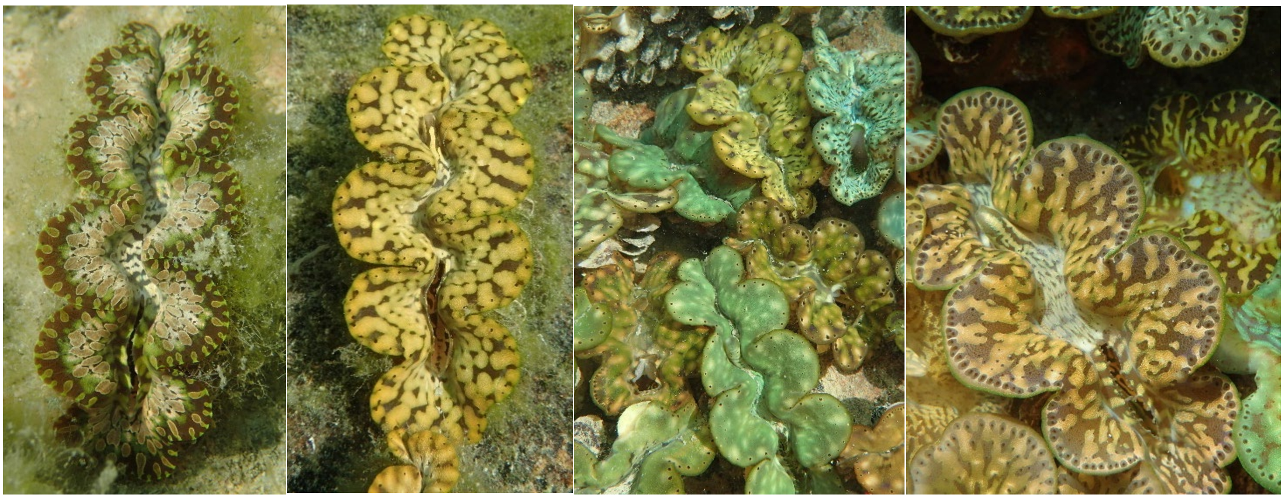
Conditional inference tree for factors predicting the ingestion of microalgae concentrates by pediveliger larvae of *Tridacna noae*. Dark shading indicates the proportion of larvae ingesting algal cells at each terminal node. Larval age is reported as days post-fertilisation; larval size is reported as the antero-posterior measurement.

Novel strains of giant clams of interest to the international aquarium trade: The capacity for inter-specific hybridisation to yield improvements in animal production has long been realised in the aquaculture sector. However, the extension of hybridisation to improve production of giant clams (Tridacninae) has received little research attention. Aquaculture production of giant clams is directed primarily at aquarium markets, and hybridisation offers an opportunity to diversify available products. Here we report on the successful inter-specific hybridisation of *Tridacna maxima* and *T. noae*, and assess hybrid performance during hatchery culture. Both maternal and paternal hybrid crosses of *T. maxima/T. noae* yielded competent larvae. Fertilisation success was significantly lower (40.7 ± 3.2%) for the *T. maxima*♀/*T. noae*♂ cross compared to the *T. noae* ♀/*T. maxima*♂ cross (89.3 ± 1.8%; χ^2=154.03, P < 0.01). Despite the disproportionate fertilisation success, the two hybrids had similar survival curves ($survival = 2.03 \times days^{-2.08}$, $r^2 = 0.67$, P = 0.13) for thefirst 30 days of culture. Antero-posterior shell growth (APM) was superior in the *T. maxima*♀/*T. noae*♂ hybrid ($APM = 10^{(2.158 + 0.019 \times days)}$) when compared to the *T. noae*♀/*T. maxima*♂ hybrid ($APM = 10^{(2.169 + 0.016 \times days)}$) over the same time frame ($r^2 = 0.92$, P < 0.001). Both survival and growth of the hybrids exceeded that reported in the literature for pure-strain hatchery culture of giant clam species. These results suggest capacity for hybridisation to contribute to giant clam aquaculture production. Follow-on research to genetically validate the putative hybrids produced during the Project was planned, but not possible due to the travel restrictions associated with the COVID-19 pandemic.

For further information please see:

Militz, T.A., Braley, R.D., Southgate, P.C. 2017. Captive hybridization of the giant clams *Tridacna maxima* (Röding, 1798) and *Tridacna noae* (Röding, 1798). *Journal of Shellfish Research* 36, 585-591.

Militz, T.A., Braley, R.D., Schoeman, D.S., Southgate, P.C. 2019. Larval and early juvenile culture of two giant clam (Tridacninae) hybrids. *Aquaculture* 500, 500-505.

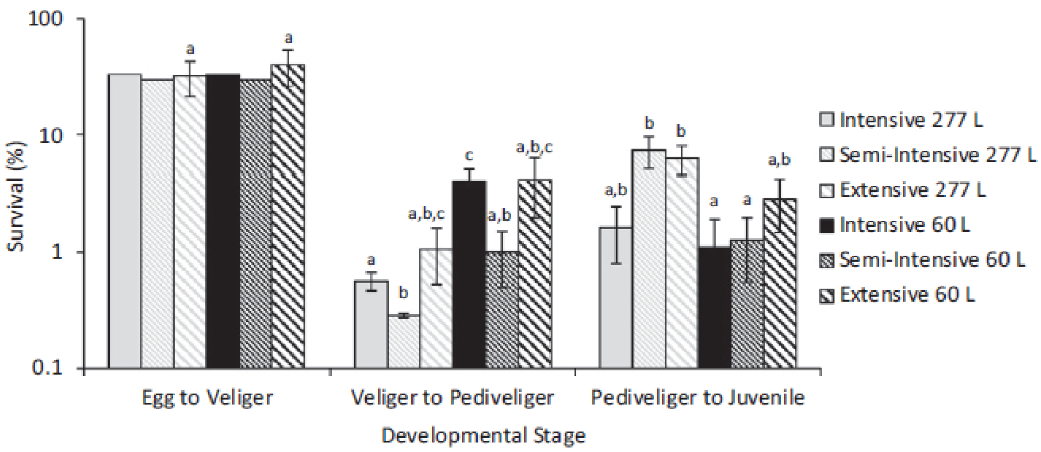


Phenotypic differences between paternal species and their hybrids at 3-years of age. From left to right: *T. noae* ×*T. noae*, *T. noae*♀×*T. maxima*♂, *T. maxima*♀×*T. noae*♂, *T. maxima* ×*T. maxima*.

Comparison of established giant clam hatchery protocols for *Tridacna noae*: The Project provided a first evaluation of different hatchery culture methods for the giant clam *Tridacna noae*. Three culture methods (intensive, semi-intensive, and extensive) using two tank designs (60 L and 277 L) were successful in producing 30-day old *T. noae* juveniles. There was no statistically significant interaction between tank design and culture method when considering cumulative survival (P=0.89) or antero-posterior growth (P=0.20), and the two tank designs did not influence cumulative survival (P=0.78) or antero-posterior growth (P=0.81). Differences in cumulative survival among the extensive (0.027 ± 0.015%), semi-intensive (0.005 ± 0.002%), and intensive (0.004 ± 0.001%) culture methods were non-significant (P=0.11). The mean antero-posterior measurements at 30-days post-fertilisation among intensive (583.57 ± 12.71 µm), semi-intensive (530.92 ± 11.02 µm), and extensive methods (541.67 ± 10.95 µm), were also non-significant (P=0.05). Further analysis of survival among different developmental stages identified significantly greater survival of *T. noae* between the pediveliger and juvenile development stages within the extensive culture method. These results show that extensive culture methods can achieve comparable hatchery production of *T. noae* to semi-intensive and intensive culture methods, which require additional managerial, infrastructural, and nutritional inputs.

For further information please see:

Braley, R.D., Militz, T.A., Southgate, P.C. 2018. Comparison of three hatchery culture methods for the giant clam *Tridacna noae*. *Aquaculture* 495, 881-887.

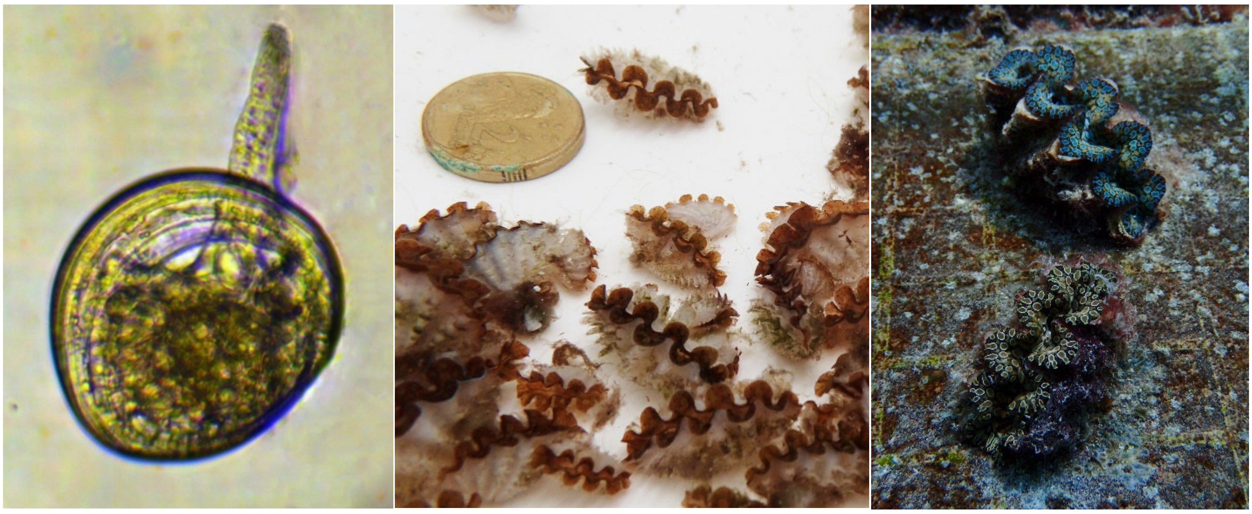


Mean (± SE) survival during different stages of *Tridacna noae* development during the first 30-days of culture among the different culture treatments and tank sizes. Survival is presented on a logarithmic scale and is not cumulative. Means with different superscripts are significantly different (P < 0.05) within a given stage.

Routine hatchery production of *Tridacna noae*: The Project developed a protocol for routine hatchery production of *T. noae* which was further refined based on targeted research. Spawning was induced by serotonin injection into the gonad. Unfertilized eggs had a mean (±SE) diameter of 101.14 ± 0.47 mm and spermatozoa heads were 8.92 ± 0.09 mm in length. Embryonic development had progressed to the 8-cell and 16-cell stages by 3 h postfertilization and to the 32-cell stage by 4 h postfertilization. Rotating gastrulae accounted for 82% of developing embryos at 9 h postfertilization. Trochophore larvae accounted for 54% of embryos at 16 h postfertilization, and 98% of larvae at 20 h postfertilization. Straight hinged (D-stage) veligers comprised 74% of developing larvae at 22 h postfertilization with mean (±SE) anteroposterior measurement (APM) of 146.32 ± 0.58 mm, dorsoventral measurement (DVM) of 118.12 ± 0.74 mm, and hinge length of 77.46 ± 0.73 mm at 24 h postfertilization. At 96 h postfertilization, 74% of veligers had settled but had retained the velum without showing development of the foot and, by 120 h postfertilization, 78% of settled veligers had become pediveligers with a probing foot. The mean (±SE) APM of pediveligers at 144 h postfertilization was 176.50 ± 0.97 mm, DVM was 151.86 ± 1.01 mm, and hinge length was 63.50 ± 0.95 mm. Gills were first observed in settled individuals 11 days after fertilization, indicating completion of metamorphosis. The protocol used during the Project supported successful larval culture of *T. noae* and provide a basis for large-scale propagation of this species.

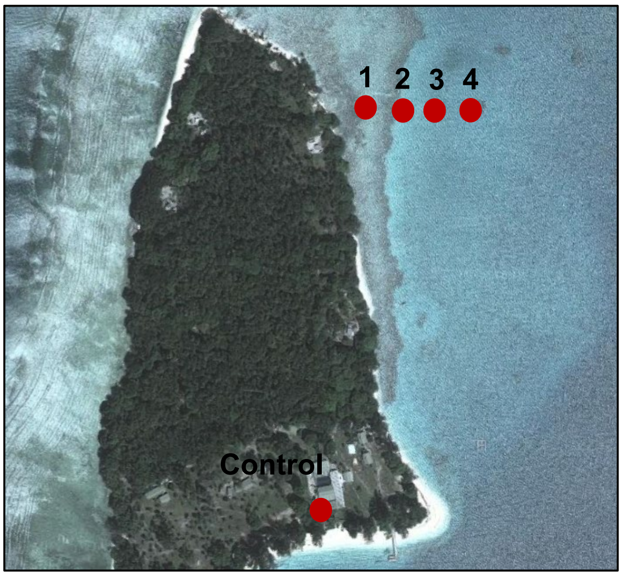
For further information please see:

Southgate, P.C., Braley, R.D., Militz, T.A. 2016. Embryonic and larval development of the giant clam *Tridacna noae* (Röding, 1798) (Cardiidae: Tridacninae). *Journal of Shellfish Research* 35, 777-783.



Pediveliger larvae of *Tridacna noae* (left), juvenile *T. noae at* 5-months of age with Australian $2 coin for size reference (centre), and juvenile *T. noae* at 12-months of age on-growing at a community farm.

