Papua New Guinea

(Appendixes 2.1 to 2.7)

Appendix 2.1

MS0805

Feasibility of establishing specific pathogen free stocks of shrimp in the Pacific

ACIAR Pacific Aquaculture Grant: **Project Summary**		**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Feasibility of establishing specific pathogen free stocks of shrimp in the Pacific (MS0805)**
Goal:	To determine the incidence of WSSV, IHHNV, YHV, GAV, TSV, MBV and HPV in *Penaeus monodon* from various Pacific Island countries.
Objective(s):	Specific objectives are to: 1) Determine whether shrimp sampled from natural populations in the participating countries carry any of the major shrimp viruses: WSSV, IHHNV, YHV, GAV, TSV, MBV, and HPV; 2) Provide the participating countries with scientific information to underpin their management of shrimp imports or translocations
Participating country/ies:	Papua New Guinea, Solomon Islands, Vanuatu, Palau
Project partner(s):	Fisheries agencies in participating countries, CSIRO
Dates / duration:	July 2008 to July 2009
Project description:	This mini-project will facilitate the collection and transport of *P. monodon* tissue samples from four PICs for PCR testing of seven viruses. Tissue samples (gills, pleopods and hepatopancreas) from 25-50 wild *P. monodon* are required from each location. These must be preserved in analytical grade ethanol (95%). Individual PICs will be responsible for sourcing the samples but the mini-project will meet associated costs. The four PICs have also elected to take part in an optional genetic study. Information on viral and genetic status will assist PICs in three ways: (1) development of a shrimp aquaculture industry if that is desired; (2) development of a supply industry for SPF broodstock of *P. monodon*; or (3) in maintaining biosecure SPF status of a PIC for the future.
Justification:	The Pacific Islands region has the advantage of natural biosecurity which may confer an advantage in the supply of specific pathogen free (SPF) *P. monodon* stocks. This mini-project will investigate the viral-disease status of *P. monodon* stocks in four PICs and follows on from a previous ACIAR mini-project on the disease status of *P. monodon* stocks in Fiji Islands.
Expected outcomes:	Data on presence or absence of seven viruses in PIC wild *P. monodon* stocks. Genetic analysis of *P. monodon* samples.
Funding:	$15,420

Feasibility of establishing specific pathogen free stocks of shrimp in the Pacific

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1. Background:

Shrimp disease is a major constraint to the shrimp industry worldwide. These industries have been hit hard especially by viral outbreaks. In 1988 Taiwan's *Penaeus monodon* industry was devastated by an outbreak of White Spot Syndrome Virus, resulting in a 70% drop in production and 80% fall in exports, approximately US$376 million was lost. Similarly, Taura Syndrome Virus cost Ecuador about US$763 million in 1999 (Kautsky, 2000). At present, there are no known captive viral-free (specific pathogen free 'SPF' or 'freedom of agent') populations of *P. monodon*. It is now nearly impossible to find viral-free *P. monodon* wild shrimp where *P. monodon* are farmed. The move to *P. vannamei* and similar species will continue without the culture and domestication (isolation) of viral-free *P. monodon* stocks.

Due to its relative isolation, large numbers of small scattered islands separated by expanses of ocean, the Pacific Islands region has the advantage of natural biosecurity. This is thought to confer an advantage in the supply of SPF *P. monodon* stocks. The Pacific's status as a clean, viral-free area for shrimp is often quoted but not proven. This mini-project represents an opportunity to obtain accurate and current information on disease status of *P. monodon* stocks in a number of PICs and follows on from a previous ACIAR mini-project on the disease status of *P. monodon* stocks in Fiji Islands. The earlier mini-project was concluded in 2005 (Waqairatu 2007) and found that Fiji did not have some of the major shrimp viruses but nor was it pathogen free. PCR analysis revealed that a number of shrimp viruses were present in *P. monodon* sourced from Fiji but two particularly problematic viruses, White Spot Syndrome Virus and Yellow Head Virus, were absent. Furthermore, although viruses were detected, disease was not recorded because the environmental factors that favour development of disease were absent. This information has had important implications for the development and management of the shrimp industry in Fiji.

The current mini-project widens the study to include all Pacific Island Countries where *P. monodon* occur: Papua New Guinea, Solomon Islands, Palau and Vanuatu. Information on viral status may assist PICs in three ways:

1. development of a shrimp aquaculture industry if that is desired;
2. development of a supply industry for SPF broodstock of *P. monodon*; or
3. maintaining biosecure SPF status of a PIC for the future.

2. Project Methodolgy

2.1 Sample collection

In the first instance, an email was sent to inform a range of PIC Fisheries agencies what the study involves and determine whether they wished to participate. Four PICs which have wild *P. monodon* stocks (Fig. 1), Papua New Guinea, Solomon Islands, Palau and Vanuatu, confirmed their interest for inclusion in the study. Each participating country was asked to submit four gill filaments, four pleopods and a 2 mm^2 piece of hepatopancreas tissue from at least 25, but ideally as many as 50, *P. monodon* individuals (adult or juvenile). Fisheries Officers from each PIC either collected shrimp themselves or obtained them from commercial fishing operations or resource owners. They were

provided with a collecting kit (containing sample jars, preservative, dissecting equipment, instructions and guide to dissection of the appropriate body parts). After collection and dissection, fresh or frozen *P. monodon* samples were preserved in analytical grade ethanol (95%) for transport to CSIRO in Brisbane, Australia.

Figure 1. Black tiger shrimp (*P. monodon)*.

The export from country of collection and import into Australia adhered to the relevant quarantine regulations required to move such samples. Import permits were not required as the samples were preserved in ethanol. A Genetic Material Transfer agreement was signed by CSIRO and the participating country prior to any movement of samples.

Extra samples were not needed for the genetic study, samples submitted for virus testing were split and shared between the Queensland Biosecurity PC2-rated Tropical and Aquatic Animal Health Laboratory (Townsville) and CSIRO (Brisbane). Prior to initiating the mini-project, all countries participating in the study were approached and agreed that they wish to obtain the extra genetic information.

2.2 PCR testing for virus

Molecular PCR techniques (polymerase chain reaction) were used to test for the following seven viral infections in *P. monodon* from a range of PICs:

1. White Spot Syndrome Virus (WSSV);
2. Infectious Hypodermal and Haematopoietic Necrosis Virus (IHHNV, both infectious and non-infectious strains);
3. Yellow Head Virus (YHV);
4. Gill Associated Virus (GAV);
5. Taura Syndrome Virus (TSV);
6. Monodonbaculovirus (MBV); and
7. Hepatopancreatic Parvovirus (HPV)

The shrimp samples for viruses 1-5 above were analysed at the Biosecurity QLD laboratory in Townsville in composite samples (pools). Pools consisted of gill and pleopod of 2-5 animals combined. The following information was provided on the tests carried out there: WSSV PCR assay was based on the method described by Tang and Lightner (2000); the dual detection PCR

assay for YHV/GAV was based on methods described by Cowley et al. (2004); the TSV PCR assay was based on methods described by Navarro et al. (2009); the PCR procedure for IHHNV was based on methods described by Tang et al. (2007). With respect to the IHHNV tests, the PCR procedure utilised two different PCRs, referred to as 309 and 389 assays (based on the size of the amplicon product produced). Infectious Types 1 and 2 IHHNV are detected by the 309 assay, while the non-infectious Type 3 IHHNV-related sequences are picked up by the 389 assay.

The shrimp samples for viruses 6-7 above were analysed by Ms Waqairatu at the Aquaculture Health Laboratory, CSIRO Livestock Industries, Brisbane. DNA pools extracted from hepatopancreatic tissue, comprised 2-5 animals.

2.3 Genetic analyses

An add-on to the project provided an opportunity for PICs to obtain genetic information on their *P. monodon* samples from CSIRO in Brisbane, Australia.

Microsatellite genetic markers have been developed by the Prawn Genetics group at CLI (CSIRO Livestock Industries) for *P. monodon* sourced from Thailand and Australia. The over-arching project at CSIRO is examining *P. monodon* from a wide geographical range, and this mini-project introduced a component on genetic diversity within the South Pacific region. The region was divided into Micronesia (Palau) and Melanesia (PNG, Solomon Islands and Vanuatu).

3. Outcomes

3.1. Country participation

Vanuatu did not participate in the study as very low numbers of *P. monodon* were found. PNG had problems sourcing *P. monodon* from the Milne Bay area as commercial fishing has ceased and submitted 20 shrimp from Gulf of Papua stocks only. Solomon Islands submitted 13 and Palau submitted 50 samples of *P. monodon*. Results for *P. monodon* samples from Palau are presented in a separate report.

3.2. Virus results

The PCR testing indicated presence or absence of the seven viruses in PIC *P. monodon* stocks from PNG and Solomon Islands (Table 1).

Table 1. Summary of results of shrimp virus testing on *P. monodon* sent from three PICs.

Virus	**PNG**	**Sol Is.**
Number of samples / pools for testing	*20 / 7*	*13 / 4*
White Spot Syndrome Virus (WSSV)	-	-
Infectious Hypodermal and Haematopoietic Necrosis Virus (IHHNV) (309 Types 1 and 2 infectious)	-	-
IHHNV (389 non- infectious)	+	+ (weak)
Yellow Head Virus (YHV)	-	-
Gill Associated Virus (GAV)	-	-
Taura Syndrome Virus (TSV)	-	-
Monodonbaculovirus (MBV)	+ (weak)	+ (weak)
Hepatopancreatic Parvovirus (HPV)	+	+

3.3. Genetic results

The PNG *P. monodon* population was able to be genotyped using the microsatellite markers. PNG was seen to be genetically more similar to East Australian strains. The genetic markers were not able to produce any results using the population from the Solomon Islands.

4. Impacts

4.1 Scientific impacts

The virus testing was the most comprehensive for these countries and the results are valuable in describing what is and is not present in each country.

However, the genetic aspect of the mini-project provided the most important and interesting scientific impacts. *P. monodon* sourced from the Solomon Islands is a unique population within the region. The inability to genotype the Solomon Islands tiger shrimp suggest they are very divergent (i.e. genetically different) from the Australian and Thai *P. monodon* that the markers were originally designed from. The similarity of PNG shrimp to East Australian strains may be due to past events in the evolution of the species or recent events such as the translocation of shrimp due to routine aquaculture practice.

4.2 Capacity impacts

The virus testing was done in laboratories outside the PICs, and there was no capacity building in terms of analyses or virus detection for PIC fisheries staff. PIC Fisheries staff did, however, gain experience in collection, proper dissection and storage techniques for samples to be used in PCR. They also now have a better knowledge of location of shrimp populations in their marine waters.

Further capacity building resulted from this study being linked to a Fijian John Allwright Fellowship PhD student who was testing the microsatellite genetic markers that have been developed by the CSIRO Prawn Genetics group. The provision of Pacific Island samples strengthened the thesis results while providing valuable additional information at low cost.

4.3 Community impacts

The main result was that *P. monodon* from PNG and Solomon Islands were free from the major viruses that cause the worst production and economic problems in the industry elsewhere in the world. WSSV presently overshadows all other disease agents as the leading cause of production losses in Asia. Both countries had positive results for MBV and HPV. However, the difference between presence of a virus and a disease outbreak must be emphasised. Lightner (1998) states that a disease outbreak may occur if the host organism and the disease agent are present together in an environment that favours the development of the disease (e.g. poor water quality or high stocking density). In farming situations this means that a disease outbreak can be avoided through the establishment and maintenance of optimum hatchery and pond conditions. The results indicate that these PICs may have a competitive advantage in *P. monodon* grow-out and/or supply because of their lack of major viruses. Since PNG and Solomons are WSSV-free, this had implications for them as potential suppliers of *P. monodon* postlarvae to other countries.

The genetic result that the Solomon Islands are a unique population, coupled with a similar result from Fiji (unpublished data, S. Waqairatu) may provide industry benefits to PNG. These countries could potentially boost genetic diversity by breeding with strains within the Pacific Islands, such as Fiji and the Solomons and therefore may also minimise the introduction of new pathogens from outside the region.

5. Conclusions

While many viruses are known to infect penaeid shrimp, only WSSV, YHV, IHHNV, and TSV, pose a threat to successful shrimp farming (Lightner 1998). All shrimp samples from PNG and Solomons tested in this study were negative for WSSV, GAV, TSV, GAV and infectious IHHNV. This virus, also known as Penaeus styloris Densovirus (PstDNV), is one of the smallest prawn viruses and is classified as a parvovirus (OIE 2009). IHHNV can cause mass mortalities in *P. styliostris*, particularly in juvenile and sub-adult life stages. In *P. vannamei*, however, the virus causes a chronic disease "runt deformity syndrome" with reduced and irregular growth and cuticular deformities, rather than mortalities. A similar disease is seen in *P. monodon*. According to OIE (2009), IHHNV has almost world-wide distribution in both wild and cultured penaeid shrimp and has been reported from Pacific islands such as Hawaii, French Polynesia, Guam and New Caledonia. In the Indo-Pacific, there are reports from East Asia, and South-East Asia. Therefore the absence of the infectious form of IHHNV from PNG and Solomons is an important find. The non-infectious Type 3 IHHNV-related sequence that was found in all shrimp tested in this study is not recognised as a pathogen in Australia (or elsewhere). MBV and HPV were detected across all populations sampled however weaker MBV signals were detected amongst pools from PNG and the Solomons. When detected in *P. monodon* larval stages, HPV and MBV are known to cause mortality. However, when detected during juvenile and adult stages these viruses cause slow growth, which can lead to high production costs for farmers.

Results from the genetic component of this study have important implications for the industry. Translocation of brooders is common in aquaculture but can also be harmful since potential pathogens are also transported. *P. monodon* sourced from the Solomon Islands is a unique population within the region and preliminary results from a study currently carried out by Miss Waqairatu also showed that *P. monodon* from Fiji are similarly a unique group amongst other Indo-Pacific populations examined. The possibility of improving genetic diversity of black tiger shrimp populations in PNG from breeding with other strains within the Pacific Islands region could greatly benefit industry development, and also assist in controlling disease introduction. If this were to be a practice, then the monitoring of these "new genetic lines" of *P. monodon* shrimp would have to be monitored closely to avoid escapes into the wild. Strategies for establishing and maintaining high genetic diversity in farmed stocks would also need to be developed.

This mini-project only goes so far as to carry out the analyses. However, should one of the participating PICs be interested in establishing an aquaculture industry based on *P. monodon*, the information provided will underpin further development. Knowledge on the genetic diversity of *P. monodon* will also assist them to assess which sites are genetically better to source brooders from and further help manage and maintain the genetic diversity of their wild stocks.

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5. Acknowledgements

We would like to acknowledge the assistance from Fisheries officers in the contributing Pacific Island countries who collected and sent samples: Gideon Pama (PNG) and James Teri (Solomon Islands). Also thanks to Tim Pickering who assisted with shrimp collection in Solomon Islands, and Kelly Condon of DEEDI (Oonoomba Veterinary Laboratory) for analyses and advice on virus test results.

Appendix 2.2

MS0808

Assessment of Fly River herring for fish meal and as an aquafeed ingredient, PNG

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU James Cook University WorldFish Center USP The University of the South Pacific	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Post-harvest storage, preservation and handling techniques for Fly River herring (*Nematalosa* spp) for fishmeal production (MS0808)**
Goal:	The overall goal of this project is to determine the optimum post harvest handling, storage and processing methods for herring fish to ensure an acceptable and quality fish meal product.
Objective(s):	The specific objectives of the project are to: 1. Determine appropriate storage, preservation and handling methods on board the fishing vessel up until landing. 2. Evaluate the extent of physical damage on herring catches and its subsequent effect on chemical and microbial spoilage considering time/temperature factors and storage methods on board fishing vessel to landing.
Participating country:	PNG
Project partner(s):	Ok Tedi Development Foundation (OTDF), Western Province Sustainable Aquaculture (WPSA).
Dates / duration:	Start late 2008, 12 months duration
Project description	Fishmeal, as a supplemental source for protein, is a costly ingredient for aquafeeds (between 1994 and 2006, price increased US$370 to US$880/MT). The Fly River system in Western Province of Papua New Guinea, is a source of abundant and under-exploited Fly River Herrings (*Nematalosa* spp), which could form the basis of a fishery to supply herring for fishmeal production to support aquaculture initiatives in the Fly River. Fly River herring was found to contain approx. 62% crude protein, with valuable amino and fatty acid profiles. However the nutrient quality of fish meal product depends very much on post harvest preservation, storage and method of production. Given the hot climate and nature of the area, investigation into best methods for catching, storing and transporting the fish in order to produce and maintain high quality fishmeal is imperative before further development of this fishery.
Funding:	AUD$7,550

Post-Harvest study on storage, preservation and handling techniques for Fly River herring (*Nematalosa papuensis*)

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[2] James Cook University, Townsville, Australia

1. Background

Fish meal is a common protein source in aquafeeds (and also in many other livestock feeds such as poultry, pig, etc). It is, however, a costly ingredient and increased in price from US$370 to US$880/MT between 1994 and 2006. Since feed alone can constitute up to 70% of the overall fish farming costs, the success of any aquaculture activities in PNG is very much dependant on the availability and cost of feeds. Fish meal produced from Fly River herring, *Nematalosa papuensis*. can make an excellent source of protein, it has been shown to have an approximate crude protein content of 62% (UNITECH, Lae, 2005). This fish is an under-exploited resource in the Fly River, and according to OTML environmental data, accounted for about 40% of the river's fish biomass. A recent study conducted by Storey and Hortle (2006) suggested that the fishery had a maximum sustainable yield (MSY) of about 5,000 tons per annum.

As the nutrient quality of fish meal products depend very much on the post harvest handling and storage of fresh fish, this mini-project investigated the best method of preservation and storage of fresh Fly River herring on the fishing vessel from capture until landing and processing. Results from this study will be incorporated into the collaborative PNG Sustainable Development Program (PNGSDP) Limited and Ok Tedi Development Foundation (OTDF) Fisheries Program Barramundi Feed Trial. The feed trial is a component of the Western Province Sustainable Aquaculture (WPSA) Barramundi Cage Culture Commercial trial. The Barramundi feed project plans to use fresh herring and herring meal combined with other local food ingredients to assess the growth of caged farmed barramundi. Mini-project results will also provide valuable information to underpin plans for a fish meal processing plant in the area.

2. Materials and Methods

The goal of the mini-project was to determine the optimum post harvest storage and preservation methods for Fly River herring from capture on board the fishing vessel through to landing. This was achieved by evaluating the extent of physical and chemical spoilage on the herring catches using different storage conditions and duration.

2.1 Experimental design

We investigated the best storage method for the fish by determining the extent of spoilage in three types of storage treatment left for three time periods. The three storage treatments were: freshly caught fish in a container with ice, freshly caught fish in a container with no ice but kept shaded and freshly caught fish left in the sun (no ice, no shade). The time periods were 4, 8 and 16 hours for the first two treatments and 4 hours for the third treatment (Fig. 1).

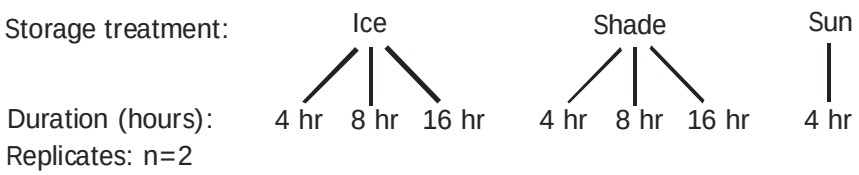

Figure 1. Experimental design for storage trial.

2.2 Sampling

Herring samples were collected from lakes Komovai and Pangua, two adjoining Fly River ox-bow lakes in the vicinity of Obo in the Middle Fly region (Fig. 2).

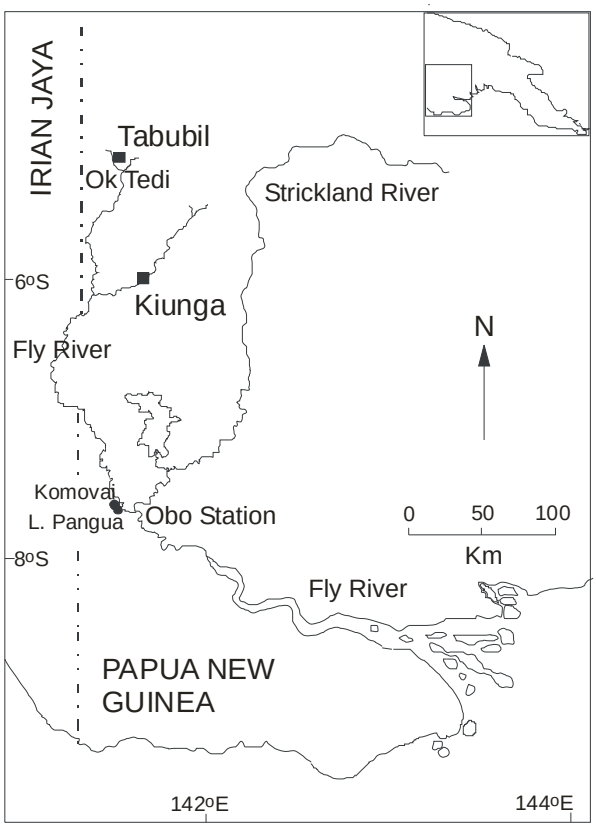

Figure 2. Map of western Papua New Guinea mainland, showing the Ok Tedi mine site, Fly River system and Obo station, where the study was conducted.

Fish were collected using two 3.5 inch mesh gill nets set along the grassy edges of the lakes between 10.00 and 11.00 hours. On retrieval, several kilograms of herring were packed into each of two plastic nally bins, one with ice and the other without ice but kept in the shade (Fig. 3). Some fish were left unshaded in direct sunlight. The time was recorded the moment the bins were filled.

Figure 3. Freshly caught Fly River herring, *Nematalosa papuensis*, in a nally bin.

After four hours, about 600 g of fish were selected from each storage treatment. About 250 g of each sample was placed in replicate (*n*=2) plastic jars and frozen immediately. Each sample jar was labeled with date, description of contents, treatment details (storage method, duration and replicate), and Australian Quarantine and Inspection

Service (AQIS) permit number. This process was repeated after eight and sixteen hours for the ice and shade treatments.

Data were also collected on the temperature of holding container at time of processing, and the physical appearance of the fish (colour, odour, texture).

2.3 Analyses

The samples were imported into Australia following all AQIS quarantine protocols. They were sent to Australia and analysed on an "as is" basis at two Class 5 Quarantine Approved Premises (i.e. laboratories).

At the National Measurement Institute (NMI) in Victoria, analyses were carried out on:

1. Proximate content – including crude protein (CP), gross energy (GE), fat, moisture and ash;
2. Free fatty acid – the breaking up of oil glycerides (lypolysis) into free fatty acids (i.e. spoilage of fat) results in reduced quality of oil. This analysis will provide additional information in case there is interest in fish oil production in the future;
3. Total Volatile Nitrogen (TVN) – measure of protein deterioration in fish from microbial activities and is regarded as a good measure of degradation. Bacterial breakdown of amino acids that can result in significant loss of protein.

The second laboratory, Victoria Department of Primary Industry chemistry laboratory, analysed four biogenic amines (degradation indicators) – histamine, putrescine, cadaverine and beta-phenylethylamine. These are good indicators of fish spoilage. These biogenic amines are formed as a result of decarboxylation of free amino acid (Ricque-Marie & Pike, 1996). They are heat stable and can provide information on the freshness of the raw material prior to processing.

3. Results

3.1 Observations

Observations made on the fish during processing (i.e. after 4, 8 and 16 hours) are presented below (Table 1).

Table 1. Temperature in storage container (^{o}C), colour (dark red, pale red or maroon), texture and odour (normal fishy or foul smelling) of Fly River herring held under the various trial treatments.

	Ice 4 hr	Ice 8 hr	Ice 16 hr	Shade 4 hr	Shade 8 hr	Shade 16 hr	Sun 4 hr
Temp. (^{o}C)	10	8	12	29	29	28	32
Colour	Dark red	Pale red	Maroon	Dark red	Maroon	Maroon	Dark red
Texture	Firm	Firm	Soft	Firm	Bit soft	Soft	Firm
Odour	Fishy	Fishy	Foul	Fishy	Bit foul	Foul	Fishy

3.2 Analytical results

The tables below summarise the test results from the two laboratories. Fish were analysed on an "as is" basis (Table 2). However, since similar studies analysed fish meal rather than fresh fish, the fresh fish results were converted to provide approximate comparison data for fish meal by multiplying the "as is" figure by 100/(% dry matter) (Table 3).

There was one anomalous value for Total Volatile Nitrogen for the Ice 8 hrs treatment, which was unusually high and cannot be explained as the Shade 8 hrs value was comparatively low (Table 2). However, other values for Ice 8 hrs were within expected levels and conformed to general trends in the data.

Table 2. Proximate and biogenic amine analysis results for Fly River herring experimental treatments ("as is" basis). Anomalous values shaded in grey.

	Ice 4 hr	Ice 8 hr	Ice 16 hr	Shade 4 hr	Shade 8 hr	Shade 16 hr	Sun 4 hr
Moisture (mg/100g)	73.5	74.6	72.7	72.6	73.2	72.2	72.7
Fat (mg/100g)	4.7	6	7.1	7.1	5.7	3.6	5.6
Crude protein (mg/100g)	17.4	16.2	16.2	18.4	16.7	17.6	18.2
Ash (mg/100g)	3.5	5.2	5.2	3.7	4.7	5.7	5.4
Carbohydrates (mg/100g)	<1	<1	<1	<1	<1	<1	<1
Energy (kj/100g)	475	495	535	575	495	485	515
Free fatty Acids (mg/100g)	7.6	7	7.7	6.6	5.8	6.8	6.6
TVN (mg/100g)	1	11	12	1	1	64	17
Beta-Phenylethylamine (mg/kg)	2	2	2	4	8	41	2
Putrescine (mg/kg)	2	2	2	2	2	33	3
Cadaverine (mg/kg)	6	3	6	17	11	110	17
Histamine (mg/kg)	2	2	2	3	12	23	3

Table 3. TVN and biogenic amine analysis results for Fly River herring experimental treatments. Unless indicated otherwise, all units are (mg/kg).

	Ice 4 hr	Ice 8 hr	Ice 16 hr	Shade 4 hr	Shade 8 hr	Shade 16 hr	Sun 4 hr
TVN (mg/100g)	3.8	43.3	44.0	3.6	3.7	230.2	62.3
Beta-Phenylethylamine	7.5	7.9	7.3	14.6	29.9	147.5	7.3
Putrescine	7.5	7.9	7.3	7.3	7.5	118.7	11.0
Cadaverine	22.6	11.8	22.0	62.0	41.0	395.7	62.3
Histamine	7.5	7.9	7.3	10.9	44.8	82.7	11.0
Total of 4 biogenic amines	45.3	35.4	44.0	94.9	123.1	744.6	91.6

Suggested thresholds for these compounds are: 28 ppm of cadaverine, 51 ppm of putrescine and 35 ppm of histamine (Pike and Hardy 1997); 30 mg/kg beta-phenylethylamine (Rasodevich 2006); TVN 40 mg/100g for human consumption (Kirk and Sawyer 1991), 30 mg/kg for fish meal production (Pike and Hardy 1997) or <50 mg/kg for high quality fish meal (Ricque-Marie et al. 1998); maximum of 2,000 ppm for the four main biogenic amines for a moderately high quality fish meal (www.soyaaqua.ors). Most of the storage treatments and times returned values well within the suggested limits for fish meal (Fig. 4).

