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1 Acknowledgments

We acknowledge the inputs of numerous National Fisheries Authority (NFA) and Nago Island Mariculture and Research Facility (NIMRF) staff who supported establishment of full functional capacity of NIMRF during this project and the research reported. We also acknowledge the willing and enthusiastic engagement of partner community members, particularly Village Planning Committee and community members of Limanak, Ungakum and Enuk villages, and partner NGOs, including John Aini of Ailan Awareness and officers of the Wildlife Conservation Society who greatly assisted this project.

Executive summary

This project operated from the newly completed Nago Island Mariculture and Research Facility (NIMRF) in Kavieng, Papua New Guinea (PNG), which was purpose built to support mariculture research and training. Modifications to the facility during the project included extension of general indoor and outdoor culture facilities supporting replicated experiments with larvae and juveniles, additional raceways, construction of a seawater pond, expansion of pumping capacity, and upgrading of the seawater system to provide a more reliable water supply supporting routine production of target species.

Hatchery production of sea cucumbers (sandfish) was developed early in the project and by the final year of the project, routine production was managed by NIMRF staff, with 2-3 hatchery runs per year. Simplification of the larval rearing protocol by replacing cultured live micro-algae with commercial micro-algae concentrates as a larval food source, was an important development that eliminated many technical constraints often associated with hatchery production. This was a major breakthrough for this project with broad application within the global mariculture sector. A hatchery culture manual for sandfish was developed for training purposes. Land-based husbandry of hatchery-produced juveniles, however, was a bottleneck to production of large numbers of juveniles for field-based culture activities. Further research is required to address this issue and this aspect is a major focus of research in the follow-on project (FIS-2014-061[1]).

A range of land-based and community nursery systems were trialled and evaluated to produce release-size sandfish juveniles of >3 grams. Results provide a basis for ongoing fine-tuning of grow-out systems. Three local communities actively participated in sandfish field-based grow-out trials, supporting either experimental sea pens, ocean-based grow-out nets or trial sea ranches. Biophysical parameters were monitored at field sites, using protocols that were standardised with those used in similar ACIAR funded research in the Philippines, northern Australia and Vietnam[2]. They contributed to a multi-country, broad-scale experiment to identify optimum sea ranching habitats for sandfish. Pen culture grow-out results have been highly variable, for example, one site supported exceptionally high growth rates and survival of sandfish juveniles (compared to that reported internationally), while another suffered total mortality. Important information on the key biophysical parameters which drive growth has been collected. Multivariate analysis of bio-physical factors shows promise for identifying key factors influencing sandfish culture performance, with preliminary principal component analysis clearly differentiating prime sites. Preliminary research findings have been published and the results of a broader international study, including data from this project, are being prepared for publication. Both hapas and sea pens established at partner community field sites are cared for by community wardens who liaise with project staff. Considerable socio-economic data has been collected on past wild fishery practices with respect to sea cucumber, community-based fishery management and attitudes towards mariculture.

A primary site for spat collection of edible oysters was identified and the long-term spat collection program established in 2013. Collector design was modified to better suit local conditions. Plastic slats covered in a cement/lime slurry supported greater recruitment and better handling than other collector types and were adopted as a 'standard' across all project sites. However, relatively poor recruitment to spat collectors greatly limited the extent to which growth trials could be established. A grow-out trial was conducted at the

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[1] *FIS/2014/061: "Improving technical and institutional capacity to support development of mariculture based livelihoods and industry in New Ireland, Papua New Guinea"*

[2] *FIS/2010/042: ""Expansion and Diversification of Production and management Systems for Sea Cucumbers in the Philippines, Vietnam and northern Australia*"

main NFA wharf site in Kavieng, but oysters suffered close to 100% mortality in all treatments over a month-long period through predation by *Cymatium* gastropods that recruited to oyster culture units. In a follow-up trial using sub-tidal baskets on the floating pontoon at NIMRF, *Saccostrea cucullata* spat reached an average weight of 3.75 g while *S. mytiloides* spat reached 9-16 g after 8 months. Survival of both was relatively low at around 40%. When *S. cucullata* spat were deployed in intertidal baskets at Losogul and Panapai, those at Panapai performed better and reached an average weight of 3.45 g after 6 months with survival of 95%. Poor recruitment of oyster spat to collectors at all research sites limited the scope of grow out trials and is likely to limit the potential of spat-based oyster mariculture in the Kavieng region. Hatchery production of *S. cucculata* at NIMRF may provide a future option to address this bottleneck.

Field surveys of marine organisms with potential value to marine aquarium markets occurred in the first year of the project. They revealed several species of fishes, coral, and giant clams in New Ireland Province to be ideal candidates for mariculture. Surveys also revealed regionally endemic phenotypes of several Amphiprioninae (clownfishes) and research was undertaken to document the ecological parameters associated with these high value commodities. Successful production of “Nemo” (*Amphiprion percula*) was achieved in the second year of the project and successful production of the “maroon clownfish” (*Premnas biaculeatus*) was achieved in the third year of the project. By the final year of the project, production of these two species became routine at NIMRF, with several thousand market-sized individuals on hand. Coral propagation was also trialled at two field-sites and in land-based raceways. Production of corals was found to be optimal in community reef areas exposed to regular fishing activity. This has led to the development of semi-commercial scale culture (2,000 pieces biannually) in partnership with the Nago Island community. Ongoing research is evaluating the ideal coral substrates for propagation and the economic potential of this mariculture activity for local communities in New Ireland. In the last year of the project, the teardrop giant clam (*Tridacna noae*) was successfully cultured and this is the first documentation of captive production of this species.

Aquaculture curriculum development at the NFA National Fisheries College (NFC) progressed via an Aquaculture Training Package (ATP) which meets the requirements of the National Training Council (NTC) and was endorsed by the Fisheries Training and Advisory Committee (FTAC). Specific lesson plans were developed for the ATP and an Aquaculture Instructor has been recruited by NFA to begin implementing and delivering the ATP through the NFC and NIMRF. A series of best practice booklets have been developed for aquaculture operations with a focus on NIMRF activities, including a hatchery manual for sandfish and ornamental fish. Project staff contributed directly to development of Certificate 1 and Certificate 2 level mariculture curriculums for NFC students and have provided face-to-face tuition of these students. Graduate students from UNRE have also been accommodated within project research activities at NIMRF, working directly with project staff involved in sea cucumber and ornamental fish culture.

There were regular visits to NIMRF by project staff, commodity specialists and research students throughout the project, that have worked directly with NFA/NIMRF staff. Community members from Limanak, Ungakum, Belifu and Enuk have received training on field-based sea cucumber culture, survey techniques and data collection, and one or two community members from three of these communities were engaged to look after ocean nursery culture systems for sea cucumbers. Community members from all village sites have visited the NIMRF hatchery during operation and were given a live demonstration on aspects of life-cycle and culture methods. Short handouts have been developed to assist community awareness of field-based research activities with sea cucumbers and oysters. Both were developed through consultation with a partner local NGO (Ailan Awareness) and translated into Tokpisin. Larger more comprehensive extension materials were also developed to support future project activities. Regular community meeting were held to disseminate project research results and key points are delivered using a Tokspisin handout.

2 Background

The vast coastline of PNG supports numerous communities that depend primarily on marine resources for their livelihoods. The coastal environment and fish stocks are comparatively healthy, but beyond the immediate resource, communities do not maximise the potential economic and livelihood opportunities provided by this environment. There has been depletion of some fishery resources, including the collapse of the sea cucumber fishery, which was the main village-based fishery generating significant export income. In response, the NFA implemented a nationwide moratorium in September 2009. There was an urgent need for economic activities, as alternatives to the sea cucumber fishery, to provide livelihood opportunities for coastal communities in PNG, and the NFA was under political pressure in this regard.

There is no tradition of mariculture in the coastal communities of PNG, so awareness of possibilities is low. However, development of mariculture opportunities in PNG was enhanced by the NFA NIMRF at Kavieng, New Ireland Province. This multi-species marine hatchery and research facility, the first in PNG, was operational from 2012. The role of the facility is to develop marine aquaculture based livelihood opportunities for PNG and to become a training centre for students from the NFC. The NFC is located in Kavieng and, at the start of this project, hosted 2nd and 3rd year students from University of Natural Resources and Environment (UNRE) though a Memorandum of Understanding.

For NIMRF to achieve its desired impacts there was an immediate need for capacity building, and for identification of local species which have potential to support viable, sustainable mariculture industries for coastal communities in PNG. This project partnered with NFA, NFC and UNRE to address this, and to develop a strategy for long-term strengthening of institutional mariculture training capacity in PNG. This project addressed these capacity and feasibility issues.

Some scoping work was conducted in prior ACIAR projects (FIS/2006/138[3] and FIS/2010/017[4]) to identify marine commodities that may support community-based mariculture activities and income generation opportunities in PNG. This project assessed the potential of three major commodities identified in these prior studies: sea cucumbers, edible oysters and marine ornamentals, for which there are established national and international markets. All three are priority commodities within the PNG National Aquaculture Development Policy.

Overfishing of sea cucumbers, a traditional source of income for coastal communities in PNG, forced a nationwide moratorium on the fishery. Developing alternative means of income is an imperative, and one of the more obvious options is development of sea cucumber mariculture. Prior ACIAR research (FIS/2006/138) showed that the sea cucumber species, sandfish (*Holuthuria scabra*) can be reliably propagated in a hatchery and that 'sea-ranching' can be successfully undertaken using village-based culture systems (Hair et al., 2011). Another ACIAR project is further refining culture methods for sandfish (FIS/2010/042[5]), and this provided an opportunity, strong linkage and synergy for assessing current sandfish culture methods in PNG. Given the traditional importance of sea cucumber as an income source for coastal communities in PNG, closure of the fishery

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[3] *FIS/2006/138: 'Developing Aquaculture based livelihoods in the Pacific Islands region and Tropical Australia'*

[4] *FIS/2010/017: 'Building mariculture capacity in Papua New Guinea'*

[5] *FIS/2010/042: 'Expansion and diversification of production and management systems for sea cucumbers, in the Philippines, Vietnam and Northern Australia'*

because of depleted stocks, and high international demand for bêche-de-mer, developing sea cucumber mariculture in PNG is a high priority for the NFA. There is opportunity to introduce sandfish culture to communities in areas where the NFA have established seaweed culture. Sandfish and seaweed require similar habitats and can be co-cultured.

Edible oysters are consumed by locals and are also sold to hotels, restaurants and tourist facilities. Prior ACIAR research (FIS/2006/138) showed that oyster juveniles (spat) readily recruit to spat collectors in the Kavieng area and can be grown to market size within months. However, more research is required to optimise spat collection protocols and culture methods to maximise growth and survival. Oyster culture is well suited to coastal communities with limited technical capacity. Oysters are the only commodity with mariculture potential (identified in FIS/2006/138 and prioritised by NFA) which relates, albeit marginally, to food security, a priority issue for NFA.

A sustainable, equitable, and profitable marine aquarium trade in PNG was to be started through the SEASMART Program which began in 2008 though the contracting of a US-based consultancy firm EcoEZ Inc. The SEAMSART Program aimed to develop a commercial scale marine aquarium trade in PNG but failed to achieve any of the contractual milestones necessary for this to happen. As a result, the arrangement between the NFA and EcoEZ was terminated in 2010. NFA is currently 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. This project aimed to facilitate development of the NFA Marine Aquarium Program by assessing the feasibility of captive breeding of valuable marine aquarium species.

Strengthening institutional capacity for mariculture training in PNG, and appropriate training of mariculture graduates, are key priorities for the NFA. Prior to this project, the aquaculture component of the UNRE diploma and degree program was only three weeks long and focused on freshwater, not marine aquaculture (mariculture). A key component of sustainable mariculture development in PNG will be development of a separate training program focused on mariculture. The recent SPC joint-country strategy included a request from NFA for support with curriculum development for mariculture. This project reviewed aquaculture/mariculture training opportunities and curricula as a basis for developing an appropriate mariculture curriculum at NFC with an initial aim of developing a larger AusAID-funded university 'twinning' program'[6]. Given that there is no tradition of mariculture in New Ireland, another important step was to build mariculture capacity within local communities and extension organisations such as Provincial fisheries and appropriate NGOs, as a basis for long-term and sustainable mariculture development.

This project aligned closely with the SPC Aquaculture Action Plan (2007) which identified sea cucumbers and marine ornamentals as high priority commodities for aquaculture development within the region.

The project supported NFA priorities for development of Aquaculture as laid out in the NFA Corporate Plan 2008-2012 and the National Aquaculture Development Policy, and directly addressed a number of key components and research objectives outlined in the National Development Policy. Results provided an improved basis for the NFA to make improved decisions related to policy development for the target commodities of this project, and strengthen institutional, community and extension capacity to implement NFA's Aquaculture Development Policy at both national and provincial levels.

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[6] *The targeted AusAID twinning program was closed shortly after the start of this project. Furthermore, the training relationship between NFC and UNRE changed. As a result, the project shifted its focus towards independent assistance to NFC with mariculture curriculum development.*

3 Objectives

The overall aim of this project was to provide a sustainable basis for development of a mariculture sector in PNG, and to build capacity within country partner organisations to support this development. Specific objectives were to:

- Develop community based sea cucumber culture methodologies;
- Trial and assess other mariculture commodities; and
- Improve the capacity of PNG institutions to support mariculture development in New Ireland Province

Research activities within these Objectives were:

Objective 1: Develop community-based sea cucumber culture methodologies

- Identify suitable grow-out sites within the Kavieng area and establish village based partnerships
- Develop hatchery culture of sea cucumbers at the Nago Island facility.
- Refine raceway/tank culture methodologies for juvenile sea cucumbers and optimise transfer methodology
- Establish village-based culture facilities for nursery and grow-out culture
- Undertake village-based sea cucumber trials
- Training of local communities relating to field-based sea cucumber culture

Objective 2: Trial and assess other mariculture commodities

2.1 Oysters

- Identify potential spat collection sites
- Assess spat collection sites and spat collecting materials
- Identify appropriate grow-out sites
- Establish village-based grow-out trials
- Assess marketing options and business case for cultured oysters

2.2 Aquarium species

- Review regional aquarium industry
- Conduct a business case study to establish industry feasibility
- Undertake scoping studies to identify high value or highly demanded species that might be suited to captive breeding (fish) and propagation (corals)
- Establish captive breeding program at the Nago Island facility to generate information on the culture performances of a small number of key fish species
- Establish land-based and field-based coral culture trials at Nago Island to generate culture information for key species.