Potential for seaweed culture in Kavieng: There is a small domestic market in Kavieng for the sale of edible seaweeds. The Kavieng waterfront market typically trades ca. 100+ kg of *Caulerpa* sp. (primarily *Caulerpa racemosa*, but also *Caulerpa serrulata*) on a weekly basis, priced at ~$1 PGK per handful (ca. 250 g). The traded seaweed is wild-harvested and sold fresh, without post-harvest processing. This requires the consumer to clean the seaweed of sediment by removing the fronds from the stolons, a time-consuming process that reduces the product's market appeal. There is potential for aquaculture of *Caulerpa* spp. to improve the quality of traded product by culturing *Caulerpa* spp. in suspension, resulting in a final product free of sediment. The aquaculture of *Caulerpa* spp. could also improve the livelihoods of those dependent on the wild-harvest of *Caulerpa* spp. for income if aquaculture proves more reliable or productive than wild-harvest. Lastly, as *Caulerpa* spp. are a component of local diets, successful aquaculture of *Caulerpa* spp. will help to ensure food security for communities engaged in farming.

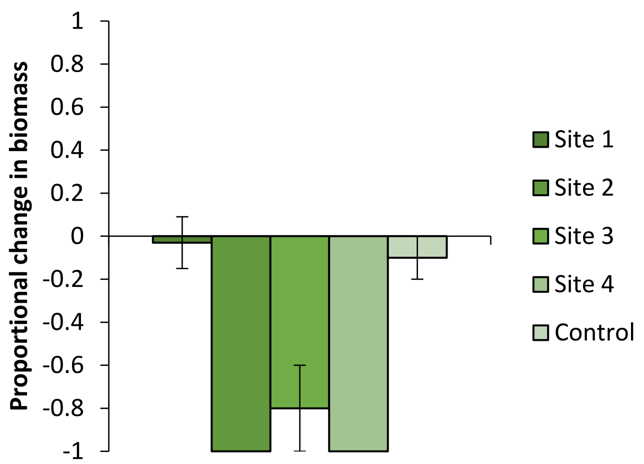


Location of trial culture sites at Nago Island

The starting biomass of *C. racemosa* was harvested from the reef flat of the mainland (Sivisat) adjacent to Nago Island and stocked into square (90 × 90 × 6 cm) perforated plastic trays at a density of 3 kg m^{-2} (Paul et al., 2014). Three trays were suspended 50 cm above the substrate by means of an iron trestle at each of five culture sites. Once stocked, the seaweed culture units were left undisturbed for a 3-week culture period (Paul et al., 2014) after which the change in biomass was assessed.

The mean proportional change in biomass over the 3-week culture period was negative for all five culture sites. The best performing sites were Site 1 (reef flat) and the Control (NIMRF pond) which had a mean biomass change of -3 ± 12 % and -10 ± 10%, respectively. There was a noticeable change in morphology of the stocked biomass at these sites; the quantity of fronds was noticeably reduced with an elongation of frond-less stolons and rhizoids extending from the bottom of the perforated trays.

Results revealed methods developed for commercial tank-based culture of *C. racemosa* in Australia (Paul et al., 2014) were not directly transferable to field-based culture in Kavieng, Papua New Guinea. Further extension of *C. racemosa* culture to partner communities was not undertaken on the basis of the unsuccessful culture trial. The results indicated the cost of culture material and labour could not be justified on the potential return from investment.

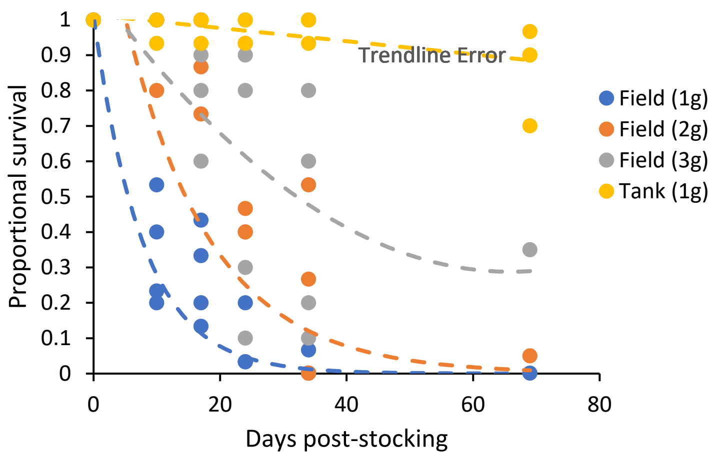


Mean (±SE) proportional change in biomass over the 3 week culture period for *Caulerpa racemosa* at Nago Island among the five sites.

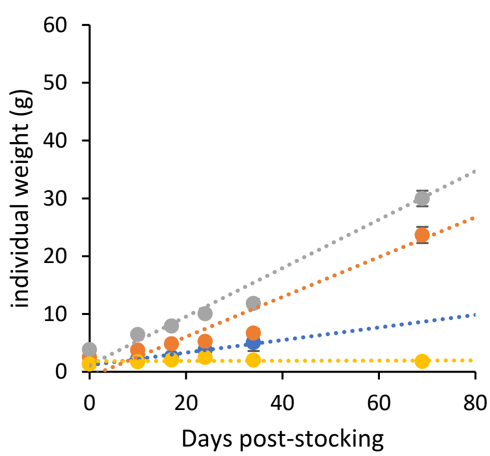
Growth morphology after 3-weeks of culture – extensive stolon extension coinciding with regression of the fronds.

7.2 To develop community-based sea cucumber culture methodology to a level potentially supporting income generation.

Minimum appropriate size to stock sandfish into sea ranches: Due to bottlenecks in juvenile sandfish production at the NIMRF, consequent of available nursery systems and stochasticity among cohorts (see Section 7.1), the Project investigated the minimum appropriate size to stock sandfish into sea ranches. If sandfish smaller than the proposed release size (3 g) had comparable (or better) survival and growth than sandfish retained in land-based nursery systems, there would be ample justification to stock sandfish at smaller sizes. Sandfish of 1 g, 2 g, and 3 g were stocked into replicate pens at a site appropriate for sea ranching. Four replicate 1 m^2 pens were established for each size class, and stocked to a density of 30 g m^{-2}. Additionally, four 1 m^2 tanks at the NIMRF, filled with sediment from the field-site to a depth of 10 cm, were stocked with 1 g sandfish at a density of 30 g m^{-2} as a control. Sandfish were maintained in their respective treatments for 69 days during which they were routinely assessed for survival and growth. Within the first 34 days, the 1 g sandfish in ocean pens experienced 92.5% mortality with no individuals surviving until the end of the experiment. This compared to only 28.3% mortality of 1 g sandfish maintained in land-based tanks at the NIMRF. Similarly, survival of 2 g sandfish in ocean pens was poor with 95.0% mortality by the end of the experiment. Only 3 g sandfish in ocean pens survived in any significant number, with 40% survival until 102 days after stocking. These results reaffirm the limited potential for ocean nursery culture systems (see Section 7.1) for sandfish < 3 g and confirm the minimum size appropriate for stocking sea ranches is 3 g.



Proportional survival of juvenile sandfish stocked into ocean pens or maintained in land-based nursery systems for 69 days.

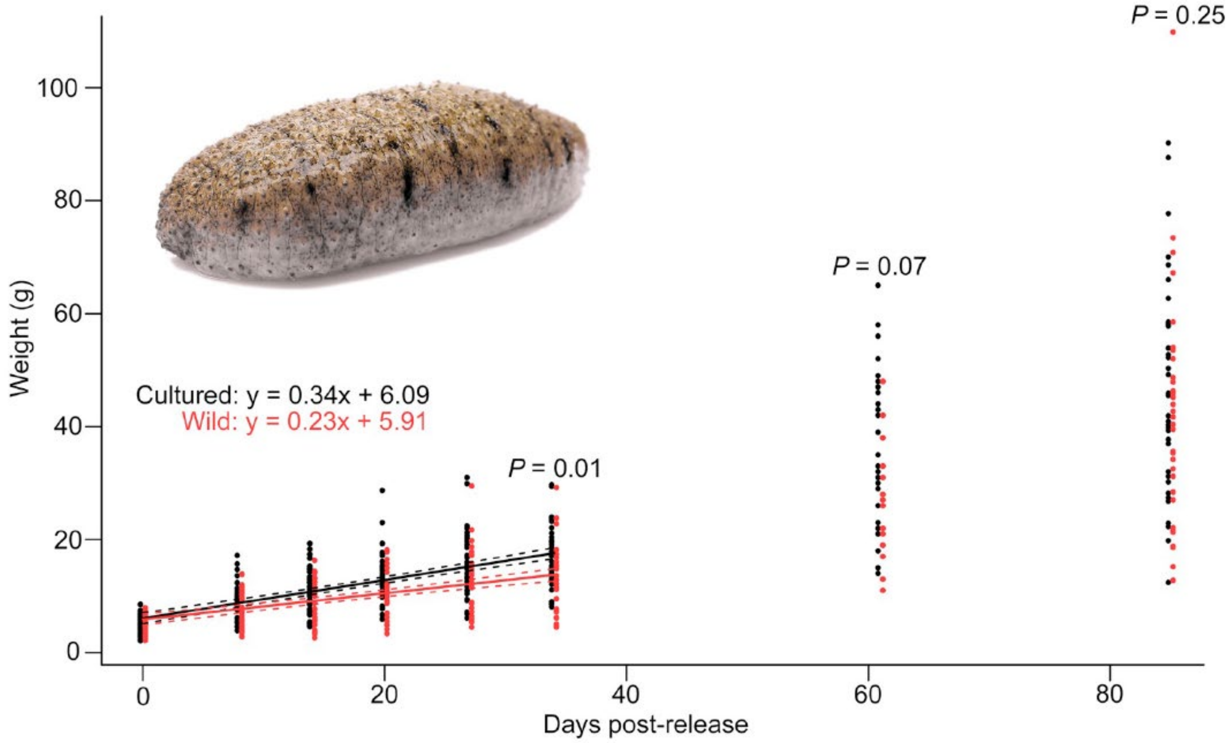


Mean (±SE) weight of juvenile sandfish stocked into ocean pens or maintained in land-based nursery systems for 69 days.

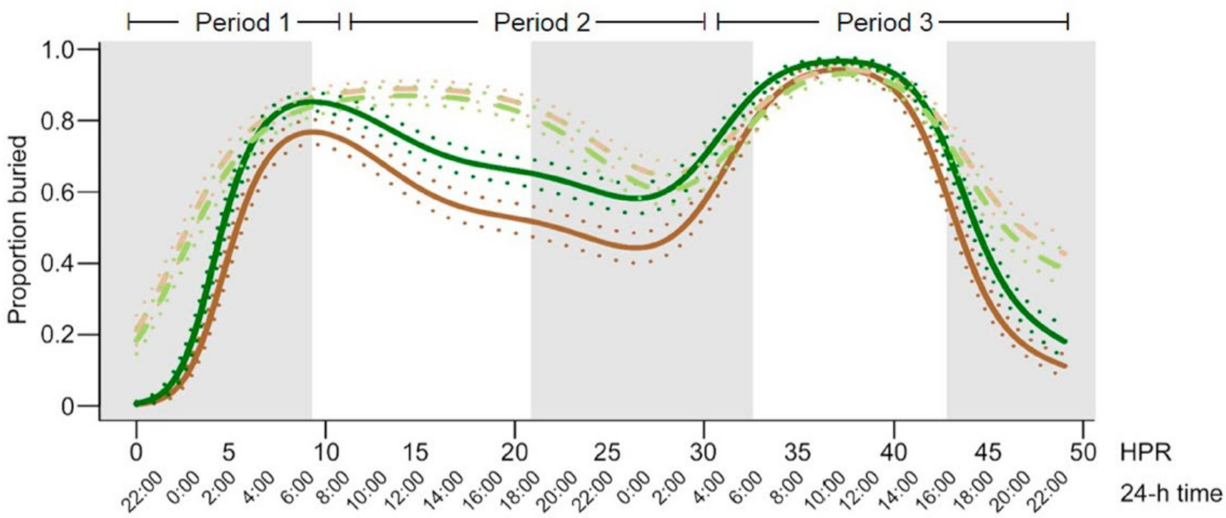
Improving success when stocking sandfish into sea ranches: The success of mariculture activities involving the release of cultured marine invertebrates into the ocean is contingent on high survival and appropriate growth rates. Physical, physiological or behavioural characteristics that differ from those of wild conspecifics may be acquired through hatchery rearing, or as a result of stress induced by the release process. Such differences may compromise the 'fitness' of cultured animals. The Project investigated the influence of hatchery rearing and transport/handling stress on a commercial sea cucumber, sandfish, by comparing survival, growth and behaviour of release-size (5–15 g) cultured juveniles to those of like-size wild conspecifics. At the conclusion of an 85-day growth experiment in natural habitat, there was no significant difference in weight between cultured and wild sandfish juveniles. Burying behaviour of cultured and wild sandfish juveniles was observed over a 48-h period in natural habitat with or without seagrass. A generalized additive model showed that cultured juveniles were slower to bury in the substrate after release, less likely to be buried at most times, and more likely to be buried in substrate where seagrass was present. However, they became better synchronized with their wild counterparts after 30 h. Survival of cultured and wild sandfish was high in both experiments (> 85%), but reduced burying by cultured individuals may increase the potential for predation because diel burying is the main predator avoidance strategy of sandfish juveniles. The research was supportive of the suitability of cultured sandfish for ocean mariculture in PNG, and provides increased awareness of key behavioural differences between cultured and wild juveniles that can assist in improving the success of release programs.

For further information please see:

Hair, C., Militz, T., Daniels, N., Southgate, P.C. 2020. Comparison of survival, growth and burying behaviour of cultured and wild sandfish (*Holothuria scabra*) juveniles: Implications for ocean mariculture. *Aquaculture* 526, 735355.