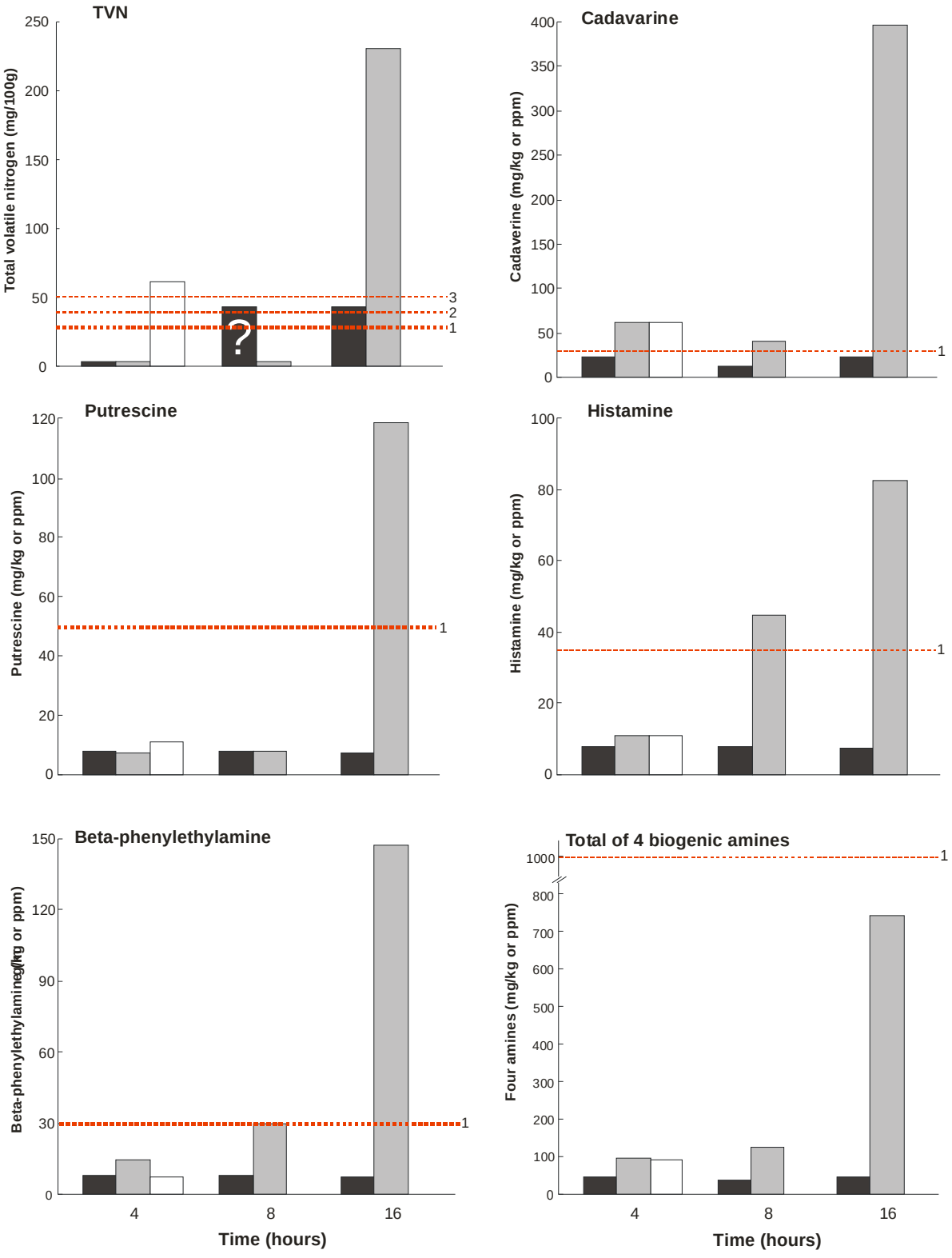

Figure 4. Level of Total volatile nitrogen and biogenic amine analysis results for Fly River herring experimental treatments. Black bars represent the Ice, grey bars Shade and White bars sun treatments. Red lines show recommended or suggested limits from the literature (1=Pike and Hardy 1997; 2=Kirk and Sawyer 1991; 3=Radosevich 2006). Anomolous Ice 8 hrs results marked with a question mark.

4. Impacts

4.1 Scientific impacts

This report describes the first study of the effects of time and storage on the degradation of Fly River herring, a tropical freshwater fish species. Studies elsewhere examined different species (generally coldwater or marine fish) or investigated degradation of fish meal produced from fish of varying freshness. However, this mini-project produced original data on a species of interest to PNG. The data will be of practical use to the collaborative PNGSDP Limited and OTDF Fisheries Program Barramundi Feed Trials to be carried out in the future.

4.2 Capacity impacts

This mini-project enhanced capacity of the officers who conducted the trial in sampling, processing, experimental design and reporting.

4.3 Community impacts

This result has important implications for the barramundi cage culture initiatives underway in the middle Fly River and for the potential of a fish meal plant in the area. The fact that the herring do not degrade quickly provides an opportunity for more potential fish farmers to be involved in cage culture and local fishers to provide raw product for fish meal. The fishmeal and barramundi industries will provide opportunities for fishers to earn an alternative non-mine related income, a major goal of the OTDF. Cheaper fishmeal for the industry will support the farming of higher value species, which have a need for a high-protein diet (such as barramundi). It will promote the growth of aquaculture and other livestock industries.

5. Conclusions and recommendations

It is recommended that fish meal should be prepared from fish in which spoilage has been minimised (Pike and Hardy 1997). Fish spoilage depends on temperature and duration of storage, condition of the fish and microbial contamination (Pike and Hardy 1997). Fish meals prepared from spoiled fish have elevated levels of TVN and biogenic amines and can affect the health of the organisms which consume it. According to Radosevich (2006), however, the threshold of toxicity is difficult to define as it depends on the detoxification efficiency of the individual consuming the “spoiled” feed. Trials on shrimp and salmon show that fish meal prepared from stale or spoiled fish can negatively affect growth (see data in Ricque-Marie et al. 1998). Fish freshness is the most important factor in producing a high quality fish meal (www.soyaqua.ors).

It was difficult to find recommended limits for all the degradation products analysed in this study. Most past studies deal with fish freshness as it affects production of fish meal or human consumption. In many cases it is a question of degree, there can be a fine line between a high quality fish meal and one of acceptable quality. Pike and Hardy (1997) suggest that fish meal for shrimp should be made from fresh fish: an example was given of 28 ppm of cadaverine, 51 ppm of putrescine and 35 ppm of histamine for a warm water anchovy species. A value of 30 mg/kg for beta-phenylethylamine for human consumption was quoted by Rasodevich (2006). Kirk and Sawyer 1991 found that if TVN is less than 20 mg/100g, fish is fit for human consumption; if 30 mg/100g, fish is "stale" and if 40 mg/100g fish is not fit for human consumption. This agrees with a recommended TVN of less than 30 mg/kg for fish meal production (Pike and Hardy 1997). There are reported enhanced effects of histamine when other biogenic amines are present in combination (Radosevich 2006). Furthermore, the amount of amines formed varies with the type of fish (Pike and Hardy 1997). Hence, the standard for a moderately high quality fish meal includes a value of 1,000 ppm for the most prominent

amine, as well as a maximum total of 2,000 ppm for the four main biogenic amines (www.soyaqua.ors). However, Pike and hardy (1997) recommended an amine content of 3,400 ppm as the maximum to be used for fish meal for shrimp.

Given the recommended (or suggested) levels cited, our study shows that fresh Fly River herring is fit as a direct fish feed or to be used as an ingredient in fish meal for up to four hours, regardless of whether or not it is iced. Beyond that time, the treatment becomes important. Iced fish is good up to 16 hours post harvest, but fish that had been left un-iced for eight hours is at the limit and should not be used for feeds beyond this time. Although fish left in the sun for four hours was still usable, we did not analyse longer periods and suggest that fish left in the sun for more than four hours may be unfit for use as a fish feed or for fishmeal. In a tropical climate like PNG, oily fish like herring could be expected to deteriorate relatively quickly. We speculated that fishers in the Fly River area may need to paddle long distances to catch fish and then transport them un-iced back to a depot for sale or to barramundi fish cages to be used as a direct feed. While we are not advocating poor treatment of fish, we recognise that ice will not always be available and may be unaffordable for fishers when it is. These results suggest that ice should be used if possible, otherwise fish should be looked after as well as the circumstances permit up to the times limits indicated here. That is, keep fresh herring out of direct sunlight as much as possible and cover them with whatever material is available (e.g. wet leaves, hessian sack, etc).

6. References

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7. Acknowledgements

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Appendix 2.3

MS0903

Recruitment patterns of commercial molluscs and other species to spat collectors in PNG

ACIAR Pacific Aquaculture Grant: **Project Summary**		**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**
Project Title:	**Recruitment patterns of commercial molluscs and other species to spat collectors in PNG (MS0903)**	
Goal:	To determine the availability and seasonality of commercial species that recruit to surface and benthic spat collectors in PNG.	
Objective(s):	The project will achieve this goal through the following objectives: 1) Describe spatial and temporal variability in recruitment of molluscs (e.g. edible and pearl oyster species, *Tridacna* spp) and other species (e.g. ornamental species) at two sites in PNG; and 2) Grow-out a range of species (on longlines or in raceways).	
Project location:	Kavieng (New Ireland Province), PNG	
Project partner(s):	PNG National Fisheries Authority (NFA), National Fisheries College (NFC)	
Dates / duration:	2 years	
Project description	This mini-project will monitor mollusc and other recruitment at sites near Kavieng, PNG, over an 18-month period. The research will determine what mollusc spat can be collected using surface spat collectors (likely to collect pearl oyster and giant clam species) and benthic, fixed collectors (likely to collect edible oyster species). The project will also monitor the recruitment of other potentially commercial species such as ornamental molluscs (e.g. cowries) and other species (crustaceans, fish). Data on water quality will also be collected. It will also add to the body of knowledge regarding the mechanisms determining the distribution of spat.	
Justification	There is a great deal of interest in mariculture in the Islands region of PNG but little knowledge of species available to kick-start such industries. This project will provide important information on what commercial species can be effectively and reliably collected using different kinds of spat collectors. NFA will facilitate adoption and extension of results to interested local entrepreneurs.	
Expected outcomes	1. Collect baseline information that will assist in the development of aquaculture industry in the PNG Islands region, by identifying the commercial potential of abundant and valuable species 2. Knowledge of spat availability and variability in supply; 3. Increased knowledge on what factors affect spat distribution. 4. Capacity building within NFA.	
Funding sought:	$21,120	

Recruitment patterns of commercial molluscs and other species to spat collectors in PNG

Andrew Beer[1], Peter Minimulu[2], Hugh Walton[2] & Paul Southgate[1]

[1] James Cook University, Townsville, Australia
[2] National Fisheries Authority, Kavieng, Papua New Guinea

1. Background

Commercial molluscs form the basis of several important aquaculture industries in the Pacific Islands region. The pearl industry, for example, is a major export earner for many countries. The industry utilizes the black-lip pearl oyster (*Pinctada margaritifera*), and gold/silver/white–lip pearl oyster (*P. maxima*) for round pearl production, and the winged pearl oyster, *Pteria penguin*, for half-pearl ('mabé') production. The latter has considerable potential in supporting development of local handicraft industries. Molluscs are also cultured for the ornamental and food trades, notably giant clams (*Tridacna* spp.), and edible oysters, mussels and scallops, respectively.

The pearl industry has a long history in PNG, with initial attempts and some success in the mid-1960s but the industry was closed in the 1980s. Since 1998, a commercial pearl farm in Milne Bay has been in operation with more farms expected pending licences. Edible oyster culture was also attempted in the 1950s but the operations did not last. One of the main challenges faced by these industries is access to a consistent and adequate supply of stock. Stock can be obtained by: (1) collection of larger juveniles or adults from the wild; (2) hatchery production; or (3) spat collection. Collection from the wild can place pressure on natural populations and supply from the wild can be unreliable at times; however, many commercial bivalve aquaculture industries (e.g. NSW oyster industry) have traditional reliance on wild spat collection as a source of culture stock. Also, while many species can be produced in hatcheries, this process can be expensive and technologically demanding and restricting for a fledgling industry. In the Pacific, therefore, many mariculture operations rely on spat collection because it is a cheap and easy way to obtain large numbers of the target species and requires limited resources.

Spat collection is the process of 'catching' larval molluscs (or other species) on deliberately deployed substrates (spat collectors) onto which they settle and from where they can be harvested. Different types of spat collectors can be used to obtain mollusc spat depending on the biological characteristics of the target species. Generally species that cement to a surface (e.g. rock oysters) are collected on two-dimensional solid surfaces (such as tiles, slabs) while species that attach using byssus (thread secreted by the mollusk to anchor it to a substrate), such as pearl oysters and mussels, are collected using 3-dimensional collectors such as mesh bags filled with shade cloth or frayed rope. These two types of spat collectors are generally deployed at the ocean surface and on the bottom substrate, respectively. Surface spat collectors are usually made of dark light weight material with maximum surface area that is suspended in the sea at shallow depths. These typically collect pearl oysters, scallops and other molluscs, as well as a variety of non-mollusc species that may be commercially valuable (e.g. aquarium species of shrimp and fish). Bottom spat collectors are fixed to the sea floor (such as racks or plates) and are generally positioned to collect intertidal species such as edible oysters. The success of spat collection is related to a number of factors including the length of time the collectors are deployed (possibly related to the number of predators that also settled on or were attracted to the collectors, and overcrowding by other species); distance from

shore; season; degree of biofilm accumulation on the collector; and environmental parameters such as primary productivity, dissolved oxygen, salinity, water temperature and current.

The primary aim of this mini-project was to determine the availability and seasonality of commercial species of molluscs and other species that recruit to surface and benthic spat collectors in the Kavieng area in New Ireland Province, PNG. The Nago Island Mariculture and Research Facility (NIMRF) near Kavieng, operated by the National Fisheries Authority (NFA), was the major support infrastructure for this research and staff based at NIMRF were the key local counterparts for the project.

2. Materials and Methods

Spat collection infrastructure was established between 9–26 July 2009 by Mr Andrew Beer of James Cook University (JCU). Two follow up trips to harvest the collectors and identify spat were conducted by Professor Paul Southgate of JCU.

Materials and methods are organised into separate sections for: (1) Longlines – suspended sub-tidal spat collectors; and (2) benthic collectors – intertidal fixed spat collectors.

2.1 Longlines (suspended sub-tidal spat collectors)

2.1.1 Site selection

Site selection was based upon considerations of human interactions, natural processes and operational requirements (Fig. 1). NFA staff were involved in the site selection process and the relevant constraints were identified and discussed.

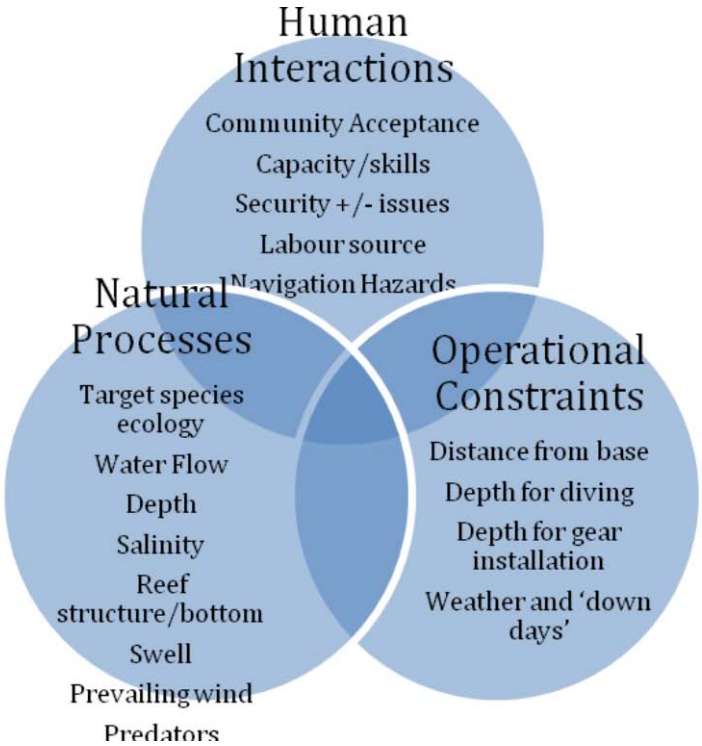


Fig. 1. Diagram showing the factors to be considered when siting spat collectors.

Two sites for installation of subsurface long-lines were sought – an 'exposed' channel site, and a more sheltered 'bay' site. The Australian Naval 666 chart was consulted and several sites were short listed based on proximity to NIMRF, depth and exposure. These sites were then 'ground truthed' and local knowledge sought regarding year-round sea conditions. Several were considered unsuitable due to weather exposure and swell, while the promising sites were further investigated with a sounder and diving. Two long-line sites were selected (Fig. 2):

1. Nusalik (GPS coordinates 2° 35.314' S 150° 46.836 E). This site was in a channel northeast of Nago Island (Fig. 3a). The channel was 12-14 m deep. It had a sandy bottom with rubble (20 m W and E) and the reef slope was 40 m W and 80 m E. The site was protected from summer swell and had high water flow over the reef and through the channel.
2. Usenlik (GPS coordinates 2° 38.851' S 150° 46.341' E). This was a bay site, located to the south of Nago Island (Fig. 3b). The site was 13-19 m deep with a rubble bottom and the reef slope was 40 m SE and 80 m NE. The site was protected from summer swell with some protection form SE winds. It had high water flow from the bay through the channel.

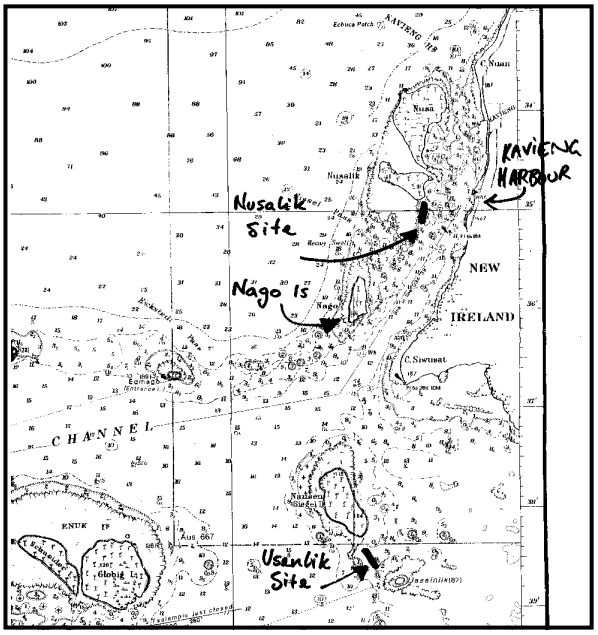


Fig. 2. Kavieng region and longline sites (from Aust 666 Admiralty Chart).

A  B 

Fig. 3. (a) Nusalik Channel long-line site (Nusalik in the background) and (b) Usenlik Bay long-line site (Usenlik in the background).

2.1.2 Long-line structure

Long-lines were submerged 3 m below the surface in order to reduce the risk of damage or theft and to avoid collision with boating traffic. Long-lines were made of 20 mm rope, consisting of 50 m of 'headline' and >30 m of anchor lines. Anchors were made of heavy steel I-beam sections with angle iron flukes and shackle connected with 3 m chain. Mid-line anchors were made of car tyres filled with concrete (Fig. 4)

Spat collectors were made of onion bags stuffed with 1.5 m^2 of 90% shade cloth. The bags were tied to 6 mm poly rope dropper lines (Fig. 4) at two points so that following deployment, spat collector bags were at two depths, 3 and 6 m. They were weighted to maintain depth.

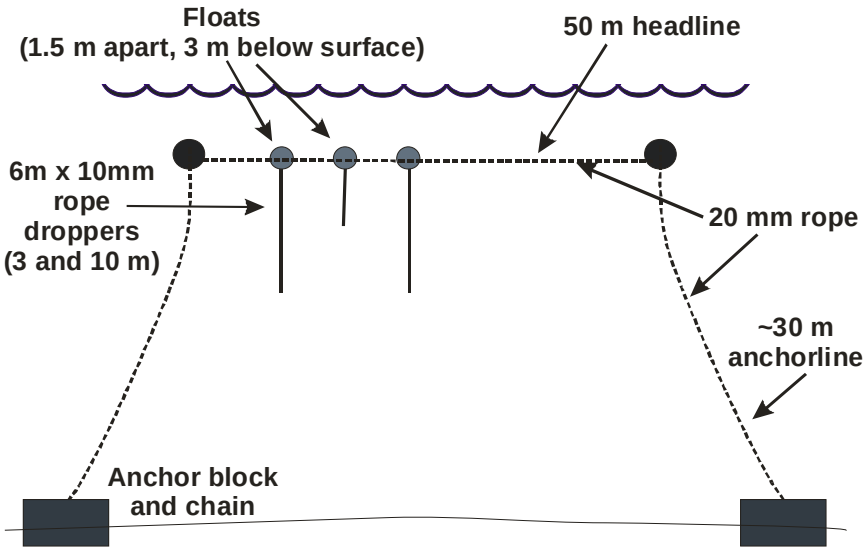


Fig. 4. Schematic of suspended culture long line

2.1.3 Experimental design and sampling schedule for long-lines

The experimental design consisted of: two sites; two depths at each site (3 m and 6 m); five replicates at each depth at each site. Five replicates at each depth provides significantly greater statistical 'power' compared to three replicates, particularly when dealing with patchy and low abundances commonly encountered in spat collection. More replicates using collectors of smaller size/surface area are of greater value in the data analysis. The area of shade cloth (1.5 m^2) consists of a 0.83 m strip of cloth by 1.8 m wide (standard roll width).

In order to obtain a greater volume of spat in the first collection for grow out, another 25 collectors (3 x onion bags within onion bag) were attached at 3 m depth.

The long-line collector deployment and sampling schedule operated as follows: new spat collectors are added every 6 weeks, but each set of spat collectors was removed at 8 weekly intervals allowing a 2-week overlap. For example, the initial 'Soak 1' collectors were deployed and left for 6 weeks, then new 'Soak 2' collectors were added after 6 weeks. The Soak 1 collectors are removed 2 weeks later, i.e. 8 weeks after they were deployed, and so on for subsequent soaks (see Table 1 schedule).

Table 1. Soak and sampling schedule for long-line spat collectors.

Soak	Soak begins	Soak ends	Date bags out - Sample
1	21-July-2009	01-September-2009	15-September-2009
2	01-September-2009	13-October-2009	27-October-2009
3	13-October-2009	24-November-2009	08-December-2009
4	24-November-2009	05-January-2010	19-January-2010
5	05-January-2010	16-February-2010	02-March-2010
6	16-February-2010	30-March-2010	13-April-2010
7	30-March-2010	11-May-2010	25-May-2010
8	11-May-2010	22-June-2010	06-July-2010
9	22-June-2010	03-August-2010	17-August-2010
10	03-August-2010	14-September-2010	28-September-2010
11	14-September-2010	26-October-2010	09-November-2010
12	26-October-2010	07-December-2010	21-December-2010

2.2 Benthic collectors (intertidal fixed collectors)

2.2.1 Intertidal benthic collector structure

'Fence line' collector systems were made by driving angle iron pickets (1.8 m) into the sediment to at least 0.5 m and joining these across the top with twisted wire to form a fenceline 'header'. Spat collector media were installed on the fence line collector (Fig. 5).

A second type of intertidal collector system was employed during the study; a 'suspended' system was hung from a fixed point above the water (Fig. 6).

Two types of spat collector media were installed on the fence line and suspended collector systems:

1. PVC pipe (split and roughened, 40 cm long). The PVC slats were cut from a 6 m length of 100 mm pressure pipe. The PVC pipe was split in half length wise and cut into 400 mm lengths, each with a surface area of 0.0785 m^2 per side (0.157 m^2 total surface area), and
2. Fibre cement (or 'fibro') (40 x 20 cm). The media were separated by 15 mm conduit spacers 10 cm long. The area of each fibro slat was determined by the maximum number cut from a 2.4 x 1.2 m sheet of fibre cement. Slats of 400 x 200 mm give a surface area of 0.08 m^2 per side (0.16 m^2 total surface area).

While not exactly the same dimensions and surface area, the two substrates were prepared to be effectively equal in order to eliminate the issue of an area effect on settlement.

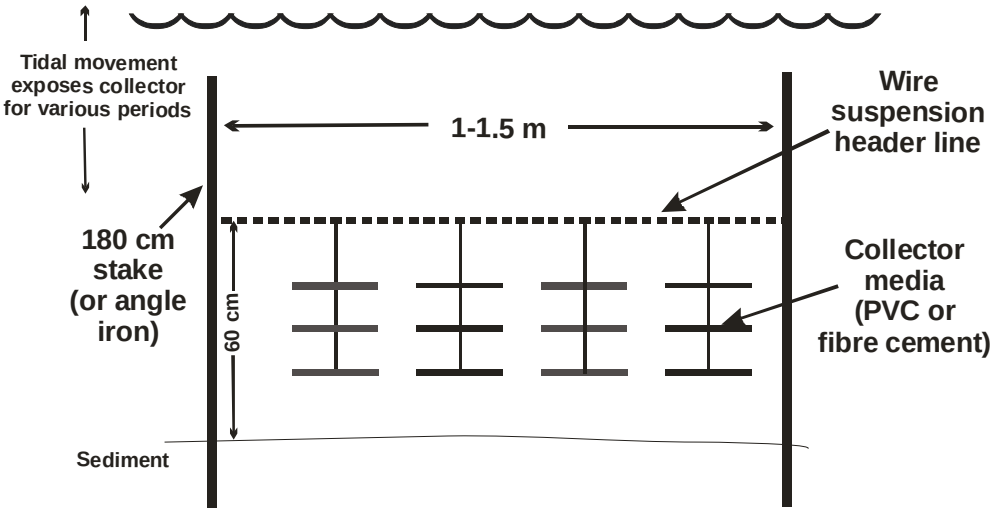


Fig. 5. Schematic of intertidal 'fence line' collector system.

Fig. 6. Caspar Dako installing suspended intertidal collectors at the Harbour Wharf site.

2.2.2 Site selection and experimental design (intertidal collectors)

Site selection was based upon considerations of the same factors as for the long-lines (Fig. 1) although slightly different physical attributes were desirable. One exposed channel site (Nusa) and one bay site (Kavieng harbor) were selected after attempts to survey tidal height within the intertidal zone against mangrove roots to get in the 'settlement zone' for rock oysters. The following sampling designs were used:

1. Nusa Channel. A set of PVC slat (n=4) and fibro slat (n=4) fenceline collectors were deployed at each of three depths: 'shallow', 'mid' and 'deep', moving along the tidal depth gradient with the top slat of one station being continuous with the bottom slat of the adjacent collector.
2. Kavieng Harbour Wharf. At this site, three collector systems, each comprising seven slats, were suspended below the wharf so they were located above and below the ideal settlement zone, as observed at low tide (Fig. 6). Pieces of 10 cm long PVC pipe were used to space the slats (Fig. 6).