Objective 3: Improve the capacity of PNG institutions to support mariculture development in New Ireland province

3.1 Develop and initiate a strategy for long-term institutional mariculture training capacity in PNG

- Review the current curriculum and practical training in mariculture at NFC/UNRE
- Develop a strategy for improved training capacity in mariculture
- Develop and submit a university "twinning" application in consultation with AusAID.

3.2 Build capacity amongst NFA, Provincial fisheries, NGOs and local communities

- Appoint an appropriately qualified expatriate Project Scientist to be based at Nago Island
- Establish a steering committee comprising project staff, NFA, Provincial fisheries officers, and representatives from NGOs and communities to guide project activities
- Support Nago Island facility operations and production of selected species (i.e. technology transfer, expert personnel)
- Develop mariculture training activities with key communities using local counterparts as liaison and facilitators
- Train specific community members of participating villages to undertake project activities (i.e. hands-on training, workshops)
- Develop manuals on specific aspects of selected culture commodities to support workshops and other training activities

4 Methodology

Objective 1: Develop community based sea cucumber culture methodologies

The sea cucumber component of the project was based on production of the commercial holothurian, *Holothuria scabra* (common name, sandfish). It was conducted at the NIMRF multi-species hatchery and at field sites within two hours boat travel of the NIMRF. Two to three sea cucumber hatchery runs were carried out each year as training exercises for the hatchery staff and to produce juvenile sandfish for use in experiments and other aspects of the project. Hatchery experiments included research into ways to increase production (i.e. better survival and growth of larvae and small juveniles through husbandry and system improvements). An important component involved research to assess the use of commercially available micro-algae pastes to rear larvae and juveniles. The grow-out of juveniles after the larval rearing phase from approximately 3 mm in length (or one-month old) up to the recommended release size of 3 g, is a major bottleneck in the scaling-up of *sandfish* culture. Much of the research at NIMRF has focused on identifying ways to improve survival and growth during this nursery stage. A proportion of the juveniles produced were grown to the minimum recommended release size of 3 g (Purcell and Simutoga 2008) within ocean and land-based nursery systems, including tanks, raceways, hapa nets and bag nets. Hatchery experiments and field trials were carried out to identify ways to increase juvenile survival and growth in all the grow-out systems utilised. Juveniles of ≥3 g size were tagged with fluorochromes and stocked into round 100 m^2 sea pens (part of a large-scale experiment in collaboration with ACIAR Project FIS/2010/042) at village sites. Survival and growth of sandfish in these pens were monitored at regular intervals for up to two years.

Field sites for sea cucumber mariculture were identified in collaboration with NFA officers, community members and local NGOs. Site selection was based upon: presence of suitable juvenile sandfish habitats as suggested by Purcell (2004) and Tsiresy *et al*. (2011); proximity of a community to release sites; willingness of the community to be involved in the study; and a range of socio-economic aspects related to each community. The three sites selected were: (1) Limanak (encompassing Limellon and Nusailas); (2) Enuk; and (3) Ungakum. The first two sites are located close to NIMRF in the Tigak Island group and the third is on the north east side of New Hanover (Lavongai) in a large lagoon. GPS was used to map all sampling areas and to classify the habitats in relation to their suitability for sea cucumber mariculture activities. These sites provided a range of habitats, environments and social situations for research. A participatory approach was employed in the establishment and management of the trial sites and prospective sea ranches. Partner communities at each site were involved in all aspects of the research from the time the juveniles left the hatchery. Local community members were paid to assist with the research at each village, and to maintain the experimental and grow-out systems between visits by project staff. The broader community was kept up to date with research progress via regular meetings.

Juveniles were released into the wild using the methods detailed by WorldFish (Purcell 2004) but also reared in different release micro-habitats and using different grow-out systems developed in the Philippines (Juinio-Meňez et al. 2012) and Madagascar (Tsiresy et al. 2011, Robinson and Pascal, 2012) and as demonstrated to be effective in PNG. Initial ocean-rearing trials were done in 100 m^2 sea pens using methods developed in collaboration with scientists from FIS/2010/042, in order to produce directly comparable data. A number of rearing systems were tested to determine what level of protection is most effective in various habitats for various sized juveniles. In the last year of the project, large-scale releases were made into sea ranches, set up with partner communities, also using methods developed with FIS/2010/042. Techniques for collection and analysis of biophysical data were also developed collaboratively with FIS/2010/042. Data on spatial

and temporal variability in release micro-habitat variables (seagrass species diversity, seagrass cover, canopy height, epiphyte growth, sediment penetrability, anoxic layer, sediment organic matter and chlorophyll-*a* content, and grain size) were collected in order to identify the optimum release habitat for 3 g sandfish juveniles.

The social constraints and opportunities relating to development of mariculture as an alternative source of livelihoods in collaborating communities were also investigated. Community members were surveyed on: (1) the compatibility of community attitudes to marine resource management with development of mariculture; (2) attitudes to 'farmed' products compared to wild harvest; and (3) the differential roles for men and women and their implications for livelihoods. Pre-aquaculture interviews were conducted by Cathy Hair during this project. However, extension of the sea cucumber fishery moratorium meant that commercial village mariculture activities could not be initiated, therefore social-economic factors relating to success, or otherwise, of mariculture were not assessed. This aspect is continued in the follow-on project (FIS/2014/061).

The sandfish hatchery was overseen by De'arne Kershler (AVID), assisted by NFA aquaculture technician, Esther Leini. A JCU PhD student, Nguyen Duy, conducted most of his larval sandfish research at NIMRF, and provided larval rearing training to Esther Leini, who assumed responsibility for the hatchery in mid-2015.

The field research was overseen by Cathy Hair. She was employed full-time on this Project as Principal Research Scientist. The sea cucumber research was assisted by the PNG-based Research Scientist, Rowan McIntyre, up to mid-2015. NFA technicians Peni Bitalen and Posolok Kanawi were trained in (and assisted with) all research and field activities. A senior technician, Nicholas Daniels, joined the team in early 2016. Research outputs from this Project were complementary to (and augmented) those from FIS/2010/042 and the Project benefitted considerably from this linkage. Ms Hair also spent 20% of her time overseeing extension of sea cucumber sea ranching activities in northern Australia within FIS/2010/042. Ms Hair is undertaking a part time PhD on development of community-based sea cucumber mariculture during the Project, and this continues in the follow-on project. Her research was supervised by Paul Southgate, Dr Simon Foale of James Cook University's Department of Anthropology as well as Dr David Mills (WorldFish).

Objective 2: Trial and assess other mariculture commodities

2.1. Edible Oysters

The edible oyster culture component of this project was undertaken using routine methodology for these species. Established edible oyster spat collection methods were used in an extended spat collection program (Muthiah, 1987). Oyster grow-out was also undertaken using a range of proven culture method with oysters grown in trays or baskets held on racks in shallow intertidal sites; results were used to assess the relative merits of each. Inexpensive culture units made from local materials were also investigated. Due to the different collection and grow-out requirements of oysters, different communities were involved in this research. The NFA wharf (Kavieng) was selected as the initial site for spat collection and oyster growth trials, and research was later extended to two community sites (Losogul (Manne) and Panapai).

The study addressed questions relating to the potential of more distant markets such as hotels and resorts in Port Moresby and other parts of PNG. A business case study was conducted to assess the long-term economic feasibility of oyster culture in Kavieng. It assessed marketing options and value-chain bottlenecks and opportunities. The business

case study was undertaken by a value chain specialist involved in the ACIAR-PARDI[7] project.

All edible oyster research activities were carried out by Rowan McIntyre, the NIMRF-based Project Scientist. He was assisted by and trained NFA technicians, Casper Dako, Peni Bitalen and Posolok Kanawi.

2.2 Aquarium Species

There were five elements to this component of the project: (1) a desk-top review of the marine aquarium industry; (2) a business case study; (3) a field-based scoping study; (4) a captive breeding program was established at the NIMRF for fish; and (5) land and field-based coral culture trials were established at Nago Island to generate culture information for key species.

A desktop review was undertaken to assess the current status of the aquarium industry for fish and corals from PNG. The study considered the major species, wholesale and retail prices, suitability of species for holding and transportation, major transport nodes and main markets. The study provided baseline information for a business case study and was conducted by aquarium industry experts.

A business case study was conducted to assess the long-term economic feasibility of developing a marine ornamental industry in Papua New Guinea. Based on information from the desktop study, it assessed the value chain and the strengths and weaknesses of each component within the chain, as well as the economic feasibility, costs involved with capture, transport, holding, and assessment of economic feasibility. The study made recommendations on relevant development strategies for the marine aquarium trade in PNG

A two-week field-based sampling study was conducted in the Kavieng region to record species with commercial potential in the marine ornamental aquarium trade. Survey work was conducted using diver-based census methods as well as capture of some species for transfer to the aquarium system at NIMRF. Survey results were cross-referenced to the desktop study and provided a narrower focus of the species with aquarium potential in the Kavieng area. Furthermore, it identified local colour morphs of popular aquarium species, which have particularly high value in the aquarium trade. The census produced a short list of species that are in high demand by the aquarium industry and amenable to captive breeding and transportation. A small number of fish and corals were identified for assessment of their suitability for captive breeding.

Established pairs of key species with culture potential were captured from the wild, and breeding pairs of fish were established in aquaria at NIMRF and were maintained by NFA staff following appropriate training. Culture of “Nemo” (*Amphiprion percula*) was prioritised as the desktop review showed this species to be the most significant export from the PNG aquarium fishery in terms of both value and volume. This species was also the only organism with wild collections approaching the annual total allowable catch limit (84.8 % of limit collected) set for the fishery. The second target species was *Premnas biaculeatus* as select phenotypes of these species represented the highest value export commodity for the marine aquarium trade in PNG.

Given the CITES Appendix II listing of hard corals (Scleractinia) there is a need to establish captive production of such species to facilitate exports. The field surveys identified species of blue and yellow *Acropora* of interest to the marine aquarium trade. These species were cultured asexually through fragmentation in tanks and field culture systems at NIMRF. Research in various aspects relating to the growth rates and survival

[7] *PARDI – Pacific Agribusiness Research and Development Initiative*

of these species was (and continues to be) undertaken. The coral propagation outputs of the project were completed with assistance from the Nago Island community, who received training in the establishment and long-term maintenance of a field-based coral farm.

A private company, EcoAquariums PNG, began export of wild-collected fish from PNG to aquarium markets in the USA and Europe in 2011. It also developed community-based coral culture in PNG to promote sustainable aquarium supply practices and income generating opportunities. EcoAquariums PNG was aware of the objectives of this Project and expressed interest in developing a collaborative linkage. Discussions with EcoAquariums PNG were held during the early stages of this project with a view to developing this collaboration. EcoAquariums PNG were consulted during the business case study in this Project to which it had significant input. However, EcoAquariums PNG ceased operation during the first year of the project and there was no further input.

Field surveys also revealed a high abundance of the teardrop giant clam, *Tridacna noae*, which was recently 'resurrected' from synonymy with *T. maxima* and is a sought-after aquarium species. Broodstock clams were collected and spawning was undertaken with successful production of settled juvenile clams achieved in the final year of this project.

All aquarium species activities were carried out by Thane Militz, JCU PhD student and Project Scientist, with assistance from professional marine aquarium operators. Antoine Teitelbaum and Tony Nahacky are industry leaders in sustainable collection of marine aquarium fish in New Caledonia and Hawaii, respectively. Both Antoine and Tony participated in the desktop review of the PNG aquarium industry, the business case study, and field-based scoping studies. The mariculture activities at NIMRF were carried out by Thane Militz with assistance from NFA technicians, Casper Dako, Noah Piliman and Steven Namangan. These technicians received direct training from Thane in relation to facility maintenance and mariculture of fishes, corals, and clams.

Objective 3: Improve the capacity of PNG institutions to support mariculture development in New Ireland province

3.1 Develop and initiate a strategy for long-term institutional mariculture training capacity in PNG

This project's original concept partnered JCU with NFA, NFC and UNRE and provided an opportunity to develop institutional capacity for delivery of high quality mariculture graduates. Completion of the NIMRF provided much broader capacity to support the training and research of high quality graduates and to broaden the scope of training in terms of species and general mariculture practices.

Preliminary discussions with AusAID indicated support for development of a 'twinning' program to enhance university capacity and in this case specifically mariculture training capacity in PNG. A major output of this Project objective was initially to be an application to AusAID for support for a twinning project between JCU, NFC and UNRE. However, the targeted AusAID twinning program was closed shortly after the start of this project and the relationship between NFC and UNRE changed. As a result, the project shifted its focus marginally towards independent assistance to NFC with mariculture curriculum development.

The aquaculture curriculum at NFC was developed independently of UNRE using the expertise of Dr. Gay Marsden (Aquaculture lecturer from Broome TAFE, Australia) who developed an Aquaculture Training Package (ATP) to meet the requirements of the National Training Council (NTC). The Package was subsequently endorsed by the Fisheries Training and Advisory Committee (FTAC). Specific lesson plans were developed for the ATP and an Aquaculture Instructor was recruited by the NFA (Ms. Philomena Sinkau) to begin implementing and delivering the ATP through NFC and NIMRF.

3.2 Build capacity amongst NFA, Provincial fisheries, NGOs and local communities

This Project involved NFA aquaculture officers, Provincial Fisheries extension staff, local NGOs and communities. Qualified Project Scientist, Rowan McIntyre (to 2015) and Thane Militz (2015-present) were based full-time at NIMRF during the project. A 'steering committee' composed of project staff and local partners was established to guide and coordinate project activities on the ground in New Ireland, soon after the start of the project and roles and responsibilities of participants were designated at the first meeting.