Temporal change in weight for cultured (black) and wild (red) sandfish juveniles (pictured) following release into natural habitat.



Fitted values from the generalised additive model illustrating temporal change in burial state following release of cultured (solid lines) and wild (dashed lines) sandfish juveniles into habitats where seagrass was either present (green) or absent (brown). Standard errors (dotted lines) are also shown.

Performance of a trial sea ranch with best practice culture protocols: In determining whether releases of cultured sandfish into a sea ranch have the desired effect of providing economic benefits to the community, questions remain around how many of these individuals can be recovered, when will they reach commercial size, how much area is needed and what are the effects on wild conspecifics and other sea cucumbers in the ranch. Research into survival and growth of farmed sandfish in enclosures, as a proxy for sea ranch performance, is biased since emigration is constrained and husbandry can improve outcomes (e.g., culling predators). Before and after monitoring of sea cucumber within a sea ranch can provide information needed to ascertain whether the cost and effort associated with hatchery production of juveniles, stocking and security is justified. As such, the Project monitored the community structure of the sea cucumber population within a sea ranch to address how impacts associated with closure of the sea ranch to fishing compares with the direct effects of stocking on the target species and the broader sea cucumber population.

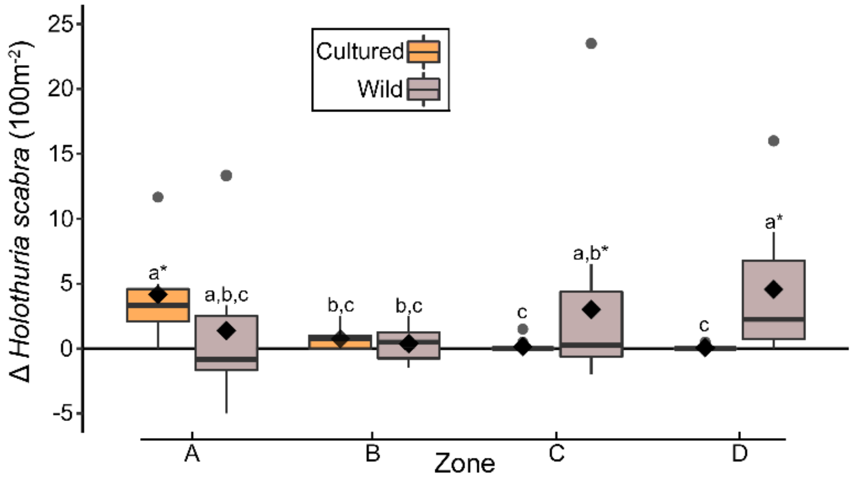
Juvenile sandfish starting to bury after release into natural habitat at Enuk.

Of 5,655 cultured sandfish juveniles stocked into the sea ranch, an estimated 3.7 ± 0.9 % were recoverable seven months after stocking concluded. The post-stocking densities of cultured sandfish declined with increasing distance from the release site. Cultured sandfish ($\bar{x}$ = 324.4 ± 9.2 g) were significantly larger than wild sandfish ($\bar{x}$ = 297.1 ± 4.7 g) harvested from the study area ($t_{1,591}$ = 2.82, p = 0.005) and the percentage of cultured sandfish exceeding the estimated legal size limit (400 g) was 21.4%, which was significantly more than for wild sandfish (12.2%, χ^2 = 6.84; p = 0.009). Sea cucumber community structure was initially uniform throughout the sea ranch, but underwent significant change in response to stocking and protecting the sea ranch (PERMAVONA: $F_{7,67}$ = 2.14, p < 0.001). The structural isolation of the post-stocking sea cucumber community within zone A, nearest the release site, was mainly due to increases in sandfish and chalkfish.

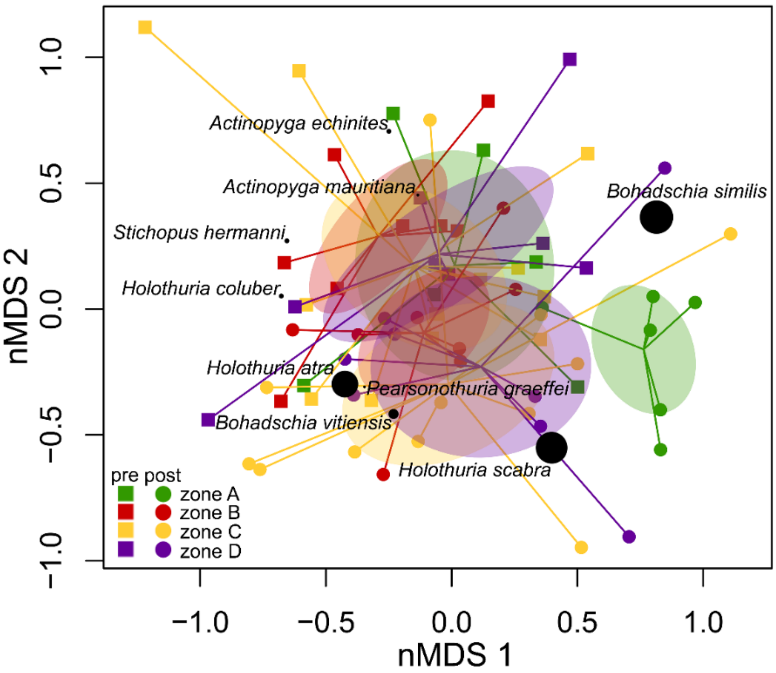
These results did not support the use of mariculture intervention of sea ranching as the most cost-effective or useful way to rebuild stocks of sandfish in order to generate income for an island community in PNG. Protection from harvest is an easier and cheaper option, and had a greater impact on increasing sandfish density within the sea ranch than stocking. The high costs associated with hatchery production and the poor recovery suggest greater benefit can be derived from supporting natural recruitment.

For further information please see the forthcoming publication:

Hair, C., Militz, T.A., Daniels, N., Southgate, P.C. Performance of a trial sea ranch for the commercial sea cucumber, sandfish (*Holothuria scabra*), in Papua New Guinea. *Aquaculture Reports* (submitted)



Boxplots showing the change (Δ) in cultured and wild sandfish densities (100 m^{-2}) among sea ranch zones in response to stocking, where the diamonds (◆) illustrate mean Δdensity. Shared alphabetical superscripts indicate statistically similar (p > 0.05) Δdensity and asterisks (*) indicate Δdensities statistically different (p ≤ 0.05) from zero. Zones A, B, C, D represent increasing distances from the site of cultured sandfish release into the sea ranch.



nMDS biplot (based on Bray-Curtis resemblance of effort-adjusted data) of pre- (squares) and post-stocking (circles) sea cucumber community structure of the sea ranch, with respect to zonation. Shaded ellipses indicate the 95% confidence interval of zone plot positions. Positioning of species (black points) reflects associations with the nMDS ordination, and point size is scaled to reflect the relative surveyed abundance.

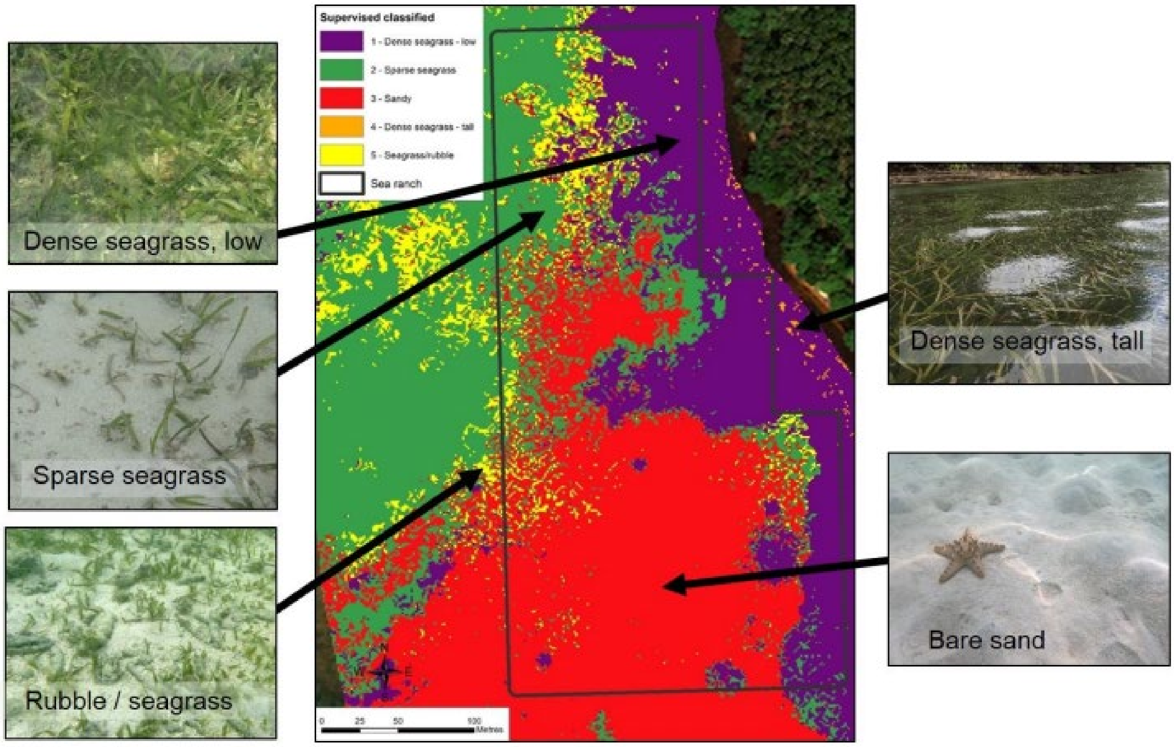
Remote sensing techniques to identify suitable areas for sandfish sea ranching: Remote sensing can potentially be used to identify habitats that promote high survival and growth of sea cucumber for optimal mariculture outcomes. There is scope for this methodology to be applied to sandfish mariculture site selection in PNG and the Pacific Islands region where there is growing interest in ocean-based culture of sea cucumber. This region is characterised by vast expanses of ocean dotted with thousands of islands, many of them remote, and with associated high travel costs. The use of remote sensing to survey and assess sandfish habitat in remote and inaccessible areas would have substantial logistic and economic benefits, including reduced requirement for on-site activity, and staff/equipment travel, and capacity to access data quickly and easily early in a Project. Effort and funds could then be directed towards sites with more optimal characteristics supporting the best chance of success.

During the Project, remote sensing and field data were obtained for two shallow (0.1–2-m depth) sandfish mariculture sites: a 7-ha trial sea ranch at Limanak and a 5-ha trial sea ranch at Ungakum. Detailed information on wild sandfish abundance and size was compared with remote sensing maps to explore how effective these methods are in describing sandfish distribution. By comparing knowledge acquired during on-site field work and the supervised classification, the Limanak sea ranch site can be shown to contain five distinct habitat zones. In contrast, the Ungakum sea ranch site comprised a more heterogeneous mosaic including bare habitat with sandy mounds, interspersed with sparse-medium seagrass patches, mostly *T. hemprichii* and some *E. acoroides*.

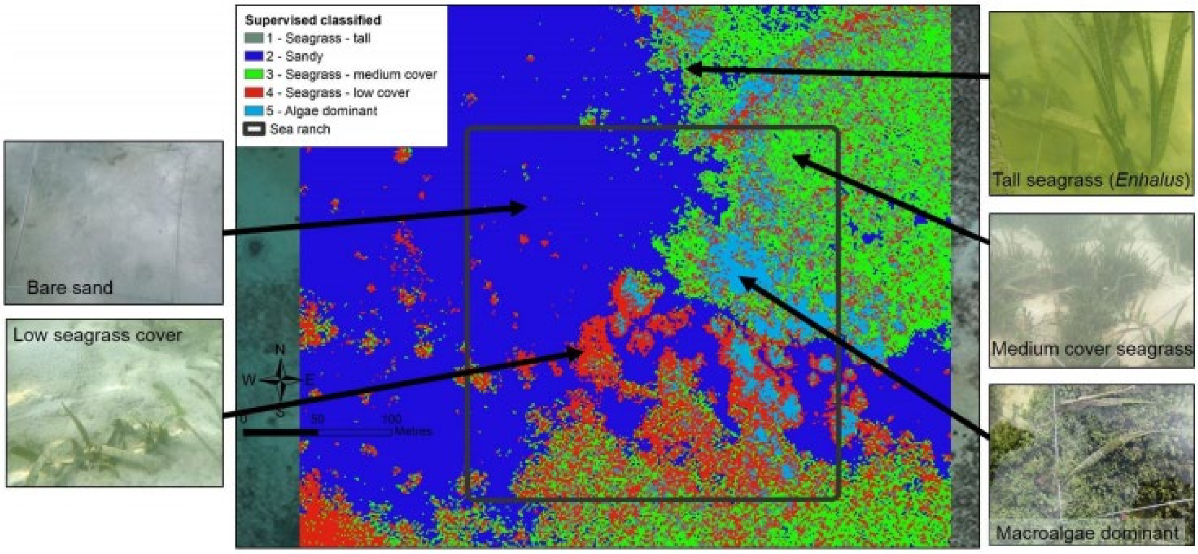
Despite some acceptable preliminary remote sensing results, using these techniques for marine habitats is not precise and has limitations. Misclassification occurred using supervised classification; for example, deep sandy habitat presented as the same class (colour) as shallow, dense seagrass in the Limanak sea ranch. Due to constraints such as image limitation, cost, image availability, the need for ground truth data, and the unique nature of supervised classification algorithms per site, these results suggest that remote sensing alone cannot be used to predict suitable sandfish mariculture sites at this time. However, it can contribute usefully to a broader GIS approach. As an example, the Project outlined a flexible and cost-effective three-stage GIS protocol that could be customised for PNG and Pacific Island fisheries and aquaculture departments to reduce dependence on traditional field scouting in identifying potentially suitable locations for ocean-based mariculture of sandfish. This three-stage GIS approach is designed primarily to assist in assessing and prioritising community requests for sandfish mariculture.