Soak schedule for the benthic spat collectors was effectively the same as for the long-line spat collectors (Table 2). New spat collectors should be added every 6 weeks, and then sampled 8 weeks later, allowing a 2-week overlap.

Table 2. Proposed soak and sampling schedule for intertidal spat collectors.

Soak	Soak begins	Soak ends	Date collectors sampled
1	21-July-2009	01-September-2009	15-September-2009
2	01-September-2009	13-October-2009	27-October-2009
3	13-October-2009	24-November-2009	08-December-2009
4	24-November-2009	05-January-2010	19-January-2010
5	05-January-2010	16-February-2010	02-March-2010
6	16-February-2010	30-March-2010	13-April-2010
7	30-March-2010	11-May-2010	25-May-2010
8	11-May-2010	22-June-2010	06-July-2010
9	22-June-2010	03-August-2010	17-August-2010
10	03-August-2010	14-September-2010	28-September-2010
11	14-September-2010	26-October-2010	09-November-2010
12	26-October-2010	07-December-2010	21-December-2010

2.3 Retrieval of spat collectors

Long-line spat collectors deployed by Andrew Beer were harvested during a trip to Kavieng by Paul Southgate from 5–12 September 2009. Spat collectors were retrieved and taken to Fisheries Wharf where they were sampled. A second sampling was carried out on 10 January 2010, supervised by Paul Southgate.

2.3.1 Long-line collectors

Collector material was removed from the protective onion bag and inspected for animals of potential commercial interest: shrimp, fish and molluscs. Collector bags were also inspected in the same way. Animals were categorised and placed into small aquaria and later counted. Spat collectors from each site were counted in two groups: (1) the replicated five 'experimental' spat collectors (from two depths); and (2) the extra 25 'onion

bag' spat collectors deployed at the shallower depth. Data were recorded on data sheets (Appendix 1).

2.3.2 Intertidal collectors

Spat collectors from each site and at each tidal level were split into their component slats which were numbered so that pattern of recruitment relative to tidal height could be monitored. These spat collectors targeted rock oysters specifically and the numbers of oyster spat on the top and bottom surfaces of each slat were counted. Data were recorded on data sheets (Appendix 1).

2.4 Methodology modifications

Based on the results of the first harvest (September 2009), the following changes were made to the collection design for the second deployment of spat collectors (January 2010):

Long-line collectors:

- The number of spat collectors at each of the long-line sites was altered to reflect differences in the number of recruits (particularly pearl oysters) at the two sites and a desire to collect as many pearl oyster spat as possible. Again, long-lines at Nusalik and Usenlik were equipped with 5 replicate dropper ropes (Fig. 4), each with **experimental collector** bags at two depths (3 m and 6 m) to continue the experimental data collection at both sites)(see sections 2.1.2 and 2.1.3). However, reflecting greater recruitment at Usenlik than Nusalik, the number of additional spat collectors was reduced to 10 at Nusalik and increased to 40 at Usenlik.
- Design of the **additional collectors** was modified slightly. Onion bags were replaced with shade-cloth. The surface area of shade cloth used remained the same but it was cut into two equal sections (to aid sampling) and was placed into the outer onion bags in a roughly 'scrunched' fashion rather than folded (to provide greater three dimensional space).
- The soak time was increased to: (1) try to increase the size of spat at harvest; and (2) on the basis that few predators were seen in the collectors and this facilitates a longer soak period. The second batch of spat collectors was deployed for 12 weeks with the subsequent set of spat collectors deployed after 10 weeks to maintain a 2 week overlap between collector sets (see section 2.1.3).

Intertidal collectors:

- The Nusa Channel site was unproductive and was abandoned.
- Spat collection efforts were continue in a more focused way at Fisheries Wharf using modified collector design with flexible PVC slats as used in the NSW oyster industry.
- Space between collector slats (spacers) was initially too large and allowed too much light into collector structure which encouraged algae growth and discourage oyster settlement.
- A new collector design with closer (~ 20 mm) spacing between layers of flexible PVC slats orientated at 90^{o} to each other was tried and targeted the zone with heaviest oyster recruitment.
- Flexible PVC slats were sent to NFC from JCU with a suitable collector design.

3. Outcomes

In order to engage local communities and gain their co-operation, an information bulletin 'Tok Save' in Tok Pisin and English (Appendix 2) was produced and given to the communities. This information provided the basis for discussions between JCU and NFA staff and the Nusalik and Usen communities.

3.1 Long-line spat collector harvest

The species that recruited to spat collectors at Nusalik and Usenlik and their numbers at the two sampling times are shown in Tables 3 and 4, and Tables 5 and 6, respectively.

Table 3. Total spat harvested from experimental shade-cloth collectors (n=5) held at two depths (top = 3 m; bottom = 6 m) at Nusalik (channel site) and from additional onion bag collectors (n=25), in September 2009.

Family	Species	Additional collectors (n=25)	Experimental (top) (n=5)	Experimental (bottom) (n=5)
Pteriidae (pearl oysters)	*Pinctada* spp. (*P. margaritifera* or *P. maxima*)	29	22	10
	Pteria penguin	7	17	3
Pectinidae (scallops)	*Cryptopecten nux*	24	13	4
	Mimachlamys lentiginosa	10	10	5
	Palliolum minutulum	6	5	6
	Juxtamusium coudeni	0	0	1
	Decatopecten radula	0	1	1
	Laevichlamys squamosa	0	1	18
Pinnidae (razor clams)	*Pinna bicolour*	0	0	1
Ornamental shrimp	At least 6 species	57	16	35

Table 4. Total spat harvested from experimental shade-cloth collectors (n=10) from two depths (combined) and from additional collectors (n=10) at Nusalik (channel site) in January 2010.

Family	Species	Experimental collectors (n=10)	Additional collectors (n=10)
Pteriidae (pearl oysters)	*Pinctada fucata*	49	82
	Pteria penguin	7	-
	Lima sp.	12	1
Pectinidae (scallops)	*Mimachlamys lentiginosa*	17	22
	Gloripallium pallium	1	5
	Cryptopecten nux		3
	Decatopecten radula	3	5
	Mimachlamys gloriosa	4	1
	Excellichlamys histrionica	5	4
	Laevichlamys squamosa	10	2
Crustaceans	Shrimp (several species)	15	70
	Spider crab	1	-
	Squat lobster	6	-
	Stomatopod	3	-
Gastropods	*Cymatium* spp.	9	28
	cowries		3

	bubble shells	6	3
	Aplysia sp.	1	3
	Strombus sp.	1	-
Fish	Pufferfish	2	-
	Damsels	53	-

Table 5. Total spat harvested from experimental shade-cloth collectors (n=5) held at two depths (top = 3 m; bottom = 6 m) at Usenlik (bay site) and from additional onion bag collectors (n=25), in September 2009.

Family	**Species**	**Additional collectors (n=25)**	**Experimental (top) (n=5)**	**Experimental (bottom) (n=5**
Pteriidae (pearl oysters)	*Pinctada* spp. (mainly *P. fucata*)	75	21	7
	Pinctada margaritifera	2	0	0
	Pinctada maxima	1	0	0
	Pteria penguin	24	8	5
	Electroma spp.	110	32	48
Pectinidae (scallops)	*Cryptopecten nux*	34	18	11
	Mimachlamys lentiginosa	15	5	3
	Palliolum minutulum	129	55	22
	Laevichlamys squamosa	118	38	288
	Mimachlamys gloriosa	14	4	1
	Dectopecten radula	11	5	0
	Juxtamusium coudeni	1	1	0
Pinnidae	*Pinna* sp.	0	3	0
Limidae	*Lima* sp.	62	2	0
Gastropods	*Nassarius* sp., *Cymatium* sp., trochid, wentletrap, *Conus* sp.	1 of each	0	0
Gastropods	*Strombus* sp.	0	1	0
Nudibranchs	Two species sp	11	1	0
Urchin	*Diadema* sp.	3	3	0
Ornamental shrimp	Two main spp. (>six in total)	33	5	6
Sea cucumber	Two species	2	0	0
Fish	Fang blenny Blue damsel	9 2	2 2	0 1

Table 6. Total spat harvested from experimental shade-cloth collectors (n=10) from two depths and from additional collectors (n=40) at Usenlik (bay site) in January 2010.The values shown are collective for all experimental and additional spat collectors (n=50).

Family	**Species**	**Total**
Pteriidae (pearl oysters)	*Pinctada fucata*	74
	P. margaritifera	1
	P.maxima	1
	Pteria penguin	11
	Lima sp.	359
Pectinidae (scallops)	*Mimachlamys lentiginosa*	64
	Gloripallium pallium	12
	Juxtamusium coudeni	10
	Decatopecten radula	19

	Mimachlamys gloriosa	9
	Excellichlamys histrionica	4
	Laevichlamys squamosa	174
Crustaceans	Shrimp (several species)	29
	Purple crab	4
	Stomatopod	7
Gastropods	*Cymatium* spp.	38
	Cypraea spp.	6
	Bubble shells	23
	Aplysia sp.	51
	Nudibranchs	2
Urchins		3
Fish	Pufferfish	2
	Damsels	3

General observations

In September 2009, spat collectors at Nusalik collected more silt and this site was subject to a strong current. Many ornamental shrimp were collected at Nusalik compared to Usenlik but relatively few predators (e.g. crabs, *Cymatium*) were seen on collectors in Nusalik. Usenlik collectors had good coverage of algae, encrusting organisms (bryozoans and ascidians) and appeared more 'alive' than collectors from Nusalik. Pearl oysters were also collected in greater numbers at Usenlik and there was generally much greater diversity of species on collectors from this site. Although data are not presented, in January 2010, it was noted that deeper collectors were generally more productive and had contained fewer predator species. More pearl oyster spat (*Pteria*) were present in deeper water.

3.2 Intertidal spat collector harvest

Oyster spat belonging to (*Crassostrea* sp.) were recorded from PVC and fibro slat collectors at the two sites: Nusa passage (Table 7) and Kavieng Fisheries Wharf (Tables 8 and 9). However, holes made in the fibro slats to accommodate the rope connecting adjacent slats, in spat collectors underneath Kavieng wharf, wore over time and increased in size. As a result, spacers between slats did not function and slats often came together. Also, a number of fibro slats were lost during deployment, presumed broken.

Table 7. Total and mean number of oysters spat counted from replicate PVC slat collectors and fibro slats (n=4 per collector at each tidal height) at Nusa passage.

		Upper surface		Lower surface		Both surfaces	
Tidal height	Material	No. spat	Mean (±se)	No. spat	Mean (±se)	No. spat	Mean (±se)
High	Fibro sheet	10	2.5 ± 1.0	0	0	10	2.5 ± 1.0
	PVC slat	0	0	5	1.25 ± 1.0	5	1.25 ± 1.0
Mid	Fibro sheet	8	2.0 ± 1.1	0	0	8	2.0 ± 1.1
	PVC slat	1	0.3 ± 0.3	0	0	1	0.3 ± 0.3
Low	Fibro sheet	12	3.0 ± 0.8	0	0	12	3.0 ± 0.8
	PVC slat	1	0.3 ± 0.3	0	0	1	0.3 ± 0.3

Table 8. Total oysters spat counted from fibro slats (rep 1 = 5 slats; rep 2 = 7 slats; rep 3 = 6 slats *) at Kavieng Fisheries wharf.

Collector replicate	Upper surface		Lower surface		Both surfaces	
	Total spat	Mean (±se)	Total spat	Mean (±se)	Total spat	Mean (±se)
1	2	0.4 ± 0.2	4	0.8 ± 0.6	6	1.2 ± 0.6
2	1	0.14 ± 0.14	3	0.4 ± 0.2	4	0.6 ± 0.2
3 **	1	0.17 ± 0.17	4	0.7 ± 0.3	5	0.8 ± 0.3

* slats missing, presumed broken.

**All slats together, spacers not working properly.

Table 9. Total and mean number of oysters spat counted from replicate PVC slat collectors (n=10 slats per rep) at Kavieng Fisheries wharf.

Collector replicate	Upper surface		Lower surface		Both surfaces	
	Total spat	Mean (±se)	Total spat	Mean (±se)	Total spat	Mean (±se)
1	3	0.3 ± 0.3	19	1.9 ± 1.3	22	2.3 ± 1.4
2	5	0.5 ± 0.3	28	2.8 ± 1.2	33	3.3 ± 1.2
3	7	0.7 ± 0.4	34	3.4 ± 1.5	41	4.1 ± 1.7

General observations from intertidal collectors sampling

Settlement of oysters was higher and spat were larger (up to 10 mm) at Fisheries Wharf than at Nusa passage, where low numbers of smaller oysters (2–3 mm) were recorded. Oyster spat tended to settle on rough cut edge of fibro slats not the top or bottom surfaces. At Nusa Passage, algal overgrowth correlated with immersion time, while high coverage of some wharf site collectors by ascidians prevented oyster settlement. Settlement occurred in a relatively narrow tidal zone at the wharf site, and this area should be targeted in future spat collection. Regarding the collector materials, purpose made PVC collectors should be used in future research; oyster spat could not be easily removed fibro collectors which were also too fragile and too brittle to be used at the Harbour Wharf site or other sites with strong wave action.

3.3 Grow out of species of interest

Attempts to on-grow species of interest (e.g. *Pteria penguin*) below the wharf at Nago Island after the first harvest in September 2009 were unsuccessful. A purpose built long-line for grow-out of commercial species was deployed off the beach at Nago in March 2010 and small grow-out experiments with pearl oysters were begun by NFA staff.

4. Impacts

4.1 Scientific impacts

Information on the type and abundance of spat was collected for the first time in this locality. Identification of more productive spat collecting sites in the Kavieng area and the performance of various spat collector structures and materials, again, provided information that will be valuable in follow-up research. This mini-project generated data that were used as a basis for two large follow-up ACIAR projects: FIS/2010/054[1] includes a component focused on assessing the feasibility of rock oyster culture in Kavieng, based on spat collection; FIS/2009/057[2] includes a component to assess the potential of pearl culture based on *Pteria penguin* obtained using spat collectors. Both will involve development of larger scale spat collection programs, based on the methods used and developed during this mini-project.

4.2 Capacity impacts

NFA mariculture staff were trained in a range of techniques and acquired new skills through the project, e.g. setting-up and deployment long-lines; making various types of spat collectors and their deployment; spat sampling and identification, spat/juvenile husbandry, data collection and collation etc.

4.3 Community impacts

There were no community impacts from this mini-project.

5. Discussion and recommendations

Working in a remote location like Kavieng comes with a range of challenges, potential problems and constraints including the following:

- It is estimated that each long-line will take two staff (at least one of these being a diver) two days to harvest (i.e. retrieve bags, clean, remove and count spat and place in grow out system). Two long-lines will require 4 days labour, and needs to include a day before and a day after to prepare grow out gear, etc. Therefore, 6 days are needed to perform each harvest.
- Tight and relatively inflexible timelines for deploying collectors means that staff must be available at spat collector harvest times. Good forward planning is essential.
- The life span and durability of the gear depends on the maintenance. A schedule and checklist has been prepared (Appendix 3) for regular maintenance.
- The station dive gear is new and in excellent condition. However, there are few qualified divers and attention should be paid to the number of divers and certification/training of those involved in project.
- NFA should provide safety kits for the work boats. Radios and GPSs would be extremely useful once NIMRF is operating. The latter has particular relevance in assisting long-line location. The long-lines used in this study were deployed sub-

[1] *FIS/2010/054: 'Mariculture development in New Ireland, Papua New Guinea'*
[2] *FIS/2009/057: 'Pearl industry development in the western Pacific'*

tidally with no visible cue on the surface. On rough days in particular, much time can be lost in searching for long-lines.

There are a number of opportunities for future development, particularly once NIMRF is commissioned:

- Demonstration farm – the two existing long-lines may be used to provide hands on demonstration to the relevant communities on bivalve culture. There may also be tourist potential here. Other grow out long-lines deployed adjacent to NIMRF may prove useful in the future.
- National Fisheries College connections – the management, staff and students within the college are an asset and likely future resource base for trainees in farm operations and animal husbandry. The profile and infrastructure of the college will provide a range of benefit to future research projects.

6. Acknowledgements

Thanks to Jeff Kinch (Principal of the National Fisheries College, Kavieng) for facililtating field trips and assisting with logistical arrangements. Special thanks for the valuable contribution of Casper Dako in all aspects of the study. The authors also acknowledge Beni Bitalen and crew, NFC Staff, John Aini, George (the Wonder Welder), and Jerry, Malakai and crew of the Leilani the Nusalik, Uesein and Ueseinlik communities, Shaun, Shannon and staff of Nusa Island Retreat, Adam Smith and Dietmar Amon.

Appendix 1. Data collection sheets.

(a) Longline Spat data collection sheet.

DATE:

LOCATION: Nusalik / Usenlik

SOAK:

Dropper	Depth	*Pteria penguin*	*Pteria sp*	*Pinctada margaritifera*	*Pinctada maxima*	*Pinctada sp.*	*Pinctada sp.*	Scallop *A*	Scallop B	Others	Predators	Comments
1	3											
	6											
2	3											
	6											
3	3											
	6											
4	3											
	6											
5	3											
	6											

DATA ENTERED BY:..... SIGN:.....

DATE ENTERED:.....

(b) Benthic collectors spat data collection sheet.

DATE IN DATE OUT

LOCATION: Nusalik Channel

SOAK:

Collector number:

Collector Type: Cement sheet / PVC

LINE	Plate	*C. echinata*	*S. glomerata*	Oyster sp 1	Oyster sp 2	*Pt. penguin*	*P. margaritifera*	*P. maxima*	*Pinctada sp.*	Others	Predators	Comments
1	1											
	2											
	3											
	4											
2	1											
	2											
	3											
	4											
3	1											
	2											
	3											
	4											

DATA ENTERED BY:..... SIGN:.....

DATE ENTERED:.....

Appendix 2. Awareness notice ('Toksave') to local communities regarding the deployment of spat collector longlines.

NATIONAL FISHERIES AUTHORITY
NAGO ISLAND MARICULTURE AND RESEACH FACILITY
TOK SAVE
BIKPELA WOK PAINIM AUT

National Fisheries Atoriti wantaim James Cook University na Australia Senta blong Intanesenal wok painim aut blong didiman (Australian Centre for International Agricultural Research - ACIAR) I statim pinis nambawan wok painim aut blong dispela nupela Nago Ailan Marikalsa and Wok painim aut Senta (Nago Island Mariculture and Research Facility).

Dispela wok painim aut I blong lukluk long au ol shell yumi save salim blong kisim moni isave karim na kamap long ol spat kolecta o ol rop we bai i anga long solwara insait long PNG. Olsem tasol na bai sampela blong ol dispela rop we bai oli mas putim insait long ol solwara blong yumi. Sampela bai oli putim klostu long graon blong solwara na sampela bai i tirip antap long solwara.

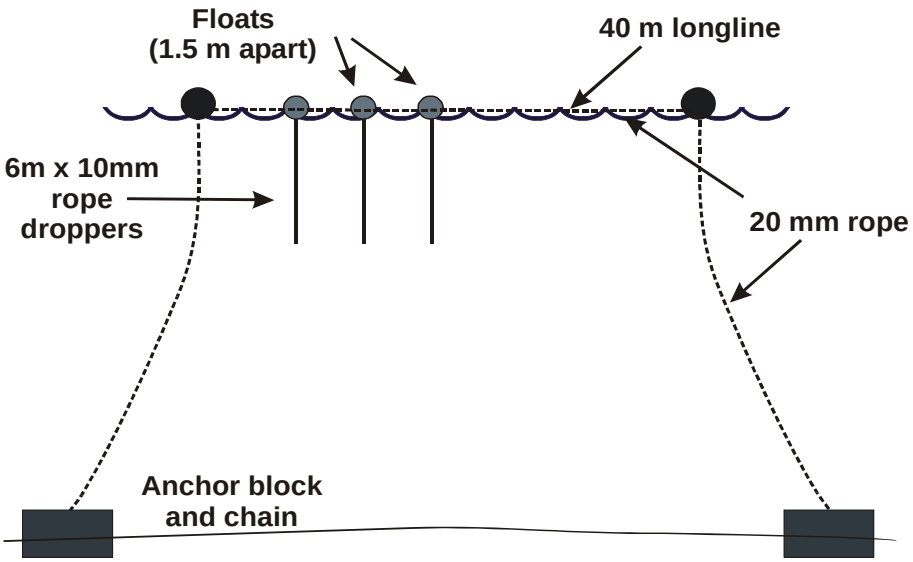
AS blong dispela wok painim aut I blong painim wonem kaen ol shell istap na pulap long Kavieng na tu blong lukluk sopos yumi nap kamapim blong pasin blong kisim moni. Ol shell ia karamapim oista, pear shell and ol kaen olsem ol garam shell. Ol dispela ol rop we bai istap long solwara ino nap bagarapim solwara na ol narapela enviromen blong solwara. Ol rop ia bai oli anga im ol, bai igat flota long ol wantaim ol narapela rop na shell blong kokonas we ol liklik sell bai ipas long ol na kamap bikpela.

Bihaen long ol dispela istap insait long solwara long tupela mun, bai Fisheries bai i kisim igo bek gen long Nago we bai oli painim name blong ol na grow im ol long ol tank inap oli bikpela. Blong dispela project o wok painim aut blong karim kaikai I impoten moa bai yumi noken bagarapim ol dispela ol rop istap insait long solwara o stilim ol. Askim igo long yumi olgeta long halvim long lukautim ol dispela ol rop na moa long en husat ol komuniti istap klostu long ol rip na solwara we bai oli anga im ol dispela rop long halvim long lukautim na was nogut ol narapela man bai I bagarapim o stealim long dispela taim oli stap long solwara.

Dispela em wanpela impoten wok painim aut na iken halvim long painim ol narapela rot blong kisim moni long taim yumi growim o farm im ol shell. Mipela I askim gen wok bung wantaim na halvim blong yupela ol komuniti long wok wantaim mipela na halvim long mekim dispela project or wok painim aut bai I karim kaikai blong gutpela blong yumi long Kavieng na Papua Niu Gini olgeta.

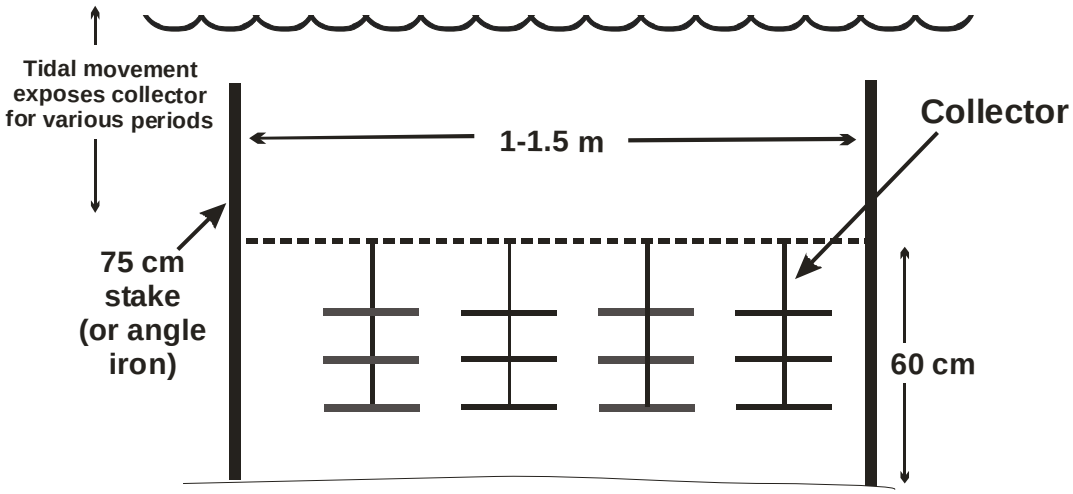
Hugh Walton, Principal, National Fisheries College

Pelagic Spat Collector



This collector is deployed at front side long Nusa lik and front side long Usen lik

Benthic Spat Collector



This collector is deployed at Nusa passage

ASKIM LONG HALVIM NA GUTPELA LUKSAVE BLONG YU

PLIS HALVIM LONG LUKAUTIM OL DISPELA ROP BLONG KISIM OL LIKLIK SEL. NOKEN HOLIM, BAGARAPIM O STILIM PLIS. EM I BLONG HALVIM YUMI NA OL PIKININI BLONG YUMI NAU NA BIHAEN TAIM.

Appendix 3. Spat collector and longline maintenance program.

Suspended Long Lines

WEEKLY TASKS

WHAT TASK	HOW/REMEDY
Go to site and check gear	Get into water and check ropes and floats are there
Check long line buoyancy	If line is sinking, add small pressure floats or reduce dropper weights if possible over spat collector droppers to maintain 2.5m at headline.
Check for tangles	Get into water and check spat collectors around ropes and floats.
	ALL ABOVE TASKS SHOULD BE REPEATED EVERY TIME YOU VISIT THE LONGLINE

6-weekly TASKS

WHAT TASK	HOW/REMEDY
Make new spat collectors prior to Tuesday deployment	Purchase shade cloth if needed (may require 3 full sets of collector shade cloth ie: 60 x shade cloth sheets cut 0.83m x 1.8m)
Make droppers with collectors connected	Cut ropes to 5.5m, mark off 0.5m (to connect to headline), 1.0m (attach 3m collector), 4m (attach 6m collector) and have 1.5m ‘tail’ to connect weight block.
Deploy droppers and collectors	Tie droppers to long line where there is space

8-weekly TASKS

WHAT TASK	HOW/REMEDY
Check anchors and chain	SCUBA inspection of anchors. Add more anchors and lines if gear is dragging. Run out anchor in the direction current is coming from.
Remove old collectors and count spat	Remove old droppers and collectors and place in esky box for transport to Nago for counting
Counting spat	Remove bag noting date, location, dropper (where on line1-5), depth and species present as written on data sheet.
Data Entry	Insert data into computer, check and sign off on entry. File hard copy for future reference if required.
Spat Grow Out	Commercial species (and those of uncertain identity) are placed in grow out nets/panels and placed on long line for further growth. Further training will be required.
COMMUNITY CONSULTATION	Talk to communities where collectors are located and give them some feedback and discuss what is going on. Show them some of the collected spat.

<u>Fence Lines</u>

WEEKLY TASKS

WHAT TASK	HOW/REMEDY
Go to site and check gear	Check posts, wire and floats.
Check for tangles / breakages	Check spat collector plates
	ALL ABOVE TASKS SHOULD BE REPEATED EVERY TIME YOU VISIT THE SITE

6-weekly TASKS

WHAT TASK	HOW/REMEDY
Make new spat collectors the week prior to deployment	Purchase pipe/sheeting if needed. You will require several full sets of collectors as spat will be retained on collectors for grow out over time.
Make wire droppers with collectors connected	Cut wire to length, add spacers and collectors.
Deploy droppers and collectors	Wire droppers to fence line where there is space. Make new fence lines under jetty as required.