With support from Project staff, NIMRF staff produced juvenile sandfish for distribution to partner communities and were responsible for setting up edible oyster spat collection systems and supplying spat for village grow-out. Additional hatchery-produced aquarium species were introduced as the Project progressed including fishes (*Amphiprion percula* and *Premnas biaculeatus*), corals (*Acropora* spp.)*,* and giant clams (*Tridacna noae and T. maxima*). For other commodities (e.g., micro-algae and rotifer production used for hatchery culture activities) on-going training was provided through the permanent presence of the Project Scientists at NIMRF, technical and trouble-shooting support from Peter Graham of QDEEDI and Jamie Whitford (consultants), regular visits and hands-on training from commodity experts, targeted workshops and dedicated extension materials. In addition to the transfer of production technology and day-to-day running of NIMRF, they also gained experience in experimental and equipment design, sampling methods, data collection and management, reporting and project management. NFA personnel were involved in all project and research management decisions and had an important role in guiding Project strategy and activities.

Ailan Awareness (AA) was the main NGO partner in this Project but ties were also established with Wildlife Conservation Society (WCS). Both organisations have strong relationships with village groups and undertake active extension and awareness programs in a variety of marine conservation and community-based fisheries management topics. Their role(s) included assistance with site selection, facilitating dissemination of project results, training workshops and liaison with village leaders and project workers to maximise project benefits to communities.

In the New Ireland community, village representatives (appointed by village leaders) were the primary point of contact for the Project and were informed of Project outputs through regular meetings. For day-to-day running of the Project, one or two people from each participating village were trained and paid a stipend to assist with data collection and maintenance, and security of experimental set ups. These assistants received training and all equipment necessary to fulfil their duties. Project staff supported the village casuals through frequent visits, and supply of phone credit for communication. Capacity was further strengthened by community participation in hands-on training relating to specific aspects of project research (e.g., establishing enclosures for sea cucumber juveniles, establishing grow-out sites for oysters or deploying spat collectors, establishing grow-out sites for corals). Methods for community-based mariculture of sandfish are not yet finalised and it is too early for a manual on village sandfish ranching[8]. However, an educational poster has been produced and regular slide nights provided information to enhance familiarity with the concepts.

Commercial-sized sandfish have been produced during the life of this Project but could not be marketed because the moratorium on sea cucumber fishing (and bêche-de-mer trade) in PNG was in place for the entire Project. NFA is responsible for developing future sea cucumber management policies and results of the sea cucumber component were provided to NFA to guide these policies. Further, Project staff were available to provide input if requested by NFA. Good communication lines were established with NFA fisheries managers to facilitate this process.

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[8] *Continuing knowledge gaps are being addressed in the follow-on project FIS-2014-061*

5 Achievements against activities and outputs/milestones

Objective 1: Develop community-based sea cucumber culture methodologies

no.	activity	outputs/ milestones	completion date	comments
1.1	Identify suitable grow-out sites	Selection of suitable grow-out sites in Kavieng area.	Y1, M3	The three project sites (Limanak / Limellon, Ungakum, and Enuk) were selected. These sites were the primary data collection and community engagement sites.
		Establish village-based partnerships	Y1, M3	Strong village-based partnerships were established at all sites. Awareness meetings were conducted at all sites and the communities were fully engaged and committed to the project aims. Local NGOs, Ailan Awareness (AA) and Wildlife Conservation Society (WCS) assisted in regular community engagement activities.

1.2	Hatchery culture of sea cucumbers	Two successful hatchery culture runs per year. Sufficient juveniles to support other research activities	Y1,M3 - Y4,M6 Y1,M3 – Y4,M12	Two to three hatchery runs were completed. More consistent larval culture conditions resulted from a full NIMRF facility upgrade (completed in mid-2016): installation of new submersible pumps to triple existing seawater supply to facility; construction of swirl separator filtration for particle removal and an 8T sand filter; simplification of seawater delivery pipework within facility; and a hatchery ring line constructed to regulate water quality to larval rearing tanks. Reliable production methods support routine production of tens of thousands of early juveniles, and thousands of larger juveniles (>1 g), sufficient to support planned research activities Hatchery production benefitted from the input of Duy Nguyen who developed a routine hatchery protocol for sandfish at NIMRF. Ms. Esther Leini (NFA hatchery technician) is now competent to produce sandfish juveniles through hatchery culture without instruction. A hatchery culture manual was produced to support staff training. Hatchery culture of sandfish larvae and juveniles using commercially available micro-algae pastes as a food source has simplified culture methods and eliminated a major technical bottlenecks (live micro-algae production). The PhD research of Duy Nguyen showed that micro-algae pastes support good survival rates of larvae through to the early juvenile stage (e.g. 13.7% survival to a size range of 0.5-10 mm) (see section 5). A 20 x 25 m earthen saltwater pond was constructed at NIMRF in 2015 in order to provide a secure holding facility for 200 broodstock sandfish to support future hatchery production. JCU Honours student Samantha Nowland showed that genetic variation among a range of PNG sandfish populations was very low. PNG populations are largely panmictic, but distinct from the northern Australia population. These results provide valuable information relating to sea cucumber translocation and broodstock use.

1.3	Refine race-way tank culture methods and transfer methods.	Reliable production of juveniles for transfer to field based culture systems. Improved survival of juveniles and reduced tank-culture duration.	Y1,M3 - Y4,M8 Y1,M3- Y4,M12	There is limited capacity to grow large numbers of juveniles to release size (>3 g) using NIMRF land-based facilities. Despite relatively slow growth in ocean nursery systems, they remain an essential step in the production process. Young hatchery-produced juveniles are grown out in floating, fine-mesh bag nets deployed in protected channels at Ungakum and Enuk village sites. Best results were gained through good husbandry (cleaning) and regular exchange of fouled nets. Local village labour is used to clean and maintain nets, with supervision by NIMRF staff. Land-based culture systems for juveniles now include four fibreglass raceways in addition to the existing four plastic raceways. The NIMRF seawater pond became operational in December 2015. Early juveniles can be transferred directly from larval rearing tanks to fine mesh hapa nets in the pond (*sensu* Vietnamese grow-out system). This has reduced tank-culture duration and provided additional area for production of release-size juveniles.
1.4	Establish village-based culture facilities.	Three secure field sites supporting project research. Culture sites that can be supported through village and provincial fisheries input.	Y1,M8	Three secure field sites were established to support project research: Limanak / Limellon (Tigak), Ungakum (Tsoi) and Enuk (Tigak). Ungakum and Enuk are used for the bag net grow-out of early juveniles (ocean nursery phase). All three sites were used for sea pen experiments. Trial sea ranches have been established at Limanak and Ungakum during this Project. Community groups at all project sites are very supportive of the project. Project team members were active in community work and dissemination of information to communities. The point of contact in most villages is the Village Planning Committee. Ocean nursery systems such as bag nets (Ungakum, Enuk) and sea pens (all three sites) were maintained by community members who receive a modest stipend. Community members have helped to build and maintain other experimental systems and are involved in data collection and monitoring. Local NGOs (AA and WCS) are also involved. We were unsuccessful in recruiting a Provincial Fisheries Officer to participate in the project.

1.5	Undertake village-based sea cucumber culture trials.	Information basis for improving field-based culture methods Improved growth rates and survival of field-cultured sea cucumbers	Y1,M8 – Y4,M12	Four round 100 m^2 sea pens (part of a large-scale experiment in collaboration with ACIAR Project FIS/2010/042[9]) were deployed at the village sites and each stocked with 200 fluoro-chrome tagged juveniles (>3-g). Survival and growth of sandfish in these pens was monitored at regular intervals for up to 2 years. Highest survival was at Limanak 1 (93%), followed by Limanak 2 (87%), Enuk (53%) and Ungakum (0%). Limanak 1 sandfish showed the best growth, with commercial size sandfish after one year. Subsequent pens installed at Ungakum and Limellon also showed promising survival and growth. Reduced pen density led to higher individual sandfish sizes. Short-term protection did not improve survival in sea pens. Maximum carrying capacity ($g.m^2$) varied depending on specific site characteristics. The first trial sea ranch was established at Limellon (part of the Limanak community) in September 2015. This 7 ha site has been surveyed twice for biophysical characteristics using standard methods. Wild sea cucumbers were surveyed before and after the release of 3,000 fluorochrome-tagged, cultured juveniles. Ongoing research will monitor survival, growth and movement of juveniles within the sea ranch. A sea ranch has also been established at Ungakum and pre-stocking sea cucumber and biophysical surveys completed. Preliminary consultation has been started with the Enuk community regarding a sea ranch in their marine tenure area. Biophysical parameters (habitat features and sediment chemistry) are recorded from sea pens and sea ranches at routine sampling times. Sediment organic matter and chlorophyll-*a* content, and grain size are analysed at NIMRF. Habitat monitoring methods have been developed and shared with Philippine and NT partners (ACIAR Project FIS/2010/042) for multi-country comparisons. Multivariate analysis clearly differentiates the pen habitats and indicates the key features of good grow-out sites (i.e. high survival and growth). Novel GIS techniques are being explored via high resolution, multispectral band satellite images for habitat classification and prediction of 'good' culture sites. 'Pre-aquaculture' interviews to gather information on community attitudes to the sea cucumber fishery and mariculture adoption have been carried out in Limanak, Ungakum and Enuk.
		Better understanding of environmental factors influencing growth rates and survival during field- based culture Better understanding of the social constraints and opportunities relating to development of		

		mariculture as an alternative source of livelihoods		
1.6	Training of local communities	Key community members trained in sea cucumber culture methods in partner communities Increased capacity within communities to support expansion of sea cucumber farming	Y1,M7-Y4,M12	At least 10 men, women and youths from partner communities were trained in building, deploying and maintaining field-based culture equipment and in on-going monitoring of sandfish performance. A stipend was paid to individuals who maintain project grow-out systems (pens or bag nets) at each village site. Because Ungakum is more distant from NIMRF, project partners also collect basic field data at this site. Project activities have promoted awareness among villagers of the life-cycle, culture and husbandry of sea cucumbers and fisheries management issues. Discussion with community members have revealed deep concern about the fate of the sea cucumber fishery when the current moratorium is lifted. There is strong interest in mariculture options and a desire to improve community-based management of the sea cucumber resource. Project staff and local NGOs (AA, WCS) have encouraged these initiatives. Project staff have collaborated closely with WCS to integrate sea ranch management in the natural resource management plans of Ungakum and Limanak communities (prepared by the community with help from WCS). A poster to explain various project activities and the functioning of a sea ranch has been designed to accompany recent sea ranch developments (Appendix 1). Posters were distributed to participating villages in late 2016 to improve awareness of sea cucumber mariculture opportunities.

PC = partner country, A = Australia

[9] FIS/2010/042 *"Expansion and Diversification of Production and management Systems for Sea Cucumbers in the Philippines, Vietnam and northern Australia*"

Objective 2: Trial and assess other mariculture commodities

Objective 2.1: Edible oysters

no.	activity	outputs/ milestones	completion date	comments
2.1.1	Identify potential spat collection sites	Establish five spat collecting sites in the Kavieng area.	Y1,M6	A primary site for spat collection was established at the NFA wharf in Kavieng. This site has high natural recruitment of oysters and restricted public access. On this basis it was selected to function as the main project site for research into recruitment, growth and culture of edible oysters. Spat collectors were also deployed a two additional sites within Kavieng Bay but were removed after one-year because no recruitment was recorded. A number of problems were encountered relating to wave action, boat activities, and shipworm that forced changes to collector types, locations and methods of deployment.. The spat collection program was extended to include two community sites: Losogul (Manne) and Panopai. These sites and the main wharf site differ in environmental characteristics.

2.1.2	Assess spat collection sites and spat collector materials	Establish spat collectors at each site and maintain spat collector program for duration of project. Information on the relative recruitment of oysters at each site over time. Assessment of the effects of depth and spat collector material on recruitment.	Y1,M6 – Y4,M12	Recruitment of oyster spat was spasmodic and initially very low. However, changes made to the spat collecting system (see 2.1.1) had a positive impact on recruitment with the first significant numbers of spat collected in February, March and April, 2014. To further increase collection numbers, further improvements were made to the collection systems. A trial was conducted at the NFA wharf site comparing the effectiveness of plain PVC slats and PVC slats covered with a cement/lime slurry. The cement/lime slurry collectors had higher recruitment than plain PVC collectors. The cement/lime slurry collectors also made it easier to remove the spat and improved the survival of the spat during and after the removal process. The "recipe" and application of the slurry has been refined to suit local conditions and the collectors. The slurry coated collectors were then used at the standard collectors across the three sites. Alternative collectors made of bamboo, PVC conduit and old "Pin" shells (*Polymesoda erosa*) were deployed at each of the three sites to compare their effectiveness as spat collectors against the slurried commercial collector. The alternative collectors deployed at the Wharf site were abandoned because of weather conditions/boat traffic. The shell pens were the most successful of the alternative materials at Losogul but failed to collect any spat at Panopai. The bamboo and conduit collectors failed to collect spat at either site and were removed. Pin shells deployed vertically through the water column, were used to assess the preferred depth of recruitment at Losogul. The shells were deployed every 10 cm from the substrate to the high tide mark. If the high tide mark is 0 cm, the greatest recruitment was recorded between -60 and -120 cm. Samples of adult oyster were collected every 6 weeks from the NFA wharf site from mid-2013. They were analysed to determine reproductive activity and to validate spat collection data. Two species of oyster were identified in the Kavieng area, *Saccostrea cucullata* and *S. mordax.* A third species of oyster was identified during the grow out trial and was provisionally identified as *Striostria mytiloides*. A fourth oyster recorded at Losogul was identified as a *Dendostrea* species.

2.1.3	Identify appropriate grow-out sites	Mapping suitable grow-out sites in Kavieng area Establish village based partnerships At least three secure field sites supporting project research Culture sites that can be supported through village and provincial fisheries input	Y1,M6 – Y1,M12	A primary site for spat collection and grow-out trials with oysters was established at the NFA wharf site in Kavieng. This site has relatively high natural recruitment of oysters and restricted public access and functioned as the main site for project research into growth and culture of edible oysters. Following negotiations with landowners facilitated by a project partner NGO (Ailan Awareness), grow-out trials were established at the two community sites -Losogul and Panopai. The Panopai site is within an area to be established as a marine protected area and is close to the landowner's house for increased security. Large numbers of oysters can be observed at the community and they are used to supply the fish processing plant.