For more information please see:

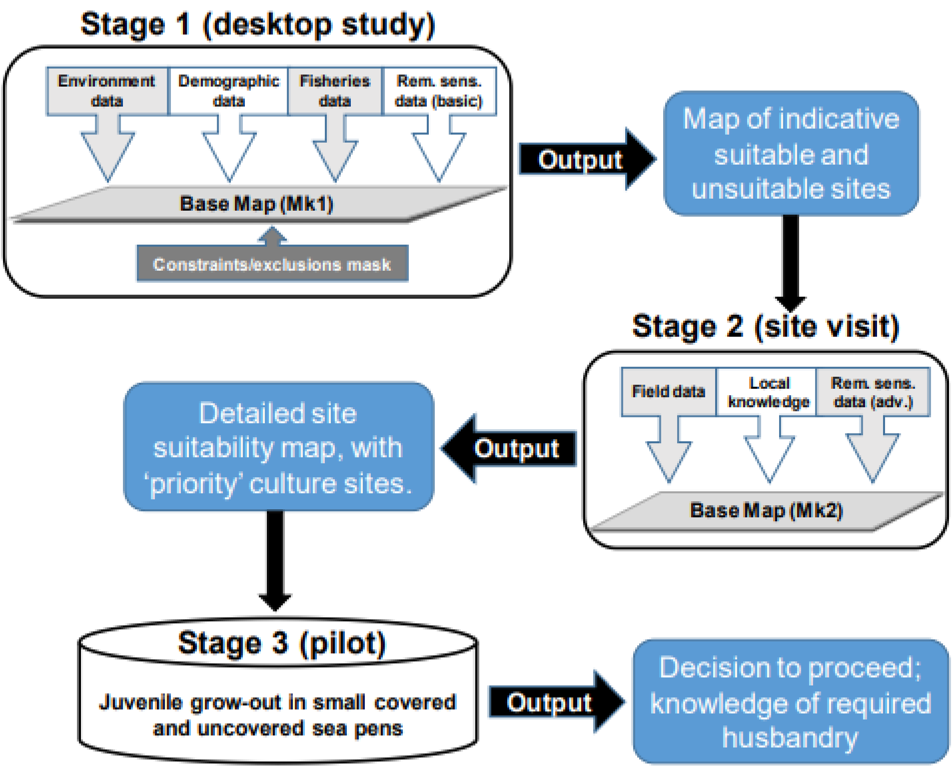
Hair, C.A. 2020. Chapter 4. Preliminary assessment of geographic information system and remote sensing for sandfish mariculture site selection. In: Development of community-based mariculture of sandfish, *Holothuria scabra*, in New Ireland Province, Papua New Guinea. PhD thesis. James Cook University.



Supervised habitat classes for the Limanak trial sea ranch compared with field data photographs.



Supervised habitat classes for the Ungakum trial sea ranch compared with field data photographs.



Schematic representation of proposed three stage GIS multi-criteria approach: Stage 1: coarse scale using available data and basic remote sensing; Stage 2: site visit for ground-truthing, field data collection, local knowledge, perform supervised classification of optimal sites; and Stage 3: pilot grow-out of juvenile sandfish in enclosures to confirm acceptable sandfish performance.

7.3 To continue building long-term institutional mariculture capacity in PNG.

Project and outside personnel visit NIMRF: The Project brought international experts with specific expertise to the NIMRF on a short-term basis to lead research and capacity building activities. The international expertise made meaningful contributions to PNG mariculture development and upskilling of NFA staff. Visits to the NIMRF were made by:

- Dr Rick Braley (Aquasearch) – mariculture of giant clams
- Dr Michel Bermudes (SPC) – mariculture advisory visit and coordination of the SPC Regional Exchange on Sandfish Aquaculture
- A/Prof Simon Foale (JCU) – socio-economic surveys
- Ian Tuart (ACIAR Project FIS/2010/098) – mariculture of macroalgae
- Ben Parker (Blue Ventures) – community-based mariculture

In addition to visits from outside personnel, Project staff regularly visited the NIMRF. During the Project, Dr Cathy Hair made eight visits to the NIMRF and spent a cumulative 424 days in-country. While Dr Thane Militz resided on-site at the NIMRF from the Project start until March 2020, his return to Australia necessitated by the travel restrictions associated with COVID-19. The hands-on training opportunities afforded by Project staff spending prolonged periods in-country working with partner institutions greatly enhanced the capacity building outputs of the Project. A major stimulant for Project success can be attributed the empathetic and skilled Project staff.

(**Left**) Ian Tuart working with NIMRF staff and OLSH students to establish a *Caulurpa racemosa* culture trials. (**Right**) Dr Rick Braley training NIMRF staff how to extract zooxanthellae from giant clam mantle tissue for inoculating larval rearing tanks.

Targeted training courses for partner organisations: The Project's target of two training courses per year relating to mariculture methods was well exceeded. Training courses delivered to UNRE and PAU BSc students were in the form of a three-month practicum placement at NIMRF. The practicum allowed students to experience mariculture research and production, and counted towards the completion of their undergraduate degree. Each student was assigned a minor research Project aligned with Project milestones and supervised by NIMRF and Project staff. Eleven students undertook practicums at NIMRF during the Project.

PAU BSc student, Evodia Anetul, undertook her three-month practicum placement at NIMRF in 2019 focused on hatchery techniques and culture of sandfish.

A week-long work experience placement at NIMRF was offered annually to Year-12 students attending the OLSH International School in Kavieng. This allows secondary students to gain practical experience in marine science before deciding on a path for higher education. Building capacity and awareness amongst local teenagers in relation to mariculture activities has helped create ambassadors who will foster greater understanding of mariculture in their communities.

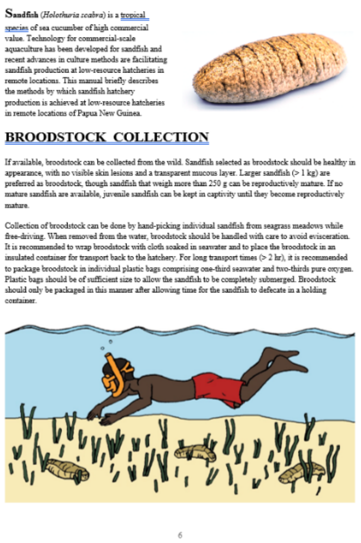
Project staff continued to provide assistance in delivering the mariculture component of the NFC Aquaculture Competency Training programme developed in FIS/2014/054. This included launching the Certificate 2, 3, and 4 courses, which had not previously been delivered. The program now delivers formal qualifications for four courses in aquaculture (Certificates 1-4) with one to five weeks of teaching at the NIMRF depending on the course. During the Project, five Certificate 1, four Certificate 2, three Certificate 3, and two Certificate 4 courses were delivered, with a total enrolment of 255 participants. Participants attending the courses include provincial aquaculture officers, provincial fisheries officers, agriculture and livestock officers, TVET school teachers, technical high school teachers, CIS officers, community development officers, SME farmers, and non-school leavers.

(T**op left**) Participants in the NFC Aquaculture Competency Training programme learn practical mariculture skills, such as broodstock handling and husbandry. (**top right**) The programme coordinator, Philomena Sinkau, is pictured instructing participants. (**bottom left**) NIMRF staff, Esther Leini, instructing participants in handling of sandfish juveniles. (**bottom right**) Participants deploying pearl oyster panel nets from a floating ponton in the Kavieng Harbour.

Formal workshops delivered in partner communities included a workshop prior to the 2017 sea cucumber fishery opening to train UNRE graduates, PC mariculture trainees, WCS officers, and NIMRF staff. The workshop covered sea cucumber identification, NFA bêche-de-mer fishery management rules, monitoring techniques, and collection of socio-economic data. Participants then undertook monitoring of sea cucumber landings and collected household social data from three partner-communities during the 2017 fishery season. A two-day workshop for 40 partner-community members on bêche-de-mer processing was held in 2018 in response to Project research revealing substantial wastage of sea cucumber harvest due to poor processing methods (Hair et al., 2018). In addition to formal workshops, weekly visits to almost all (excluding Ungakum due to logistics) partner communities allowed for Project and NIMRF staff to regularly provide hands-on training for community members and mariculture trainees.

(Left) NIMRF staff, Bitalen Peni, working with UNRE graduate, Terancehill Galiurea, to enumerate sea cucumber harvest during the 2017 fishery season. (**top right**) NIMRF staff, Nicholas Daniels, training Enuk community youth in identifying sea cucumber species. (**bottom right**) Partner-community mariculture trainee, Samuel Sition, training community members in coral propagation.

Revised culture manuals for community and NFA staff training and extension: A fully illustrated manual has been produced to better enable regional dissemination of the routine hatchery protocol developed during the Project to aquaculture technicians. The manual details application of micro-algae concentrates as a replacement for on-site culture of live micro-algae. A draft version of the hatchery manual was field-tested in Kiribati (Atoll Beauties) by Esther Leini. as part of an SPC sponsored regional technical exchange program, resulting in successful hatchery production of sandfish. The manual has also been successfully used to train additional NFA and partner organisation aquaculture technicians (e.g., Julianne Onga) in sandfish hatchery protocols. The manual is amply illustrated and presented in an easy to understand format appropriate for the intended audience.



Sandfish (*Holothuria scabra*) is a tropical species of sea cucumber of high commercial value. Technology for commercial-scale aquaculture has been developed for sandfish and recent advances in culture methods are facilitating sandfish production at low-resource hatcheries in remote locations. This manual briefly describes the methods by which sandfish hatchery production is achieved at low-resource hatcheries in remote locations of Papua New Guinea.

BROODSTOCK COLLECTION

If available, broodstock can be collected from the wild. Sandfish selected as broodstock should be healthy in appearance, with no visible skin lesions and a transparent mucous layer. Larger sandfish (> 1 kg) are preferred as broodstock, though sandfish that weigh more than 250 g can be reproductively mature. If no mature sandfish are available, juvenile sandfish can be kept in captivity until they become reproductively mature.

Collection of broodstock can be done by hand-picking individual sandfish from seagrass meadows while free-driving. When removed from the water, broodstock should be handled with care to avoid evisceration. It is recommended to wrap broodstock with cloth soaked in seawater and to place the broodstock in an insulated container for transport back to the hatchery. For long transport times (> 2 hr), it is recommended to package broodstock in individual plastic bags comprising one-third seawater and two-thirds pure oxygen. Plastic bags should be of sufficient size to allow the sandfish to be completely submerged. Broodstock should only be packaged in this manner after allowing time for the sandfish to defecate in a holding container.

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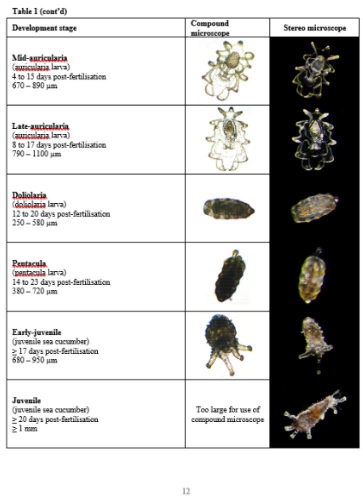

Table 1 (cont'd)

Development stage	Compound microscope	Stereo microscope
Mid-auricularia (auricularia larva) 4 to 15 days post-fertilisation 670 – 890 µm		
Late-auricularia (auricularia larva) 8 to 17 days post-fertilisation 790 – 1100 µm		
Doliolaria (doliolaria larva) 12 to 20 days post-fertilisation 250 – 580 µm		
Pentacula (pentacula larva) 14 to 23 days post-fertilisation 380 – 720 µm		
Early-juvenile (juvenile sea cucumber) ≥ 17 days post-fertilisation 680 – 950 µm		
Juvenile (juvenile sea cucumber) ≥ 20 days post-fertilisation ≥ 1 mm	Too large for use of compound microscope	

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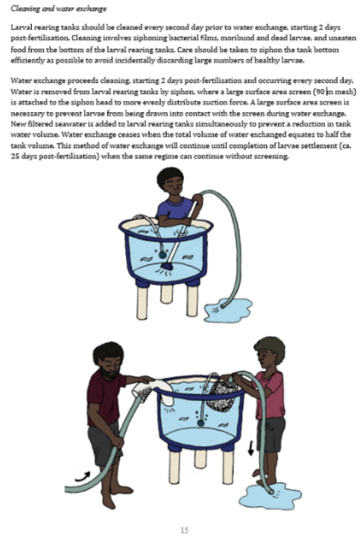


Cleaning and water exchange

Larval rearing tanks should be cleaned every second day prior to water exchange, starting 2 days post-fertilisation. Cleaning involves siphoning bacterial films, moribund and dead larvae, and uneaten food from the bottom of the larval rearing tanks. Care should be taken to siphon the tank bottom efficiently as possible to avoid incidentally discarding large numbers of healthy larvae.