8-weekly TASKS

WHAT TASK	HOW/REMEDY
Check posts and wires and chain	Close inspection of gear.
Remove old collectors	Remove droppers from channel, label station number (outer, middle, inside) and add to new fence line under jetty. Remove old collector wires and collectors and place in esky box for transport to jetty for counting and further grow out.
Counting spat	Count spat on collector plate noting information written on data sheet : i.e. date, location, dropper (position on wire from top to bottom plate – number as required noting difference between channel and jetty site), depth and species present.
Data Entry	Insert data into computer, check and sign off on entry. File hard copy for future reference if required.
Spat Grow Out	Collector plates are placed in grow out under jetty for further growth.
COMMUNITY CONSULTATION	Talk to communities where collectors are located and give them some feedback and discuss what is going on. Show them some of the collected spat.

Appendix 2.4

MS0905
Improved access to credit and grant funding for PNG fish farmers, PNG

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU James Cook University WorldFish Center USP The University of the South Pacific	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Improved access to credit and grant funding for PNG fish farmers (MS0905)**
Goal:	Conduct a workshop that will improve access to credit and grants money for PNG fish farmers and educate credit providers on the economics of fish farming
Objective(s):	Specific objectives are to conduct a workshop that will: 1) Assist fish farmers in preparation of proposals for credit/grants for PNG fish farmers, and provide them with basic business skills; 2) Equip fisheries extension officers with skills to support fish farmers; 3) Educate bank loan officers and other grant/credit providers on the economic realities of fish farming.
Project location:	Goroka, EHP, PNG
Project partner(s):	National Fisheries Authority, National Dept Agriculture and Livestock, National Development Bank Ltd
Dates / duration:	Three months
Project description:	This mini-project addresses two issues affecting access to funds for existing and prospective fish farmers in PNG. Firstly, they are unable to access loans, despite fact that NFA have put K5 million into the Fisheries Credit Scheme, specifically for fisheries and aquaculture ventures. Other sources of funds (e.g. various grants) are also available for fish farmers if they know how to apply for them. Secondly, credit and grant providers do not have the skills to properly assess aquaculture loan applications because they do not understand the basic principles and economics of fish farming. The workshops will (1) teach farmers how to make projections that will satisfy the bank and prepare effective proposals and (2) educate credit officers on the realities of fish farming to assist them in assessing loan applications. National Department of Agriculture and Livestock (NDAL) and Provincial Fisheries extension officers will attend both workshops so they can assist farmers into the future.
Justification:	Fish farming is an important activity in PNG (for food security and livelihoods) and access to credit is a major constraint in development of tilapia and trout farming now, potentially barramundi farming in the future.
Expected outcomes:	(1) Farmers and fisheries extension officers trained in loan application techniques and business skills; and (2) Bank officers trained in assessment of fish farmer's credit applications.
Funding:	$11,000

Improved access to credit and grant funding for PNG fish farmers

Cathy Hair[1], Wally Solato[2], Jacob Wani[3]

[1] James Cook University, Townsville, Australia

[2] National Department of Agriculture and Livestock, Goroka, Papua New Guinea

[3] National Fisheries Authority, Port Moresby, Papua New Guinea

1. Background:

Fish farming is an important activity in PNG but access to credit is currently a major constraint to the development of semi-commercial to commercial tilapia and trout farming, and potentially barramundi farming once barramundi fingerlings are available. Fish farmers require access to credit in order to expand their operations or establish new farming operations. However, PNG fish farmers are unable to access credit loans, despite the fact that NFA has created a Fisheries Credit Scheme under the National Development Bank (NDB) and deposited K5 million specifically for aquaculture and fisheries ventures. A fish farmer's lack of collateral is often given as the reason that he/she fails to qualify for a loan. There are also issues associated with a high turnover of bank officers in the management of Highlands' banks. Other sources of funds (e.g. grants such as Community Development Scheme under AUSAID, Project Development Funds (PDF) grants from US multilateral treaty payments, etc) are available for fish farmers with the capacity to prepare a successful application.

Some typical loan applications submitted by fish farmers were examined and found to be essentially a "character reference", lacking in information required for banks to be able to assess whether they qualified for a loan. Most applicants had no equity and little collateral (e.g. unlike coastal fishers who are able to use the funded boats and engines as equity). Nor was there any understanding of how to resolve this issue. In October 2009, a meeting was held in Goroka with local NDB bank officers, senior NDAL and EHP DAL officers, the NFA aquaculture manager and Cathy Hair (JCU-ACIAR). At that time, the bank officers admitted that fish farmers approved got loans because their applications were inadequate. However, they were willing to work with Fisheries officers to improve this situation.

There were two issues identified: (1) lack of capacity for farmers to write effective proposals to obtain loans or grants; and (2) lack of knowledge of lending/grant institutions regarding fish farming practices. This latter issue impacts on institutions' ability to fairly and effectively assess loan and grant applications. This current workshop aimed to train existing fish farmers and government fisheries extension officers how to prepare an application to obtain credit from a range of sources (including Fisheries Credit Scheme). Further, to provide fish farmers some basic accounting skills and understanding of the economics of their core business. With regard to the finance industry, the workshop educated NDB credit providers on good fish farming management and the realities of fish farming, so they are able to properly assess loan applications. NDAL and Fisheries extension officers from outside EHP attended the workshop so they will be able to assist farmers in preparing applications, even if fish farmers in their local area have not attended the workshop.

2. Project Methodolgy

The workshop activities were:

1. Identify suitable trainer/s to teach fish farmers and fisheries extension officers about basic business training and how to prepare applications for credit/grants;
2. Identify a suitable trainer/s to train bank officers and other grant/credit providers in the economic realities of fish farming;

3. Hold a four-day workshop in Goroka.

The workshop was primarily organised by Wally Solato (NDAL) and Jacob Wani (NFA). It was held from 19-22 April 2010 at the Goroka Steakhouse. Mr Mawe Gonapa (Director of NDAL, Goroka) opened the Workshop on Monday morning. Mr Bubia Muhuju (Principal Advisor, EHPDAL) and Mr Jacob Wani (NFA Aquaculture Manager) also made opening addresses (Fig. 1).

Figure 1. Workshop participants at PNG Highlands fish farming credit workshop.

The workshop content was prepared through consultation with NFA managers, the workshop trainer and economists. The Workshop Program is attached as Appendix 1. It was organised such that the first two days taught basic book-keeping and accounting skills to fish farmers and extension officers, followed by a day and a half of more advanced economic modelling (using the Excel spreadsheet based Decision Making Tool for tilapia pond culture) and sessions on how the banking loan system operates, particularly with respect to the Fisheries Credit Scheme operated by NDB (a scheme bankrolled by NFA).

For the first two days of the workshop, there were 30 participants (refer to Appendix 2). They comprised: nine fish farmers from EHP, WHP and Chimbu, including one cage farmer from Yonki Reservoir; eight extension officers (Maria Kwin Centre, Bris Kanda Inc, NFA, NDAL, EHP DAL), three teachers (Goroka University, Rosary Secondary School) and four VIPs and other observers. On the final two days of the workshop, the group was joined by four senior NDB officers: Alois Wabianik (Branch manager, Goroka), Gibson Etete (Microfinance and loans officer, Goroka), Patrick Ronkentuo (Branch manager, Mutzing) and Roger Kilembe (Head Office credit manager). There were six presenters from NFC, NFA, SSSP, NDB and JCU. Certificates were awarded to all participants who completed the training (Fig. 2).

Figure 2. Goroka fish farmer and interim Chairman of EHP fish farmers co-operative society (EHFFCS), A1 Kole, is presented his certificate of attainment from Mr Alois Wabianik of NDB and Jacob Wani of NFA.

3. Outcomes

The workshop succeeded in its objectives and fish farmers were provided basic training in financial record keeping. They carried out practical exercises which highlighted the various sources of expense and income associated with fish farming, and how to record their finances. However, it is difficult to estimate how many are likely to start keeping these records as a result of the training. Those outcomes need to be followed up with individual farmers over the next 6-12 months.

The bank representatives that attended were given a basic course in fish farming and left the workshop with a real appreciation of what is involved in establishing and operating a Highlands fish farm. They were particularly interested in application of the Economic Decision making tool, developed by Bill Johnston of QLD DPI, in assessing potential profitability of and risks associated with a fish farming operation.

The workshop generated enormous interest and many potential attendees were turned away due to restrictions on numbers. The workshop was generally deemed a success by all participants and there have been requests for follow-up workshops in other locations. NFA would like to hold similar workshops in other major centres (e.g. Lae, Mt Hagen, Chimbu) following this initial Goroka workshop.

4. Impacts

4.1 Scientific impacts

There were no scientific impacts from this mini-project.

4.2 Capacity impacts

This mini-project was a targeted capacity building workshop. It enhanced capacity in several ways: (1) it provided fish farmers with simple book-keeping skills and other basic business skills, together with knowledge of banking and loan procedures; (2) fisheries and agriculture extension officers

were trained in the same skills so they can assist fish farmers in preparation of proposals for credit/grants; and (3) credit providers were given a basic introduction to the economic realities of fish farming, and presented with a computer model to use as an economic decision making tool.

4.3 Community impacts

Fish farming is an important activity in the Highlands of PNG but access to credit is a major constraint to the development of commercial fish farming (trout, tilapia and potentially barramundi). Fish farmers require access to credit in order to expand their operations or establish new farms. This workshop taught fish farmers some basic business skills, principally on managing the costs of fish farming and keeping basic financial records. For any farmers at the stage where a bank loan would benefit their business, the loan process was demystified. Furthermore, banking officers were provided with information about fish farming which will assist them in assessing applications for credit in the future.

5. Conclusions and Recommendations

During the workshop, it became clear that record keeping skills are poorly developed in most fish farmers. However, they are an important aspect of running a profitable fish farm. Record keeping emerged as a potentially useful future training activity and was identified by farmers as beneficial.

The workshop achieved its objectives but, as the first of its kind, we identified areas which could be improved for future workshops with the same aims. Lessons learned from this workshop and some suggested ways to increase effectiveness are listed below:

1. Hold the ‘Costs of Aquaculture’ session prior to the ‘Book-Keeping’ session. This will allow the discussion abut technical issues to be resolved before getting into the book-keeping session. During this session, introduce the case study and have all fish farmers agree on the details before proceeding (see point 2 below).
2. Use a simple case study. The economic theory should (as far as possible) be kept separate from the technical aspects of fish farming. The example used for book-keeping exercises should be simple and technically sound. This will result in less time spent discussing technical issues (see point 1 above).
3. Simplify the book-keeping component. Keep the book-keeping component even simpler than what was presented in this workshop. Minimise and summarise the economic theory component and present a simplified cash accounting system.
4. Include more practical sessions. Prepare a solid (but simple) case study that runs for six months (i.e. a fish pond cycle) that the lecturers can work through and discuss over two days of the workshop. Have participants break up into small groups or work individually on exercises,
5. Include more interactive sessions. The farmers really enjoyed personal involvement in the workshop. Trainers should maximise sessions where farmers can provide information on their practices. Provide more opportunity for story and creativity – these are important learning tools for the fish farmers.
6. Check workbooks carefully for errors. This will help to get lessons across quickly and effectively. Both technical and economics lecturers should carefully check the notes before use.
7. Provide economics lecturers with background on fish farming. The economics lecturers at this workshop had little knowledge of fish farming prior to the workshop. They should be provided with information on fish farming (or other aquaculture commodity being

8. Provide fish farmers with record keeping books. For farmers that do want to attempt to keep records, provide printed template or cash book for them to use.
9. Include some sort of assessment exercise to demonstrate understanding. Participants came from different backgrounds and had varying capacity for the lessons being taught.

5. Acknowledgements

We would like to thank all of the fish farmers who took time to attend the training and express appreciation to the presenters from NFC and SSSP. We would also like to acknowledge the contribution made by the NDB Officers who spent a substantial amount of time learning about fish farming and giving presentations on banking practices to the workshop. We also appreciate additional funding and logistical support from NFA.

List of Acronyms

DAL	Department of Agriculture and Livestock
EHP	Eastern Highlands Province
EHFFCS	EHP fish farmers co-operative society
JCU	James Cook University
NDAL	National Department of Agriculture and Livestock
NDB	National Development Bank
NFC	National Fisheries College (FishColl)
PDF	Project Development Funds
PNG NFA	Papua New Guinea National Fisheries Authority
QLD DPI	Queensland Department of Primary Industries
SPC	Secretariat of the Pacific Community
SSSP	Small Services Support Pilot Project
WHP	Western Highlands Province

Appendix 2.5

MS1001

Growth of rainbow trout (*Oncorhynchus mykiss*) on locally produced feed formulation in PNG Highlands ponds

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU JAMES COOK UNIVERSITY WorldFish CENTER USP THE UNIVERSITY OF THE SOUTH PACIFIC	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Growth of rainbow trout (*Oncorhynchus mykiss*) on locally produced feed formulation in Highlands ponds in PNG (MS1001)**
Goal:	To compare the effectiveness of a pellet diet produced with locally available ingredients to imported commercial trout pellet diet.
Objective(s):	Specific objective is to: Run an on-farm trial to compare growth of rainbow trout fingerlings fed on a locally produced diet against an imported, commercial diet.
Participating country:	PNG
Project partner(s):	PNG National Fisheries Authority, National Dept Agriculture and Livestock
Dates / duration:	May 2010-April 2011, 12 months duration
Project description	Farming of rainbow trout (*O. mykiss*) commenced in the Highlands of PNG in the early 1970s. There are self-sustaining populations in the wild where water temperatures remain below 15oC and farming is viable where water temperatures are in the optimum range of 10-20oC (> ~1,300 m). Currently there are five trout farms in the Highlands: the largest one produces 10 T per annum and also supplies eyed ova to the other farms. Many more farmers have expressed interest in this species, which has a farmgate price of K22/kg whole. The impediment to trout farming in the Highlands is the high cost and difficulty of obtaining imported feeds. A high-protein trout diet, based on locally available ingredients has been formulated by Dr Geoff Allan (NSW DPI). This feed can be produced by the Goroka NDAL staff at less than half the cost of the imported feed. This mini-project will trial the local diet and, if performance is acceptable, this will assist fish farmers in the Highlands to diversify and produce this high value species..
Justification	Protein is in short supply and high demand in the Highlands of PNG, and rainbow trout is a high-value farmed fish. Imported commercial feeds are prohibitively expensive for local farmers. This project will address the issue by trialing a locally produced, cheaper pellet diet.
Expected outcomes	1. Demonstrate the feasibility of growing rainbow trout in Highlands fish ponds on a locally produced feed 2. Create an additional income generating opportunity and diversify fish farming opportunities for Highlands fish farmers 3. Build capacity in PNG project staff and fish farmers
Funding:	AUD$4,200

Growth of rainbow trout (*Oncorhynchus mykiss*) on locally produced feed formulation in Highlands ponds in PNG

Wally Solato[1] and Cathy Hair[2]

[1] National Fisheries Authority, Port Moresby, Papua New Guinea
[2] Cathy Hair, James Cook University, Townsville, Australia

1. Background

Farming of the introduced rainbow trout (*Oncorhynchus mykiss*) commenced in the Highlands of PNG in the early 1970s. There are self-sustaining populations in the wild where water temperatures remain below 15oC and farming is viable where water temperatures are in the optimum range of 10-20^{o}C (i.e. greater than around 1,300 m). Currently there are five trout farms in the Highlands, production is dominated by Lake Pindiyaundo Trout Farm near Mt Wilhelm which produces 10 tonne per annum and supplies eyed ova to smaller operators. Many more farmers have expressed interest in this species, which has a farmgate price much higher than tilapia.

The impediment to trout farming in the Highlands is the high cost and difficulty of obtaining imported feeds. A high-protein trout diet, based on locally available ingredients has been formulated. This feed does not require fish oil which is expensive and difficult to obtain in PNG. It can be produced by the Goroka-based National Department of Agriculture and Livestock (NDAL) staff at less than half the cost of the imported feed. This mini-project will trial the local diet against trout feed imported from a major feed company in Australia. The results will determine if trout can be raised successfully and economically using a locally produced diet. If performance is acceptable, this will assist fish farmers in the Highlands to diversify and produce this high value species.

2. Materials and Methods

2.1 Comparison of diets

The trial is to be a comparison of a diet prepared from locally sourced ingredients (to be prepared by NDAL staff) with imported rainbow trout feed. The local diet was developed by Dr Geoff Allan (NSW Dept Industry) using the feed formulation software, WinFeed 2.8. The 'least cost feed formulation' for the local diet is shown in Table 1. Feed for the entire trial will be produced in a single batch (Fig. 1) and used for the duration of the trial. The cost of producing the locally formulated feed has been estimated at around K5 per kilogram whereas landed cost of imported commercial feed is around K12.50 per kg.

Table 1. Least cost feed formulation for a PNG Highlands locally produced diet for rainbow trout.

Ingredients	Ratio (%)	Nutrients	Analyses
Vitamin Mineral premix	1.5	Dry Matter (%)	95.611
Fishmeal (PNG)	82	Crude protein (%)	45.691
Mill mix (PNG)	15	Lipid (%)	7.377
Broken rice (PNG)	1.5	Ash (%)	19.064
		Gross energy (MJ/kg)	18.638

The feed trial was carried out on two Eastern Highland Province fish farms near Goroka.

(1) Kotuni Farm was the main site for the trial. This purpose-built trout farm, originally established in the 1970s, is now a community trout farm. It is located a half hour drive from Goroka on a dirt road that is only 4WD accessible in wet weather. Four tanks of approximately 3,000 L volume were used for the trial, two ponds for each food type (local versus imported) (Fig. 1). Each tank was stocked with 912 fish at the start of the trial in April 2011.

(2) A1 Farm is a private tilapia farm, located at lower altitude than Kotuni and only 3 km from Goroka. Two ponds, approximately 6 x 6 m (volume approx. 18 m^3) with their own water supply were used (Fig. 2). Each pond was stocked with 500 fish at the start of the trial in April 2011.

Figure 1. Rainbow trout feed trial tanks at Kotuni trout farm.

Figure 2. Rainbow trout feed trial ponds at A1 fish farm (photo Peter Graham).

The rainbow trout were stocked at a mean starting weight of 4.3 g (± 0.02 se) on 17 March. Thereafter, a random subsample of 50 fish from each tank were weighed and measured for total length and standard length (to the nearest 5 mm) at approximately monthly intervals (Fig. 4). Prior to sampling, fish were left in a bucket of cold water with ice in efforts to 'sedate' them before handling, to reduce damage and stress. After initial stocking, fish measurements were recorded on seven sampling occasions at Kotuni farm and five occasions at A1 farm. The trial was run for a period of 5.5 months, from mid March to end of August 2011.

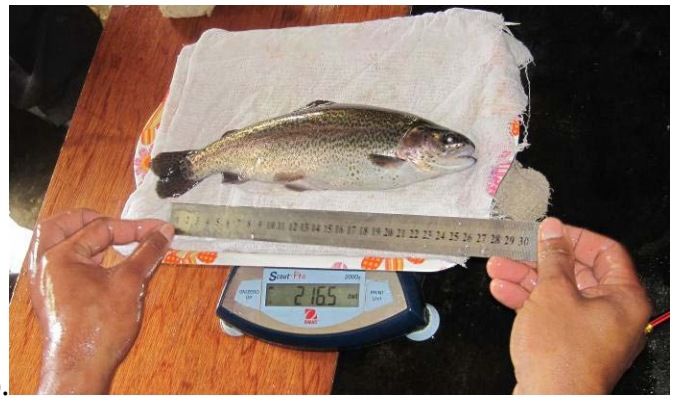
a.  b. 

Figure 4. (a) Collecting sample fish and (b) measuring rainbow trout during fourth sampling at Kotuni farm in July 2011.

Feeding was carried out using the daily ration schedule presented in the HAQDC trout farming manual (Masuda et al 1998) for the first two months of the trial and then fish were fed to satiation for the remaining three months (Fig. 5). The amount of feed given to fish was recorded to enable calculation of the feed conversion ratio (FCR).

Figure 5. feeding trout at a Highlands trout farm.

A data logger was placed in Tank 1 at Kotuni Farm, although 2 months of water temperature data were taken from a nearby trout farm (Nama) before the temperature logger was transferred to the tank at Kotuni. Water temperature at A1 farm was recorded from the intake water reservoir only for the period mid March to late May 2011.

Data on survival and growth (mean weight) provides information on the relative performance of each diet. An output of the mini-project is information on the economic viability of growing and selling trout in the PNG Highlands, taking into account possible savings obtained by using locally produced feeds.

2.2 Blind taste test

As well as fish being able to survive and grow on the locally formulated diet, it is important to assess whether the fish are acceptable to the public. To determine whether a particular diet produced a better tasting fish, a blind taste test was performed. In the taste test, people were given three types of rainbow trout to taste without being able to identify which was which. They were presented with wild trout (caught from streams nearby the Kotuni trout farm), cultured trout fed on the imported Australian diet and cultured fish fed on the Goroka formulated diet. Two groups were used in the blind taste testing: a mixed group from Goroka including university students, DAL officers, farmers, women and children (*n*=36); and a group of 24 participants from Kotuni. Note that only the Kotuni tasters had wild trout in their tasting. Fish were cooked very simply by frying in oil. Tasters were asked to judge the fish based upon three features – overall taste preference, juiciness and tenderness.

2.3 Capacity building, extension and uptake of results

The trial was managed by Goroka NDAL fisheries extension officers. They have extensive experience with preparation of tilapia diets but this will be the first feed production and feeding trial with rainbow trout. Wally Solato will visit the farms weekly to ensure the trial is being conducted properly and to collect data. This project will build capacity in feed preparation, data management, experimental protocols and husbandry for this rainbow trout.

3. Results

3.1 Growth of rainbow trout on imported versus locally formulated or diet

Fish grew on both diets at both farms.

The Kotuni fish showed a clear difference in fish weight due to diet after 5.5 months with mean weight of 161.8 ± 4.1 se for the imported diet and 128.3 ± 3.1 se for the locally formulated diet (Fig. 6). This difference first became apparent around May when growth curves of the two diets first diverged. From June onwards, however, the two diets tracked parallel to each other, suggesting that the two diets were performing roughly equal throughout most of the trial except for a short period. This is supported by the growth data presented below.

Daily growth rate was fairly stable throughout most of the trial, apart from a sharp fall in May (Fig. 7). This dip was observed in the period when the diets started to diverge, and growth rates fell to 0.06 and 0.14 g/day for the two tanks of fish being fed the Goroka diet. Growth rates for the Australian feed fell to 0.42 and 0.47 g/day. This was associated with farm staffing issues when feeding was not carried out properly for some weeks.

From June onwards, growth rates improved again and there was no clear pattern of diets out-performing the other. The final maximum daily growth rate recorded was 1.05 g/day on the imported feed and 0.9 g/day on the Goroka formulated feed.

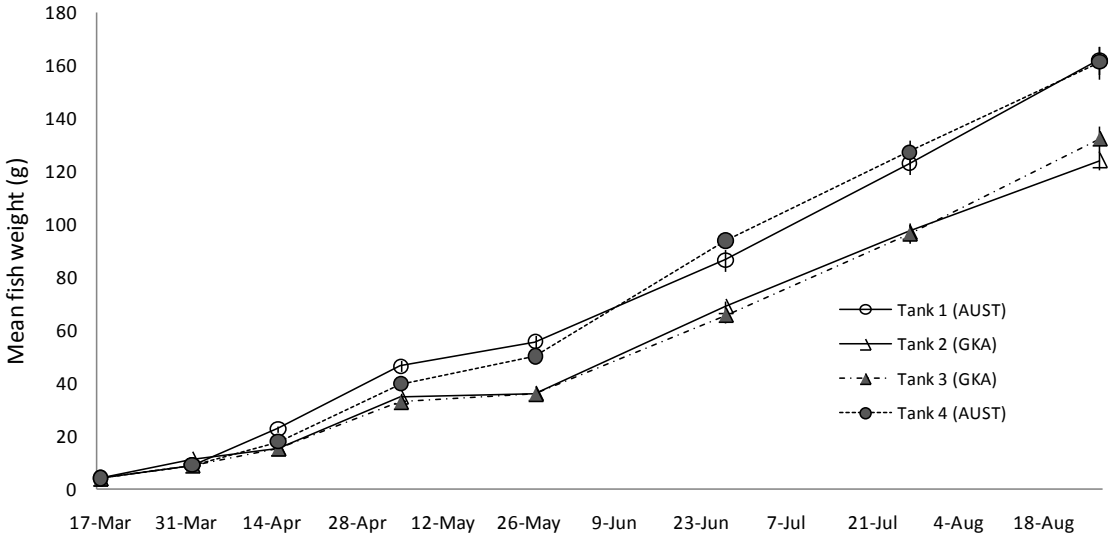


Figure 6. Rainbow trout growth (g)(±se) on two diets (n=2 tanks per diet) at Kotuni trout farm over 5.5 months from March to August 2011.

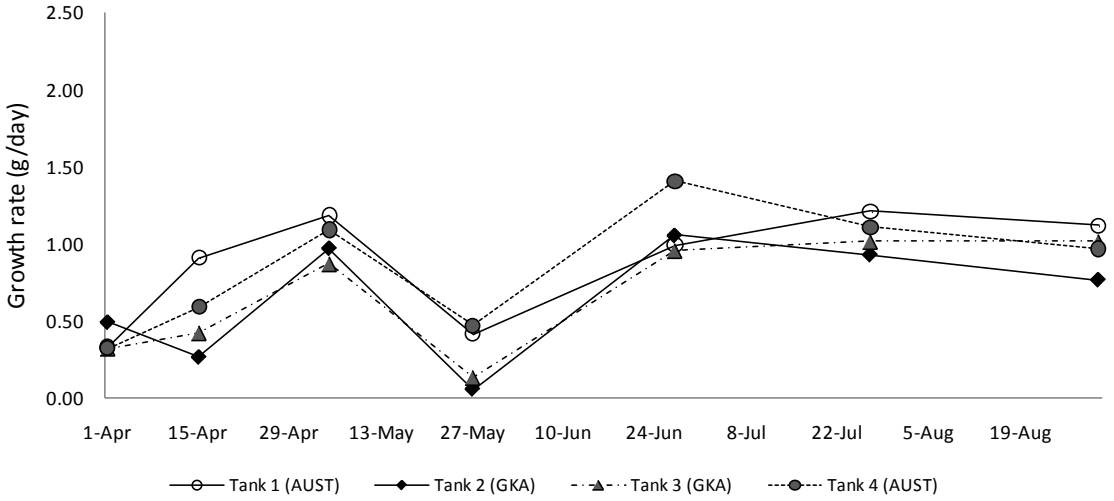


Figure 7. Mean daily growth rate (g/day) of trout fed on two diets at Kotuni trout farm.

A1 farm fish grew faster and reached higher mean weights than Kotuni fish on both diets. At this site, there was very little difference in fish growth due to diet, with mean weights of 244.6 ± 6.1 g and 245.6 ± 9.7 g for the Australian imported and Goroka formulated diet, respectively (Fig. 8). Growth rates were also higher than Kotuni fish and increased steadily throughout the trial, with a final maximum daily growth rate of 2.4 g/day on the imported feed and 2.2 g/day on the Goroka formulated feed (Fig. 9).