2.1.4	Establish village based grow-out trials	Establish growth trials at least three secure field sites Determine growth rates under different culture conditions Identification of factors that maximise growth and survival Information that will be used in training and extension	Y1,M12	See comments for 2.1.2 and 2.1.3. Poor recruitment to spat collectors limited the extent to which growth trials could be established. A grow-out trial was conducted at the main NFA wharf site with spat collected in 2014. However, oysters suffered close to 100% mortality in all treatments over a month-long period as a result of predation by *Cymatium* sp. (a gastropod) that recruit to culture units directly. Limited availability of oyster spat from poor recruitment to collectors resulted in only small-scale growth trials being established at each site. Due to high levels of predation in initial trials at the wharf site, a new trial was set up using subtidal baskets on the floating pontoon off NIMRF. Spat were individually labelled and photographed so their grow rates and morphological changes could be observed overtime. The morphologically differences observed overtime allowed differentiation of the species; primarily *Saccostria cucullata* and *Striostrea mytiloides*. After 9 months *S.cucullata* spat reached an average weight of 3.75 g whereas the only surviving two *S. mytiloides* spat reached weights of 9.24-16.3 g after 8 months. Although a higher survival rate was achieved than at the wharf site, survival was relatively low at 40%. *S. cucullata* spat were deployed in intertidal baskets at Losogul (n=40) and Panopai (n=40). The spat at Panopai reached an average weight of 3.45 g after 6 months with a survival rate of 95% whereas mass mortalities were observed in the initial weeks at the Losogul site. The influence of a tidal creek, high turbidity and lower salinity of the Panopai site differentiate it from the others and may be responsible for the lack of *Cymatium* sp. recruitment.
2.1.5	Assess marketing options and business case for cultured oysters	Detailed business case study completed Assessment of various marketing options and supply chain issues for Kavieng oysters	Y1,M12	An economic assessment of the potential of edible oyster culture in Kavieng and potential marketing options was begun in late May 2013 as scheduled. A preliminary assessment of potential markets was completed; however, full assessment of the business case requires (the anticipated) recruitment and growth rate (production) information that unfortunately did not become available during this project.

PC = partner country, A = Australia

Objective 2.2: Aquarium species

no.	activity	outputs/ milestones	completion date	comments
2.2.1	Industry review	Review of regional aquarium supply industry. Identification of key markets, most important species (groups), holding and transport mechanisms and bottlenecks.	Y1,M6	Historically, there have been two marine aquarium exporters operating out of PNG. The first was a NFA contracted consultancy group, EcoEZ Inc., that implemented the SEASMART Program in PNG from 2008-2010. This encompassed commercial exports. Funding to the program was terminated by NFA in 2010 as a result of EcoEZ Inc. failing to complete contractual milestones. A review of the EcoEZ, Inc. supply chain was undertaken by PhD student, Thane Militz, in 2013 and identified several weaknesses addressed in section 2.2.2 (below). The second marine aquarium exporter operating out of PNG was EcoAquariums Ltd. This NFA-subsidised private entrepreneur engaged in commercial exports from 2011-2012. Alpha Reef – Aquarium Consultancy was hired to review the company's operations while still commercially active in July/August 2012. The draft report was submitted for review in November 2012. It satisfied all terms of reference and identified key markets, most important species (groups), holding and transport mechanisms and bottlenecks. It identified transport as the main bottleneck to development of the ornamental industry in PNG (see also Kinch, 2008). A second post-operational review of EcoAquariums Ltd. was carried out by Thane Militz in 2014. This review identified the wild fishery to be highly selective of not only fish species, but also specific colour morphs. This selectivity raises sustainability concerns as the most demanded colour morphs tended to be the least common in natural populations, where studied. Starting in 2013 a locally run company, Paradise Aquariums in Port Moresby, began supplying the domestic market. As of 2014 domestic trade volume was less than 100 fish per annum. Given the small trade volume domestically, the primary market focus would need to be the international market in order to reach trade volumes capable of supporting livelihoods.

2.2.2	Conduct business case- study	Assessment of PNG ornamental supply/value chain and identification of weaknesses. Detailed business case-study completed.	Y1,M8	A retrospective assessment of the Seasmart Program from 2008-2010 revealed several major weaknesses in their supply chain: 1) A large proportion of fish and invertebrates caught by communities were rejected by the company. A thorough analysis of this topic was undertaken (Militz *et al*. 2016). 2) A large proportion of fish and invertebrates purchased by the exporting company died prior to export. 3) Further losses of fish and invertebrates were incurred during transport to the end market. A thorough analysis of both (2) and (3) was undertaken in comparison to other supply chains operating in the Pacific (Militz *et al.* in prep). 4) The high cost of freight. This has been reviewed in detail (see 2.2.1 or Kinch, 2008). A detailed business case-study for New Ireland to supply marine aquarium species to the global marketplace identified freight costs as the major bottleneck. A consumer-based market study was also launched in 2015 through the projects Facebook page. The findings reveal consumer preference for PNG products over competing markets in Vietnam, Indonesia, and the Philippines. The results of this study are now published as Militz et al., 2017. As a direct measure of feasibility, a trial shipment of wild-caught and aquacultured marine aquarium fish was conducted in May 2015. Fish were collected/reared in Kavieng and shipped to Singapore. The exercise highlighted difficulties in obtaining live fish packaging materials and expensive shipping with domestic airlines (Air Niugini) applying live-animal surcharges intended for shipping mammals or birds. All fish survived transport to Port Moresby (POM) but, in the case of Singapore, the need for repacking prior to on-shipping would require a main export facility to be based in Port Moresby. The Australian market would be the most economically feasible due to regular flights, allowing regional locations to supply fish to Australia without need for repackaging in POM. However, no exports of marine aquarium fish have ever been sent to Australia due to quarantine requirements. This aspect is a component of the follow-on project (FIS/2014/061) that will assess feasibility of transporting cultured fish and clams to Australia in collaboration with a major aquarium market retailer.

2.2.3	Undertake local species surveys to identify valuable species and collect potential brood fish for hatchery production	Comprehensive list of local species (fish and coral) with potential in the aquarium trade A short list of species with the greatest aquaculture potential Identification of species/forms endemic to the Kavieng are Capture of individuals to be held in aquaria at Nago for identification Pairing-up potential breeding pairs of commercially important fish species (e.g. clown-fishes)	Y1,M10	A comprehensive species survey (fish) was conducted in June 2013 by Tony Nahacky (Hawaii), Antoine Teitelbaum (New Caledonia) and Thane Militz (Australia), with a focus on identifying high-value species in the Kavieng area. Reports on species with potential to support a wild-harvest fishery (Nahacky and Teitelbaum) and of high aquaculture potential (Militz) were completed. **FISH** Several members of the subfamily Amphiprioninae (clownfish) were identified to have regionally endemic phenotypes representing a high-value commodity in the aquarium trade. A second, more detailed, survey focusing exclusively on this group of fish was conducted in July 2014. The second survey revealed select environmental conditions may cause an expression of the desired phenotypes. This information is now published (Militz et al. 2016) and is being used to inform ongoing culture of clownfish at NIMRF. A total of 24 pairs of Amphiprioninae (*A. percula* and *P.* biaculeatus) were maintained at NIMRF by NFA staff for the duration of the project. **CLAMS** During these surveys a high abundance of the giant clam, *Tridacna noae*, was noted. This species, traded by the name 'teardrop clam' is highly demanded by the aquarium trade. Throughout its range *T. noae* is particularly rare. A field survey of *T. noae* stocks in Kavieng was conducted and revealed Kavieng giant clams stocks had the highest proportion of *T. noae* ever reported. The study also identified two primary colour morphs in Kavieng: brown (91% of population) and blue (9% of population). This study was published (Militz et al. 2015). Given the high abundance of this species and the presence of a blue colour morph it was found to be an ideal candidate for aquarium species aquaculture. Broodstock clams were collected in March 2016. Spawning was undertaken in April 2016 with successful production of settled juvenile clams having been achieved by the conclusion of this project in May 2016. Research was undertaken to evaluate the early development of this species and to identify ideal hatchery feeds (Southgate et al. 2016, 2017). These publications represent the first records of successful mariculture for this species.

2.2.4	Larval culture and juvenile production of key fish species at Nago Island	Determine basic husbandry and culture parameters for key species	Y4,M6	Appropriate husbandry and culture parameters for broodstock have been determined for 7 species of Amphiprioninae with several broodstock pairs now spawning in captivity at NIMRF. Regular spawning has been achieved by both *Amphiprion percula* and *Premnas biaculeatus*.
		Fine-tune culture systems at Nago Island to support fish breeding		Early culture efforts were beset by large mortality events triggered by the original water inlet taking up water from freshwater plumes at low tide. The intake of water contaminants associated with the freshwater plume was identified as a major source of problems with the NIMRF culture systems. Water samples were sent to Triton Biotec for professional evaluation identifying this problem. Modification to the culture system began in 2014 but was only completed in 2016 given delays in transport of materials from Australia. Mortality events have not occurred since the necessary renovations were undertaken.
		Production of larvae and juveniles of key species		Importation of live food organisms (rotifers) necessary for larval culture of fish was achieved in 2014. These are now continuously cultured at NIMRF by NFA staff. NFA staff have been trained to rear *Amphiprion percula* larvae and successful hatchery production is now regularly achieved. In December 2014, NFA staff achieved survival of 85% to market size (3 months of age). At the conclusion of the project, several thousand market sized *A. percula* and *Premnas biaculeatus* had been produced and are being cared for on-site. Routine production continues weekly.
		Close the life-cycle of key species		Two methods of *A. percula* culture have been successfully achieved: (1) intensive production that uses cultured rotifers as a live food source and (2) semi-intensive production that uses wild-caught plankton as a live food source. While both methods have been successful, the use of wild-caught plankton was found to be limiting given weather limits access to this resource and natural variation in the plankton community greatly changed the quality of this resource. Pairs of F1 offspring were established for complete life-cycle closure in 2015. Egg production from F1 pairs has yet to occur.

2.2.5	Establish coral culture trials at Nago Island	Identify key species suited to tank and field culture Determine basic culture parameters for key species in land and field-based culture systems Reliable culture methods for key species Production of commercially sized corals of key species	Y4,M6	Key species of significance to the aquarium trade were identified during the local species survey (June 2013; see 2.2.3) of the Kavieng lagoon. *Acropora* species dominate the trade of stony corals globally and several high-value species of this genus are present in Kavieng. Coral culture was initially trialled on the NIMRF marine reserve reef. This encompassed the establishment of 20 broodstock colonies and 250 coral fragments in 2014. Two different adhesives (epoxy and cyanoacrylate gel) were trialled along with three different base constructions (rubble+cement; sand+cement; sand+cement+CaCO3 enrichment). A grow out period of six months was used for the study. At the conclusion of the study it was determined that the NIMRF marine reserve reef was unsuited for coral propagation because of a large population of resident parrotfish. Parrotfish were observed to feed on the growing coral tips resulted in all treatments having negative growth of fragments over the six month period and a stumped appearance. A second field site under the tenure of Nago Island community was trialled. This site is part of the community's subsistence fishery. Both coral growth and survival have proven superior to the NIMRF marine reserve site. This site currently contains 40 broodstock colonies and over 2000 coral fragments. The Nago Island village maintains this coral farm and participate in ongoing culture efforts. Current research is evaluating the economic potential of coral mariculture in New Ireland Province. Land-based culture of corals was trialled on two separate occasions at NIMRF. It was determined that in order to provide sufficient light, water delivery from the NIMRF culture system would have to be increased to manage temperature. A reduction in light intensity necessary to maintain suitable water temperature with the current water supply system resulted in 100% mortality in two months. Even with the recommended improvements, land-based culture of corals has been unsuccessful at NIMRF and is limited by available space. Future coral propagation is recommended to occur at field-based sites.

PC = partner country, A = Australia

Objective 3: Develop and initiate a strategy for long term institutional mariculture training capacity in PNG

Objective 3.1: Develop and initiate a strategy for long term institutional mariculture training capacity in PNG

no.	activity	outputs/ milestones	completion date	comments
3.1.1	Review of current curriculum and practical training in mariculture	Review outlining strengths and weaknesses in current mariculture training curriculum Recommendations to address shortfalls and weaknesses in current curriculum and training program	Y1,M6 Y1,M6	Consultation meetings (involving NFC, UNRE and JCU) were held in 2013 to establish priorities for curriculum development at NFC and UNRE. A working paper was developed as a basis for further consultation. The Aquaculture curriculum at NFC subsequently developed independently of UNRE and expertise from Australia (Gay Marsden from Broome TAFE) developed an Aquaculture Training Package which meets the requirements of the National Training Council (NTC) and was endorsed by the Fisheries Training and Advisory Committee (FTAC). Specific lesson plans were developed for this Aquaculture Training Package and an Aquaculture Instructor was recruited by the NFA to begin implementing and delivering the Aquaculture Training Package through the NFC and the NIMRF. AVID De'arne Kershler developed a series of best practice booklets for aquaculture operations with a focus on NIMRF activities, including a hatchery manual for sandfish. A second manual for ornamental fish culture has been completed. Further consultation meetings focused on how training and capacity building activities can be better implemented with a wider consortium of partners involving the NFC, UNRE, UPNG, JCU and USC.