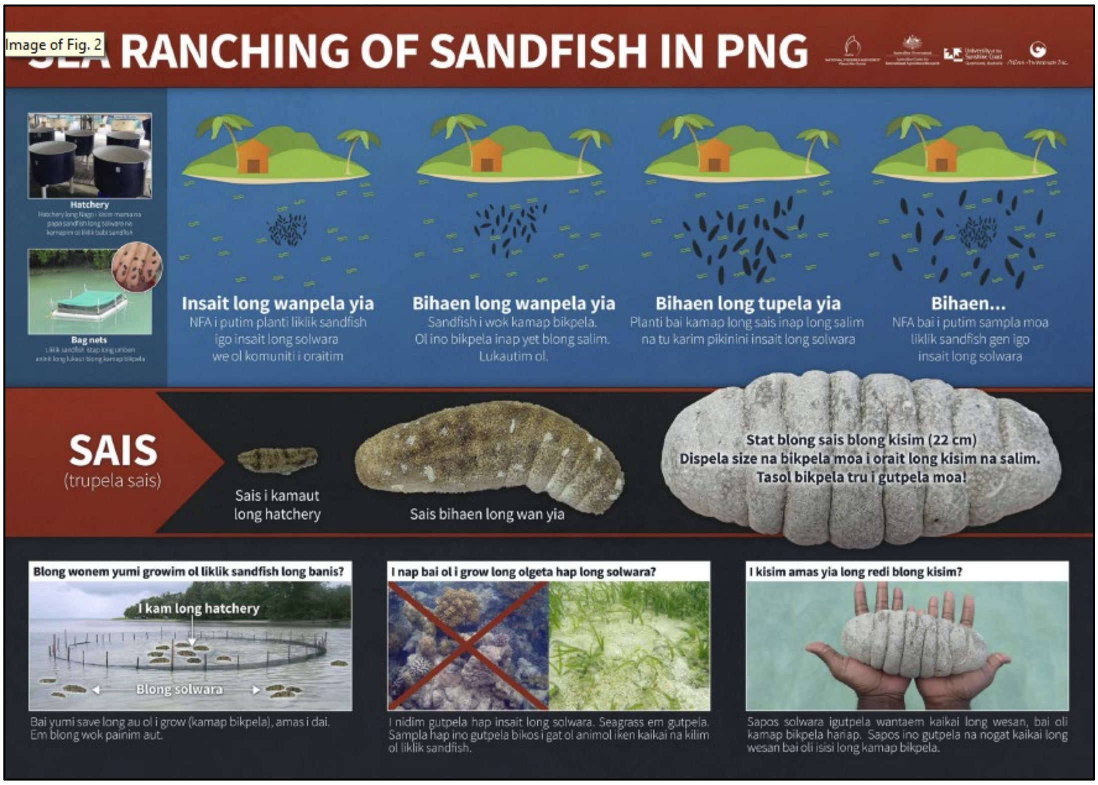
Water exchange proceeds cleaning, starting 2 days post-fertilisation and occurring every second day. Water is removed from larval rearing tanks by siphon, where a large surface area screen (90 µm mesh) is attached to the siphon head to more evenly distribute suction force. A large surface area screen is necessary to prevent larvae from being drawn into contact with the screen during water exchange. New filtered seawater is added to larval rearing tanks simultaneously to prevent a reduction in tank water volume. Water exchange ceases when the total volume of water exchanged equates to half the tank volume. This method of water exchange will continue until completion of larvae settlement (ca. 25 days post-fertilisation) when the same regime can continue without screening.

15

Sample pages from the *Seed production of sandfish (*Holothuria scabra) *using micro-algae concentrate products* manual based on the best-practice protocol derived from Project research.

In addition to manuals, more visually impactful media were produced for training partner-community members and mariculture trainees. Pamphlets/leaflets with appropriate illustration (e.g., Enuk Sea Ranch Toksave) were incorporated into training activities with partner-communities.

A poster illustrating the actual minimum legal sizes of live and processed sea cucumbers was designed, printed and distributed by Project staff to the three partner communities and posted on community notice boards (Appendix 2). Similarly, a poster describing how a community sea ranch would function was designed, printed, and distributed. Copies were also provided to conservation NGOs in Kavieng (AA and WCS) for wider distribution to non-partner communities.



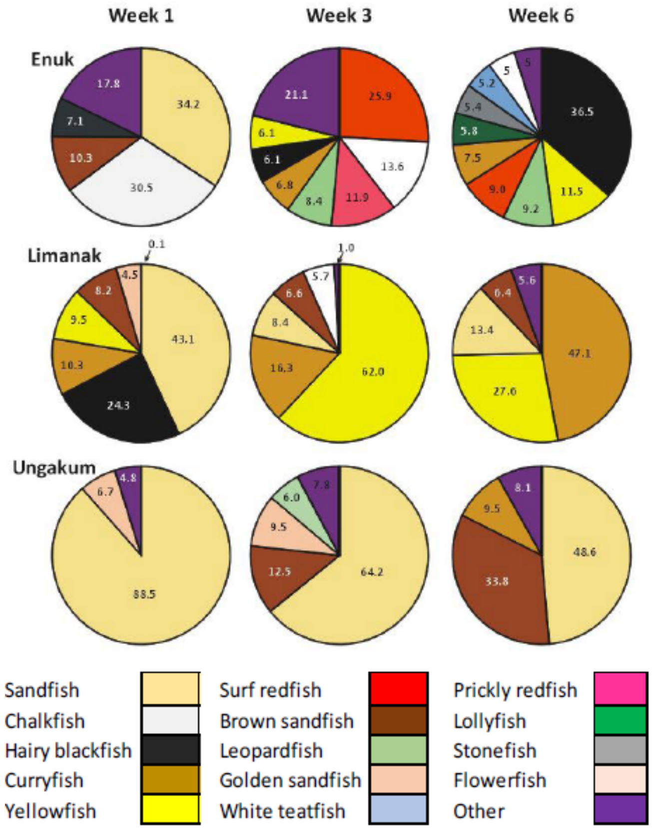
Poster describing how a community sea cucumber ranch would function.

7.4 To appraise opportunities, risks and impacts associated with sustainable community-based sea cucumber farming.

Sea cucumber fishery reveals importance of sandfish as target species for mariculture: On 1 April 2017, the Papua New Guinea (PNG) nationwide moratorium on sea cucumber fishing and the bêche-de-mer trade was lifted seven-and-a-half years after it was introduced. The National Fisheries Authority (NFA) had revised the National Bêche-de-mer Fishery Management Plan (the Plan) prior to the fishery opening and allocated provincial total allowable catch (TAC) quotas based on estimated fishable stocks of sea cucumber in each maritime province. During the Project, data were collected on the sea cucumber fishery (harvest of live animals, processing and selling of bêche-de-mer) from three partner-communities in the Tigak Islands. Almost 35,000 sea cucumbers that belong to 21 species were recorded from 10 days of catch monitoring. Catch composition and fishing patterns varied between villages and survey times. However, medium- and low-value species replaced high-value species and catch-per-unit-effort (by number and weight) decreased as the fishery progressed. The NIP fishery was closed eight weeks after opening, and the TAC of 43 tonnes (t) was exceeded by at least 36 t. Results from the Project highlight the need to increase awareness of fisheries regulations (particularly species size limits to reduce the amount of undersized beche-de-mer that is brought in for sale), to strengthen the reporting requirements for companies and also to implement extension services to improve processing so as to lower the high rejection rates of poorly processed beche-de-mer. In the first year of opening, the NFA revised Plan was not administered properly, causing multiple problems in how the fishery operated in the study area and recommendations are made for improvements in future sea cucumber fishing seasons.

For more information please see:

Hair, C., Kinch, J., Galiurea, T., Kanawi, P., Mwapweya, M., Noiney, J. 2018. Re-opening of the sea cucumber fishery in Papua New Guinea: A case study from the Tigak Islands in New Ireland Province. *SPC Beche-de-mer Information Bulletin* 38, 3-10.



Changes in sea cucumber species composition in surveyed villages 1, 2, and 6 weeks into the fishery season.

Landed weight and percentage contribution to total weight for common sea cucumber species.

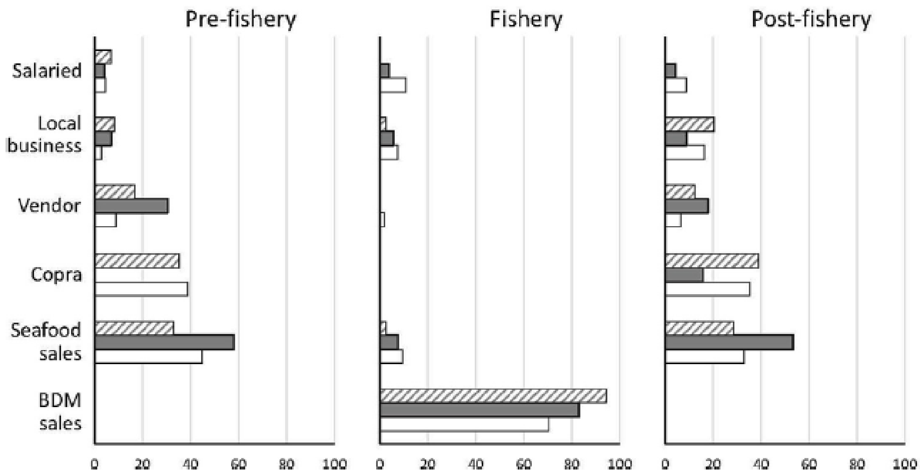
Common name	Weight (tonne)	% of total
Sandfish	11.6	40.7
Curryfish spp.	6.3	21.9
Pink curryfish	2.8	9.7
Brown sandfish	2.1	7.4
Golden sandfish	1.7	6.3
Blackfish spp.	1.8	6.0
Chalkfish	0.5	1.9
15 species	1.7	6.1

Processing of sandfish catch at Limanak partner community.

Socio-economic importance of sea cucumber in a mariculture context: Small-scale fisheries provide many benefits to coastal communities in the Indo-Pacific region, including food security, improved nutrition and cash income. However, increasing engagement with the global economy is exerting additional pressure on marine resources and opportunities to engage in alternative livelihoods are often limited by remoteness and a lack of land-based farming opportunities. Bêche-de-mer, the dried body wall of sea cucumber, is a valuable marine export commodity in the region, and an important cash-earning activity in Papua New Guinea (PNG). Sea cucumber mariculture, based on the high-value species, sandfish (*Holothuria scabra*), is also a promising community livelihood. Overfishing of sea cucumber in PNG led the National Fisheries Authority (NFA) to impose a moratorium on the fishery in October 2009. The fishery was reopened in 2017 for less than two months. The Project examined socioeconomic data generated before, during and after the 2017 sea cucumber fishing season in three villages in New Ireland Province, PNG, which were also Project partners in community-based sandfish mariculture. The fishery dominated the economies of all three communities while it was open. Increased income was accompanied by high consumption of store-bought foods and purchase of other assets intended to increase living standards. Drawing on current understandings of local culture and political economy, together with the results from the 2017 wild sea cucumber fishery, the Project examined how a livelihood based on sandfish mariculture could coexist with the wild fishery to increase benefits to coastal communities in PNG.

For more information please see:

Hair, C., Foale, S., Kinch, J., Frijlink, S., Lindsay, D., Southgate, P.C. 2019. Socioeconomic impacts of a sea cucumber fishery in Papua New Guinea: Is there an opportunity for mariculture? *Ocean & Coastal Management* 179, 104826.



Selected income source as a proportion (%) of all income sources for Enuk (open), Limanak (solid), and Ungakum (stripes) communities during pre-fishery, fishery, and post-fishery periods.

Number and proportion of households who purchased selected assets with BDM income.

Asset category	Enuk (*n* = 52)	Limanak (*n* = 43)	Ungakum (*n* = 35)	Total (*n* = 130)
Major assets				
Solar kit (light, panel, inverter)	20 (38%)	26 (60%)	14 (40%)	60 (46%)
Phone	11 (21%)	13 (30%)	5 (14%)	29 (22%)
Electronic goods (screen, radio, speaker)	4 (8%)	8 (19%)	4 (11%)	16 (12%)
Major fishing gear (e.g. net, canoe, eskie)	1 (2%)	8 (19%)	3 (9%)	12 (9%)
Generator	3 (6%)	2 (5%)		5 (4%)
Chainsaw		3 (7%)	1 (3%)	4 (3%)
Fuel drum		2 (5%)	2 (6%)	4 (3%)
Power tools		1 (2%)	2 (6%)	3 (2%)
Outboard engine		2 (5%)		2 (2%)
Business investment capital			1 (3%)	1 (1%)
Minor assets				
Minor fishing gear (e.g. torch, mask, fins, handline, spearguns)	21 (40%)	28 (65%)	14 (40%)	63 (48%)
Homewares (e.g. mattresses, plates)	4 (8%)	10 (23%)	7 (20%)	21 (16%)
Tools/hardware	9 (17%)	4 (9%)	6 (17%)	19 (15%)
Parts (generator, chainsaw, outboard)	7 (13%)	4 (9%)	3 (9%)	14 (11%)
Boat repair	1 (2%)			1 (1%)
Nil assets				
No asset purchases	14 (27%)	9 (21%)	7 (20%)	30 (23%)

A permanent house with water tank being constructed with earnings from the sea cucumber fishery.

Stability of marine tenure relationships in the context of sea ranching management: The Project conducted research into the potential of community-based mariculture of the commercial sea cucumber, sandfish (*Holothuria scabra*), as a sustainable livelihood in New Ireland Province, Papua New Guinea (PNG). Around 5000 cultured juvenile sandfish were stocked in a 5-ha trial community sea ranch. The community agreed to protect the area from fishing until researchers collected technical data on sandfish performance. However, poaching of sandfish from the trial sea ranch occurred during the 2018 annual sea cucumber fishing season and no technical data were generated. Community attitudes and responses to the fishing season, the mariculture research activity and the failure of the trial sea ranch were investigated. Widespread community approval of the trial sea ranch and respect for the fishing prohibition were reported. However, it was found that poaching within the ranch escalated to extensive fishing because community-based management proved inadequate to sanction the poachers. Increased buying pressure and higher prices led to intensified fishing effort in the 2018 season. The trial sea ranch failed due to external pressures (i.e., brief, intense fishing season; limited Project capacity), compounded by internal factors (i.e., weak local leadership; community disunity). It was concluded that research into and development of sandfish mariculture as a livelihood option in New Ireland Province might be impossible at this time due to the high value of sandfish, the annual sea cucumber fishing season, and ineffective governance at community, provincial and national levels. Lessons learned from this experience are presented and alternative models discussed.