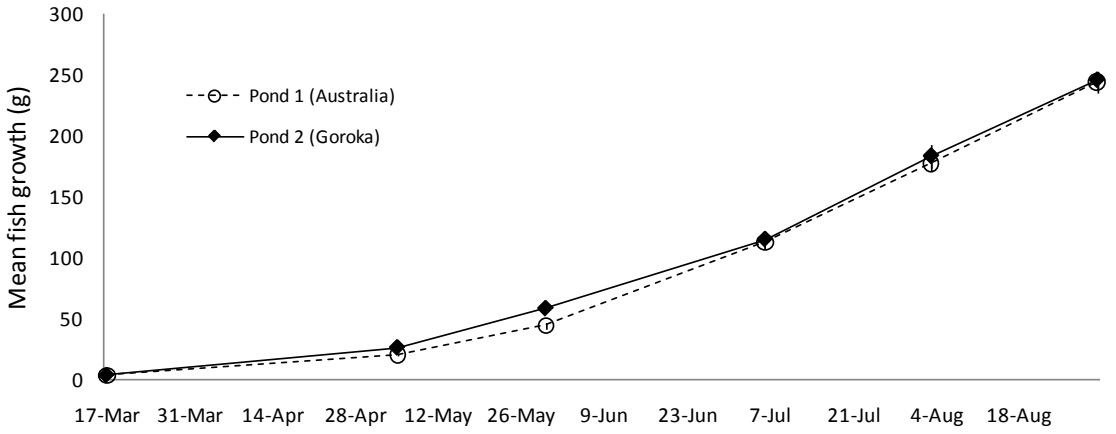


Figure 8. Rainbow trout growth (g)(±se) on two diets at A1 fish farm over 5.5 months from March to August 2011.

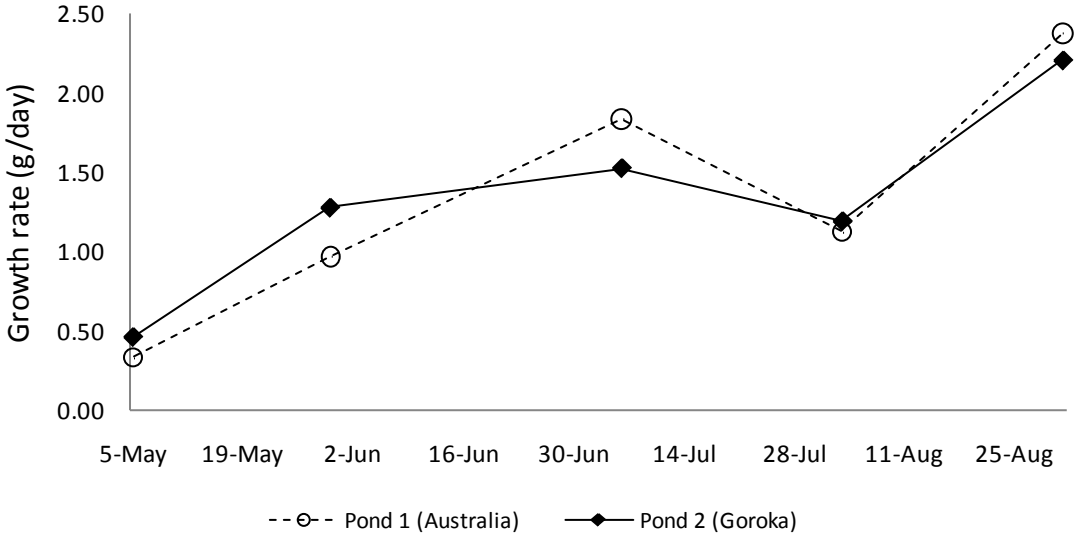


Figure 9. Mean daily growth rate (g/day) of trout fed on two diets at A1 fish farm.

3.2 Survival of rainbow trout

At the end of the Kotuni feed trial, there were 2,988 fish left in the four trial tanks, from the original 3,648 (i.e. 612 fish lost or died, overall 18% mortality). Due to sampling error, it is not possible to give survival for each tank individually. During the trial, nine fish deaths (1.5% of the total losses) were recorded, due to handling or fish leaping out of tanks. The unaccounted for fish loss may have been from poaching or unobserved deaths.

At A1 farm, survival was over 99% for both ponds (out of 500 fish in each pond, 497 and 498 fish remained in Pond 1 and 2, respectively).

3.2 Feed Conversion Ratio and economic viability of trout farming

Unfortunately, due to miscommunications by project staff and lack of staff capacity at the farm level, feed rations were not recorded accurately at either farm during the trial. Therefore, FCR cannot be calculated.

3.3 Water temperature

During the trial, Kotuni water temperatures ranged from minimum of 12.6^{o}C to a maximum of 17.9 ^{o}C, averaging around 15 ^{o}C (Fig. 10).

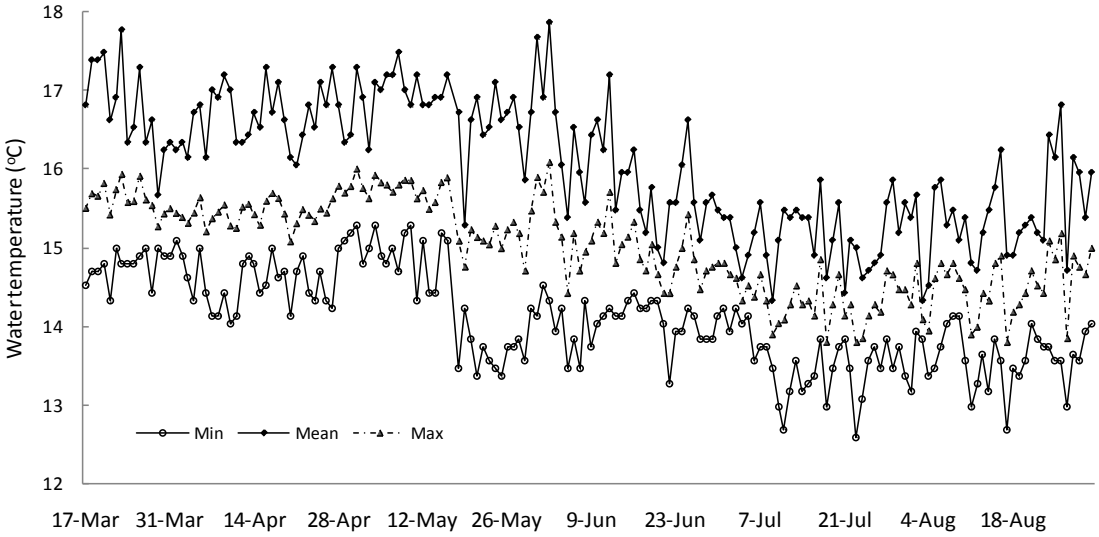


Figure 10. Minimum, maximum and mean water temperatures (^{o}C) for Kotuni trout farm for the period of the feeding trial (note that up to May 16, data was available from Nama trout farm only, used here as a proxy for Kotuni. From May 17 onward, Kotuni data were recorded from Tank 1).

For the first 2 months of the trial, A1 intake water temperatures ranged from a minimum of 14.1 ^{o}C to a maximum of 20.9 ^{o}C, averaging around 16 ^{o}C (Fig. 11). No water temperature data are available for the remainder of the trial.

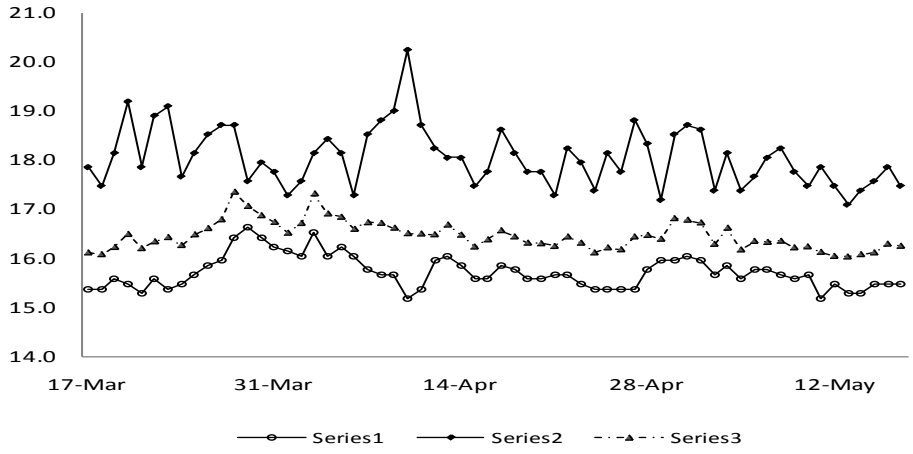


Figure 11. Minimum, maximum and mean water temperatures for A1 fish farm intake.

3.4 Blind taste testing

Between the cultured fish fed on different diets, both groups of tasters preferred the fish fed with the local Goroka feed compared to the imported Australian feed (Table 2), in the following categories: overall taste preference, juiciness and tenderness. However, when offered wild rainbow trout (Kotuni tasters only), the wild fish was most preferred. The full report on the blind taste testing is presented in Appendix 1. In general, the rainbow trout have been well accepted and enjoyed by the community. There are no problems with fish produced using the locally formulated diet, although it was noted that the flesh is a lighter colour than fish fed with the imported diet (Fig. 12).

Table 2. Results of blind taste test with percentage of participants that preferred each type of fish (taste, juiciness and tenderness).

	Overall taste		Juiciness		Tenderness	
Fish type	**Mix tasters** [1]	**Kotuni tasters** [2]	**Mix tasters**	**Kotuni tasters**	**Mix tasters**	**Kotuni tasters**
Fish fed with Australian imported feed	18%	25%	0%	0%	30%	50%
Fish fed with Goroka feed	82%	75%	100%	100%	70%	50%

[1] Mix= a mixed group of Goroka participants; [2] Kotuni= A group of Kotuni participants,

Figure 12. The fish is well accepted and enjoyed by locals (left) although pale flesh colour is associated with the use of the locally formulated feed (right).

4. Impacts

4.1 Scientific impacts

This report describes a feeding trial on a well-studied species and there are no scientific impacts. However, some valuable new knowledge was gained with respect to Highland areas suitable for trout farming. One of the successful trial sites was A1 farm located at around 1,600 m and which has previously grown tilapia. This is at lower altitude than traditional trout farms, which are generally above 1,800 m. Results from the mini-project

indicate that it is feasible to grow trout over a wider altitudinal range than has been carried out in the past.

4.2 Capacity impacts

NFA officers and extension staff increased their capacity in planning and running experimental feeding trials, and data recording. Farms involved with the trial (i.e. staff at A1 and Kotuni) gained skills in sampling, data collection, fish husbandry (in particular, feeding strategies) and handling fish.

4.3 Community impacts

The production of a locally formulated (and affordable) rainbow trout feed has brought the Kotuni trout farm back to life as a community trout farm some 20 years after it closed down. It has also enabled other farms in the Eastern Highlands Province and some farms in the Southern Highlands Province to diversify into the product, and in one case has encouraged a farm to go a step further and produce fingerlings (see below). The farms that participated in the trial benefited directly through the provision of feed and support for feed management during the trial. Fish from A1 farm were sold to local guesthouses, restaurants and individuals at K32 per kilogram, (whole and gutted). However, all PNG Highlands fish farmers will benefit from the results of the trial which demonstrated that rainbow trout can be grown successfully on the local diet and do not require an expensive and difficult to obtain imported commercial diet. Already there is renewed interest in farming this species amongst community members in the Highlands (Nama, Koyuni, Berry Mini trout farm and other smaller farms). Given that trout survived and grew well on the local diet, trout feeds will be produced at an affordable price in Goroka and sold at cost to trout farmers. It will greatly benefit existing farmers who currently either cannot afford to provide an adequate diet to their trout (thereby operating inefficiently) or are paying a premium for imported feeds (thereby decreasing profitability of the farm). It may also enable other fish farmers to diversify and farm this high-value product

Nama farm (nearby Kotuni) was not involved in the actual feed trial but benefited from the mini-project and will also use the results. Nama farm established a small hatchery and the good quality commercial feed was used to condition these fish before spawning them in July 2011. The spawning was successful and in late 2011, Nama farm had 10,000 fingerlings from their first hatchery efforts. Nama farm has been using the locally formulated feed since it became available in 2009.

The fisheries officers running the trial have responsibility for advising local fish farmers and providing support for all freshwater aquaculture activities in the Eastern Highlands (and further afield). Extension will be achieved and results of this trial will be disseminated in the course of their normal duties where they visit farms or when local farmers come to the NDAL office in Goroka.

5. Conclusions and recommendations

The feed trial was a success, indicating that a good quality (i.e. acceptable to the local market) rainbow trout can be grown using a locally formulated feed pellet produced in the PNG Highlands. Fish at Kotuni farm grew well on both diets, although the imported diet led to higher growth. Results from A1 farm indicated that fish grew equally well on both the imported and the locally produced diet. However, this trial had no replication and was

carried out in ponds which had natural feed available in them, so differences in fish growth due to diet type may have been masked by natural differences in the ponds.

Unfortunately, we were unable to comprehensively assess the economics of the local feed as FCRs was not available (e.g. if fish grew to the same size on a much smaller amount of imported feed, then the economics may not come out in favour of the locally produced feed).However, access to local feed will facilitate the expansion of trout farming on the Highlands by reducing overall production costs. This is because the job of importing commercial feed from Australia or Asia is not only costly but is onerous in terms of arranging overseas payments, shipping logistics, obtaining import permits, meeting customs regulations and so on—these requirements are beyond the capacity of small Highlands farmers. Therefore, the ease of obtaining the feed is an important factor to consider.

The mini-project showed that rainbow trout could be farmed successfully at lower altitudes, such as A1 tilapia farm in Goroka. Where water temperatures were compared for the first 2 months of the trial, it can be seen that they were slightly cooler at Kotuni (higher altitude), but A1 temperatures were mostly within the recommended 10–20 oC range for growing rainbow trout (Masuda et al. 1998). Volume of water flow will affect production rates and probably varied between the farms, but these data were not collected. Even though A1 farm did not pay for feed during the trial, the high price received for the trout indicates that this activity will be profitable.

The mini-project raised the profile of this species and created a number of spin-off benefits. For the first time in over 20 years, the Goroka area, spawning was carried out (Fig. 13). Eyed ova, fry and fingerlings were produced and are being grown in local farms, important steps toward establishing an independent trout farming industry in the Eastern Province. Rainbow trout farming is poised to expand and the feed trial described here (together with associated activities) has been the major factor in this rejuvenation.

Figure 13. Small-scale hatchery at Nama trout farm (left) and .close up of eyed ova and early juvenile rainbow trout (right).

6. References

Masuda, K., Wani, J., Minimulu, P. and Soranzie, J. 1998. Trout farming manual. Highlands Aquaculture Development centre, 125 pp.

7. Acknowledgments

We thank Peter Graham for providing technical support to this mini-project during visits to Goroka. Also thanks to Tripiso Aipase for field assistance and data entry. Our gratitude is extended to the farms involved in the trial: at Kotuni, Joppa and other farm staff undertook day to day care for the trial fish and also assisted with sampling; at A1 farm, Aue Kole and his family members undertook day to day care for the trial fish and also assisted with sampling. A student from Unitech, Mr. Urakusie, also assisted with sampling. Ismael Kumuli and family at Nama trout farm were valuable contributors to other aspects of the trial. Many thanks to the casuals employed by NFA, Jack and Pape, including staff of DAL, Tony Umba, in Goroka for feed making and to Dr Geoff Allan for devising the original feed formula. Special thanks to Ian Middleton of OTDF for generously allowing us to transport the Ridley's feed to Port Moresby free of charge using his shipping container.

Appendix 1. Blind taste test report.

Prepared by Wally Solato, 5th September 2011

1.0 Introduction

A blind tasting session was organised to see what fish clients or participants prefer. The participants ranged from university students, Division of Primary Industry (DPI) staff, farmers and children. It covered a wide range of group since this will be the target group for the trout industry. Unfortunately, hotel restaurants, guest houses and grocery shop managers could not be included in the activity. The fish were prepared the same (frying with vegetable cooking oil) and served on small plate. Each was tasted and commented on as A or B (and C for Kotuni community only). A=Fish grown on Australia feed; B=Fish grown on Goroka feed and C=Fish caught from the wild from Kotuni Tasters. The tasting was carried out from fish after the last sampling done so we do not lose any quality from the feed given to the fish. Fish from both trial sites (Kotuni and A1) were tasted. A total of 36 participants tasted A and B while a total of 24 participants tasted A, B and C that included those caught from the wild using bait and fishing lines.

1.1 Fish Preparation

The fish were caught using a scoop (dip) net. There were five (5) fish per tank (tank 1-4) and similarly for A1's ponds and stunned to kill them. The visceral parts were cleaned including the gills and later clearly labeled and packed in plastic bags before placing in an esky filled with ice (to keep them fresh). The fish was cooked/fried whole.

1.2 Frying

A frying pan was heated with oil and fish placed on the frying pan. Fried fish was removed and placed on clearly labeled plates before tasters could taste. The following is a tabled result from the tasting session:

	Overall preference		Juiciness		Tenderness	
Fish type	Mix tasters [1]	Kotuni tasters [2]	Mix tasters	Kotuni tasters	Mix tasters	Kotuni tasters
Fish fed with Australian imported feed	18%	25%	0%	0%	30%	50%
Fish fed with Goroka feed	82%	75%	100%	100%	70%	50%
Wild rainbow trout	NA	100%	NA	100%	NA	100%

Two groups of tasters were used:

[1] Mix= a mixed group of 36 participants from Goroka, including university students, officers, farmers, women and children

[2] Kotuni= A group of 24 participants from Kotuni,

2.0 Discussion

From the tasting sessions, we can say that the wild fish from Kotuni tasters had 100% preference followed by Fish fed with Goroka's DAL feed and then the Ridley feed scored the lowest in preference. There was no difference with juiciness and tenderness as per the table above in order of wild fish compared with Goroka and Ridley feed for Kotuni tasters.

The Mix participants had Goroka Feed as the better preference in all aspects, taste, juiciness and tenderness. There were close to 10% who said that A was crunchy and it has strong flesh texture compared to B.

The colour was also mentioned but that did not act as one of our questions for the tasters. A fish had clear flesh colour compared to B.

Preparation of fish and postharvest procedures is another aspect to consider that may affect taste of fish. Different recipes and preparation of fish may produce other results as compared to what we have in the table.

Conclusion and recommendation

As per the tasting sessions, wild catch would be highly preferred by tasters, followed by fish raised using Goroka diet and Ridley would be the last but had the advantage of coloration for commercial clientele.

Adding carotenoid ingredients would be an advantage for commercial clients but otherwise we have our feed and fish for now.

3.0 Acknowledgement

I wish to personally thank all those who participated in the tasting sessions and especially Joppa for organising the catch of wild trout for the session at Kotuni farm.

Tasting photographs (1-4), Fresh trout; cleaning (insert); frying; and tasting by one of the participants

Appendix 2.6

MS1005
Pen culture trial of mud crab (*Scylla* sp.) in mangrove habitat, PNG

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU James Cook University WorldFish Center USP The University of the South Pacific	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**
Project Title:	**Mud crab (*Scylla* sp.) culture in pens in mangrove habitat in PNG (MS1005)**	
Goal:	Determine feasibility of mud crab pen culture in PNG.	
Objective(s):	The specific objectives of the project are to: 1. Determine the feasibility of rearing undersized mud crab in pens in mangrove habitats in PNG; 2. Assist in development of a new aquaculture industry in coastal rural communities of PNG; 3. Increase capacity in PNG (Fisheries officers and community members) to carry out mud crab pen culture. 4. Increase awareness of 'mangrove-friendly' culture practices	
Participating country:	PNG	
Project partner(s):	Bris Kanda, PNG National Fisheries Authority	
Dates / duration:	Sept 2010-Aug 2011, 12 months duration	
Project description	Farming mud crabs in mangrove systems is likely to be a suitable aquaculture activity for Pacific Island communities given the low level of technical expertise required, reduced operational costs and a high demand for mud crabs. A trial project for extensive pen culture of undersized mud crabs and fattening of marketable size but lean crabs in mangrove systems in PNG will investigate the culture potential of mud crabs in the area. The economic viability of this culture practice in PNG conditions will also be determined.	
Justification	There are limited opportunities for income generation in coastal areas of PNG (and elsewhere in the Pacific Islands region). Lean and half-grown crabs are being harvested despite their poor meat quality and low market value. The crabs can be turned into a high value product by fattening them as practiced in Southeast Asia.	
Expected outcomes	1. Production of commercial size mud crab from undersized wild crabs; 2. Experience gained in mud crab husbandry (in mangrove pens); 3. Improved capacity among government and NGO extension officers and community members; 4. Possible creation of new livelihood for PNG coastal communities (and other PIC communities interested in this commodity).	
Funding:	AUD$20,000	

Mud crab (*Scylla* sp.) culture in pens in mangrove habitat in PNG

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1. Background

Commercial, village-based opportunities in aquaculture are sought as a livelihood and also a means of increasing and varying protein intake for people living around the PNG coastline. Pen culture of mud crab within mangroves is a co-management approach to resource use that is beneficial to the natural habitat and the farmed commodity, since mangroves do not need to be cut down for the farming activity to occur. Communities in PNG are interested in farming mud crab; hence it is important to investigate the feasibility of pen culture of mud crab as a potential livelihood option for these areas. Mud crab culture in pens is seen as an appropriate industry in remote coastal communities where employment opportunities other than fishing are desperately needed. Pen culture of mud crabs uses very simple technology, needs no electricity or aeration, requires minimal capital outlay and easily comprehended by fishers (Chang and Ikhwanuddin 1999). Four species of mud crab are commonly found in the Asia Pacific region: *Scylla serrata* (giant mud crab), *S. olivacea* (orange mud crab), *S. paramamosain* (green mud crab) and *S. tranquebarica* (purple mud crab) (Keenan 1999). More than one species may be present in PNG.

Mud crab fattening generally refers to the further rearing of marketable size but lean crabs but the same term is also used to describe the further rearing of half-grown crabs (e.g. 150-250 g S*. olivacea* or 350-400 g *S. serrata*) for another 40 days or up to just one moult. These crabs usually require one more molt to be able to attain the size that commands better price in the market. In Asia, fattening is usually done in small ponds or pen compartments or in cages to facilitate intensive monitoring and feeding for the duration of 15 to 40 days. The practice of mud crab fattening was inspired by the market's (both local and export) preference for "fat" crabs and is kept profitable by big price difference between "lean" and "fat" crabs. In PNG this can be a factor at 3 or 4 times (K5 for small undersized crabs, or K15-20 for large crabs).

Grow-out systems are categorised by Shelley (2008) as either open or closed. The former include ponds and mangrove pens while in the latter, crabs are grown individually in containers or held in fattening ponds. In open systems, crabs can be farmed extensively (1 crab/2-10 m2) or intensively (0.5-1.5 crabs/m2). Adequate feed and the provision of shelter can reduce the rate of cannibalistic behavior common with mud crabs, which is a major impediment to high density production (Shelley 2008).

This mini-project trial of mud crab pen culture will investigate their culture potential in mangrove habitat at two sites and determine the economic viability of mud crab fattening in PNG. The objectives of the mini-project are to:

1. Determine the feasibility of fattening undersized as well as lean mud crab in pens in mangrove habitats in PNG;
2. Assist in development of a new aquaculture industry for coastal rural communities of PNG;
3. Increase capacity in PNG (Fisheries officers and community members) to carry out mud crab pen culture.
4. Create awareness among coastal communities of co-management of mangroves with farming mud crabs and other aquaculture species such as prawn or fish farming without destroying mangroves.

2. Materials and Methods

Mud crab pen culture techniques based on overseas experience (principally Philippines) were transferred to PNG counterparts: Bris Kanda in Lae, (Morobe Province), and NFA in Port Moresby (National Capital District), together with a coastal community at each of these locations. The JCU technical advisor, Jerome Genodepa, who has practical expertise from the Philippines, provided training in all aspects of mud crab pen culture (Fig. 1). The initial project sites are Labubutu, near Lae, and Derekone village, near Port Moresby. The trials did not involve experimental manipulation.

Figure 1. Jerome Genodepa conducted practical lessons on crab identification, and differentiating lean and fat crabs.

Jerome made two visits to the field sites, the first from 29 January to 9 February 2011 and the second from 1-13 July 2011. During these trips, NFA officers, Bris Kanda officers and community counterparts were provided with training in: site selection, mangrove pen and individual holding cage construction; species identification and classification of fat and lean crabs; mud crab husbandry (stocking, feeding, etc) and; handling, harvest and storage.

2.1 Site selection

Baliao et al. (1999) recommend that water depth should be between 0.3-1.0 m at high tide. The site should also be free of large waves, pollution and not subject to freshwater flooding. In addition to the physical characteristics of the site, there are other important considerations such as security. Locating the pen close to the village should allow better control of poaching, and make daily feeding and pen maintenance more convenient. Further, the communities of Labubutu and Derekone must have tenure over the proposed mangrove culture area and commit to the time and labour requirements of maintaining the pen structure and cultured animals for the required fattening period.

Prior to Jerome visiting PNG, local collaborators collected data on site characteristics using a site selection criteria checklist provided by Jerome (Appendix 1).

2.2 Pen and cage construction

Two types of fattening system were recommended for the participating villages:

(1) Pens made by enclosing a portion of the mangrove forest with a fence. The enclosure was square or rectangular in shape and the area (approximately 100 square meters) was adjusted in order to avoid cutting down of mangrove trees and minimize damage to their roots during construction of the fence. Fencing material was made of bamboo slats, fence height was 30-40 cm above the highest tide and the base was embedded by at least 60 cm into the ground. Trenches or canals were built within the enclosure to hold water during low tide and prevent dehydration of crabs. Shelters made twigs and tree branches were provided to decrease the incidence of cannibalism reducing the chance of encounter among crabs.

(2) Small cages for holding individual or groups of crabs for short fattening period. The cages were also intended for temporarily holding of batches of crabs for stocking of pens and holding crabs that are ready for the market.

During both visits, Jerome provided training on pen and cage construction including practical demonstrations on use of local materials such as bamboo.

2.3 Mud crab surveys and availability

During both trips, Jerome trained local staff in identification of the species of mud crabs, differentiating male crabs from females and fat from lean crabs, data collection (length, width and weight measurements with calipers and scales) and ways of tying crabs (Fig. 2).

Figure 2. Tying and measuring mud crab.

Jerome visited the different markets around Port Moresby to interview crab fisherman and to investigate potential supplies of lean mud crabs. The different markets visited

include: Manu Auto-port Market, Koki Market, Pari Village Market, Gabutu Village Market; Tatana Village Market; Rainbow Village Market; Gerehu Market; Waigani Market; RH Hypermarket and SVS Harbor City. NFA staff also conducted a survey to gather additional information. The survey questions are as follows:

1. What village are you from?
2. Where did the crabs come from?
3. Are you a fisherman or a middleman?
4. How do you catch you crabs?
5. How often do you go fishing?
6. How much do you sell the crabs for and do you sell all the crabs?

In Lae, project staff visited Papindo Trading to inquire about crabs they receive from suppliers.