3.1.2	Develop a strategy for improved training capacity in mariculture	Draft strategy based on recommendations from review Stakeholder agreement on recommendations in draft strategy document	Y1,M8 Y1,M10	See 3.1.1 To advance this activity, several approaches were suggested, including: • Secondment of NFA Aquaculture Business Unit staff to assist ACIAR researchers when they are onsite or when specific hatchery activities are being undertaken at the NIMRF. • Conducting a Training Needs Analysis with existing commercial aquaculture facilities which would include assessments on operational procedures; staffing structure; qualifications of staff; and training requirements. • Constant operation of the NIMRF hatchery to allow NIMRF staff skills to be continuously honed, and provide a program of activity as a basis for the incoming NFC Aquaculture Instructor to plan teaching and training courses utilising the NIMRF, particularly for promising students from UPNG and the UNRE who could become involved in identified mini-projects and short-term research activities. • Both NIMRF and project staff have been involved in training of NFC Aquaculture students at NIMRF at Cert. 1, Cert 2, and Cert 3 levels.
3.1.3	Develop and submit university 'twinning' application to AusAID	Draft funding application for stakeholder consultation based on outputs of Activities 3.1.1 & 3.1.2 Submission of application for funding to AusAID in support of university twinning arrangement for capacity building in mariculture training	Y1,M12 Y2,M3	During early 2013 it became unclear whether mariculture remained an appropriate topic for a 'twinning' application to AusAID because of the distinctions between NFC/NIMRF and UNRE. The recent integration of AusAID within DFAT and streamlining and realignment of the Australian aid program further diminished the possibility that this project activity could be pursued. There is no doubt of the long-term value of a 'twinning' style arrangement with an established mariculture institution and possible mechanisms to support such a development are being actively examined in the follow-on project. A possible way forward is for ACIAR/USC and the NFA to approach DFAT for the implementation of a training program that would see students from UPNG and UNRE access a post-graduate program at JCU or USC that could include research at the NIMRF or in the field with some level of supervision from JCU or USC staff or project staff. Such a program could also be supported by the new NFA/NFC Aquaculture Instructor.

PC = partner country, A = Australia

Objective 3.2: Build capacity amongst NFA, Provincial fisheries, NGOs and local communities

no.	activity	outputs/ milestones	completion date	comments
3.2.1	Appoint an appropriately qualified Project Scientist to be based permanently at Nago Island	Qualified Project Scientist on site at Nago Island	Y1,M6	Rowan McIntyre, a JCU Aquaculture graduate with experience of commercial fish and pearl oyster farming was employed as Project Scientist at NIMRF from October 2012 to April 2015. He was replaced by Thane Militz, a JCU PhD student, in mid-2015.
3.2.2	Establish a Steering Committee comprising project staff, NFA, UNRE, Provincial fisheries officers, NGOs and community reps to guide project activities	Identify suitable team member Determine roles and responsibilities for all participants Conduct regular planning and update meetings	Y1,M6 Y1,M8 Ongoing	A project steering committee composed of members from core project partners (NFA, JCU, SPC, UNRE) was established at the first project meeting in June 2012. Roles and responsibilities for partner institutions were reviewed and agreed. Annual project meetings provided a venue to review and plan project research activities. Steering committee meetings were replaced by annual meeting once research programs were established and as a result of changes in the relationship between NFC and UNRE. The participants in annual meetings changed as the project progressed and has required broader inputs from NGOs relating, in particular, to community engagement and extension activities.
3.2.3	Support Nago Island hatchery and culture operations and production of selected species (i.e. technology transfer, expert personnel)	Project personnel to visit Nago Island regularly for trouble-shooting and capacity building in day to day hatchery management Commodity experts to visit regularly to transfer technology in specific areas of expertise	Ongoing	Over the course of the Project there have been regular visits by project staff and directly associated students to NIMRF including: P. Southgate, C. Hair, P. Graham, T. Militz (on-site in Kavieng), N.D.Q. Duy, S. Nowland. Other commodity experts that have visited and worked with NIMRF/NFA staff during this project include: J. Moorhead (ornamental fish) A, Teitelbaum (ornamental fish) T. Nahacky (ornamental fish) J. Whitford (facility systems) G. Marsden (curriculum development and management) R. Garcia (biosecurity, SPC mariculture) R. Braley (clam culture) P. Lee (cobia) L. Dutney (cobia) Two others that visited and worked with NIMRF staff associated with another ACIAR project (FIS/2009/057) were: P. Kishore (mabé pearl) M. Wingfield (pearl oyster hatchery)

3.2.4	Develop mariculture training activities with key communities using local partners as liaison and facilitators	Conduct small workshops on aspects of selected commodities (e.g. spat collection, sea cucumber) Involve key community members in larger workshops	Y2,M12 – Y3,M6 Y2,M12 – Y3,M6	Pen keepers in charge of family group pens in Limanak received assistance with pen construction and training on pen care. Project staff visited regularly to also advise on any issues that were encountered. The Nago Island community in charge of maintaining the coral propagation farm engaged in a two-week workshop on the production of coral nubbins. Project staffs regularly visit the coral farm and consult with the community on farm progress. Given the time required to fully establish research facilities required by the project and development of appropriate culture methods for target species, workshops to disseminate project findings were conducted more effectively in the final year of this project.
3.2.5	Train specific community members of participating villages to undertake project activities (i.e. hands-on training, workshops)	In consultation with village leaders, select two suitable candidates from each participating village Negotiate fair remuneration for their effort Facilitate one-on-one training and involvement in other training activities	Y1,M12– Y2,M12 Y1,M12– Y2,M12 Y1,M2 – Y4,M12	Specific community members from Limanak, Ungakum and Enuk received hands-on training on field-based sandfish culture, survey techniques and data collection. Specific community members from Nago Island have received hands-on training on field-based asexual coral propagation and grow-out. Up to three community members from each field site have been engaged to look after the ocean bag nets and 100 m^2 sea pens. Fair remuneration based on estimated work hours is provided to each, as well as the equipment required for the work and regular phone credit to facilitate communication with project staff. Sea ranch surveys involve assistance from 1-2 locals who receive payment for the hours worked. One community member from Nago Island is engaged to look after the community coral farm. Fair remuneration is calculated in the same manner as for sandfish wardens. Community members from all village sites have visited the NIMRF hatchery during operation for a demonstration on aspects of life-cycle and culture methods.

3.2.6	Develop manuals on specific aspects of selected culture commodities to support workshops and other training activities	Simple manuals produced for village sea cucumber grow out and oyster culture Small handouts produced for technical workshops during the project under Activity 4 (e.g. algae culture, coral fragging, spat identification etc.) Handouts compiled into a single reference document at conclusion of project	Y2,M12 – Y3,M6 Y2,M12 – Y3,M6 Y3,M12	Short handouts have been developed to assist community awareness of field-based research activities with sandfish and oysters. Both were developed through consultation with a partner local NGO (Ailan Awareness) and translated into Tokpisin. Larger more comprehensive extension materials will be developed to support future project activities. Regular community meeting were held to disseminate project research results and the key points translated to a Tokspisin handout. Comprehensive manuals detailing husbandry, broodstock conditioning, rotifer culture and larval rearing pertaining to ornamental fish culture have been developed and are regularly used by NFA staff at NIMRF. A poster entitled “Sea ranching of sandfish in PNG” was distributed to partner communities to explain the key concepts of sea ranch operation (Appendix 1).

PC = partner country, A = Australia

6 Key results and discussion

Key results of this project include:

- Successful engagement of three local communities and training in mariculture systems for sea cucumber.
- Successful development of methods for hatchery production and routine production of juveniles sandfish at NIMRF
- Successful grow-out of juvenile sandfish to release size (>3 g) for use in experiments and community trials.
- Identification of optimum sandfish habitat in the project area and comparable survival and growth to studies in other countries.
- NIMRF staff trained to produce and grow-out sandfish larvae and juveniles in hatchery and community grow-out systems.
- Improved capacity within NIMRF staff for experimental design, research planning, data collection, analysis and reporting.
- Comprehensive review of PNG marine aquarium fishery.
- Successful hatchery production of key ornamental commodities: *Amphiprion percula*, *Premnas biaculeatus*, and *Tridacna* spp.
- Successful grow-out of hatchery-produced ornamental commodities: *Amphiprion percula*, *Premnas biaculeatus*, and *Tridacna* spp, and asexual production and grow-out of *Acropora* spp.
- NIMRF staff trained in live food production and other skills to support live fish production.
- Genetic variation within PNG sandfish populations was very low and these data will inform sea cucumber translocation and broodstock use protocols. Two journal publications resulted from this aspect of project research.
- A dedicated Aquaculture Training Package (ATP) was developed and endorsed by the Fisheries Training and Advisory Committee. Specific lesson plans were developed and an Aquaculture Instructor was recruited by NFA/NFC to begin implementation and delivery of the ATP through the NFC and NIMRF.

6.1 Development of community-based sea cucumber methodologies

6.1.1 Hatchery

Two to three hatchery runs were conducted annually and production has increased with each run. More consistent larval culture conditions have been provided from a full NIMRF facility upgrade (completed in mid-2016): installation of new submersible pumps to triple existing seawater supply to facility; construction of swirl separator filtration for particle removal and an 8T sand filter; simplification of seawater delivery pipework within facility; and a hatchery ring line that was constructed to regulate water quality to larval rearing tanks. Reliable production methods support routine production of tens of thousands of early juveniles, and thousands of larger juveniles (>1 g), sufficient to support planned research activities.

PhD student, Duy Nguyen, developed a routine hatchery protocol for sandfish at NIMRF and trained Esther Leini (NFA hatchery technician) to produce sandfish juveniles. The

PhD research of Duy showed that micro-algae pastes support good survival rates of larvae through to the early juvenile stage (e.g. 13.7% survival to a size range of 0.5-10 mm). Hatchery culture of sandfish larvae and juveniles using commercially available micro-algae pastes as a food source has simplified culture methods and eliminated a major technical bottleneck (live micro-algae production). De'arne Kershler (AVID) and Esther Leini produced a hatchery culture manual to support staff training.

6.1.2 Early juvenile grow-out

Land- and ocean-based grow-out nursery systems were utilised for grow-out of early juveniles at NIMRF. Land-based culture systems were eight 2 tonne round tanks, four fibreglass raceways and a seawater pond that became operational in late 2015. The fibreglass tanks and raceways depend on natural biofilm growing on the sides to provide food for recently settled juveniles, while fine-mesh hapa nets (white colour, 800-µm mesh size) are suspended in the pond. Juveniles held inside the hapas feed on biofilm growing on the mesh surface. To date, the fibreglass raceways have supported the best survival and growth. Ocean nursery systems were also used in order to increase the area available for grow-out and to further engage communities in the mariculture process.

Local village labour was used to clean and maintain nets, with supervision by NIMRF staff. Trial grow-out of early juveniles was carried out in bottom-set and floating bag nets (black colour, 1-mm mesh size) at the 3 village sites, Limanak, Enuk and Ungakum. The former site was in an exposed area and the latter two sites were in sheltered channels. Different stocking size and density were also tested. Best results were obtained in floating bag nets in sheltered environments, using juveniles greater than 5 mm in length, stocked at medium density (approx. 500 per 2 m^2 net). Due to the highly variable growth of juvenile sandfish, we investigated whether grading would improve growth but there was only marginal improvement. Due to the very fast growth of biofilm and clogging of the net mesh, best results were gained through good husbandry (cleaning) and regular exchange of fouled nets. Growth and survival were higher at Enuk than Ungakum, possibly a result of closer supervision from project staff and more frequent net exchange. In mid-2016, the Ungakum site was dropped from the bag net grow-out. Hapas in the NIMRF pond replaced the production from Ungakum bag nets, and establishment of a sea ranch replaced the community engagement aspect.

With the construction of seawater pond at NIMRF, we now have the option to grow-out juveniles in hapa nets in a calm and accessible environment (as successfully developed in Vietnam). Proximity to the hatchery means that more dedicated husbandry is possible and more rigorous experimentation can be carried out. Early results have indicated that growth can be better than that in ocean bag nets, although time of year (e.g. water temperature and salinity, algal blooms) influences survival and growth. One experiment has shown that additional substrate in the hapas improved growth. However, pest species such as sea hares, flatworms and molluscs have had negative effects on juvenile sandfish and there have also been problems with low salinity and insufficient drainage from the pond. Management of these issues will be the subject of future work.

6.1.3 Community-based mariculture activities

The three project sites (Limanak / Limellon, Ungakum, Enuk) were selected as primary data collection and community engagement sites. Strong village-based partnerships were established at all sites. Awareness meetings were conducted at all sites prior to the project commencing with all communities expressing willingness to be involved and committed to the project aims. Project team members were active in community work and dissemination of information to communities. The point of contact in most villages is the Village Planning Committee. Local NGOs, Ailan Awareness and WCS also assisted in regular community engagement activities. Ocean nursery systems such as bag nets (Ungakum, Enuk) and sea pens (all three sites) were maintained by community members

who received a weekly stipend. Community members have helped to build and maintain other experimental systems and are involved in data collection and monitoring (paid and unpaid).

The highest survival of juvenile sandfish was at Limanak 1 (93%), followed by Limanak 2 (87%), then Enuk (53%) but there was total mortality at Ungakum (0%). Limanak 1 sandfish also showed the best growth, in fact, this site had higher survival and growth than any reported sandfish mariculture activity in any country where juveniles are released into the sea (e.g. Madagascar, the Philippines, New Caledonia, etc). Growth in Limanak 1 pen was almost as high as growth in ponds in Vietnam, with sandfish attaining a mean individual weight of 400 g after 12 months in the sea. Subsequent pens installed at Ungakum and Limellon also showed acceptable survival and growth. Growth in the pens eventually plateaued and reducing the pen density at Limanak led to higher individual sandfish weight in the short term, indicating that high density will limit growth of penned sandfish, supporting the case for sea ranching in larger areas. Cage protection at release of juveniles into the wild did not improve survival in a sea pen experiment. Carrying capacity ($g.m^2$) varied depending on specific site characteristics and reached a maximum of around 650 g m^{-2} at Limanak.

The first trial sea ranch, a 7 ha area of shallow sandy-seagrass habitat near Limellon (part of the Limanak community), was surveyed twice for biophysical characteristics using standard quadrant methods developed with ACIAR Project FIS/2010/042. Sea cucumber abundance and diversity were surveyed using transects before the release of 3,000 fluorochrome-tagged cultured juveniles (in batches of 200-500 juveniles), and 8 months after the first batch was released. Preliminary analysis of skin samples from the surveyed sandfish resulted in 4 recaptures of cultured sandfish, weighing between 41-370 g, and maximum dispersal distance of 150 m from the release site. The Ungakum trial sea ranch site has been surveyed once for biophysical characteristics and once for wild sea cucumber abundance and diversity (pre-stocking survey). The habitat of this trial sea ranch is more homogeneous in nature. Further, the resident sandfish are much fewer in number and generally larger in size. These features make it a more convenient location for monitoring released cultured sandfish movement and growth. The Ungakum community also has experience with managing a protected reef area and are likely to not collect sea cucumber from the ranch if the moratorium on fishing is lifted during the lifetime of the follow-on Project. Community negotiations have commenced for a third sea ranch at Enuk although this will depend on hatchery production as to when stocking will be possible.