For more information please see:

Hair, C., Foale, S., Daniels, N., Minimulu, P., Aini, J., Southgate, P.C. 2020. Social and economic challenges to community-based sea cucumber mariculture development in New Ireland Province, Papua New Guinea. *Marine Policy* 117, 103940.

Comparison of private farm and community sea ranch models for sea cucumber mariculture in New Ireland Province.

Factor	Private farm	Community sea ranch
Technical factors		
Per-capita cost	High	Low
Initial and ongoing time and labour requirement	High (with risk of stock loss from lax pen maintenance)	Low
Social factors		
Requisite CBFM capacity	Mostly unnecessary (individual pen ownership)	Highly functional (community ranch ownership)
Requisite community leadership capacity	Moderately functional (e.g., to manage conflict)	Highly functional (e.g., distribution of benefits)
External support/co-management	High (equipment cost and management assistance)	Medium to high (management assistance)
Benefit to women, elderly	Potentially high (improved access)	Potentially high (improved access)
Ownership and distribution of benefits	1 Clear individual ownership 2 Hard work rewards individual farmer/s 3 Potential for intra-family disputes 4 Risk of stock loss from lax pen maintenance	1 Potential for disputes over distribution of benefits 2 Opportunity for free-rider behavior and harvest by outsiders 3 Possibility of stock migration beyond ranch borders
Risk of stock theft	High (security needed)	High (security needed)
Overlapping technical and social factors		
Environmental conditions	1. Suitable sandfish grow-out habitat necessary 2. Owner access necessary 3. Suitable for sea pen stability (low wave energy/current/tidal flow, shallow depth, suitable sediment profile)	1. Suitable sandfish grow-out habitat necessary 2. Community access necessary
Infrastructure impacts and potential for increased community conflict/discord	1. Inconvenience to motor boat traffic and accident risk (small tidal range, pen damage, compensation claims) 2. Loss of traditional fishing grounds (i.e., impacting livelihoods and food security) 3. Sea tenure disputes	None

8 Impacts

8.1 Scientific impacts – now and in 5 years

Protocols developed by the Project for application of micro-algae concentrates in the hatchery production of marine invertebrates (sea cucumber and giant clam) are now being utilised for routine production by private and government hatcheries in Fiji (Civa Pearls), Federated States of Micronesia (Micronesia Management & Marketing Enterprises), Kiribati (Atoll Beauties) and Vietnam (RIA No. 3). Broader adoption of these protocols in the Pacific are anticipated to result from Esther Leini's and Nicholas Daniels' participation in SPC-sponsored regional knowledge exchange activities (see Section 8.2).

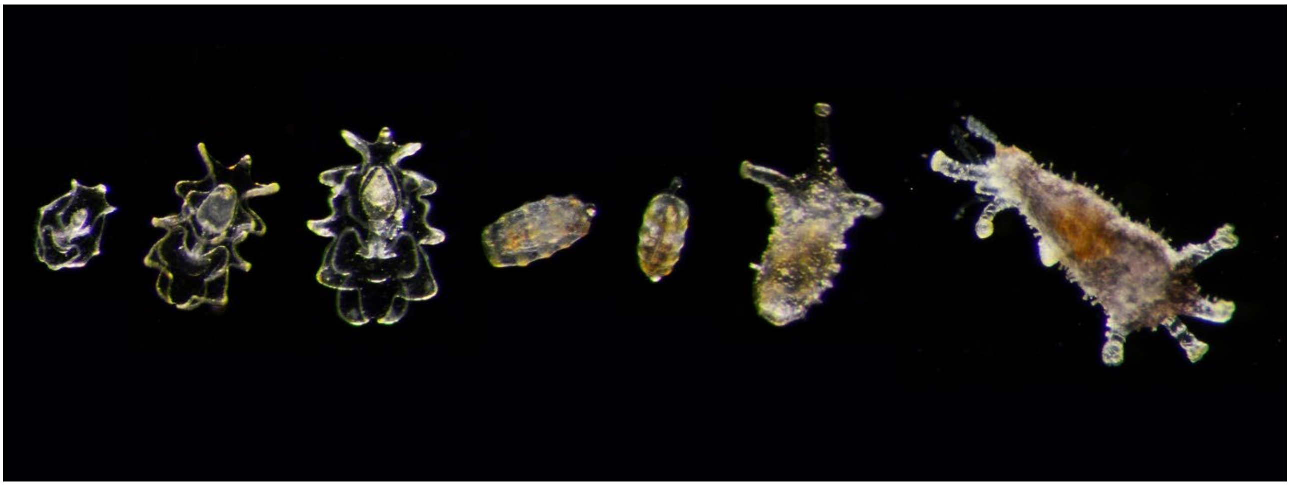
Cathy Hair completed her PhD thesis "Development of community-based mariculture of sandfish, *Holothuria scabra*, in New Ireland Province, Papua New Guinea" in February 2020. It was successfully examined and passed for award in June 2020. The thesis generated novel information on sandfish culture and the sea cucumber fishery in PNG and it has so far generated six scientific journal publications, all which have worldwide audience.

Scientific impact was among the many significant achievements identified by the Project review panel. Of particular note was their view that the scientific impact of the Project enhanced the profile of ACIAR as a research-in-development funder with technologies developed during the course of the Project having a transformational impact. In their words:

"*Outstanding research output from the Project. Of particular note is the scope of the publications, from highly technical laboratory-based research, to hatchery production, through to social aspects of community engagement in mariculture. As much as the publications are a contribution to science, they also enhance the profiles of ACIAR as a research-in-development funder, and PNG/NIMRF as a place where quality mariculture research can be undertaken.*"

"Demonstration that commercially available algal pastes are effective in reducing the costs and complexity of sandfish hatchery production. This technology is transformational."

"Producing sandfish using commercially available micro-algae concentrates, rather than traditional live algae, is more appropriate to local resources, simpler, cheaper and more reliable. Hatcheries in other countries are now adopting these protocols."



Sandfish, *Holothuria scabra*, were successfully produced with the novel culture methods developed during the Project. Large-scale culture of this species is no longer reliant on on-site live micro-algae culture.

8.2 Capacity impacts – now and in 5 years

NIMRF staff: Frequent visits of Project staff and outside personnel in combination with a resident Project Scientist at NIMRF afforded numerous opportunities for NIMRF staff to acquire new knowledge and skills related to mariculture, research methods, and leadership. The example below provides evidence that the impact extends beyond the scope of the Project.

In 2017, Esther Leini and Nicholas Daniels participated in the SPC Regional Exchange on Sandfish Aquaculture which included travel to Fiji and New Caledonia. As distilled by the program coordinator (Dr Michel Bermudes):

"*Esther and Nicholas showed a lot of passion for what they do and both showed some outstanding qualities and were always positively engaged in all the activities they were involved with, in the field and during workshop activities. Both Esther and Nicholas took the opportunity to show natural leadership qualities when they gave very comprehensive presentations in Fiji and in New Caledonia about the activities taking place at NIMRF and how they were able to demonstrate some of the techniques used in the hatchery and in the field to other participants.*"

In 2019, Esther was engaged by SPC to independently train private-sector aquaculture technicians in Kiribati (Atoll Beauties) in the hatchery culture of sandfish with micro-algae concentrates (see Section 8.1). Esther's capacity to train others in sandfish culture techniques developed by the Project has also been extended to training additional NIMRF staff (Julianne Onga) and supervision of BSc students undertaking their practicums at NIMRF. Feedback from students working under Esther has been overwhelmingly positive and demonstrates the capacity of NIMRF staff as future educators in mariculture research.

As acknowledged in one of the PAU BSc Practicum reports:

"As students still developing skills, we really appreciate and sincerely thank Esther Leini for coaching and chipping in parts that we lack skills and understanding in. The Project has gained us great knowledge and understanding on the culture of sandfish." – Joel Laklen

Joel Laklan (left) and Evodia Anetul (right), PAU BSc practicum students, washing sandfish eggs prior to transfer to larval tanks.

Linkages with other ACIAR projects have allowed NIMRF staff to build confidence in applying their new knowledge and skills related to mariculture, research methods, and leadership. Both Esther Leini and Nicholas Daniels successfully completed their Graduate Certificate in Research Skills from the University of Tasmania as part of ACIAR Project FIS/2010/055[5]. The in-country institutional capacity building program offered a unique opportunity for participants to gain essential skills without having to disengage from NIMRF activities and travel to Australia. Affording NIMRF staff opportunity to contextualise their mariculture skills in a broader context of research and project management will help ensure long-term institutional mariculture capacity beyond the Project. As indicated by Nicholas:

[5] *FIS/2010/055: "Building research and project management skills in fisheries staff in Papua New Guinea."*

"The course has greatly enhanced my skills in managing others. It really helped me understand myself as a supervisor… It has built me up in a different way to my earlier studies. It has adjusted my mind and my mindset, how I think and how I approach other people."

Nicholas Daniels celebrating successful completion of the Grad. Cert. in Research Skills.

Broader research networks are also anticipated to provide support to NIMRF staff beyond the Project. Both Peter Minimulu and Esther Leini participated in the ACIAR and Papua New Guinea Australia Awards Alumni (PNGAAA) workshop aimed at improving agriculture research and development outcomes in PNG. The workshop engaged researchers participating in ACIAR Projects in establishing a vibrant, creative and action-oriented alumni association that is inclusive and empowering.

During the course of the Project, several other NIMRF staff (Casper Dako, Steven Ngamagan, Posolok Kanawi) successfully transitioned to employment within the private-sector (as fisheries and aquaculture officers for St. Barbara Ltd) where they directly utilise knowledge and skills developed during this Project.

NIMRF infrastructure: Improvements to infrastructure at NIMRF occurred over the course of the Project and improved capacity for NIMRF to function as a mariculture research station. One of the significant achievements of the Project identified by the Project review panel was:

"In conjunction with NFA, operationalising and gaining recognition for NIMRF as the best mariculture research facility in the Pacific region. That is said notwithstanding the need for better staffing levels, dedicated funding, and more outdoor ponds."

New NIMRF infrastructure supported by the Project – 6,000 L cement raceways and light attenuating shelter

The reliability of seawater delivery to NIMRF was improved through upgrading the existing seawater submersible pumping system with Tsurumi titanium pumps and anti-wicking cable connections. This upgrade rectified the frequent maintenance issues experienced with the Sulzer stainless steel pumps and epoxy cable connections originally installed. The quality of seawater supply was improved through completion of the seawater delivery ring-line (construction commenced in FIS/2010/54). The ring-line ensures a continuous, unidirectional flow of seawater moves through the NIMRF seawater supply system. This upgrade has reduced instances of hydrogen sulphide (resulting from pockets of stagnant seawater in pipework) poisoning of cultured stock.

Production potential of the NIMRF was increased through the addition of 24 tonnes in holding capacity with the construction of four 6,000 L cement raceways designed by Dr Rick Braley. The raceways were used throughout the Project for culturing larval and juvenile giant clams and can be adapted for use with other species.

The improved infrastructure has also greatly benefited domestic training programs, including the UNRE/PAU BSc practicum placements and the NFC Aquaculture Competency Training, and regional knowledge exchange programs, such as the SPC Regional Exchange on Sandfish Aquaculture and FRI aquaculture technician exchange, delivered at the NIMRF. As explained by one of the UNRE BSc practicum students in her practicum report:

"Personally, I think NIMRF is a very outstanding facility compared to the training facility back at my University. I have learnt so many new things while being here for the last 3 months. […] This experience has better prepared me to work with the National Fisheries Authority, especially in the field of Research. […] I would recommend this training to future UNRE students in the Fisheries course." – Junnel Yendo

Junnel Yendo, UNRE BSc practicum student, providing husbandry to ocean hapa nursery systems at Enuk.

NFC's Aquaculture Competency Training: The Project continued to support in-country capacity building through inputs to NFC's Aquaculture Competency Training programme. The curriculum for formal qualifications in aquaculture was developed under FIS/2010/54 and received endorsement from the National Training Council and the Fisheries Training and Advisory Committee. The curriculum covers both freshwater and marine aquaculture, with the marine component occurring at the NIMRF instructed by NIMRF staff. The integration of guest lectures from Project staff and engagement of students in Project activities as part of practical training has greatly enriched student experience. As communicated by the programme coordinator (Philomena Sinkau):

"My sincere gratitude towards the ACIAR team, you have done an excellent contribution to the development of mariculture, through training the provincial fisheries officers and other stakeholders, as part of enhancing capacity skill gaps. Thus, greatly impacting their communities to venture into mariculture activities."

During the course of the Project, the curriculum for Certificates 2, 3, and 4 of the programmes were launched for the first time and a total of 255 participants received training. Participants attending the training came from various government organizations (e.g., provincial fisheries officers, local level government officers, CIS officers, secondary school teachers), non-government organizations (e.g., TVET school teachers), and private-sector enterprises. Parts of the curriculum are now being delivered in TVET schools by graduates of the programme. The capacity to continue this programme beyond the end date of the Project has been demonstrated through the recent successful delivery of two courses (Cert. 1 & 4) in the absence of Project staff, necessitated by COVID-19 travel restrictions.