2.5 Stocking and harvesting

Marketable but lean and half-grown mud crabs of either sex will be used to stock the trial pens. Crabs for stocking will be sorted and those of similar size and degree of fatness will be stocked in the same pen to facilitate easier stock management and harvesting. Some crabs just needs to be fattened and would require 2 to 3 weeks of culture while others (half-grown crabs) need one more moult to reach sizes that have better market value and would require 4 to 6 weeks of culture. Since crabs will not fatten all at the same time, staggered harvesting is recommended and this requires weekly sampling of crabs using baited traps or lift nets. The crabs stocked and harvested in each pen compartment will be recorded plus data on individual carapace width (CW), weight and sex.

The pilot mud crab fattening project in Port Moresby will be on fattening of marketable but lean crabs. Crabs which are at least 14 cm carapace width will be purchased from suppliers/dealers and fattened for 2 to 3 weeks. Crabs that require lesser period of fattening will be reared in cages while those that require longer period of fattening will be stocked in the pen.

In Lae, the pen will be stocked with crabs that need one more moult (~10 to 12 cm CW) to reach the ideal marketable size while the fattening cages will be stocked with big but lean crabs (at least 14 cm CW). Crabs from the pens that have moulted to the next size will be collected and further reared in the fattening cages. Continuous stocking and selective harvesting will be done in both the pen and cages.

Pre-stocking protocols described by Baliao et al. (1999) will be followed. This includes careful checking of the pen for holes and potential escape routes of crabs. Prior to release, the crabs will be acclimated to the water temperature and salinity of the pen site. Release of crabs into the pen will be at a time when it is cool and is tidal water available. Mud crabs will be marketed live. The mud crabs' pincers (chelipeds) will be tied at harvest in preparation for marketing in order to prevent damage to handlers and other crabs.

2.6 Feeds and feed management

Feeds constitute 40-50% of the total cost of mud crab production (Quinitio 2004), hence identification of an inexpensive, locally available feed source is vital to the economic and environmental sustainability of the fattening activity. Trash fish is generally fed to crabs but other locally available feeds can also be used (e.g. mussels, oysters, snails, by catch from other fishing activities, kitchen leftovers, animal entrails, etc). Mud crabs have been shown to grow well on diet containing 32-42% protein and 6-12% lipid (Quinitio 2004).

Feeding management will be based on Baliao et al. (1999). Feeds will be administered at 5-10% of total biomass per day throughout culture and adjusted according to left over feed. Crabs will fed daily (or every other day depending on feed availability) during the incoming tide by broadcasting throughout the pen.

During Jerome's visits, feed sources were investigated and appropriate feeding regimes discussed.

2.7 Data collection

Project counterparts were instructed on data collection to be undertaken during all culture trials. The sex of all mud crabs will be noted together with individual weight (to the nearest gram) and carapace measurement (mm carapace width) prior to stocking Thereafter, weekly sampling of crabs should record sex, weight and carapace width for growth. Crabs will be sampled using baited lift nets and crab traps.

Water temperature, salinity, and turbidity measurements will be taken regularly, at least three times a week (Baliao et al. 1999). Feed consumption, abnormal swimming behavior and incidence of berried females will be noted.

Jerome provided a data sheet for recording data from the stocking trial (Appendix 2).

2.8 Capacity building, extension and uptake of results

Training focused on providing skills to local counterparts in the Bris Kanda NGO, PNG NFA Fisheries extension officers and community members in Labubutu and Derekone. The trial was undertaken at two locations initially but local counterparts may expand this activity to other suitable communities if trial results show the potential of mud crab pen and cage culture. Jerome has produced detailed instructions on this activity, which will provide a useful guide for other PNG (or other Pacific) communities that may want to trial mud crab fattening in the future.

Crab fishers were informed about the project and invited to attend a seminar on the culture methods.

3. Results

3.1 Site selection

On his first trip in February, Jerome visited both locations and identified suitable sites for building mangrove pens. At Derekone, within Bootless Bay, Port Moresby, he met with members of the Gorogaha clan (Roy, Momo and Sokai) who own the land and are the project collaborators. He checked the proposed site and selected the particular spot in the mangrove area most suitable for a trial pen (Fig. 3). In Lae, Jerome traveled to the site at Labu Butu #1 Village, Wampar LLG, Huon Gulf District, Morobe Province and marked out a suitable trial pen area in the mangrove forest (Fig. 4).

Figure 3. A view of Bootless Bay and the mangrove area where the pen for mud crabs will be constructed.

Figure 4. Measuring and marking out of the mud crab mangrove pen at Labubutu.

3.2 Pen and cage construction

Pen construction was undertaken at both locations on both visits and also when Jerome was absent However, hold-ups with supply of building materials delayed construction at Labubutu. There were also delays experienced at Derekone due to other demands on the time of the collaborators.

At Derekone, a 10 x 10 m (100 m^2) mangrove culture pen was constructed of bamboo slats nailed to horizontal frames and supported by wooden posts (Fig. 5a). A construction barrier net (Fig. 5a, orange material) was also used as additional fencing material. This was not part of the recommended material but local project staff used it to reinforce the bamboo fence. An individual fattening cage (around 30 cm wide x 30 cm high x 300 cm long, divided into several compartments)(Fig. 5b) was also constructed using lumber as framework and construction barrier net as material for the walls. A group fattening cage (120 -150 cm wide, 100-120 cm high, 200-300 cm long) has been built.

(a) (b)

Figure 5. Derekone mud crab culture systems (a) mangrove pen, and (b) fattening cage.

At Labubutu, the pen was also constructed using bamboo slats nailed to horizontal frames and supported by wooden posts (Fig. 6a). The original size of the pen area was reduced to 12 x 9 m (108 m^2) due to shortage of building materials and time constraints in acquiring additional materials. A cage with compartments for individual fattening (30 cm x 30 cm x 300 cm, with six compartments) was constructed during the July trip (Fig. 6b). The cage frame was made of wood and the wall material used was galvanized chicken wire screen as no other suitable netting material can be purchased at that time and there was no extra bamboo from the pens.

(a) (b)

Figure 6. Labubutu mud crab culture systems (a) mangrove pen, and (b) fattening cage.

Pen construction work still needed to be completed after Jerome's departure in July. These included: closing gaps within the fencing; strengthening the fencing with extra bamboo slats; driving fencing stakes 50-70 cm into the mud around the perimeter of the pen and in the canals; building a catwalk (around and within the pen, also from shoreline to the pen allowing access at any tide); digging trenches inside the pen; and providing shelters of branches and tree trunks inside the pens. Group fattening cages are still to be constructed.

3.3 Mud crab

Two species of crabs were observed in Port Moresby; *Scylla serrata* (~80-90% of crabs surveyed) and *Scylla olivacea* (~10-20%). Medium to large size crabs are sold in the market from K4-10 per piece regardless of sex, species or degree of fatness. There appeared to be an adequate supply of crabs from the market that could be used for fattening or pen culture (Fig. 7).

Figure 7. Port Moresby market mud crabs (covered in mud to keep them alive).

A one-day survey of the markets in Port Moresby revealed that only two of the five markets visited had crabs for sale and they all came from Lealea. In a follow-up survey interview conducted by NFA staff, it was noted that all the crabs in Port Moresby come from Gorohu and Lealea area of the Central Province. Most sellers were middle persons who purchase crabs between K5-6/kg in these villages and sell them in Moresby Markets at K4-8 per piece, depending on the size. Traditional methods (i.e. using sticks) are employed to harvest crabs from the wild. All the crabs are usually sold each day by lowering prices of crabs, especially in the afternoon when sellers are ready to leave and when the crabs are stressed and in poor condition. The team also found one supermarket selling crabs (*S. olivacea*) at K17.95 per kg (about 4 crabs per kg, each crab normally sells at K3-4 in the local market).

The Port Moresby project team has identified several crab suppliers from whom they will purchase crabs of a specific size, whether they are lean or not. Mud crabs may also be sourced from local fishers familiar with the fishery or caught by community members or purchased from markets if necessary.

In Lae, the dominant mud crab species is *Scylla olivacea* (~90 %) based on samples presented by co-operators and interviews. A second species is also present, and this is

most likely *S. serrata* as identified by locals in the pictures presented to them. Samples presented by co-operators were small and medium sizes of *S. olivacea* with cost ranging from K3-5 per piece. Usually the crabs are brought to the market on Saturdays. Papindo supermarket buys crabs from suppliers in Labu at K10 per kg (at least 300 g) according to Mr. Ayong Tan (Freezer Distribution Manager, Paindo Trading Company Ltd). The company supplies the local market only and they can absorb only 30 kgs per week if supply is available.

It appeared that suitable mud crab for fattening and pen culture in Lae may be collected locally. The team went around the mangroves and Labu Lake to assess the potential of the area for mud crab aquaculture. There were some unresolved issues associated with obtaining crabs for stocking the pens. For example, most of the mangrove area was not utilised for collection of crabs. Each village has specific areas where they can go fishing and they are not allowed to use resources beyond their village. Usually the fishermen don't go far to collect the crabs.

At Labubutu, only 26 out of the required 200 crabs were obtained for stocking before Jerome departed but most were small and not suitable for stocking. The target was to stock crabs that will require only one moult to reach the ideal marketable size but most of the crabs brought-in for stocking would require two moults to reach marketable size. The collaborators committed to obtaining more following Jerome's departure.

3.4 Husbandry

At the time of this report, no stocking had been undertaken but steps have been taken to develop a stocking plan and obtain feeds.

Stocking

At Derekone, the 100 m^2 fattening pen will be stocked with around 1-2 crab per square meter. Once pen construction is complete, crabs can be purchased and stocked. Only the big crabs (*S. serrata* >130mm and *S. olivacea* >120mm) will be stocked into the cages and pens. About 200 mud crabs will be bought from Gorohu at K10 per kg. The crabs will sorted and the lean ones will be stocked in the pens while the not so lean ones will be stocked in the cages. The group fattening cage will be stocked at 25-50 kg per m^2 while the cage with compartments will be used to temporarily hold injured or weak crabs or hold crabs that are ready for the market.

At Labubutu the 108 m^2 fattening pen will also be stocked with around 1-2 crab per square meter. Around 200 crabs were required and these will be collected by the cooperators with the help of the community members. The initial collection of crabs will be temporarily held in cages until sufficient number is available for stocking in pens and the needed improvements in the pen are completed. The pen will be stocked with crabs that need one more moult to reach the ideal marketable size while the fattening cages will be stocked with big but lean crabs. Culture in the pens will be for only one moult (approximately 3-5 weeks) and crabs that have moulted to the next size will be collected and further reared in the fattening cages. Continuous stocking and selective harvesting will be done in both the pen and cages.

Feeding

NFA has liaised with a local seafood company, United Seafood Limited, to supply low-cost by-catch and trash fish as feed for the crabs at Derekone. However, this supply will only be limited to the duration of this research project, unless further marketing arrangements be made between the farmer and the seafood exporter. A fishing net (2.5 inch gill net) will also be purchased for the project proponent for fishing only when feed supply from the seafood company is unavailable. NFA staff and project cooperators were

cautioned to carefully assess the possible impacts of this plan of catching fish to feed the crabs

Project staff visited Frabelle (PNG) Limited in Lae to inquire about possible supply of feeds for the Labubutu trial. According to General Manger Alex Bernardino, the company is willing to help the project in whatever way they can. They have a processing facility in Lae and can supply the following products for mud crab feeds: a) fishmeal powder which can be used as feed ingredient; b) dried fishmeal - boiled and then dried tuna processing wastes prior to grinding; c) fresh tuna heads, guts and dark muscles. Fresh tuna processing wastes from Frabelle were used to feed the crabs that were initially collected for stocking that were temporarily held in the fattening cages, according to John Ben of Bris Kanda.

3.5 Pen culture trials

Derekone farm site in Central Province stocked cages with 239 crabs in November 2011. The crabs were fed with frozen or sun dried fish rejects and trash fish from local fish processors. However, the stocked crabs were all stolen before harvest due to the inability of the proponents to provide security. However, from project team observation and reports from the technical assistant, both species grew bigger than they were first introduced in the pens. Anecdotally, *Scylla serrata* grew well in the area and no casualties were reported, whereas *S. olivacea* were reported dying. In comparison, Scylla serrata grows better than Scylla olivacea as observed and reported.

The Bris Kanda proponents at Labu had not stocked any crabs in their pens at time of reporting.

4. Impacts

4.1 Scientific impacts

This report describes the first efforts to carry out pen culture of mud crabs in a mangrove environment in PNG. However, there are unlikely to be any scientific impacts since the technology has been developed elsewhere and transferred to PNG.

4.2 Capacity impacts

This mini-project was primarily a technology transfer activity and it enhanced the capacity of the officers who were trained in mud crab culture techniques. Officers from the NFA in Port Moresby and Bris Kanda in Lae learnt how to select suitable crab culture sites and construct grow-out systems (pens and fattening cages) in mangrove habitats. They also gained new skills and knowledge about mud crab biology, husbandry, sampling, processing and marketing. Community members from Drekone and Labubutu who participated in the trial also gained new skills in construction of grow-out systems, mud crab husbandry and marketing.

4.3 Community impacts

No economic community impacts can be reported because mud crabs were stocked at only one site (Derekone) and results of sales and profitability were not obtained due to theft of crabs before harvest. If stocking occurs in the future, and if the methods are found to be economically viable, then communities will benefit from the project. Social impacts for the participating communities will also depend upon the feasibility of mud crab culture as an income-generating activity. If the activity proves to be successfully adopted and profitable, then it may result in fewer people moving to the large urban

centres to look for work and will bring more wealth into the community through the sale of fat mud crab at a premium price. There is potential for the development of this industry, however, it is essential that the market can distinguish between the types and quality of crabs – Fishermen, crab processors and crab buyers must know the difference between fat and lean crabs and different prices associated with it. Currently, the same price is paid for fat and lean crabs. This industry can develop once the market rewards better quality product, i.e. a smaller fat crab should be more valuable than for a bigger lean crab.

The use of undersized crabs for this trial was responsible as the results will determine the feasibility of this culture activity in PNG and allow the technical transfer of grow-out husbandry practices without the need for expensive and difficult hatchery larval production. By fattening undersized crabs, value of the current catch will be optimised, improving livelihood option for the fishers and farmers while not taking any more crabs than the normal harvest. Nonetheless, project partners should be mindful of the possibility of over-harvesting if this industry is adopted in PNG as a result of these trials. Numbers of undersized crabs collected and possible effects on the overall fishery should be monitored and managed accordingly. The sustainability of wild seed collection should be considered in any capture-based culture activity. There are fears of over-fishing in a number of countries where wild mud crab juveniles are used to support aquaculture (e.g. the Philippines). There are also other limits to mud crab supply, including mangrove deforestation, pollution and their seasonal, variable recruitment (Shelley 2008). The need for a consistent supply of crablets has led to the development of hatchery technology in a number of countries, such as China, Vietnam, Philippines and Australia.

Mud crab culture is 'mangrove-friendly' supporting conservation of this valuable habitat. Positive environmental impacts may occur if natural mangrove habitat is perceived as having increased value, i.e. it can be used to generate income without being cut down.

5. Conclusions

For mud crab culture to be economically viable in PNG, the Asian crab marketing system needs to be in operation (i.e. where higher prices are paid for females as compared to males, for big compared to small, and for fat as compared to lean crabs). Security for this valuable resource will, however, be a priority, as the Derekone trial was unsuccessful due to theft of the cultured crabs and limited information was obtained on its viability. The Labubutu trial did not proceed due to insufficient funding following initial training.

Communities were very keen to be involved, however, and if properly resourced, should continue to progress with this activity in other PNG provinces. PNG NFA project staff propose to introduce the technology to other sites where *Scylla serrata* are abundant. Local people will be employed to provide security and technical assistance to the project. Other trials may be initiated in Milne Bay and Niugini Islands provinces following awareness on mudcrab farming.

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7. Acknowledgements

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Appendix 1. Site selection criteria checklist

Indicate level you agree or disagree with the statements below. Ticking 1 means you fully agree and 5 means you fully disagree.

Criteria	Scores				
	1	2	3	4	5
1. The site is protected from big waves.					
2. The site is protected from floods.					
3. The site is secure from vandals and poachers.					
4. The site is free from pollution.					
5. The site is near the caretaker's residence.					
6. The site is near sources of feeds.					
7. The site is near the market.					
8. Mud crab seeds can be collected or purchased near the site.					
9. The site is reached by seawater every day during high tide.					
10. The level of water during the highest tide in not more than 2 meters.					
11. The site is without water for not more than 6 hours during low tides.					
12. The tidal water that comes into the site does not become like freshwater during certain parts of the year.					
13. Mud crabs are found in the area year round.					
14. The site has thick layer of mud and the soil is not easily eroded by water currents.					
15. A fence can easily be built in the site.					
Total -					

Get the total score for each column by multiplying the score by the number of ticks and then add the total scores of the columns. Compare the scores obtained from different sites. The site that gets a mark of "1" for criteria 9 to 15 and has the lowest total score and should be most ideal.

Appendix 2. Stocking harvest datsheet

CULTURE SYSTEM ______________________________										
Stocking Data						**Harvest Data**				
Date	CW-Male	CW-Female	Weight (g)	Gonad Stage		Date	CW-Male	CW-Female	Weight (g)	Gonad Stage

Appendix 2.7

MS1007
Pacific islands aquaculture feed ingredients inventory

ACIAR Pacific Aquaculture Grant: **Project Summary**		**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex New Caledonia Tel: +687 26.20.00; Fax: +687 26.38.18; E-mail: spc@spc.int**
Project Title:	**Pacific islands aquaculture feed ingredients inventory (MS1007)**	
Goal:	To review and augment current knowledge about locally-available shrimp, prawn and fish aquafeed ingredients in selected Pacific island countries.	
Objective(s):	Specific objectives are: (1) Review existing knowledge, information and nutritional analyses about locally-available aquafeed ingredients in selected PICs; (2) Identify, collect and analyse any additional feed ingredients for nutritional composition; (3) Compile and publish a regional aquaculture feed ingredients inventory.	
Project location:	Fiji, Vanuatu, Samoa, Solomon Islands, Papua New Guinea	
Project partner(s):	PIC Fisheries and Agriculture departments	
Dates / duration:	Oct 2010 to Dec 2011	
Project description:	A desktop review will be conducted to compile a list of possible aquaculture ingredients currently available in ACIAR countries, which are of interest for aquaculture. Information will be collated from across fisheries and agricultural spheres, in particular taking into account the findings of past fish-feeds projects. From this review any new potential ingredients or feedstuffs, and any gaps in the range of available nutritional analyses, will be identified. In-country collections will be made of potential feed materials for which analyses still need to be obtained. Price and availability information will be sought. The information reviewed and generated will be compiled into a regional aquaculture feeds inventory.	
Justification:	There is renewed emphasis being placed upon aquaculture species for food security and livelihoods in the region. The desired approach is one of low-cost, utilising locally available (and preferably on-farm) feed sources.	
Expected outcomes:	1. A publication outlining available aquafeeds information in the region; 2. Identification and analysis of any new feeds not previously evaluated for priority aquaculture species; 3. Build capacity in country project staff on ingredients appraisal; 4. Provide baseline information to support links to the agriculture, livestock human nutrition and other programs involved in food security.	
Funding sought:	$30,100	

Pacific islands aquaculture feed ingredients inventory

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1. Background

The potential for culture of tilapia and *Macrobrachium* as an important source of protein and income for small-scale fish-farmers is substantial in many Pacific island countries (PICs). There is also renewed emphasis being placed upon aquaculture species with potentially high importance for food security and livelihoods in the region particularly lower trophic-level species suitable for inland-pond or inshore-cage culture. However, lack of appropriate resources and capacity has contributed to low productivity of aquaculture in PICs. One of the key constraints has been identified as the poor quality and limited availability of supplementary feeds. The limited availability of ingredients and lack of information on cost-effective ways to make and deliver feeds often result in poor quality feed and hence reduced production and profitability. The aquaculture sector needs information about the agricultural feed resources available. This information can then improve the efficient use of these resources towards aquaculture feeding strategies. This information presented here will assist in overcoming this constraint by providing clear information on what ingredients are available, their cost, availability and any seasonal aspects to their supply.

The mini-project approach took advantage of low-cost, locally available ingredients that had not been assessed for use in aquaculture. Information has been collated from across fisheries and agricultural spheres (in particular, fish-feeds projects such as the mini-project, 'Development of commercial and farm-made feeds for tilapia and *Macrobrachium* in PNG and Fiji', which was done under the auspices of ACIAR FIS/2001/075[1]) have been collated and reviewed. Suggested follow-on actions to extend their results to other places have been identified. In-country collections were made of potential feed materials for which analyses still need to be obtained or re-analysed some ingredients that have been done in previous studies. Current price and availability information was sought. Information from the review and new data generated will be compiled into a Pacific regional aquaculture feeds inventory suitable for use with Aquafeed formulation software such as Winfeed.

Specific objectives of the mini-project were:

(1) Review existing knowledge, information and nutritional analyses about locally-available feed ingredients in selected Pacific island countries, with respect to key aquaculture commodities;
(2) Identify any gaps in knowledge, collect and analyse any additional feed ingredients for nutritional composition;
(3) Compile and publish a regional aquaculture feed ingredients inventory.

[1] *FIS/2001/075 'Sustainable aquaculture development in the Pacific Island region and northern Australia'*

This mini-project built upon the results of and followed similar methods to the previous ACIAR Feeds Formulation mini-project. It focussed on the ACIAR target PICs with the greatest demand for aquafeeds: Fiji, Vanuatu, Samoa, Solomon Islands and Papua New Guinea

2. Materials and Methods

2.1 Desktop study

A desktop study was carried out to identify local feed ingredients available in the region, tabulate their nutritive values (primarily using data from published sources) and identify links to other sources/projects where there is useful information available. There are already a number of excellent publications which comprehensively review proximate and nutritional composition of ingredients and their use in aquaculture diets. These include Tacon (1987), Hertrampf and Piedad-Pascual (2000), Lim et al. (2008) and Tacon et al. (2009). These are all invaluable resources from which to make well informed decisions on feed formulations for aquaculture species. Rather than attempt to summarise these detailed and extensive texts, the objective of this review was to obtain an overview of the potential aquafeed ingredients from mini-project partner countries based on feedback from survey questionnaires and a review of the published literature.

2.2 In-country ingredients surveys and sample collection

Survey Forms with detailed instructions were sent to Fiji, Vanuatu, Samoa, and the Solomon Islands so the local counterparts could commence researching the potential sources of feeds in each PIC. The nutritionist visited each country to gain an appreciation of the project area and to assist the local counterparts in Fiji, Vanuatu, Samoa, and Solomon Islands with completion of questionnaires, site visits, interview potential ingredient source manufacturers and collect ingredient samples for compositional analyses. In PNG, information and ingredient samples for analysis were collected by project staff of ACIAR project FIS/2008/023[2], which also contains an aquafeeds ingredients analysis component.

Information on potential aquafeed ingredients included, where relevant and possible, their cost, availability and seasonality. Based on the desktop review and in-country information collection, any potential new ingredients or feedstuffs, and any gaps in the available nutritional information, were identified.

2.3 Compositional analyses

Samples were prepared for compositional analyses by oven drying at <80^{o}C and then ground to a meal consistency. Proximate composition of all sampled ingredients was determined for: energy, moisture, nitrogen, crude protein (CP), ash, and total fat. Total amino acid composition was also determined for a limited number of samples. Protein was calculated as N x 5.6 (after Mariotti, et al., 2008). This conversion factor can be considered, on average, more accurate than the accepted factor of 6.25 currently used by the AOAC (2005) for N to protein conversion. Heavy metal analyses (arsenic, cadmium, lead, mercury) were carried out on fish processing waste from Fiji (fish bones/frames, skins and dust).

[2] *FIS/2008/023 'Increasing production from inland aquaculture in Papua New Guinea for food and income security'*

2.4 Feed formulation software training

Training in diet formulation using Winfeed feed formulation software was carried out in Fiji, Samoa, Solomon Islands, Port Vila and Santo for local Fisheries and Aquaculture Officers.

3. Outcomes

3.1 Desktop Review

Tables 1, 2, 3, 4 and 5 summarise the relevant aquafeed ingredients that have been identified from the literature, survey questionnaires and field work. Where no costs are reported for ingredients referenced as "Current Study", samples were either sourced as 'bush' ingredients or obtained for free as waste products from commercial produce manufacturers (e.g. agricultural, fishery or brewery waste material). There were many instances of ingredients being commonly available amongst different countries, (e.g. copra, cassava, etc.) and for the most part repetitive reporting of the same ingredient was avoided.

The bulk of published information on feed ingredients and their proximate composition pertains to PNG, Fiji and Solomon Islands. These data are predominantly compiled from previous ACIAR projects FIS/2001/075 (Fiji and Papua New Guinea), FIS/2005/108[3] (Fiji Islands) and LPS/2003/054[4] (Solomon Islands). By comparison, there is a dearth of published information on locally available feeds and ingredients for the other mini-project partner countries (Samoa and Vanuatu). For some countries, such as Vanuatu and PNG, there are no commercial aquafeeds manufactured locally and all commercial diets for local use are imported from either Australia or Fiji or made using mini-mills. The ingredients used in commercially formulated feeds in Fiji are well known (e.g. fishmeal, meatmeal, copra etc), however, the main knowledge gap in most of the PIC's exists for indigenous or novel ingredients such as leaves, berries or roots of local terrestrial plants or local animal (e.g. shellfish) or animal by-products which may have potential as aquafeeds or aquafeed ingredients.

A relatively large amount of published information exists for both livestock and aquafeed ingredients in the Fiji Islands. For this review, the bulk of the information on ingredients and their proximate analyses was sourced from the findings of ACIAR projects FIS 2005/108 and a previous mini-project within FIS/2001/075, 'Development of commercial and farm-made feeds for tilapia and *Macrobrachium* in PNG and Fiji'. Fiji also has a considerable livestock industry with two local feed manufacturers; Pacific Feeds Ltd. and Goodman Fielder Fiji Ltd., which are another source of ingredients; although imported ingredients constitute a significant portion of the formulated feeds these two companies produce.

PNG shares a similarity with the Fiji Islands in that a relatively large amount of published information exists for both livestock and aquafeed ingredients. Previous ACIAR projects such as FIS2001/075 'Development of commercial and farm-made feeds for tilapia and *Macrobrachium* in PNG and Fiji' have contributed to the bulk of the information presented in this review. A sizeable livestock industry also exists in PNG, with Goodman Fielder International, also present in Fiji, having livestock operations there. However, they do not produce aquafeeds.

[3] *FIS/2005/108 'Freshwater prawn aquaculture in the Pacific: improving culture stock quality and nutrition in Fiji'*
[4] *LPS/2003/054 'Feeding village poultry in Solomon Islands'*

There is scant published information specifically relating to aquafeeds and aquafeed ingredients in the Solomon Islands; however, research into livestock feed ingredients in the Solomon Islands has been carried out by previous researchers with a focus on poultry and pigs (e.g. Glatz, et al., 2009). This is a useful knowledge base to make decisions on suitability of ingredients for use in aquafeeds.