6.1.4 Socio-economic aspects of sea cucumber mariculture

'Pre-aquaculture' interviews carried out in Limanak and Ungakum show that sea cucumber fishing was an extremely important livelihood in both these areas. However, the moratorium was generally accepted with approval as most fishers acknowledged that stocks were badly depleted. The capacity to develop and enforce management measures (such as tambu areas, fishing limits, etc), varies markedly between the two communities. Preliminary results suggest that the key drivers of these differences include proximity to the market place (i.e. Kavieng), strength of customary leadership, influence of conservation NGOs, and degree of intermarriage outside the community (i.e. as it relates to how many "outsiders" can access customary marine resources). Both communities have recently ratified marine resource management plans (facilitated by WCS) and each has incorporated protected sea cucumber sea ranch areas into the plans. This research is ongoing and will be finalised during the follow-on project.

6.1.5 Description, analysis and classification of sea cucumber habitat

Biophysical parameters (habitat features and sediment chemistry) and other features (e.g. proximity to humans, oceanographic factors) are recorded for sea pens and sea ranches

at regular sampling times. Preliminary multivariate analysis clearly differentiated the four pen habitats and indicated key features of good grow-out sites (i.e. those with high survival and growth). However, further research is needed to elucidate which biophysical or other factors are most useful in predicting the quality of potential sea ranch sites and whether these change through time. Novel GIS techniques were explored via high resolution, multispectral-band satellite images for habitat classification. Further results from the sea ranches will be incorporated into the classification system to improve our capacity to predict 'good' culture sites and estimate suitable areas for sea cucumber mariculture. This research is ongoing and will be finalised during FIS/2014/061.

6.1.6 Other

JCU Honours student Samantha Nowland completed a study on the population genetic structure of sandfish in PNG. She developed a non-destructive shave biopsy tissue sampling method for holothurians. Results showed that genetic variation among all populations sampled was very low and PNG populations have a largely panmictic stock structure, which was genetically distinct from the northern Australia population. These results provide valuable information relating to sea cucumber translocation and broodstock use. This research is reported in Nowland *et al*. (2015) and Nowland *et al*. (2017).

When adult cultured sandfish were culled in order to decrease biomass in a sea pen, we had an opportunity to compare the recovery rate (i.e. bêche-de-mer yield expressed as a percentage of the wet gutted weight) of cultured sandfish with that of similarly-sized wild conspecifics. NFA gave special permission for the collection of wild sandfish of a similar size range to the cultured individuals. Results indicated no significant differences between ocean-cultured and wild-caught *H. scabra* for important attributes such as recovery rate, dry body wall thickness or collagen composition. This is good news for sea cucumber mariculture proponents because our data disproves published yet anecdotal claims that bêche-de-mer produced from cultured sandfish have a much lower recovery rate and thinner body wall than wild-caught sandfish.

6.2 Other mariculture commodities

6.2.1 Edible oysters:

Recruitment of oyster spat was spasmodic and initially very low. However, changes made to the spat collecting system resulted in significant numbers of spat collected in February, March and April, 2014. The NFA wharf in Kavieng had natural recruitment of oysters, while two additional sites within Balgai Bay (Losogul (Manne) and Panopai) were dropped after one year because no recruitment was recorded.

The cement/lime slurry collectors had higher recruitment than plain PVC collectors. The cement/lime slurry collectors also made it easier to remove the spat and improved the survival of the spat during and after the removal process. The "recipe" and application of the slurry has been refined to suit local conditions and the collectors. Alternative collectors made of bamboo, PVC conduit and old "Pin" shells (*Polymesoda erosa*) were not successful, the former two collected no spat and the latter was successful at one site only.

Pin shells deployed vertically through the water column, were used to assess the preferred depth of recruitment at Losogul. The shells were deployed every 10 cm from the substrate to the high tide mark. Assuming a high tide mark of 0 cm, the greatest recruitment was recorded between -60 and -120 cm.

Two species of oyster have been provisionally identified in the Kavieng area, *Saccostrea cucullata* and *S. mordax*. A third species of oyster has been identified during the grow out

trial and has been provisionally identified as *Striostria mytiloides*. A fourth oyster recorded at Losogul was identified as a *Dendostrea species*.

Poor recruitment to spat collectors limited the extent to which growth trials could be established. A grow-out trial was conducted at the main NFA wharf site with spat collected in 2014. However, the oysters suffered close to 100% mortality in all treatments over a month long period as a result of predation by *Cymatium* sp. (a gastropod).

Limited availability of oyster spat from poor recruitment to collectors has resulted in only small scale growth trials being established at each site. Due to high levels of predation in initial trials at the wharf site, a new trial was set up using subtidal baskets on the floating pontoon off NIMRF. Spat were individually labelled and photographed so their grow rates and morphological changes could be observed overtime. The morphologically differences observed overtime allowed for the differentiation of the species; primarily *Saccostrea cucullata* and *Striostrea mytiloides*. After 9 months *S. cucullata* spat had reached an average weight of 3.75 g whereas the only surviving two *S. mytiloides* spat had reached weights of 9.24-16.3 g after 8 months. Although a higher survival rate was achieved than at the wharf site, survival was relatively low at 40%. *S. cucullata* spat were deployed in intertidal baskets at Losogul (n=40) and Panapai (n=40). The spat at Panapai reached an average weight of 3.45 g after 6 months with a survival rate of 95% whereas mass mortalities were observed in the initial weeks at the Losogul site. The influence of a tidal creek, high turbidity and lower salinity of the Panapai site differentiate it from the others and may be responsible for the lack of *Cymatium* sp. recruitment.

An economic assessment of the potential of edible oyster culture in Kavieng and potential marketing options was begun in late May 2013 as scheduled. A preliminary assessment of potential markets was completed; however, full assessment of the business case requires recruitment and growth rate (production) information that is not available at this point. This activity is ongoing.

6.2.2 Aquarium species:

Historically, there have been two marine aquarium exporters operating out of PNG. The first was a NFA contracted consultancy group, EcoEZ Inc., that implemented the SEASMART Program in PNG from 2008-2010. This encompassed some commercial exports. Funding to the program was terminated by NFA in 2010 as a result of EcoEZ Inc. failing to complete contractual milestones. A review of the EcoEZ, Inc. supply chain was undertaken by this Project and identified several weaknesses highlighted below.

The second marine aquarium exporter operating out of PNG was EcoAquariums Ltd. This NFA-subsidised private entrepreneur engaged in commercial exports from 2011-2012. The overlap of operations with the commencement of this project allowed for this Project to conduct both active and post-operational reviews of EcoAquariums Ltd.

Major industry weaknesses are summarised below:

- A large proportion of fish caught by communities were rejected by the companies;
- A large proportion of fish purchased by the exporting companies died prior to export;
- Further losses of fish were incurred during transport to the end market; and
- The high cost of freight. This has been reviewed in detail both in this Project and by Kinch (2008).

While both EcoEZ Inc. and EcoAquariums Ltd. attempted mariculture of marine ornamental commodities to supplement fisheries catch, neither company succeeded in

bringing maricultured fishes, giant clams, or hard corals (Scleractinia) to market. Soft corals were successful cultured by EcoAquariums Ltd. and exported in small quantities. The absence of both in-country facilities and technical capacity to support marine ornamental mariculture has resulted in missed opportunities for the PNG marine aquarium industry. Where rare and/or endemic phenotypes of organisms have been discovered, these items were exported to buyers in the US and Europe that then began their own captive production of these fishes. This resulted in a shift in economic base as consumers demonstrate preference for cultured specimens (Militz, 2017).

This project addressed these weaknesses in several areas. The development of the NFC Aquaculture Training Package now offers the opportunity for in-country skill development in marine aquatic animal husbandry, handling, and production. This will give future marine aquarium companies the opportunity to hire staff trained in this area. The ability to obtain staff trained in aquatic animal husbandry, handling, and production is anticipated to help reduce the high mortality along the supply-chain observed in previous operations.

Further, the desktop review of the marine aquarium fishery has found several areas where company management can be improved to reduce rejections and mortality along the supply chain. The review also found ways to reduce the management burden imposed on NFA by an expanding fishery that is high diversity but low volume.

Successful culture of clownfishes, giant clams, and hard corals at NIMRF and training of NFA staff offers potential for the NFA to more fully support future aquarium industry development. The captive production of giant clams and hard corals is of particular value given the listing of these species on CITES Appendix II which limits the capacity to export wild-collected organisms. NIMRF has capacity to produce semi-commercial quantities of clownfishes, giant clams, and corals as evidenced from the outputs of this project. In future, the NIMRF can produce organisms to directly contribute to aquarium industry operations or serve as a training facility to transfer knowledge to industry participants. By developing routine production methods for clownfish, future discoveries of high value fish phenotypes can be cultured in-country so that most of the economic potential of such fish can be realised by PNG rather than the importing countries.

6.3 Long term institutional mariculture training capacity in PNG

6.3.1 Institutional mariculture training capacity in PNG

Gay Marsden (ex-Broome TAFE) developed an Aquaculture Training Package which met the requirements of the National Training Council (NTC) and was endorsed by the Fisheries Training and Advisory Committee (FTAC) in 2015. Specific lesson plans have been developed for this ATP and an Aquaculture Instructor (Philomena Sinkau) has begun implementing and delivering the package through the NFC and the NIMRF

AVID De'arne Kershler developed a series of best practice booklets for aquaculture operations with a focus on NIMRF activities, including a hatchery manual for sandfish. A second manual for ornamental fish culture has been completed.

During early 2013 it became unclear whether mariculture remained an appropriate topic for a 'twinning' application to AusAID because of the distinctions between NFC/NIMRF and UNRE. Subsequent integration of AusAID within DFAT and streamlining and realignment of the Australian aid program has further diminished the possibility of this project activity.

There is no doubt of the long-term value of a 'twinning' style arrangement with an established mariculture institution. Possible mechanisms to support such a development

were discussed conceptually in the final year of this project and will be further developed in the follow-on project (FIS/2014/061).

A possible way forward is for ACIAR/USC and the NFA to approach DFAT for the implementation of a training program that would see students from UPNG and UNRE access a post-graduate program at JCU or USC that could include research at the NIMRF or in the field with some level of supervision from JCU or USC staff or project staff. Such a program could also be supported by the NFC Aquaculture Instructor.

6.3.2 Capacity amongst NFA, Provincial fisheries, NGOs and local communities

Capacity-building at NIMRF has been achieved through the activities of the Project Scientists based on site (Rowan McIntyre and Thane Militz). They were responsible for oversight of research projects and hatchery facility upgrading and maintenance. An MoU signed with Ailan Awareness facilitated broader inputs from NGOs relating, in particular, to community engagement and extension activities.

Over the course of the Project there have been regular visits by Project staff and Project-associated post-graduate students to NIMRF, which have contributed to increased staff capacity. These are listed in full in Section 3.2. Inputs included regular contributions from the core project team (Paul Southgate, Cathy Hair, and Thane Militz) as well as targeted research projects or trouble-shooting by officers from organisations such as Queensland Department of Fisheries and Forestry, SPC, and consultants with expertise in facility systems, curriculum development, bio-security, and culture of relevant commodities. Comprehensive manuals detailing husbandry, broodstock conditioning, rotifer culture and larval rearing pertaining to ornamental fish culture have been developed and are regularly used by NFA staff at NIMRF.

Community capacity building was achieved through the involvement of community members in maintaining field-based sea cucumber culture systems (floating and bottom-set bag nets, sea pens, etc). Specific community members from Limanak, Ungakum and Enuk also received practical training on survey techniques and data collection. Pen keepers in charge of family group pens in Limanak received assistance with pen construction and training on pen care.

Community members from all village sites have visited the NIMRF hatchery during operation for a demonstration on aspects of sandfish culture methods to increase their understanding of the life-cycle processes. Short handouts were developed to assist community awareness of field-based research activities with sea cucumbers and oysters. Both were developed through consultation with a partner local NGO (Ailan Awareness) and translated into Tokpisin. A poster entitled “Sea ranching of sandfish in PNG” has been produced for distribution to partner communities to explain the key concepts of sea ranch operation. Regular community meetings were held to disseminate project research findings.

7 Impacts

7.1 Scientific impacts – now and in 5 years

This project targeted a broad range of species and employed a range of mariculture practices. It also involved, to a significant extent, postgraduate research students. The NIMRF system is now well set-up to support ongoing mariculture research and training due to improvements made throughout the project. This supported progress in all aspects of project research and scientific impacts have so far occurred in the following areas:

Sea cucumber:

Hatchery: New information relating to larval culture of sandfish which has improved culture methods. Particular impacts relate to the development of larval culture protocols using commercially available micro-algae pastes as the sole larval food source during hatchery culture, supporting high larval survival through to the early juvenile stage (e.g. 13.7% survival to a size range of 0.5-10 mm). Small juveniles can also be grown on these pastes. This development supports simpler hatchery culture methods that are less technically demanding and more appropriate to developing countries.

Nursery and grow-out: New information on the growth rates of hatchery-produced juveniles and field-based culture methods appropriate to New Ireland conditions including: (1) a greater understanding of bio-physical characteristics in field-based culture and identification of key factors influencing culture success; (2) greater understanding of optimal stocking density in field-based culture and husbandry requirements; and (3) the suitability and acceptance of sea cucumber culture as an income generating activity for coastal communities in PNG. Additionally, this sea cucumber mariculture research had close collaborative links with ACIAR Project FIS/2010/042 which undertook similar research relating to field culture and ranching of sandfish. This collaboration includes a large-scale experiment conducted in the Philippines, northern Australia and PNG, where 100 m^2 pens were stocked with >3 g juveniles and their survival and growth monitored to commercial size. The broad geographic scale of this combined study has generated a unique data set and provides new and important information on the biology and culture requirements of sandfish.