Partner Communities: Capacity impacts within each of the four mariculture partner communities included:

- Community members trained in research activities such as survey methods for target species, marine habitat description techniques, use of technical equipment (e.g., GPS, weighing balance), data recording and analytical field methods.
- Community members trained in installation and maintenance of mariculture infrastructure such as sea pens, floating hapas, holding enclosures, and trays.
- Community members trained in providing husbandry for target species, such as proper handling, transport, and stocking of the target species.
- Community members trained in post-harvest processing of beche-de-mer.
- Awareness of sustainable fishery management approaches.

Personalised training was also provided to the community liaison, sea ranch warden, and nursery systems carer employed by the Project at each community to foster leadership and decision-making skills essential to effective mariculture management. The Project review panel, which visited partner communities and spoke with community members, concluded that a significant achievement of the Project was:

"*Successful introduction of mariculture activities to PNG communities for the first time. Following training, community oversight of grow-out was used successfully for giant clam culture and for sandfish. This is significant given no history of mariculture in PNG, and demonstrates the potential for mariculture development in the country.*"

Unagkum mariculture trainees and community members assisting with biophysical sampling.

Formal training activities supported by the Project.

Date	Location	Trainer(s)	Activities	Trainees
2016, Mar – 2020, Mar	NIMRF	Dr Thane Militz	Continuous training in day-to-day operations and maintenance of a mariculture facility; planning, management, and conducting mariculture research activities.	NIMRF staff
2016, Feb 29th – Mar 3rd	NIMRF	Prof Paul Southgate	Aquaculture research, student supervision and Project management.	NIMRF staff
2016, Apr 11th – May 2nd	NIMRF	Dr Rick Braley	Giant clam research and production	NIMRF staff, Thane Militz
2016, May 16th – May 20th	NIMRF	Prof Paul Southgate	Aquaculture research, student supervision and Project management	NIMRF staff
2016, Jun 9th	NIMRF	NFC staff	Workplace OHS training	NIMRF staff, Thane Militz

2016, Jun 9th – Jul 1st	NFC, NIMRF	Project, NIMRF, NFC staff	FQ117 – Certificate 1 in Aquaculture	15 students
2016, Oct 10th – Nov 4th	NFC, NIMRF	Project, NIMRF, NFC staff	FQ217 - Certificate 2 in Aquaculture (launch of course)	14 students
2016, Sep 18th – Oct 17th	NIMRF	Dr Rick Braley	Giant clam research	NIMRF staff, Thane Militz
2016, Dec 8th – 2017, Jan 10th	NIMRF, PC	Dr Cathy Hair	Training in underwater visual surveys, mark-recapture of sea cucumbers, mariculture husbandry and infrastructure maintenance	NIMRF staff, PC trainees, PC members, WCS officers
2017, Mar 13th – Apr 7th	NFC, NIMRF	Project, NIMRF, NFC staff	FQ117 - Certificate 1 in Aquaculture	17 students
2017, Mar 15th – May 1st	NIMRF, PC	Dr Cathy Hair	Training in socio-economic surveys, sea cucumber identification, fishery surveys, mariculture husbandry and infrastructure maintenance	NIMRF staff, PC trainees, PC members, WCS officers, UNRE/UPNG graduates
2017, May 22nd – Jun 16th	NFC, NIMRF	Project, NIMRF, NFC staff	FQ217 - Certificate 2 in Aquaculture	23 students
2017, Aug 15th – Sep 19th	NFC, NIMRF	Dr Cathy Hair	Training in social surveys, mariculture husbandry and infrastructure maintenance Research results presented to communities.	NIMRF staff, UNRE graduate, PC trainees, PC members
2017, Aug 28th – Sep 29th	NIMRF	Dr Rick Braley	Giant clam research and production	NIMRF staff, Thane Militz
2017, Sep 11th – Sep 16th	NIMRF	Prof Paul Southgate	Aquaculture research, student supervision and Project management	NIMRF staff
2017, Sep 11th – Oct 6th	NFC, NIMRF	Project, NIMRF, NFC staff	FQ317 - Certificate 3 in Aquaculture (launch of course)	15 students
2017, Nov 14th – Nov 18th	NIMRF	Prof Paul Southgate	Aquaculture research, student supervision and Project management	NIMRF staff

2018, Jan 26th – Jul 31st	NIMRF, PC	Dr Cathy Hair	Supervision of BSc student internship; BDM processing workshop; training in mariculture husbandry and infrastructure maintenance	NIMRF staff, PAU BSc student, PC trainees, PC members
2018, Apr 2nd – Apr 27th	NFC, NIMRF	Project, NIMRF, NFC staff	FQ117 - Certificate 1 in Aquaculture	17 students
2018, May 14th – May 19th	NIMRF	Prof Paul Southgate	Aquaculture research, student supervision and Project management	NIMRF staff
2018, Jun 18th – Jul 20th	NFC, NIMRF	Project, NIMRF, NFC staff	FQ317 - Certificate 3 in Aquaculture	13 students
2018, Sep 28th – Oct 16th	NIMRF, PC	Dr Cathy Hair	Training in mariculture husbandry and infrastructure maintenance	NIMRF staff, PC trainees, PC members, WCS officers
2018, Oct 2nd – Oct 30th	NIMRF	Esther Leini	Spawning induction, larval rearing, water quality monitoring, microscope use	FRI officer
2018, Oct 21st – Oct 27th	NIMRF, PC	Ian Tuart	Training in macroalgae mariculture site selection, husbandry, infrastructure, and culture.	NIMRF staff, PC members
2018, Oct 29th – Nov 30th	NFC, NIMRF	Project, NIMRF, NFC staff	FQ417 – Certificate 4 in Aquaculture (launch of course)	15 students
2018, Nov 21st – 2019 Jan 4th	NIMRF, PC	Dr Cathy Hair	Training in social surveys, mariculture husbandry and infrastructure maintenance	NIMRF staff, PC trainees, PC MMC, UNRE BSc students
2019, Jan-Feb	NIMRF	Esther Leini	Spawning induction, larval rearing, water quality monitoring, microscope use, data curation, report writing	PAU BSc students
2019, Mar 1st – Apr 2nd	NIMRF, PC	Dr Cathy Hair	Training in GIS classification, sea ranch best practice, mariculture husbandry and infrastructure maintenance	NIMRF staff, PC trainees, PC VPC, PC members

2019, Mar 18th – Apr 12th	NFC, NIMRF	Project, NIMRF, NFC staff	FQ117 - Certificate 1 in Aquaculture	27 students
2019, May 6th – May 11th	NIMRF	Prof Paul Southgate	Aquaculture research, student supervision and Project management	NIMRF staff
2019, May 6th – May 31st	NFC, NIMRF	Project, NIMRF, NFC staff	FQ217 - Certificate 2 in Aquaculture	16 students
2019, Jun 24th – Jul 23rd	NIMRF, PC	Dr Cathy Hair	Training in sea ranch best practice, stocking of sandfish, mariculture husbandry and infrastructure maintenance	NIMRF staff, PC trainees, PC VPC, PC MMC, PC members
2019, Oct 7th – Nov 1st	NFC, NIMRF	Project, NIMRF, NFC staff	FQ217 - Certificate 2 in Aquaculture	20 students
2020, Feb 10th – Mar 13th	NFC, NIMRF	Project, NIMRF, NFC staff	FQ317 - Certificate 3 in Aquaculture	19 students
2020, Feb 10th – Feb 27th	NIMRF, PC	Dr Cathy Hair	Training in underwater visual surveys, mark-recapture of sea cucumbers. Research results presented to communities.	NIMRF staff, PC trainees, PC MMC, PC VPC
2020, Jul 13th – Aug 14th	NFC, NIMRF	NIMRF, NFC staff	FQ417 – Certificate 4 in Aquaculture	18 students
2020, Oct 12th – Nov 6th	NFC, NIMRF	NIMRF, NFC staff	FQ117 – Certificate 1 in Aquaculture	26 students

8.3 Community impacts – now and in 5 years

Community impacts of the Project have been realised through participation in Project activities by the following individuals, groups and NGOs:

- Ailan Awareness
- CEPA
- NAQIA
- NFC
- OLSH Year 12 students
- Partner communities (Enuk, Limanak, Nago, Ungakum)
- Provincial fisheries officers
- UNRE BSc students

- PAU BSc students
- WCS

Collaboration occurred primarily with two NGO research partners, Ailan Awareness and Wildlife Conservation Society (WCS). Ailan Awareness was involved in partner community awareness meetings and fishery management education, as well as sea cucumber and socio-economic survey activities. WCS worked with the USC-NFA Project team on sea cucumber landings monitoring and socio-economic surveys during the 2017 sea cucumber open fishing season.

8.3.1 Economic impacts

Adoption of community-based sea cucumber mariculture presumably led to income generation for all partner communities engaged in this activity. Unfortunately, limited data are available on the potential contribution of cultured sandfish to household income. This was due to the mariculture activities (2017-2021) coinciding with a highly lucrative wild fishery that opened for intense fishing several months each year. Poaching at two of the three partner communities undermined community efforts to coordinate harvest of their sea ranches to maximise income generation and enable distribution of benefits. Socio-economic data obtained from the open fishing seasons indicates that sandfish were the most targeted and valuable species and poached cultured sandfish formed part of the commercial harvest. There was widespread support for the sea ranching activities and most community members felt that Project activities increased the number of sandfish available in their fishing grounds. However, we found that governance of the wild fishery was lacking at National, Provincial and community levels. In the short-term, we speculate that profitable sea ranching of sandfish would be almost impossible due to the annual fishery opening, lax enforcement of fishery regulations and high probability of poaching. Training in high-quality bêche-de-mer production provided by the Project resulted in improved earnings for some fishers during the annual fishing seasons. This economic benefit was not quantified but communicated to Project staff by several fishers.

Release of juvenile *Holothuria scabra* into Ungakum sea ranch.

Survival, growth and movement of sandfish in the third trial sea ranch at Enuk provided the only data on sea ranch performance. Minimum survival of 3.7 ± 0.9% released cultured sandfish was recorded. This is at the lower end of sea ranching estimates based on modelling, and much lower than pen grow-out suggested for this location. Sandfish were recorded in transects on the border of the trial sea ranch, suggesting that some may have emigrated out of the ranch. Sandfish growth was strong and 21.4% of cultured sandfish had reached commercial size. The NFA beche-de-mer export records indicate that sandfish earn disproportionately greater income than lower value sea cucumbers. Also, that wild sandfish landings decreased in the first two years of reopening the fishery. It is likely that harvest of sandfish will continue to decline with more fishing, which may incentivise communities to improve community-based management and enhance the potential for economic gains. If this occurs, more research is needed to increase survival of released, cultured juvenile sandfish and to improve monitoring capacity in large-scale community sea ranches.

Giant clams from community farms were sold domestically during the Project generating revenue for farmers and the NFA.

Adoption of community-based giant clam farming as an income generating activity led to a new income stream of PGK 2,601 in 2018 and PGK 2,704 in 2019 in sales at harvest for participating families. The NFA generated PGK 300 from the resale (domestic) of giant clams purchased from farmers. Adoption of community-based coral farming as an income generating activity led to a new income stream of PGK 936 in 2019 in sales at harvest for the Nago Island community. A greater magnitude of economic impact from giant clam and coral farming is unlikely to be realised until licenced aquarium export businesses commence operations in PNG (see Activity 1.4). Advancement of the *National Marine Aquarium Fishery Management and Development Plan 2020* during the Project demonstrates NFAs commitment to developing the ornamental mariculture, which specific provisions in the Plan to support sustainable mariculture development of giant clams and hard corals. Once the licenced aquarium export businesses commence operations in PNG, further economic impacts from giant clam and coral farming can be anticipated.

8.3.2 Social impacts

Social and economic drivers in the lucrative sea cucumber fishery were investigated during two open sea cucumber fishing seasons. The results indicated that sandfish, in particular, is a target species of fishing communities for income generation. Money earned from bêche-de-mer sales was used to increase standards of living within communities through the purchase of food, clothes, major assets, and permanent housing items (see Section 7.4). These results reflect the anticipated social and economic impacts that sustainable development of sea cucumber mariculture will have on coastal communities in the future.

Dr Cathy Hair conducting an interview at Ungakum village.

Sea ranching of sandfish was found to be a culturally compatible activity due to its value, familiarity, and preference among fishers, combined with minimal husbandry demands. Unfortunately, the research also revealed unsustainable practices such as uncontrolled harvest of undersized sandfish and poor-quality bêche-de-mer processing, which will reduce potential profits from sandfish mariculture and threatens future fishery productivity. The failure of two trial sea ranches was due to weak and/or unstable leadership and political disunity, that are common to many rural Melanesian communities (Schoeffel, 1997), and can quickly undermine attempts to communally manage such a high-value, easy-to-access commodity. We concluded that research into, and development of, sandfish mariculture livelihoods would require reduced collective fishing effort, increased local leadership and cohesion, and/or stronger support from government and/or external agencies before the anticipated social and economic benefits can realistically be achieved.

8.3.3 Environmental impacts

Environmental impacts were realised from continued engagement with partner communities over the course of the Project. Capacity building, awareness, and educational activities carried out within communities produced changes in how environmental resources were managed. These impacts were variable and, in some cases, took years to emerge. For example, Limanak community leaders had no control over sea cucumber harvest prior to the sea cucumber moratorium, but over two successive annual fishing seasons they increased pressure on fishers to comply with community-based fisheries management rules. Similarly, the Nago community had previously fished resident giant clam populations to the point of extirpation but now protect wild clams as a source of broodstock supporting their farming activities. NGO collaborators (WCS and Ailan Awareness) also contributed to these outcomes. The following positive impacts were observed in partner communities:

1. Increased awareness and knowledge of the biology and ecology of target species;
2. Increased awareness and knowledge of fishery regulations;
3. Improved capacity for community-based management of target species, resulting from better knowledge about the spawning and juvenile stages of target species and the rationale for regulations such as minimum size limits (for sea cucumbers);
4. Motivation to practice community-based management of target species resources due to continued contact with Project staff, positive feedback from experimental work within communities, reopening of fishery (in the case of sea cucumbers), and desire not to repeat mistakes of the past.