Vanuatu has limited commercial-scale feed processing operations; however, there are important aquafeed ingredient resources such as copra, where exports in 2010 were in excess of 12,000 tonnes (VNSO, 2011) and meatmeal (Val Pacific beef processors). Commercial aquafeeds are not manufactured in Vanuatu and are imported, typically from Australia and Fiji (Alo pers comm., 2011). There is virtually no information on aquafeeds and local aquafeed ingredients relating to Vanuatu in the published literature.

Previous work assessing the feasibility of using locally sourced ingredients to sustain high productivity in the commercial broiler industry in Samoa indicates that this is an unlikely prospect without the continued reliance upon imported ingredients to sustain the industry (Ajuyah and Okere, 2003). As with Vanuatu, there is virtually no information in the published literature on aquafeeds and local aquafeed ingredients relating to Samoa.

3.2 Compositional analyses

Proximate composition of ingredients sampled in PIC's and PNG during this project are referenced as "Current Study" in Tables 1, 2, 3, 4 and 5.

Protein analysis

High protein sources include fishmeal, meat meal, soybean meal, African snail meal and prawn heads, all containing >40% CP. Fish dust, fine particulate waste matter from processing fish carcasses using high-speed band saws, has a high moisture content (~71%) reducing its as fed CP level to ~24%; however, on a dry matter (DM) basis, CP levels of fish dust are in excess of 80% which is the highest of any ingredient reported in this document. Conversely, fat content in fish dust (5% DM) was, on average, approximately 10% less than that of other fish processing waste ingredients.

Commercially and locally formulated pellet aquafeeds analysis

Protein levels (as fed) in handmade aquafeeds from PNG for tilapia (26% CP) were at the low range recommended for this species (26–40%CP) although appropriate for fish >1.5 kg (NRC, 2011). This of course doesn't take into account supplementary nutritional intake from natural pond productivity. Dietary CP levels in handmade feeds for rainbow trout from PNG (28% CP) were below the recommended level of 36-48% CP for this species (NRC, 2011). The commercial tilapia feed from Samoa was found to have very low protein content (15.6%CP), well below the recommended dietary CP requirement for tilapia. It must be noted that this feed sample was obtained from a local farm and not directly from the feed manufacturer. Handmade aquafeeds from Vanuatu (28%CP) using African snail meal (Figure 1) as the protein source would be appropriate for tilapia >500 g (NRC, 2011).

Figure 1. Live African snails on a banana tree (left) and snails being boiled in preparation for making snailmeal, Solomon Islands.

Amino acids analysis

Amino acid composition of selected ingredients are reported in Table 6. On a dry matter basis, the shellfish kai (*Batissa violacea*)(Fig. 2) and giant African snail are excellent protein sources containing high levels of all the essential amino acids (EAA) required for growth and metabolic function. As an example, Table 7 represents the dietary essential amino acid requirements of tilapia for which kai and African snail per unit basis (DM) adequately supply (Table 8). Saijan leaves (DM basis) are deficient in 5 of 10 essential amino acids for tilapia with lysine and methionine being the first two limiting aminos. The commercial tilapia feed from Samoa was of extremely poor quality protein, deficient in all essential amino acids for tilapia with the exception of arginine (Table 8). The handmade tilapia pellet from PNG was low in several EAA's for this species including methionine, isoleucine, histidine and valine. In contrast, the handmade rainbow trout pellet from PNG provided a good source of all EAA's for this species (Table 9).

Tryptophan was not analysed for some samples, however, this EAA is rarely the first limiting AA and is typically required in the least quantity relative to other EAA's to meet the requirements of most teleost fish and penaeid shrimp species (NRC, 2011).

Figure 2. Freshwater clam (kai) for sale at markets in Solomon Islands (left) and boiled kai prepared for making meal, Fiji (right)

Heavy metals analysis

Heavy metal (arsenic, cadmium, lead, mercury) composition of fish bones/frames, fish dust and fish skins are reported in Table 10. All samples contained levels below the maximum permissible levels recommended by the EU for feedstuffs intended for farmed animals and fish (EFSA, 2005).

Table 1. Proximate composition of feed ingredients ("as sampled" unless otherwise noted) for the Fiji Islands. NFE calculated by difference. Protein calculated as N x 5.6 (after Mariotti, et al., 2008) for ingredients referenced as "Current Study".

FIJI ISLANDS			**Cost**	**Moisture**	**N**	**Protein**	**Fat**	**Ash**	**NFE**	**Gross Energy**	
Ingredient/common name	**Scientific Name**	**Source/Component**	**($/tonne)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(MJ/Kg)**	**Reference**
Bele leaves	*Abelmosschus manihot*	Fresh		82.5	0.9	4.9	0.8	2.1	9.8	3.3	Current Study
Brown broken rice		Various rice millers	220	11.3		8.1	0.6	0.7	79.3		Allan, et al. (2007)
Brewery waste		Carlton Brewery Ltd.	50			6.1	3.0	1.2		1.7	Allan, et al. (2007)
Cassava leaves	*Manihot esculenta*	Fresh		69.1	1.5	8.3	2.7	2.1	17.8	6.7	Current Study
Coconut meal (29% CP)		Flour Mills of Fiji Ltd.	240	9.8		21.9	2.2	6.9	59.2		Allan, et al. (2007)
Copra meal		Not specified	580	2.7		23.2	1.3	0.6	72.2	20.8	Gonzalez (2011)
Elephant grass leaves	*Pennisetum purpureum*	Fresh		63.0	1.1	6.1	1.5	4.0	25.4	7.1	Current Study
Fish bones/frames		Golden Ocean Fish Ltd.; Suva		55.6	3.8	21.0	8.2	13.0	2.2	8.3	Current Study
Fish dust		Golden Ocean Fish Ltd.; Suva		71.1	4.3	23.8	1.5	2.2	1.3	6.6	Current Study
Fish meal		Not specified		9.3		67.7	1.4	2.2	19.4	23.7	Allan, et al. (2007)
Fish meal		Not specified		10.0		57.3	1.2	1.9	29.6	21.6	Allan, et al. (2007)
Fish meal 48 % CP		PAFCO	550	9.6		47.7	5.0	13.3	24.4	19.1	Allan, et al. (2007)
Fish meal 50 % CP		PAFCO	580	4.7		50.3	16.5	21.2	7.3	18.9	Allan, et al. (2007)
Fish meal 52 % CP		PAFCO	580	4.0		52.1	17.5	21.6	4.8	17.0	Allan, et al. (2007)
Fish skins		Golden Ocean Fish Ltd.; Suva		59.0	5.1	28.8	5.6	5.0	1.5	9.2	Current Study
Husk rice		Various rice millers	50	10.0		3.1	1.0	17.4	68.5		Allan, et al. (2007)
Husk rice (Dreketi)		Various rice millers	120	10.0		3.1	1.0	17.4	68.5		Allan, et al. (2007)
Ivi	*Inocarpus fagifer*	Fresh		58.8	0.7	4.1	1.3	1.2	34.6	7.3	Current Study
Kai	*Batissa violacea*	Shucked, boiled		73.0	2.7	15.3	1.6	6.1	4.1	4.9	Current Study
Kai	*Batissa violacea*	Shucked, fresh		83.9	1.6	9.2	0.9	2.6	3.3	3.1	Current Study
Meat and fish meal		Not specified	800	9.0		61.9	1.5	2.6	24.9	20.3	Gonzalez (2011)
Meat bone meal		Not specified	760	3.9		53.8	1.9	2.5	38.0	19.8	Gonzalez (2011)
Meat bone meal		Unspecified Nausori source	760	7.6		71.4	1.6	1.3	18.0	22.6	Gonzalez (2011)
Mill mix		Flour Mills of Fiji Ltd.	190	10.6		15.9	4.1	5.4	64.0	16.2	Allan, et al. (2007)
Molasses		Fiji Sugar Corporation	60			4.0		0.8	95.3		Cuzon (1989)

Table 1 continued. Proximate composition of feed ingredients ("as sampled" unless otherwise noted) for the Fiji Islands. NFE calculated by difference. Protein calculated as N x 5.6 (after Mariotti, et al., 2008) for ingredients referenced as "Current Study".

FIJI ISLANDS			**Cost**	**Moisture**	**N**	**Protein**	**Fat**	**Ash**	**NFE**	**Gross Energy**	
Ingredient/common name	**Scientific Name**	**Source/Component**	**($/tonne)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(MJ/Kg)**	**Reference**
Paragrass	*Brachiaria mutica*	Leaves, fresh		76.8	0.6	3.6	0.8	2.8	16.1	4.2	Current Study
Paragrass whole	*Brachiaria mutica*	Stem & leaves, fresh		78.9	0.5	2.5	0.5	2.6	15.5	3.7	Current Study
Pea meal		Not specified	310	12.7		9.7	1.5	2.7	73.4	16.8	Allan, et al. (2007)
Rice bran		Various rice millers	310	9.1		13.9	22.2	10.6	44.2		Allan, et al. (2007)
Rice meal		Not specified	560	8.7		16.4	2.3	0.9	71.8	22.4	Gonzalez (2011)
Rice pollard		Various rice millers	150	11.1		12.8	11.7	8.8	55.6		Allan, et al. (2007)
Saijan leaves	*Moringa oleifera*			75.9	1.0	5.9	1.9	2.5	13.8	4.7	Current Study
Sorghum		Not specified	650	11.7		11.3	0.4	0.1	76.5	18.7	Gonzalez (2011)
Soyabean meal		Corticated		9.4		45.9	1.0	6.3	37.4		Hertrampf & Piedad-Pascual (2000)
Soyabean meal		Decorticated		10.5		49.8	0.8	5.6	33.3		Hertrampf & Piedad-Pascual (2000)
Soyabean meal		Full fat		9.8		37.4	18.9	5.5	28.4		Hertrampf & Piedad-Pascual (2000)
Spent brewery grains		Carlton Breweries; Suva		74.6	0.9	5.1	2.4	1.0	16.9	5.3	Current Study
Spent brewery yeast		Vonu Breweries; Nadi		65.4	0.3	1.5	0.0	29.5	3.6	0.9	Current Study
Split peas		Not specified	310	15.2		19.9	1.9	2.7	60.3		Allan, et al. (2007)
Tallow			240			0.0	98.7	0.0	1.3		Allan, et al. (2007)
Vaivai 1	*Gliricidia sepium*			65.0	1.2	6.8	1.8	3.1	23.3	6.9	Current Study
Vaivai 2	*Leucaena leucocephala*			58.8	1.8	9.8	1.5	2.6	27.3	8.4	Current Study
Wheat		Pacific Feeds Ltd	250	12.1		11.5	1.7	1.7	73.0	16.0	Allan, et al. (2007)

Table 2. Proximate composition of feed ingredients ("as sampled" unless otherwise noted) for Papua New Guinea. NFE calculated by difference. Protein calculated as N x 5.6 (after Mariotti, et al., 2008) for ingredients referenced as "Current Study".

PAPUA NEW GUINEA			**Cost**	**Moisture**	**N**	**Protein**	**Fat**	**Ash**	**NFE**	**Gross Energy**	
Ingredient/common name	**Scientific Name**	**Source/Component**	**($/tonne)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(MJ/Kg)**	**Reference**
Barley Brewery Waste		SP Brewery, Lae		4.2		23.1	10.7	3.9	58.1	22.1	Allan, et al. (2007)
Broken rice			101	11.3		8.1	0.6	0.7	79.3		Allan, et al. (2007)
Brown broken rice			220	11.3		8.1	0.6	0.7	79.3	15.8	Allan, et al. (2007)
Cabbage				91.4		1.6	3.1	1.2	2.7	12.5	Glatz et al. (2009)
Cocoa pod	*Theobroma cacao*			11.5		5.8	0.7	7.6	74.4		Allan, et al. (2007)
Coconut meal			240	9.8		21.9	0.2	6.9	61.3	31.1	Allan, et al. (2007)
Copra meal				6.5		23.4	10.4	5.9	53.8	20.1	Allan, et al. (2007)
Corn			400	9.7		2.5	0.1	0.2	87.6	15.6	Allan, et al. (2007)
Dessicated Coconut				4.2		8.2	62.4	2.2	23.0	30.3	Allan, et al. (2007)
Feed pellets - tilapia				9.5	4.6	26.0	8.6	9.9	46.0	16.1	Current study
Feed pellets - trout				8.7	5.0	28.1	9.8	11.0	42.4	16.5	Current Study
Fishmeal			610	4.7		50.3	16.5	21.2	7.3	18.9	Allan, et al. (2007)
Leucena	*Leucaena leucocephala*	Leaves		8.5	3.5	19.6	2.9	3.9	65.0	17.3	Current Study
Leucena	*Leucaena leucocephala*	Seeds		7.6	4.8	26.7	4.0	3.2	58.5	17.1	Current Study
Marmar	*Albizia sp.*			8.4	3.2	17.8	2.7	4.6	66.5	17.8	Current Study
Mill mix			190	10.6		15.9	4.1	5.4	64.0	16.2	Allan, et al. (2007)
Mill run			180	11.8		16.7	3.6	5.3	62.6	17.7	Allan, et al. (2007)
Palm kernel cake	*Elaeis guineensis*			4.1	2.3	13.0	11.4	3.4	68.2	19.5	Current Study
Prawn heads				7.8	7.2	40.1	5.3	18.2	28.7	14.4	Current Study
Rice bran		Unspecified	310	9.6		12.0	15.6	12.2	50.7	17.6	Allan, et al. (2007)
Rice bran	*Oryza sativa*	NARI Nepal variety		7.4	0.8	4.6	3.6	5.0	79.4	15.5	Current Study
Rice Pollard				10.9		16.0	9.3	6.4	57.4	19.9	Allan, et al. (2007)
Swamp cabbage				90.8		3.2	0.9	1.2	3.9		Glatz et al. (2009)
Thickhead	*Crassocephalum crepidioides*			7.5	3.2	18.1	3.0	11.5	60.0	16.0	Current Study

Table 3. Proximate composition of feed ingredients ("as sampled" unless otherwise noted) for Samoa. NFE calculated by difference. Protein calculated as N x 5.6 (after Mariotti, et al., 2008) for ingredients referenced as "Current Study". Commercial tilapia feed obtained from local tilapia farm.

SAMOA			Cost	Moisture	N	Protein	Fat	Ash	NFE	Gross Energy	
Ingredient/common name	**Scientific Name**	**Source/Component**	**($/unit)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(MJ/Kg)**	**Reference**
Breadfruit	*Artocarpus altilis*	Fruit, ripe, fresh		70.2		1.7	0.3	2.0	25.8	5.0	Tacon (1987)
	Artocarpus altilis	Fruit meal, dehydrated		15.1		2.7	0.8	2.6	78.8	14.5	Tacon (1987)
	Artocarpus altilis	Fruit, ripe, cooked & peeled		68.2		1.5	0.3	1.0	29.0	5.5	Tacon (1987)
Brewery waste		Vailima Brewery Company	SAT0.50/kg	69.3	0.8	4.7	2.4	1.1	22.6	6.3	Current Study
Cassava (Manioc)	*Manihot esculenta*	Fresh tuber	SAT0.50/kg	65.9		0.9	0.2	1.0	32.0	5.8	Tacon (1987)
	Manihot esculenta	Cassava meal (starch extracted)		14.8		1.3	0.6	2.3	81.0	14.5	Tacon (1987)
	Manihot esculenta	Fresh peelings		72.1		1.6	0.4	1.4	24.5	4.7	Tacon (1987)
	Manihot esculenta	Fresh tuber (peeled)		68.8		0.9	0.2	1.0	29.1	5.3	Tacon (1987)
	Manihot esculenta	Tuber, dehydrated		13.5		2.1	0.5	2.2	81.7	14.7	Tacon (1987)
Commercial tilapia feed		Farmtech, Apia	SAT20.00/20kg	12.0	2.8	15.6	4.3	6.3	61.8	16.6	Current Study
Copra meal	*Cocos nucifera*	Pacific Oil Company	SAT0.60/kg	17.0	3.1	17.5	8.6	4.6	52.2	16.6	Current Study
Corn flour (%DM)				12.2		10.2	4.8	1.6	17.1		Hertrampf & Piedad-Pascual (2000)
Fish meal		PAFCO, Fiji	SAT90.00/25kg	4.7		50.3	16.5	21.2	7.3	18.9	Allan, et al. (2007)
Fish waste		Apia Export Fish Packers		57.3	5.4	30.0	5.0	5.3	2.5	9.3	Current Study
Noni fruit pulp waste	*Morinda citrifolia*	CCK Trading Ltd.		89.0	0.1	0.8	0.6	0.4	9.2	2.2	Current Study

Table 4. Proximate composition of feed ingredients ("as sampled" unless otherwise noted) for the Solomon Islands. NFE calculated by difference. Protein calculated as N x 5.6 (after Mariotti, et al., 2008) for ingredients referenced as "Current Study".

SOLOMON ISLANDS			**Cost**	**Moisture**	**N**	**Protein**	**Fat**	**Ash**	**NFE**	**Gross Energy**	
Ingredient/common name	**Scientific Name**	**Source/Component**	**($/tonne)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(MJ/Kg)**	**Reference**
African snail	*Achatina fulica*	Whole, boiled, no shell		6.8	8.8	49.4	4.4	5.5	34.0	18.2	Current Study
Amaranth seeds (%DM)	*Amaranthus* sp.			9.8		15.2	5.8	9.1	70.0	17.5	Glatz et al. (2009)
Banana		Fruit		69.0		1.7	0.3	1.0	28.0		Glatz et al. (2009)
Banana (% DM)		Leaf meaL		5.9		9.9	11.8	8.8	69.5		Glatz et al. (2009)
Banana (% DM)		Leaves, fresh		80.5		11.4		10.9			Glatz et al. (2009)
Banana (% DM)		Ripe		69.0		5.4	0.9	3.3	90.4		Glatz et al. (2009)
Banana (% DM)		Green		79.1		4.8	1.9	4.8	88.5		Glatz et al. (2009)
Clover (%DM)		Persian (cv. Kyambro)				17.2		12.1			Glatz et al. (2009)
Clover (%DM)		Red		81.9		18.7		10.3			Glatz et al. (2009)
Clover (%DM)		cv. Junee				16.5		13.1			Glatz et al. (2009)
Clover (%DM)		White		79.5		21.3					Glatz et al. (2009)
Cocconut cake (%DM)				8.8		22.0	9.8	13.3	54.9	19.9	Glatz et al. (2009)
Cocoa bean waste	*Theobroma cacao*	C-Corp; Honiara	SI$5.00/kg	2.3	2.3	12.6	39.9	4.4	40.8	25.8	Current Study
Coconut kernel				47.6		3.7	31.7	1.0	16.0		Glatz et al. (2009)
Cow pea meal (%DM)				10.4		28.7	1.3	3.5	66.5	40.9	Glatz et al. (2009)
Fishmeal (%DM)		Aust.				73.2	9.9	14.2	2.7	21.3	Glatz et al. (2009)
Fishmeal (%DM)		Danish				72.9	11.4	13.0	2.7	21.5	Glatz et al. (2009)
Fishmeal (%DM)		Peruvian				70.2	11.3	17.6	0.9	20.9	Glatz et al. (2009)
Fishmeal		tuna cannery waste		13.2		56.9	7.7	21.7	0.5		Glatz et al. (2009)
Kang kong	*Ipomea aquatica*	Leaves, fresh		3.8	2.8	15.9	5.7	10.7	63.9	17.1	Current Study
Koa	*Brugeria sp.*	Whole pod		4.8	0.6	3.2	0.3	7.0	84.7	14.9	Current Study
Leucaena leaf meal (%DM)	*Leucaena sp.*			10.3		21.3	7.0	7.9	63.8		Glatz et al. (2009)
Mung beans (%DM)				9.7		25.2	3.2	1.1	70.6	16.8	Glatz et al. (2009)

Table 4 continued. Proximate composition of feed ingredients ("as sampled" unless otherwise noted) for the Solomon Islands. NFE calculated by difference. Protein calculated as N x 5.6 (after Mariotti, et al., 2008) for ingredients referenced as "Current Study".

SOLOMON ISLANDS			Cost	Moisture	N	Protein	Fat	Ash	NFE	Gross Energy	
Ingredient/common name	**Scientific Name**	**Source/Component**	**($/tonne)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(MJ/Kg)**	**Reference**
Papaya (%DM)	*Carica papaya*	Leaves, fresh		78.0		26.8	7.2	13.2	52.8		Glatz et al. (2009)
Papaya (%DM)	*Carica papaya*	Seeds		6.2		27.8	28.3	3.5	40.4		Glatz et al. (2009)
Papaya (%DM)	*Carica papaya*	Skin		10.8		24.1	2.9	6.2	66.9		Glatz et al. (2009)
Papaya (%DM)	*Carica papaya*	Whole fruit		91.9		11.3	1.0	8.4	79.4		Glatz et al. (2009)
Pigeon pea (%DM)	*Cajanus cajan*	Hay		6.9		29.4					Glatz et al. (2009)
Pigeon pea (%DM)	*Cajanus cajan*	Leaves and branches				15.2					Glatz et al. (2009)
Pigeon pea (%DM)	*Cajanus cajan*	Leaves, fresh		59.8		31.6					Glatz et al. (2009)
Sunflower meal (%DM)		Meal				33.1	2.8	7.0	57.1	19.4	Glatz et al. (2009)
Sunflower seed (%DM)						17.8	46.6	3.8	31.8	26.3	Glatz et al. (2009)
Sweet potato (%DM)	*Ipomoea batatas*	Tuber		11.3		4.4	0.6	3.0	92.1	17.1	Glatz et al. (2009)
Sweet potato (%DM)	*Ipomoea batatas*	Leaves		82.0		26.9	0.7				Glatz et al. (2009)
Sweet potato (%DM)	*Ipomoea batatas*	Vines		87.7		17.9	6.3	15.0	60.8		Glatz et al. (2009)

Table 5. Proximate composition of feed ingredients ("as sampled" unless otherwise noted) for Vanuatu. NFE calculated by difference. Protein calculated as N x 5.6 (after Mariotti, et al., 2008) for ingredients referenced as "Current Study".

VANUATU			**Cost**	**Moisture**	**N**	**Protein**	**Fat**	**Ash**	**NFE**	**Gross Energy**	
Ingredient/common name	**Scientific Name**	**Source/Component**	**($/tonne)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(MJ/Kg)**	**Reference**
Cucumber	*Cucumis sativus*	Whole fruit		95.2		0.7	0.1	0.4	3.6	0.7	USDA (2011)
Bevu	*Dioscorea bulbifera*	Fruit/nut; Sun dried		16.3	0.6	3.4	0.7	3.3	76.2	12.0	Current Study
Fig	*Ficus sp.*	Dried fruit		30.1		3.3	0.9	1.9	63.9	10.4	USDA (2011)
Fijian taro	*Colocasia esculenta*	Fresh		73.1		1.5	0.4	1.5	23.6	4.1	USDA (2011)
Fish feed pellets (tilapia)		African snail meal		15.0	5.1	28.3	9.6	16.9	30.2	15.4	Current Study
Groundnut/peanut	*Arachis hypogaea*	Hulls		11.4		6.2	1.6	5.1	75.7	15.1	Tacon (1987)
	Arachis hypogaea	Oilcake, dec., mechanically extracted		9.6		46.2	6.7	5.2	32.3	19.1	Tacon (1987)
	Arachis hypogaea	Oilcake, undec., mechanically extracted		10.0		30.2	9.1	5.7	45.0	18.5	Tacon (1987)
	Arachis hypogaea	Oilmeal, dec., solvent extracted		8.7		48.7	1.1	6.0	35.5	18.0	Tacon (1987)
	Arachis hypogaea	Oilmeal, undec., solvent extracted		7.8		31.7	1.9	4.3	54.3	17.6	Tacon (1987)
	Arachis hypogaea	Seed undec.		7.1		20.2	36.3	2.5	33.9	24.9	Tacon (1987)
	Arachis hypogaea	Seed dec.		6.5		28.4	44.7	2.3	18.1	27.5	Tacon (1987)
Guava	*Psidium guajava*	Leaves		62.5		3.8	2.8	2.9	28.0	6.8	Tacon (1987)
	Psidium guajava	Fruit		80.8		2.6	1.0	1.4	14.3	2.9	USDA (2011)
Mango	*Mangifera sp.*	Fruit kernel (seed), fresh		50.0		4.2	4.4	2.7	38.7	9.4	Tacon (1987)
	Mangifera sp.	Fruit pulp (immature fruit), fresh		82.3		6.2	<0.1	0.3			Tacon (1987)
	Mangifera sp.	Fruit pulp (mature fruit), fresh		82.7		1.0	0.1	0.4	15.8	3.0	Tacon (1987)
	Mangifera sp.	Fruit silage, wet		84.0		0.8	1.0	1.5	12.7	2.8	Tacon (1987)
Meat meal		Val Pacific Beef	?	7.9	6.6	41.0	12.7	28.7	9.7	15.3	Current Study
Nakatambol	*Dracontomelon vitiense*	Sun dried		12.8	1.4	7.9	1.1	7.9	70.2	12.6	Current Study

Table 5 continued. Proximate composition of feed ingredients ("as sampled" unless otherwise noted) for Vanuatu. NFE calculated by difference. Protein calculated as N x 5.6 (after Mariotti, et al., 2008) for ingredients referenced as "Current Study".

VANUATU			Cost	Moisture	N	Protein	Fat	Ash	NFE	Gross Energy	
Ingredient/common name	**Scientific Name**	**Source/Component**	**($/tonne)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(MJ/Kg)**	**Reference**
Nakavika	*Syzygium sp.*	Fruit/nut; Sun dried		18.4	0.6	3.5	1.2	3.1	73.8	11.7	Current Study
Nalai	*Pangium edule*	Fruit/nut; Sun dried		14.2	2.1	11.8	1.5	6.3	66.2	13.2	Current Study
Namambe	*Inocarpus fagifer*	Fruit/nut; Sun dried		12.8	1.3	7.3	2.6	2.3	75.0	14.4	Current Study
Nangai	*Canarium indicum*	Fruit/nut; Sun dried		5.1	2.0	11.3	62.7	3.3	17.5	28.5	Current Study
Natapoa	*Terminalia catappa*	Fruit/nut; Sun dried		5.6	3.2	18.1	49.9	3.7	22.7	25.9	Current Study
Naus	*Spondias dulcis*	Fruit/nut; Sun dried		15.9	0.1	0.8	0.1	1.6	81.7	12.1	Current Study
Navele	*Barringtonia edulis*	Fruit/nut; Sun dried		7.9	2.0	11.2	28.2	3.0	49.7	20.7	Current Study
Noni	*Morinda citrifolia*	Fruit/nut; Sun dried		16.7	0.7	4.2	1.6	4.0	73.5	12.7	Current Study
Pine fruit	*Castanospermum australae*	Fruit/nut; Sun dried		15.6	0.9	4.8	0.4	2.2	77.0	12.8	Current Study
Pumpkin/squash/gourd	*Cucurbita sp.*			91.5		1.2	0.4	0.7	6.2	1.5	Tacon (1987)
Snake rope, vine		Fruit/nut; Sun dried		8.5	3.6	20.3	10.9	3.2	57.2	18.9	Current Study
Soursop	*Annona muricata*	Fresh		81.2		1.0	0.3	0.7	16.8	2.8	USDA (2011)
Susut	*Sechium edule*	Fruit/nut; Sun dried		16.3	0.7	3.7	0.6	3.1	76.3	12.2	Current Study
Sweet potato	*Ipomoea batatas*	Leaves		88.0		4.0	0.3	1.4	6.4	1.5	USDA (2011)
Taro	*Colocasia esculenta*	Root		74.0		2.0	0.7	1.0	22.3		FAO (1998)
Taro	*Colocasia esculenta*	Leaves		89.8		2.2	0.8	1.3	5.9	1.9	Tacon (1987)
Yam (%DM)	*Dioscorea alata*			72.7		7.4	1.0	3.4		15.3	Wanasundera (1994)

Table 6. Amino acid composition of selected ingredients. African snail meal from Solomon Islands. Kai (fresh) and saijan leaves from Suva, Fiji. Meatmeal from Vanuatu. Tilapia and trout aquafeed (PNG) handmade feeds from Papua New Guinea. Commercial tilapia aquafeed (Samoa) obtained from local tilapia farm, Apia, Samoa.