Genetics: Baseline genetic data for *Holothuria scabra* within PNG and the region was generated and a non-destructive shave biopsy tissue sampling method for holothurians was developed. The research provided new information on sandfish population genetics in PNG and within a broader regional context, and a research foundation for improved management of restocking programs and sustainable development of a future sandfish mariculture industry.

Production: Unique data were obtained on the recovery rate, body wall thickness and collagen content of ocean-cultured and wild-harvested sandfish. Analysis showed there was no significant differences between cultured and wild sandfish for these important attributes which contribute to the value of the final dried product, bêche-de-mer.

In five years' time, the improved feeding methods for larval and small juvenile sandfish will promote increased juvenile supply at NIMRF, enabling all aspects of this research to progress more quickly towards commercial viability. This development also has important and widespread application for other countries where hatchery production of sea cucumbers is undertaken. Without the need for live micro-algae production, the uptake of hatchery technology will increase over the next 5 years. This will facilitate research in grow-out and field mariculture activities. In PNG and other countries providing data on field-based culture and biophysical factors, it will be possible to select sites that support

high survival and growth. Not all communities will have optimal habitat but there will be greater capacity to predict mariculture outcomes. This will be valuable in maximising production, managing community expectations and proving semi-commercial viability. The results of Project research will be useful in developing management plans for mariculture activities (farms, sea ranches, etc). At least one demonstration sandfish sea ranch will be operating and several other communities will have sea ranches being monitored by NFA project staff.

Other species:

Aquarium Species: The immediate scientific impacts from the ornamental components of the project encompass:

- A first quantification of pre-export supply chain losses of marine aquarium fishes and invertebrates attributed to quality-control rejections;
- Quantification of pre-export supply chain losses of marine aquarium fishes and invertebrates attributed to mortality;
- Quantification of mortality of marine aquarium fishes and invertebrates while in international transit;
- An assessment of total allowable catch to regulate high-diversity, low-volume marine aquarium fisheries;
- Potential to improve fishing efficiency through opportunistic exploitation;
- An evaluation of consumer demands for marine aquarium organisms;
- Identification of ecological variables potentially influencing the development of high-value clownfish phenotypes;
- The first population demographic study on the teardrop giant clam *Tridacna noae;*
- The first documentation of the *T. noae* embryo and larval development;
- Assessment of micro-algae concentrates as hatchery feeds for *T. noae* larvae;
- Development of culture protocols for key ornamental species at NIMRF, appropriate to local conditions, and NFA staff trained in these production methods; and
- Establishment of methodologies for in-country culture of clownfishes, giant clams, and corals.

These outputs are not only of immediate value to PNG, but will also be of great interest to partner countries in the region and of value to marine aquarium industry at a global level.

There are also scientific impacts specific to PNG:

In five years' time, these scientific outputs are likely to have significantly contributed to the re-development of PNG's marine aquarium industry. As part of this re-development, the scientific outputs offer the opportunity for mariculture to play a significant role in supplying organisms for industry. Further research will build on these outputs to: (1) evaluate improved shipping techniques to reduce transit mortality; (2) refine *T. noae* culture methods to increase production; and (3) assess capacity for cultured clownfish to restock depleted wild populations or supplement fishery catch.

Edible Oysters: New information on reproductive seasonality and growth rates of edible oysters in Kavieng was generated by the spat collection program and was used to develop more targeted spat collection methods and optimise culture methods.

The results of the oyster focused research undertaken in this project were disappointing in terms of poor recruitment, high mortality and relatively slow growth rates. Potential for

developing oysters as an economically-viable mariculture commodity in Kavieng appears to be limited. This is particularly the case because economically-viable transportation of oysters from Kavieng to main markets in Port Moresby was also identified as a major bottleneck in the economic assessment conducted in this project (Section 2.1.5).

Postgraduate students:

This project has so far involved four postgraduate students. Three PhD students (Hair, Militz, Nguyen) and an Honours student (Nowland), Nguyen and Militz have now successfully completed their studies. Involving postgraduate students broadens the relevant outputs from the project, increases the project's contributions to current scientific knowledge and raises the profiles of both ACIAR's Fisheries Program and mariculture research in the region. A significant number of publications in scientific journals resulted from these student projects. Fifteen journal publications have so far resulted from this project of which thirteen resulted from the work of research students (see Section 10).

Two UNRE graduate students undertook 2-month Industrial Placements to gain experience in the mariculture industry. One student gained experience in aspects of live food production and fish production with Thane Militz while the second gained experience in biophysical habitat analysis and grow-out of juvenile sea cucumber with Cathy Hair. A total of seven OLSH school students undertook work experience with project staff at NIMRF over course of the project. Development of research projects and further support for appropriate post-graduate students from UNRE and UPNG, with appropriate institutional supervisory support, is an aim of the follow-on project (FIS/2014/061).

7.2 Capacity impacts – now and in 5 years

Direct impacts have been made through training and capacity building activities conducted for NFA/NIMRF staff relating to hatchery production and juvenile grow-out of sandfish and marine ornamentals, deployment of spat collectors for edible oysters and collection, continual husbandry of marine ornamental broodstock and routine maintenance, husbandry and data collection from land- and field-based research activities (see *Section 4*).

Sandfish hatchery runs produced sufficient small juveniles to support project research. They involved input from Nguyen Duy, a PhD candidate at JCU with extensive experience in hatchery production and pond cultivation of sandfish in Vietnam. He has greatly assisted in developing the NIMRF hatchery system and an appropriate larval culture protocol. Duy and De'arne Kershler (AVID) worked with Esther Leini (NFA hatchery technician) to a point where Esther Leini is now competent to produce sandfish juveniles without instruction and she is the current Hatchery Manager at NIMRF. Esther Leini has also received training in micro-algae culture and in the use of commercially available micro-algae concentrates. However, there was a bottleneck in production of release-size juveniles which has constrained field-based research, particularly for large-scale stocking of sea ranches. This bottleneck will be addressed in the follow-on project (FIS/2014/061) as research at NIMRF begins to test semi-commercial viability of sea ranching at targeted communities.

Recent hatchery runs with clownfish have produced high levels of survival (~85%). Initial training was provided by Thane Militz, a PhD candidate at JCU with prior ornamental research experience. Following the initial training, NFA staff (Noah Piliman) was able to independently culture juvenile clownfish to market size. Noah and two other casual NFA staff have been trained in live food (rotifers, *Artemia*) culture, production of coral propagation substrates and coral propagation techniques, and ornamental fish broodstock husbandry and conditioning.

Junior technical staff and long-term casuals have continued to gain experience and knowledge as they are involved in field-work with an increasingly broader focus. In

particular, as ocean nursery grow-out of small juveniles and sea pen rearing of larger juveniles (>3 g released into the sediment) expands, staff are gaining valuable skills in juvenile grow-out activities, monitoring and community liaison. However, there was a chronic shortage of appropriately trained NFA staff at NIMRF and this situation greatly reduced the significant capacity building impacts that this project was designed to bring to NFA. This situation was partly addressed with the recruitment of a UNRE graduate senior technician, Nicholas Daniels, who became part of the sea cucumber team and also took on general facility duties.

Community members assisted with sandfish grow-out activities throughout this project. These groups are a valuable source of local knowledge on sandfish distribution, habitats and local sea conditions. Project staff, in collaboration with community marine resources committees and local NGOs, have been involved in developing management plans for trial sea cucumber ranches. While the sea ranches are monitored for research purposes at the moment, the way they are managed and utilised by partner communities will have important implications when the sea cucumber fishery moratorium is lifted.

Many community members have visited NIMRF to see the larval rearing process and have learnt about the life-cycle of sandfish and other marine invertebrates. With respect to sea cucumber mariculture, awareness presentations are regularly made at all villages to keep communities up to date with project research findings.

The major training activities conducted by the project are shown in Table 1 and general skill training provided to project partners is shown in Table 2.

Table 1. Summary of training activities conducted during the project.

Activity	**Type of training**	**Personnel trained**	**Trainer/s**
Sea cucumber (*Holothuria scabra*) culture	• Broodstock collection, transport, handling and raceway maintenance • Spawning induction (including dry treatment, thermal stresses, *Spirulina*) • Fertilised egg management (i.e. recording, egg washing, egg density estimates and larval rearing tank stocking) • Larval tank management (e.g. aeration, cleaning, water exchange) • Larval rearing through to settlement (including feeding with live micro-algae and commercial algal concentrates) • Monitoring of larvae (measurements, density estimates, recording condition) • Preparation of settlement plates using *Spirulina* powder • Post-settlement tank management for pentactula and juveniles (bare & sand) • Transfer of juveniles from larval rearing tanks to bare nursery • Feeding and management of nursery tanks/raceways for small juveniles • Health checking and disease management • Gear construction (cages, nets, pens) • Recording length, weight and width of juveniles, defining size classes	NIMRF hatchery technicians	Cathy Hair Rowan McIntyre Nguyen Duy De'arne Kershler Thane Militz

	• Packing, transport and acclimatisation of juveniles for release into the sea • Designing and deploying field trials (cages, bag nets, pens) • Assessing suitable release and grow-out habitat • GPS use for sea ranch boundaries, grid location, transect and quadrat positioning, sea cucumber tracking.		
Micro-algae production and use	• Outdoor large-scale production • Micro-algal density estimates and feed ration estimation • Micro-algae lab techniques (stock culture maintenance, sterilisation, scaling up cultures) • Use of micro-algae concentrates	Esther Leini	Rowan McIntyre Duy Nguyen Paul Southgate
Rotifer culture	• Batch culture methods of ss-strain rotifers • Rotifer density estimates and feed ration estimation • Rotifer culture techniques (stock culture maintenance, sterilisation, scaling up cultures).	Noah Piliman	Thane Militz
Edible oyster spat collection and grow-out	• Preparation and deployment of spat collectors • Harvest and identification of oyster spat • Design and construction of grow-out units	NIMRF staff	Rowan McIntyre Paul Southgate
Ornamentals	• Identification of high value marine ornamental fish • Collection of marine ornamental fish of high trade value using snorkelling equipment and hand nets • Construction of broodstock, larval rearing and grow-out aquariums for clownfish • Maintenance and husbandry of broodstock clownfish • Identification of clownfish eggs and egg development stages • Plankton towing for collection of larval feeds • Culture of live feeds (rotifers, *Artemia*) used in larval rearing • Larval rearing of *Amphiprion percula* clownfish • Construction of coral propagation mounts • Coral propagation using two part epoxies and cyanoacrylate gel • Spawning and larval rearing of giant clams	NIMRF staff	Paul Southgate Thane Militz Antoine Teitelbaum De'arne Kershler Rick Braley
Pearl oysters	• Mabe pearl seeding • Hatchery culture		Pranesh Kishore Max Wingfield

Table 2. Summary of general skills training provided to NIMRF staff and community members.

Skill set	Specific skills
Field techniques	• Animal handling, packing and transport (juveniles and adults) • Gear construction and deployment in the field • Field gear integrity checks and running maintenance • ID of target commodities (e.g. oysters, holothurians, etc) • Data recording • Sub-sampling • Transect survey techniques • Basic GIS skills (Hand-held GPS, Google Earth, basic mapping)
General hatchery procedures	• Tank cleaning in preparation for stocking with invertebrate eggs/larvae • Setting up filtration, aeration, plankton screens for invertebrate eggs/larvae • Appropriate hygiene procedures for person, tanks and gear (e.g. chlorination, freshwater rinsing, etc) • Feeding of larvae (appropriate rations of live algae or prepared diets delivered at designated times) • Tank drain-downs • Screening invertebrate eggs/larvae • Siphoning tanks • Water changes • Sampling/estimating density of invertebrate eggs/larvae
Laboratory techniques	• Microscope use • Loading and recording Sedgewick-Rafter counting cells with invertebrate eggs/larvae • Use of weighing balances • Preparing chemicals in appropriate dosage for tanks (e.g. EDTA)
Micro-algae production and feed preparation	• Estimating micro-algae culture density using haemocytometer • Tank preparation for inoculation (cleaning, aeration, addition of nutrients, etc) • Inoculation with live micro-algae • Preparation and use of live micro-algae and micro-algae concentrates
Aquarium and fish-keeping techniques	• Setting up aquarium tanks • Feed preparation and feeding • Cleaning • Monitoring condition
Office and computer skills	• Computer software (Excel, Word, PowerPoint) • Data entry • Basic statistics and graphing of data • Development of simple macro programmes in Excel for frequently used applications, e.g. to calculate micro-algal feed quantities
Hatchery systems maintenance	• Maintenance of mechanical filtration system (sand filters, bag filters) • Maintenance of UV unit • Maintenance of pumps • Maintenance of intake pipes • NIMRF workshop staff trained in HDPE welding construction • NIMRF workshop staff trained in HDPE electrofusion plumbing
Hatchery experimental techniques	• Basic experimental design principles • Preparation of plastic aquaria for experimental treatments and controls. • Weighing of sea cucumbers according to set protocols (24-hour starvation, draining, drying) • Feeding using exact rations and protocols • Recording data and observations of experimental animals/systems • Preparation and use of commercial micro-algae pastes
Seawater pond design,	• Application of the principles of pond design (including sea water pumping requirements, bank slope and size, site selection, outlet type/position and wall construction).

construction and management	• Management of the pond environment including pest management, salinity

In five years' time, PNG national staff should be responsible for day to day running of the NIMRF hatchery systems and production. A practical and simple guide will be available to assist in selecting suitable habitats for ranching/farming of sandfish and an economic decision-making tool will enable NFA managers and communities to determine if sea cucumber mariculture is viable at a specific site. NIMRF/NFA national staff will produce and distribute cultured sandfish to communities. Progress will be made in optimising management of sea ranches, although a one-size-fits-all model is unlikely. NFA staff will have the capacity to guide communities in developing a system that benefits them while supporting a sustainable industry. The increased capacity of project staff will facilitate capacity building of PNG national trainee researchers, and students from NFA and UNRE.

7.3 Community impacts – now and in 5 years

7.3.1 Economic impacts

Throughout this project a moratorium on sea cucumber harvest in PNG was in place. It began in 2009 and was extended for a further 3 years in November 2012. Potential economic benefits from the sandfish mariculture component of this project are unlikely until the moratorium is lifted. However, the intense interest generated by our sandfish research in local communities relates to broad knowledge that sea cucumber stocks will be quickly overfished when the moratorium is lifted and that there can be benefits from owning and rearing cultured sandfish. A number of people are earning a small salary through caring for project gear and assisting with basic data collection.