The environmental impacts of ocean-based mariculture activities were also examined in detail for commodities scaled-out to community farms under best practice protocols.

(**Left**) Enuk community members looking at posters detailing fishery regulations for sea cucumbers during a Project workshop on post-harvest processing. (**right**) Ungakum community members with a signboard detailing the community-based management rules enacted to support the success of sandfish sea ranching activities.

Giant clams culture: The environmental impacts of ocean-based giant clam farming on the substrata and fish assemblages were investigated during the 2018 and 2019 giant clam farming seasons. The data resulting from these studies are currently being prepared for publication in scientific journals. Preliminary analysis suggests the benthic impacts typical of bivalve farming (e.g., organic matter accumulation and habitat modification through shell deposits) did not occur, presumably due to sites appropriate for giant clam farming being high-energy and the giant clams being stocked at relatively low density to accommodate photosynthetic symbionts. However, significant impacts to resident fish assemblages did occur and were attributed to the deployment of the mariculture infrastructure associated with giant clam farming. The attraction of pelagic and demersal species occurred at sites where giant clam infrastructure was deployed, but the impacts of infrastructure deployment varied between sites. At sites where high densities of table fish were associated with giant clam farms, community members perceived benefits of increased subsistence fisheries catch from hook and line fishing in the vicinity of these farms. The review panel for the Project has recommend the unanticipated effect of giant clam mariculture infrastructure acting as fish aggregating devices be captured in future work, investigating and quantifying the potential benefits realised by farmers such as increased subsistence catch, dietary change, and the nutritional implications. Future economic modelling of giant clam farms should also consider such secondary benefits.

Multispecies finfish aggregation underneath a community giant clam farm at Nago Island. All species present are a component of artisanal and subsistence fisheries catch.

Sea cucumber culture: The environmental impacts of establishing, stocking, and maintaining a sea ranch for sandfish farming were investigated in partnership with the Enuk community (see Section 7.1). The data resulting from this investigation is currently being prepared for publication in a scientific journal. Preliminary analysis suggests a best practice protocol of closing the sea ranch to harvest until the stocked individuals reach commercial size (ca. 9-12 months) has positive indirect environmental impacts, such as population growth of all sea cucumber species due to natural recruitment. At the Enuk sea ranch, the contribution of natural recruitment to wild conspecifics of the target species (sandfish) exceeded the population growth attributed to the stocking cultured individuals. Furthermore, the stocking of cultured sandfish did not negatively impact populations of other commercially harvest sea cucumber species nor did it significantly alter sea cucumber community structures beyond the immediate (0.25 ha) area surrounding the release site. The increased density of sea cucumbers within the sea ranch likely resulted in further environmental benefits being realised beyond the scope of the assessment. For example, sea cucumbers play an important ecological role as bio-perturbators, in reducing organic matter in the sediment, and in recycling nutrients. Mariculture areas with healthy sea cucumber populations and sustainable management are also likely to produce benefits, such as increased seagrass diversity and increased recruitment of sea cucumbers elsewhere through spawning and emigration.

A female snakefish (*Holothuria flavomaculata*) releasing eggs at the site of the Limellon sea ranch.

8.4 Communication and dissemination activities

Internal: Project meetings were both regular and ad-hoc. Weekly operational meetings held at the NIMRF were attended by the in-country Project Scientist (Dr Thane Militz) and provided opportunities to share outcomes from Project research, plan research and training activities, and prepare meeting briefs for Project leaders and stakeholders. There was also regular email communication between Australian scientists and PNG counterparts to ensure issues were addressed and the schedule was maintained. In addition to a six-monthly coordination meeting of the Project reference committee, once a year there was an annual Project meeting held in Kavieng that was attended by the entire Project team, providing an opportunity to review progress, plan future work and maintain momentum. Consistent communication between NIMRF and Australia as well as annual reviews formed the basis for communication among the Project team.

Partner-communities: The communication and extension provided by the Project was appropriate for the level of understanding in partner-communities. Project meetings and community awareness activities, which included the Village Planning Committees (VPC) and Marine Management Committees (MCC), were maintained throughout the Project. Regular (weekly) visits to partner-communities were ongoing for nearby sites but not possible for the furthest partner-community (Ungakum) due to logistical constraints. Easy to understand pamphlets/leaflets with appropriate illustration (e.g., Enuk Sea Ranch Toksave and Toksave blo Clam Fam) were incorporated into training activities with partner-community mariculture trainees. A poster illustrating the actual minimum legal sizes of live and processed sea cucumbers was designed, printed and distributed by Project staff to the three partner communities. Copies were also provided to conservation NGOs in Kavieng (AA and WCS) for wider distribution to non-partner communities. The notice boards placed at sea-ranch sites were of high quality and appropriately worded for the community.

Regular power-point presentations within partner communities disseminated research findings and kept community members aware of ongoing research activities. Power-point presentations were delivered in all partner communities to disseminate the information collected from socio-economic surveys conducted during the sea cucumber fishery season (Activity 4.1). The presentations focussed on areas of interest to fishers, including the main species harvested, changes in species composition through the fishery, catch-per-unit-effort (CPUE), spending patterns, changes in diet, income earned from the fishery and patterns in exporters' purchases. Community members were able to interact with Project staff after the presentation. These presentations were well received, and printouts of the presentations were given to the VPC, MMC, and other relevant contacts (e.g., mariculture trainees) within each community.

Community members studying a copy of the presentation.

At the conclusion of field-based research activities with sandfish, a detailed report was distributed to each of the three sea cucumber partner communities. The reports addressed all Project-related activities relevant to each particular community. The report format was chronological and written in plain English, featuring "What we did", "What we found out" and "What this means" sections. The reports were illustrated with photos of community members who participated in research activities and with educational materials. Three copies were presented to each community: to the MMC; the VPC Chair; and the Mai Mai (chief) or equivalent.

Pamphlet provided to all families involved in giant clam farming, illustrating best practice husbandry.

External stakeholders: Presentations at various international and local conferences lifted the profile of the Project and drew attention to the activities being undertaken. This included Cathy Hair co-chairing the sea cucumber session of the *World Aquaculture Society Conference* in 2017. There were also visits by local and international dignitaries and politicians (e.g., APEC delegates) where the importance of sustainable livelihoods for coastal communities was impressed. Finally, Facebook was used to update key developments and significant activities – this was an important medium of communication and dissemination to the wider community (see Appendix 1). Copies of all communication material shared with partner communities were also given to conservation NGOs in Kavieng (AA and WCS).

The following presentations were given by team members at national and international conferences:

1. Hair, C. Using GIS classification methods to predict suitable habitat for sea ranching of cultured sandfish (*Holothuria scabra*) in Papua New Guinea. World Aquaculture Society Conference – 27-30 June 2017 at Cape Town, South Africa.
2. Daniels, N. Development of Sea cucumber mariculture in the Tigak Islands, PNG. – 12-13 December 2017 at Port Moresby, Papua
3. Leini, E. Hatchery production of sandfish, *Holothuria scabra*, at the NIMRF. CEPA Biodiversity and Conservation Seminar – 27-29 November 2019 at Port Moresby, Papua New Guinea.

The Honorary Julie Bishop MP, Minister for Foreign Affairs (Australia) and the Honorary Rimbink Pato MP, Minister for Foreign Affairs and Trade (Papua New Guinea) visited the NIMRF to witness some of the excellent research helping to develop mariculture opportunities in Papua New Guinea for sea cucumbers and ornamental species.

9 Conclusions and recommendations

9.1 Conclusions

The Project achieved the majority of its research milestones and further developed technical and capacity needs for further development of a mariculture sector in PNG.

The Project was reviewed in May 2019 and the following three recommendations were made to maximise the benefit derived from Project outcomes:

1. A six-month, no-cost extension of the Project be approved.
2. The Fisheries Program gives high priority to a follow-on mariculture Project based at NIMRF, with a target start in the financial year 2020-2021. The Fisheries Program convenes a meeting involving NFA senior management and the current Project leaders to scope strategy and content for a follow-on Project.
3. The future Project outsources the community management aspects of ranching and pen culture of sea cucumbers.

9.2 Recommendations

The Project research team concur with these recommendations, and agree that further research is warranted to deliver the community development and livelihood outcomes from the mariculture research conducted to date. Specifically, research is required to:

- Facilitate scale-up and extension of sandfish juvenile production systems developed at the NIMRF.
- Investigate appropriateness of alternative models for community engagement in sandfish mariculture in PNG.
- Develop gendered strategies for female integration in sandfish mariculture sector development in PNG.
- Leverage opportunities through formalised collaborative engagement with private sector to provide stable and sustainable governance of community-based sandfish mariculture.
- Develop economic models for family-managed ornamental commodities (i.e., giant clams and corals) production.
- Implement a range of strategies to enhance post-graduate training opportunities for mariculture technicians in PNG.

Progression towards development of a new follow-on mariculture Project in PNG has been hampered by a number of factors including COVID. It is recommended that with anticipated reduction of these impacts beyond 2021, development of a new project should begin as soon as possible to maintain current momentum.

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10.2 List of publications produced by this Project

10.2.1 Peer-reviewed scientific publications:

1. Braley, R.D., Militz, T.A., Southgate, P.C. 2018. Autofluorescence in embryos and larvae of the giant clam *Tridacna noae*: challenges and opportunities for epifluorescence microscopy. *Journal of Molluscan Studies* 84, 463-468.
2. Braley, R.D., Militz, T.A., Southgate, P.C. 2018. Comparison of three hatchery culture methods for the giant clam *Tridacna noae*. *Aquaculture* 495, 881-887.
3. Hair, C., Foale, S., Daniels, N., Minimulu, P., Aini, J., Southgate, P.C. 2020. Social and economic challenges to community-based sea cucumber mariculture development in New Ireland Province, Papua New Guinea. *Marine Policy* 117, 103940.
4. Hair, C., Foale, S., Kinch, J., Frijlink, S., Lindsay, D., Southgate, P.C. 2019. Socioeconomic impacts of a sea cucumber fishery in Papua New Guinea: Is there an opportunity for mariculture? *Ocean & Coastal Management* 179, 104826.
5. Hair, C., Militz, T., Daniels, N., Southgate, P.C. 2020. Comparison of survival, growth and burying behaviour of cultured and wild sandfish (*Holothuria scabra*) juveniles: Implications for ocean mariculture. *Aquaculture* 526, 735355.
6. Militz, T.A., Braley, R.D., Southgate, P.C. 2021. Factors influencing the capacity for pediveliger larvae of the giant clam, *Tridacna noae*, to ingest and digest cells of microalgae concentrates. *Aquaculture* 533, 736121.
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9. Simard, N.S., Militz, T.A., Southgate, P.C. 2019. Artisanal, shell-based handicraft in Papua New Guinea: Challenges and opportunities for livelihoods development. *Ambio* 48, 374-384.

10.2.2 Outputs from investigations which commenced in FIS/2010/054 and continued under this Project:

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12. Militz, T.A., Braley, R.D., Schoeman, D.S., Southgate, P.C. 2019. Larval and early juvenile culture of two giant clam (Tridacninae) hybrids. *Aquaculture* 500, 500-505.
13. Southgate, P.C., Braley, R.D., Militz, T.A. 2016. Embryonic and larval development of the giant clam *Tridacna noae* (Röding, 1798) (Cardiidae: Tridacninae). *Journal of Shellfish Research* 35, 777-783.

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10.2.3 Book chapters:

15. Militz, T.A., Southgate, P.C. 2021. Culture of giant clams. In: Shumway, S. (Ed.), Molluscan *Shellfish Aquaculture: A Practical Guide*. 5m Publishing, Sheffield.

10.2.4 Manuscripts in late draft:

16. Hair, C., Militz, T.A., Daniels, N., Southgate, P.C. Performance of a trial sea ranch for the commercial sea cucumber, sandfish (*Holothuria scabra*), in Papua New Guinea.

17. Militz, T.A., Southgate, P.C. Diurnal finfish activity on ocean-culture giant clam farms in Papua New Guinea.

18. Militz, T.A., Southgate, P.C. Environmental impacts of ocean-culture giant clam farms on substrata and fish assemblages.

10.2.5 Student theses:

19. Hair, C.A. 2020. Development of community-based mariculture of sandfish, *Holothuria scabra*, in New Ireland Province, Papua New Guinea. PhD thesis. James Cook University.

10.2.6 Student practicum reports:

20. Anetul, E., Laklen, J. 2019. Hatchery techniques and culture of sandfish, *Holothuria scabra*. BSc practicum report. Pacific Adventist University.

21. Lacklen, J., Anetul, E. 2019. Monitoring development of sandfish (*Holothuria scabra*) larvae fed on two different diets in controlled culture tanks. BSc practicum report. Pacific Adventist University.

22. Yendo, J. 2019. Density experiment for juvenile sandfish (*Holothuria scabra*). BSc practicum report. University of Natural Resources and the Environment.

11 Appendixes

11.1 Appendix 1:

Project Facebook posts from March, 2016 – March, 2021 (see Attachment)

11.2 Appendix 2:

Posters illustrating the actual minimum legal sizes of live and processed sea cucumbers designed, printed and distributed by Project staff to the three partner communities and posted on community notice boards.