The absence of fish, giant clam, or hard coral mariculture in past-aquarium industry development efforts has limited the scope by which communities could generate income from participation in the marine aquarium industry. Given that there is no current marine aquarium exporter in operation there is unlikely to be an immediate economic impact from ornamental mariculture at present. Community members have earned small salaries through production of coral fragments and maintaining coral grow-out farms.

In five years' time, the sea cucumber fishery will be operating annually (following lifting of the moratorium in April 2017). It is likely that fishing will decrease, or at worst deplete, sea cucumber stocks. When this happens, we will be able to ascertain if the sandfish mariculture activities developed through the Project will be able to provide cash income for specific communities (i.e. those that have suitable habitat for this species and have appropriate management strategies in place).

With a proposal for re-development of PNG's marine aquarium industry having recently been submitted by private investors to the NFA, it is likely that in five years' time the outputs of this project will support real economic impacts. The extent to which these economic benefits are realised by communities in New Ireland Province will depend on where future industry is based. Even if future industry is based outside of New Ireland, the scientific impacts of this project will likely bring economic benefits to communities engaging in coral propagation and giant clam culture efforts. While fish propagation is unlikely to have direct economic impacts to communities, future research assessing the capacity to restock wild populations clownfishes with cultured fishes may reveal at pathway for community benefits to be realised.

7.3.2 Social impacts

In terms of social impacts, mariculture activities are likely to have positive impacts on health, through increased earnings contributing to food security; equity, through increased capacity, education and financial independence for women; and culture, through

empowerment of individuals and communities to better manage their marine resources. Village-based livelihoods, which can provide employment and reduce the migration of people (especially youth) to towns and cities, will improve the standard of living and accrue social benefits in the communities involved.

In five years' time, Project activities will provide additional options for people to remain in their communities and earn money from various mariculture activities, enabling the positive social impacts discussed above. There is enhanced capacity in partner communities to sustainably manage their marine resources and extract greater social benefits (e.g. increased standard of living, health, diet, etc).

7.3.3 Environmental impacts

Sandfish mariculture is a benign form of aquaculture carried out in enclosures or in free-range situations, usually in areas of seagrass beds and nearby bare sand habitats. It can potentially result in positive environmental impacts as sea cucumbers are known to have a beneficial ecological effect on the substratum through their feeding and burying habits, even being implicated in mitigating ocean acidification. Hatchery-produced sandfish, if allowed to reach commercial size, will breed and contribute to spawning biomass. The preferential and regular harvest of farmed animals under a sea ranching scenario may take pressure off local wild stocks. In a related mini-project in Fiji, an MPA was declared around the juvenile release site and locals stated that other sea cucumber species increased in number and size within the MPA. Improved knowledge of the environment and marine resources through project engagement may lead to better management, resulting in greater positive environmental impacts. Community leaders considered the need for improved management of the sea cucumber resource and attempted to control fishing activities within their marine tenure areas when the wild fishery reopened in early 2017. There are parallels with management of future mariculture activities, such as sea ranches.

The production of ornamental fish through aquaculture will lessen the pressure faced by local wild stocks when aquarium fish exportation renews. Furthermore, the pioneering research on ornamental fish restocking programs would ensure any future negative environmental impacts incurred by wild-harvest of marine ornamentals could be reversed. The production of giant clams yields not only a potential commodity for the export aquarium market, but also a product of interest to local food security. Giant clams are regarded as a food source in New Ireland Province but are endangered at a global level.

The other mariculture commodities considered in this project are suspension-feeders (bivalve molluscs and corals). Culture of these organisms is considered among the most benign forms of aquaculture with minimal environmental impacts.

In five years' time, the uptake of sandfish sea ranching (or farming) and ornamental species culture (clams, coral) will provide livelihoods for PNG villagers. These activities are compatible with sustainable management of marine resources. They also promote environmental awareness.

7.4 Communication and dissemination activities

The following communication activities have been carried out in the third year of the project:

- Regular community awareness nights and meetings with village committees were held at all partner villages to explain the sea cucumber project and present up-to-date research results. Community reports on sea cucumber project activities were prepared and distributed to partner communities approximately twice yearly.

- Regular community awareness nights and meetings with village committees were held at Nago Island community to explain the coral propagation project and present up-to-date research results.
- The PNG Food Bowl episode (featuring sea cucumber community trials) was aired at Limanak village and an ACIAR blog on the village 'premier' was produced.
- Cathy Hair has conducted four Australian ABC Regional radio interviews on bêche-de-mer and sea cucumber aquaculture.
- A poster to address common misconceptions about the project and to explain the theory of sea cucumber sea ranching has been prepared in collaboration with John Aini (Ailan Awareness) and distributed to partner communities (Appendix 1).
- Completion of the NIMRF Sandfish Hatchery Manual. This manual was developed as a staff training tool and outlines current sandfish (*Holothuria scabra*) hatchery techniques employed at the facility.
- Comprehensive manuals detailing husbandry, broodstock conditioning, rotifer culture and larval rearing pertaining to ornamental fish culture have been developed for use by NFA staff at NIMRF.
- Establishment of project Facebook page for marine ornamental components attracted over 900 followers. With project completion this Facebook page merged with the new USC Tropical Aquaculture Research Facebook page: https://www.facebook.com/USCqld (Appendix 2)
- Achievement of project milestones has been featured by several media websites
    - http://www.radioaustralia.net.au/international/2014-06-09/breeding-nemo-hopes-the-png-community-will-benefit-from-moves-towards-sustainable-aquarium-trade/1324016
    - http://reefbuilders.com/2014/06/10/png-program-establish-sustainable-fisheries/
    - http://aciarblog.blogspot.com.au/2014/06/commemorating-world-oceans-day-not-just.html
- Thane Militz conducted Pacific Beat radio interview on progress with marine ornamental components of the project (June, 2014).
- Webinar on marine ornamental research objectives published by Reef 2 Rainforest media.
    - http://www.reef2rainforest.com/2014/07/07/coral-video-png-fishery-gets-a-3rd-look/
- Thane Militz has written several blog articles for Coral Magazine on research and project outputs http://www.reef2rainforest.com/category/coral-militz/
    - Papua New Guinea Gearing up for Aquarium Market Again
    - PNG Produces its First Captive-Bred Clownfish
    - Marine Aquarium Hobbyist Survey – Have Your Say!
- Article in Business Advantage PNG in Feb 2016: "Project to revive Papua New Guinea's lucrative beche-de-mer export industry begins at new mariculture centre in Kavieng".
- Above article reproduced in Air Niugini's in-flight magazine, Paradise Vol 3 (May-June 2016), as "A fresh harvest from the sea".

- Annual meetings of FIS/2010/042[10] provided opportunities to disseminate project findings to scientists from Philippines, Vietnam and Australia working on similar research problems related to sea cucumber culture. Cathy Hair and Duy Nguyen made presentations about their research on this project.
- Cathy Hair presented on aspects of the sea cucumber component of this project at the 5th International Symposium Stock Enhancement and Sea Ranching, Sydney, October 2015. Her paper was entitled: "Optimising methods for community-based sea cucumber ranching: experimental releases of cultured juvenile *Holothuria scabra* into PNG seagrass meadows" (see *section 10*).
- Cathy Hair presented on aspects of the sea cucumber component of this project at the 6th Biennial Conference of the Australian Association for Pacific Studies, Tides of Transformation: Pacific Pasts, Pacific Futures, Cairns, April 2016. Her paper was entitled: "Can mariculture help to rebuild a traditional Sandfish (*Holothuria scabra*) industry in the Tigak Islands, Papua New Guinea?".
- Cathy Hair and Duy Nguyen gave oral presentations on aspects of the sea cucumber component of this project at the World Aquaculture Conference, Cape Town, South Africa, 2017. "Using GIS classification methods to predict suitable habitat for sea ranching of cultured sandfish, *Holothuria scabra*, in Papua New Guinea" and "A new approach to feeding larvae and early juveniles of sandfish, *Holothuria scabra*, supporting simplified hatchery culture methods".
- The University of the Sunshine Coast (USC) Facebook page "Tropical Aquaculture Research" published a number of post relating to research activities in this project (July-Sept., 2016)(Appendix 2).
- A number of publications in scientific journals resulted from this project (see *section 9.2*) and others are still in review.

10 FIS/2010/042: "*"Expansion and Diversification of Production and management Systems for Sea Cucumbers in the Philippines, Vietnam and northern Australia".*

8 Conclusions and recommendations

8.1 Conclusions

The main objectives of this project were to develop viable, sustainable mariculture livelihoods for coastal communities in PNG, based on local marine species, and build capacity in research and training in mariculture. This presented many challenges because there was no tradition of mariculture in the coastal communities of PNG, few successful commercial mariculture ventures to backstop the Project[11], and no curriculum for culture of marine commodities. The NIMRF provided the base for sandfish and ornamental culture. The Project has been responsible for building the hatchery into a functional facility producing juvenile sandfish and a range of ornamental species (fish, clams, corals) with potential to support community livelihoods. Together with the NFC, there is enhanced educational and training capacity supported by the Project. The Project has been very successful in meeting all expected milestones and establishing a solid foundation for follow-up research.

The project was reviews in May 2016. Good progress against project milestones was noted and a follow-on project recommended. FIS/201/061 “Improving technical and institutional capacity to support development of mariculture based livelihoods and industry in New Ireland, Papua New Guinea” began in 2016.

8.2 Recommendations

The follow-on project (FIS/2014/061) was based on the success of this project with research focus on those commodities showing the greatest promise in this project.

The research questions it addresses are:

- 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 semi-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?
- What are the potential socio-economic benefits from mariculture in PNG, 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?

It focuses primarily on the commodities showing most mariculture potential during this project - sea cucumbers and ornamental species.

[11] *A pearl farm at Samarai, prawn farm at Kokopo and barramundi farm at Daru were active at the start of the project but are now defunct.*

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9.2.1 Manuscripts in Review:

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Militz, T.A., Kinch, J., Schoeman, D.S., Southgate, P.C., (in review). Use of total allowable catch to regulate a selective marine aquarium fishery. **Marine Policy** (in review).

10 Appendices

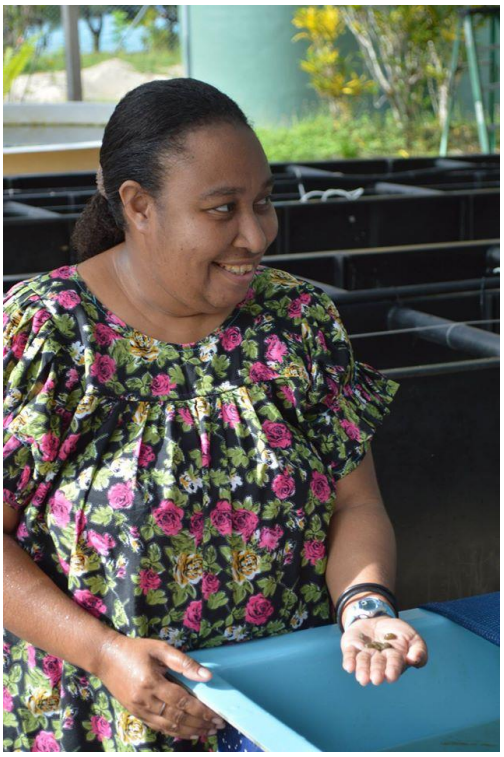
Appendix 1: Community Awareness Poster: "Sea ranching of sandfish in PNG"

Appendix 2: Posts relating to research at NIMRF from the University of the Sunshine Coast 'Tropical Aquaculture Research' Facebook page (July-Sept. 2016).

Marine aquarium

Pictured are, juvenile cultured Percula clownfish produced in Papua New Guinea (PNG) for the first time. Globally, trade in marine aquarium species is becoming contentious due to increasing pressures on our coral reefs. One way our team is improving the sustainability of marine aquarium fisheries is through captive culture of high-demand species. This successful research is a team effort involving the PNG National Fishery Authority and funding through the Australian Centre for International Agricultural Research Fisheries Program.

Sea cucumbers



The fourth successful PNG hatchery cycle of the sea cucumber, Holothuria scabra (commonly known as sandfish), recently reared 55,000 six-week old juveniles, our best result to date! Juveniles will now be used in experiments with local communities to maximise production efficiency of beche-de-mer. We would like to acknowledge the Australian Centre for International Agricultural Research (ACIAR), the National Fisheries Authority (NFA), and NFA Hatchery Manager, Esther Leini. This work is part of Tropical Aquaculture Research project, 'Mariculture development in New Ireland - PNG'.

Sea cucumbers

For the first time in PNG's history, sea ranching trials of cultured sea cucumber (Holothuria scabra - or sandfish) have been launched at community fishing villages near Kavieng, New Ireland. USC Tropical Aquaculture Research and PNG National Fisheries Authority staff have been making small releases of cultured sea cucumber into trial community sea ranches. The team will continue to release cultured sandfish over the next two years. Their survival, growth and migration will be closely monitored.

Sea cucumber ranching (growing juveniles to harvest-ready sea cucumbers), could provide a much-needed income stream to people living in remote PNG coastal communities. This work is funded by the Australian Centre for International Agricultural Research through the project: 'Mariculture Development in New Ireland Province PNG'.

Sea cucumbers

To assist with seacucumber searanching awareness and education in PNG, staff from USC Tropical Aquaculture Research, PNG National Fisheries Authority and local conservation group, Ailan Awareness, have produced a poster to explain the key principles behind growing cultured, juvenile sea cucumbers. Information is presented in Tokpisin and support is offered to community fishers. If you would like to find out more, please message via our page, or contact us at USC.

Pearls

Here's a hands-on approach to establishing a mabé culture trial in New Ireland Province, PNG! National Fisheries Authority Technical Officers participated in a recent three-day oyster seeding workshop run by USC Tropical Aquaculture Research staff. Together, the team successfully seeded over 130 oysters which will be harvested early 2017. This work is proudly funded by the Australian Centre for International Agricultural Research and is part of the USC TAR project: 'Pearl industry development in the Western Pacific'.