Sample	Ala	Arg*	Asp	Cys	Glu	Gly	His*	Ile*	Leu*	Lys*	Met*	Phe*	Pro	Ser	Thr*	Trp*	Tyr	Val*
g/kg DM																		
African snail meal (Sol. Is.)	32.46	44.96	59.42	5.93	80.83	40.95	10.27	24.82	42.49	31.30	10.31	23.91	31.40	31.08	26.79	n/t	20.54	23.53
Kai (fresh, Fiji)	37.21	45.64	72.05	8.33	103.47	32.35	11.12	24.98	44.35	45.29	14.53	19.71	25.95	27.11	27.99	6.27	19.81	27.91
Meatmeal (Van.)	35.55	32.44	31.47	2.54	51.05	70.65	5.61	13.70	24.16	18.95	6.37	15.07	53.70	17.78	16.38	n/a	7.68	15.12
Saijan leaves (Fiji)	13.62	20.16	15.00	4.49	20.32	17.33	7.82	11.24	21.83	5.66	4.65	21.89	17.14	13.22	12.73	4.18	14.94	13.70
Tilapia aquafeed (PNG)	17.54	20.41	25.95	3.75	42.21	20.81	6.86	12.25	20.32	16.17	6.74	12.66	17.48	14.08	14.75	n/a	7.50	11.83
Tilapia aquafeed (Samoa)	10.17	18.21	12.26	3.16	27.21	17.84	5.89	6.29	11.92	6.60	3.24	9.38	13.09	8.84	7.28	2.35	6.49	8.96
Trout aquafeed (PNG)	20.44	22.88	29.77	4.23	47.35	24.57	8.06	14.11	23.47	19.66	9.07	14.52	23.95	16.26	16.89	n/a	10.12	14.45
g / 17.857 g N (DM)																		
African snail meal (Sol. Is.)	6.13	8.49	11.22	1.12	15.26	7.73	1.94	4.69	8.02	5.91	1.95	4.52	5.93	5.87	5.06	n/a	3.88	4.44
Kai (fresh, Fiji)	6.48	7.95	12.55	1.45	18.03	5.64	1.94	4.35	7.73	7.89	2.53	3.43	4.52	4.72	4.88	1.09	3.45	4.86
Meatmeal (Van.)	8.92	8.14	7.89	0.64	12.80	17.72	1.41	3.43	6.06	4.75	1.60	3.78	13.47	4.46	4.11	n/a	1.93	3.79
Saijan leaves (Fiji)	5.58	8.26	6.14	1.84	8.32	7.10	3.20	4.61	8.94	2.32	1.90	8.97	7.02	5.41	5.21	1.71	6.12	5.61
Tilapia aquafeed (PNG)	6.10	7.10	9.02	1.30	14.67	7.24	2.38	4.26	7.07	5.62	2.34	4.40	6.08	4.90	5.13	n/a	2.61	4.11
Tilapia aquafeed (Samoa)	5.73	10.26	6.91	1.78	15.33	10.05	3.32	3.54	6.72	3.72	1.83	5.28	7.38	4.98	4.10	1.32	3.66	5.05
Trout aquafeed (PNG)	6.65	7.44	9.69	1.38	15.41	7.99	2.62	4.59	7.64	6.40	2.95	4.72	7.79	5.29	5.49	n/a	3.29	4.70
As Sampled %																		
African snail meal (Sol. Is.)	3.03	4.19	5.54	0.55	7.53	3.82	0.96	2.31	3.96	2.92	0.96	2.23	2.93	2.90	2.50	n/a	1.91	2.19
Kai (fresh, Fiji)	0.60	0.73	1.16	0.13	1.66	0.52	0.18	0.40	0.71	0.73	0.23	0.32	0.42	0.44	0.45	0.10	0.32	0.45
Meatmeal (Van.)	3.27	2.99	2.90	0.23	4.70	6.51	0.52	1.26	2.22	1.75	0.59	1.39	4.95	1.64	1.51	n/a	0.71	1.39
Saijan leaves (Fiji)	0.33	0.48	0.36	0.11	0.49	0.42	0.19	0.27	0.53	0.14	0.11	0.53	0.41	0.32	0.31	0.10	0.36	0.33
Tilapia aquafeed (PNG)	1.59	1.85	2.35	0.34	3.82	1.88	0.62	1.11	1.84	1.46	0.61	1.15	1.58	1.27	1.34	n/a	0.68	1.07
Tilapia aquafeed (Samoa)	0.90	1.60	1.08	0.28	2.40	1.57	0.52	0.55	1.05	0.58	0.29	0.83	1.15	0.78	0.64	0.21	0.57	0.79
Trout aquafeed (PNG)	1.87	2.09	2.72	0.39	4.32	2.24	0.74	1.29	2.14	1.79	0.83	1.33	2.19	1.48	1.54	n/a	0.92	1.32

*Essential amino acid
n/a: not analysed

Table 8. Ratio of essential amino acid (EAA) in sampled feed or ingredient to the dietary EAA requirement of tilapia (Table 7). Values ≥1 match or exceed tilapia requirement. Ratios ranked from first limiting EAA.

African snail meal (Sol. Is.)		**Kai (fresh, Fiji)**		**Meatmeal (Van.)**		**Saijan leaves (Fiji)**		**Tilapia aquafeed (PNG)**		**Tilapia aquafeed (Samoa)**		**Trout aquafeed (PNG)**	
EAA	**Feed:Req**	**EAA**	**Feed:Req**	**EAA**	**Feed:Req**	**EAA**	**Feed:Req**	**EAA**	**Feed:Req**	**EAA**	**Feed:Req**	**EAA**	**Feed:Req**
AS SAMPLED													
Histidine	0.96	Histidine	0.18	Histidine	0.52	Lysine	0.10	Methionine	0.61	Methionine	0.29	Isoleucine	0.72
Methionine	0.96	Isoleucine	0.22	Methionine	0.59	Methionine	0.11	Isoleucine	0.62	Isoleucine	0.31	Histidine	0.74
Isoleucine	1.29	Methionine	0.23	Isoleucine	0.70	Isoleucine	0.15	Histidine	0.62	Lysine	0.42	Valine	0.82
Valine	1.37	Valine	0.28	Valine	0.87	Histidine	0.19	Valine	0.67	Valine	0.49	Methionine	0.83
Phenylalanine	2.03	Phenylalanine	0.29	Leucine	1.17	Valine	0.21	Leucine	0.97	Histidine	0.52	Leucine	1.13
Lysine	2.08	Tryptophan	0.36	Lysine	1.25	Leucine	0.28	Phenylalanine	1.04	Leucine	0.55	Phenylalanine	1.21
Leucine	2.08	Leucine	0.38	Phenylalanine	1.26	Threonine	0.28	Lysine	1.05	Threonine	0.58	Lysine	1.28
Threonine	2.27	Threonine	0.41	Threonine	1.37	Tryptophan	0.36	Threonine	1.21	Tryptophan	0.74	Threonine	1.40
Arginine	3.49	Lysine	0.52	Arginine	2.49	Arginine	0.40	Arginine	1.54	Phenylalanine	0.75	Arginine	1.74
Tryptophan	n/a	Arginine	0.61	Tryptophan	n/a	Phenylalanine	0.48	Tryptophan	n/a	Arginine	1.34	Tryptophan	n/a
DRY MATTER													
Histidine	1.03	Histidine	1.11	Histidine	0.56	Lysine	0.40	Methionine	0.67	Methionine	0.32	IsoLeucine	0.78
Methionine	1.03	IsoLeucine	1.39	Methionine	0.64	Methionine	0.46	IsoLeucine	0.68	IsoLeucine	0.35	Histidine	0.81
IsoLeucine	1.38	Methionine	1.45	IsoLeucine	0.76	IsoLeucine	0.62	Histidine	0.69	Lysine	0.47	Valine	0.90
Valine	1.47	Valine	1.74	Valine	0.95	Histidine	0.78	Valine	0.74	Valine	0.56	Methionine	0.91
Phenylalanine	2.17	Phenylalanine	1.79	Leucine	1.27	Valine	0.86	Leucine	1.07	Histidine	0.59	Leucine	1.24
Lysine	2.24	Tryptophan	2.24	Lysine	1.35	Leucine	1.15	Phenylalanine	1.15	Leucine	0.63	Phenylalanine	1.32
Leucine	2.24	Leucine	2.33	Phenylalanine	1.37	Threonine	1.16	Lysine	1.15	Threonine	0.66	Lysine	1.40
Threonine	2.44	Threonine	2.54	Threonine	1.49	Tryptophan	1.49	Threonine	1.34	Tryptophan	0.84	Threonine	1.54
Arginine	3.75	Lysine	3.23	Arginine	2.70	Arginine	1.68	Arginine	1.70	Phenylalanine	0.85	Arginine	1.91
Tryptophan	n/a	Arginine	3.80	Tryptophan	n/a	Phenylalanine	1.99	Tryptophan	n/a	Arginine	1.52	Tryptophan	n/a

n/a: not analysed

Table 7. Essential amino acid requirements in feeds (as fed) for tilapia (*O. niloticus*) and rainbow trout (*O. mykiss*). Requirements expressed as a proportion of diet (% Diet) or as a proportion of dietary crude protein (% CP). Data adapted from NRC (2011).

	Tilapia		Rainbow trout	
EAA	**% Diet**	**% CP**	**% Diet**	**% CP**
Arginine	1.2	4.2	1.4	4.0
Histidine	1.0	1.7	0.6	1.1
Isoleucine	1.8	3.1	1.1	2.2
Leucine	1.9	3.4	1.3	2.6
Lysine	1.4	5.3	2.0	5.1
Methionine*	1.0	2.5	0.7	1.5
Phenylalanine**	1.1	3.8	0.7	2.0
Threonine	1.1	3.8	1.1	2.6
Tryptophan	0.3	1.0	0.2	0.5
Valine	1.6	2.8	1.2	2.6

*as total S amino acids
**with tyrosine

Table 9. Ratio of essential amino acid (EAA) in sampled PNG trout aquafeed to the dietary EAA requirement of rainbow trout (Table 7). Values ≥1 match or exceed trout requirement. Ratios ranked from first limiting EAA.

AS SAMPLED		**DRY MATTER**	
EAA	**Feed:Req**	**EAA**	**Feed:Req**
Lysine	0.90	Lysine	0.98
Valine	1.10	Valine	1.20
IsoLeucine	1.23	IsoLeucine	1.34
Methionine	1.27	Methionine	1.39
Histidine	1.34	Histidine	1.47
Threonine	1.40	Threonine	1.54
Arginine	1.49	Arginine	1.63
Leucine	1.71	Leucine	1.88
Phenylalanine	1.89	Phenylalanine	2.07
Tryptophan	n/a	Tryptophan	n/a

n/a: not analysed

Table 10. Heavy metal content (ppm) of fish waste material sampled from fish processing factory in Suva, Fiji. Samples analysed as total metal/metalloid composition (i.e. organic + inorganic forms). Data expressed as "As Sampled" or "12% Moisture" content (after EFSA, 2005). European Union data listed as current maximum permitted heavy metal levels in feedstuffs intended for farmed animals and fish.

Sample	**Arsenic**	**Cadmium**	**Lead**	**Mercury**
AS SAMPLED				
Fish bones/frames	0.621	0.058	0.012	0.031
Fish dust	0.317	0.028	0.009	0.110
Fish skins	0.655	0.026	0.051	0.049
12% MOISTURE				
Fish bones/frames	1.23	0.11	0.02	0.06
Fish dust	0.97	0.09	0.03	0.33
Fish skins	1.41	0.06	0.11	0.11
EU max permissible levels	15.0[a]	2.0[a]	10.0[c]	0.5[d]

[a] Feedingstuffs obtained from the processing of fish or other marine animals; Commission Directive 2003/100 (amending Annexe 1 to Directive 2002/32/EC), effective from 19 November 2004.
[b] Feed materials of animal origin; Commission Directive 2005/87/EC, effective 25 December 2005.
[c] Feed materials; Commission Directive 2005/87/EC, effective 25 December 2005.
[d] Feedingstuffs produced by the processing of fish or other marine animals; Commission Directive 2005/8/EC amended Annex I to Directive 2002/32/EC, effective 27th January 2005.

4. Impacts

4.1 Scientific Impacts

This mini-project reports the proximate and nutritional composition of aquaculture feed ingredients. Some of these ingredients are novel and have not been previously documented in the literature. For example, the freshwater clam, kai, was found to have a very high protein and low fat composition and an excellent amino acid profile, comparable to fishmeal on a dry matter basis.

4.2 Capacity Impacts

This study was aimed at developing the knowledge base and skills capacity of local Fisheries and Aquaculture Officers in the partner PIC's. Training in diet formulation using Winfeed feed formulation software was carried out in Fiji, Samoa, Solomon Islands and Vanuatu (Port Vila and Santo) for local Fisheries and Aquaculture Officers. These sessions provided participants with a free demonstration copy of Winfeed feed formulation software. Instruction was given on how to set up and maintain a feed ingredient database and formulate diets based on the nutritional requirement of aquaculture species. Specific examples were worked through using tilapia as the aquaculture species and diets formulated using specifications of locally available feed ingredients. These skills coupled with the feed inventory database (delivered as an Excel spreadsheet ready to be uploaded into Winfeed) will allow local Aquaculture Officers to give advice to local farmers and feed manufacturers on appropriate ingredients to use and inclusion levels in diets, and to also formulate basic experimental diets to test the suitability of different ingredients or nutrient levels on the growth of aquaculture species.

Instruction in feed ingredient preparation for laboratory analyses was also given to local Fisheries and Aquaculture Officers. Techniques were demonstrated in dry matter determination, sample grinding and also packaging to meet quarantine requirements for the importation of laboratory samples into Australia (Figure 3).

Figure 3. Preparing feed ingredient samples for drying, Suva Fiji.

4.3 Community Impacts

Broader community level impacts can be achieved with the implementation of suitably formulated diets to increase the productivity and earning capacity of local farmers and feed manufacturers by using cheaper locally sourced ingredients while decreasing the reliance on more expensive imported feeds and ingredients.

Proximate analyses of local handmade and commercial aquafeeds assessed their suitability to meet the nutritional requirements of the target species. The results of this study will be available to the fisheries and aquaculture officers in all PICs and they, in turn, will disseminate the information to the community (i.e. local fish farmers, Figure 4). The information will be of enormous benefit to small-scale farmers wishing to reduce feed costs or supplement the diet of their fish or prawns. In a minor way, the project has already contributed to the development of a novel, potentially effective and economical feeding strategy. Fresh tuna dust was identified and analysed in this report (proximates and heavy metal content) and also assessed as part of an IFREMER/SPC study on possible uses for fish wastes in the Pacific. Armed with this information, resourceful farm managers have successfully combined tuna dust with mill run and copra meal as a tilapia diet.

Figure 4. Potential end-users of the feed ingredient inventory results: tilapia farmer, Samoa (left) and *Macrobrachium* farmer, Vanuatu (right)

5. Discussion and recommendations

The feed ingredient inventory compiled in this report consolidates data from previous ACIAR projects, published literature and current fieldwork into a single document relevant for the Pacific Island countries and Papua New Guinea. These data, coupled with training in the use of feed formulation software and an understanding of the nutritional requirements of the target aquaculture species will facilitate good decision making in assessing the potential usefulness of feeds and feed ingredients by local PIC and PNG Aquaculture Officers.

However, the ability to implement the knowledge base consolidated in this project will be limited by the availability of the basic infrastructure needed to manufacture and store feeds. Investment should be made where necessary to purchase basic feed making equipment such as mixers and pelletisers and storage equipment such as refrigerators and freezers. Further, knowledge and practical skills and experience are needed on how to make and appropriately store feeds. These

can be achieved through further education training workshops similar to those short courses successfully run in PNG and Fiji (ACIAR Project FIS2001/075).

Feeding trials of aquafeeds made with novel ingredients should be carried out to assess growth and performance of aquaculture species. For example African snails are locally abundant in some countries and appear to be a very good protein source; however, their effect on growth and product quality of aquaculture species has received little attention in the published literature.

Some local ingredients such as the freshwater clam, kai, may have limited use as a main protein source in aquafeeds because they are currently used as an important food source for local communities, and, in the case of kai, relatively large volumes would be required to make practical diets as it has a very high moisture content.

The commercial tilapia feed sampled in Samoa was of an extremely poor nutritional quality. It is unclear if this result was representative of the product overall as no feeds were available to purchase or sample during site visits to the feed company. The sample analysed was obtained from a local tilapia farmer who had recently purchased the feed. Follow up assessment on the nutritional quality of these feeds is warranted.

Many of the ingredients sampled during this project were available freely as bush ingredients or as waste products from industry, some with excellent potential as quality protein sources; however, these do not include the associated costs of collection/harvesting, transport, processing and preparation etc. The true cost of these ‘free’ ingredients must be considered to determine their cost effectiveness in aquaculture diets.

6. Acknowledgements

We acknowledge the valuable support and assistance of local Aquaculture and Fisheries Officers in PNG and the PIC’s that were involved in this project: Fiji (Ronald Chandra, Kalioni Cagonibure, Temalesi Koroi); Samoa (Joyce Samuelu, Tauvae Sua, Clifton Sae); Solomon Islands (Alex Meloty, James Ngwaerobo); Vanuatu (Glen Alo, Lency Kukan); and PNG (Gideon Pama, Havini Vira, Wally Solato, Douglas Kawa, Reilly Nigro).

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Fiji Islands

(Appendixes 2.8 to 2.13)

Appendix 2.8

ML0801
Culture of juvenile sandfish for sea ranching trials in Fiji

ACIAR Pacific Aquaculture Grant: **Project Summary**	    	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**
Project Title:	**Culture of juvenile sandfish (*Holothuria scabra*) for restocking and sea ranching trials in Fiji (ML0801)**	
Goal:	To investigate the potential for sea cucumber aquaculture and grow-out of juveniles in Fiji.	
Objective(s):	Specific objectives are to: 1. Collect and maintain sandfish broodstock, carry out spawning, rear larvae and produce large numbers of juveniles of 3-5 g; 2. Transfer sandfish hatchery technology to the government (MFF) and private sector (Hunter Pearls) in Fiji; 3. Evaluate the ease of transferring culture techniques to a pearl hatchery; 4. Evaluate the growth and survival of juveniles under sea ranching conditions in community managed *qoliqoli*; 5. Evaluate the growth and survival of juveniles released in MPAs within *qoliqoli* (re-stocking); 6. Improve capacity of pearl hatchery, MFF, USP and NGO staff in sea cucumber production techniques, release and monitoring skills; 7. Scope out options in Fiji for a management framework to meet the needs of stakeholders involved in sea cucumber re-stocking/sea-ranching.	
Project location:	Vanua Levu, Fiji Islands	
Dates / duration:	May 2008 – May 2011	
Project description:	This mini-project focuses on the transfer of ACIAR-WorldFish technology on production and release strategies for the valuable tropical sea cucumber, *Holothuria scabra* (sandfish). There is increasing interest in the use of hatchery produced seed to restore depleted fisheries and create livelihoods for Pacific Islanders. However, the production and release techniques for restocking and sea ranching have not yet been shown to be economically viable. The research will link closely with and augment current WorldFish research, while developing the technology for the Pacific Islands region.	
Funding:	AUD$42,000	

Culture of juvenile sandfish (*Holothuria scabra*) for restocking and sea ranching trials in Fiji

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1. Background:

There is presently enormous interest in the Pacific Islands region regarding the potential for restoring depleted sea cucumber fisheries with hatchery-produced juveniles. Sandfish (*Holothuria scabra*, known as 'dairo' in Fiji) is a traditional food item as well as a valuable export product. It is also one of the few sea cucumber species that can be reliably cultured. However, there is still limited information on the economic viability of sea ranching using hatchery-produced sandfish juveniles. Sea ranching can be defined as the release of cultured juveniles into unenclosed coastal environments where they are allowed to grow to commercial size and later harvested by an individual or group in a "put and take" operation (Bell et al. 2008). Although hatchery techniques for sandfish are well established, the value of the final product must be weighed up against the cost of producing the juveniles, subsequent growth rates and survival to commercial size.

Fiji was selected as the location for a Pacific sandfish sea ranching trial for several reasons, including: (i) government, private sector, NGO and educational sectors were committed partners in the study; (ii) many coastal communities were interested in this species and there is marine tenure and control in the form of *qoliqolis* (a "traditional fishing rights area" under communal ownership) and; (iii) an operational pearl hatchery with microalgae facility was available for larval production.

The objectives of the project were to:

1. Collect and maintain sandfish broodstock, carry out spawning, rear larvae and produce large numbers of juveniles of 3-5 g;
2. Transfer sandfish hatchery technology to the government (MFF) and private sector (Hunter Pearls) in Fiji;
3. Evaluate the ease of transferring culture techniques to a pearl hatchery;
4. Evaluate the growth and survival of juveniles under sea ranching conditions in community managed *qoliqoli*;
5. Evaluate the growth and survival of juveniles released in MPAs within *qoliqoli* (re-stocking);
6. Improve capacity of pearl hatchery, MFF, USP and NGO staff in sea cucumber production techniques, release and monitoring skills;
7. Scope out options in Fiji for a management framework to meet the needs of stakeholders involved in sea cucumber re-stocking/sea-ranching.

This mini-project report summarises the results and outcomes of the research which was conducted between May 2008 and April 2010.

2. Project Methodology

2.1 Broodstock collection and maintenance

Broodstock were obtained from two main locations within Savusavu Bay, near to Savusavu town and from Natuvu village, Wailevu (Figure 1). Both sites were in relatively close proximity to the proposed release site at Natuvu. This was to ensure that the hatchery-produced juveniles were of the same genetic stock as those in the area they were later released.

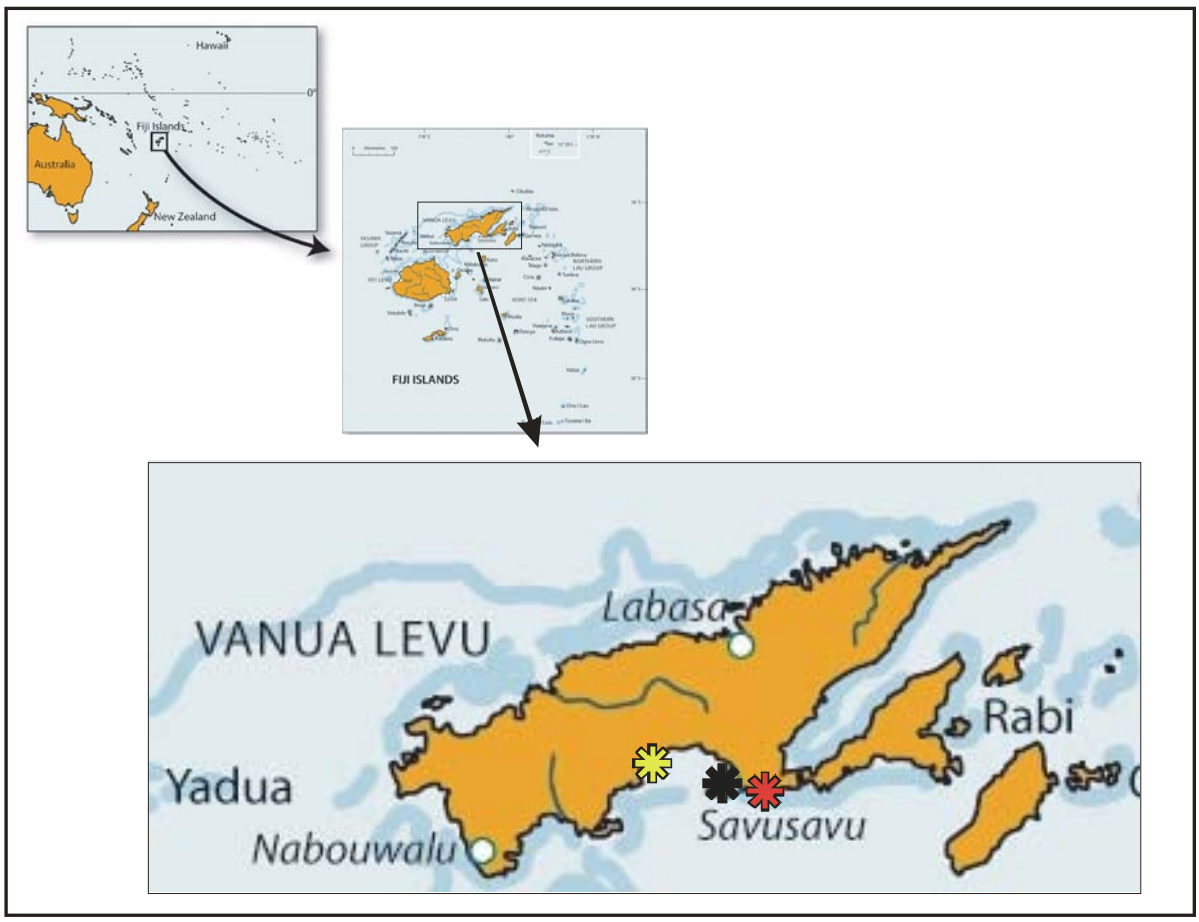

Figure 1, Map showing location of the township of Savusavu (black star), the J Hunter Pearls hatchery (red star, and Natuvu village (yellow star).

2.2 Hatchery production.

Spawning and larval rearing were carried out at J Hunter Pearls blacklip pearl hatchery at Wina (Figs 1, 2), and followed methods developed by The WorldFish Center (Agudo 2006). However, slight variations were made to accommodate the local conditions and hatchery facilities and modifications were also made towards the end of the project based on new techniques being used in Vietnam and Philippines.

Figure 2, J Hunter Pearls Blacklip pearl oyster hatchery.

2.3 Juvenile rearing

Juveniles were reared according to the methods developed by WorldFish (Agudo 2006). Small raceways were set up at the hatchery but were inadequate for large numbers of sandfish. Another established method for juvenile grow-out is the use of hapas and bag nets in ponds. However, low productivity in the pond we used limited the application of these techniques.

2.4 Release and monitoring

Juveniles greater than 1 g in weight were marked by immersing them in a tetracycline solution (7.5 g in 75 L) for a 24-hour period, one week prior to release. Four 100 m^2 pens made of 3 mm black plastic mesh were deployed in the seagrass beds in areas where they would still have some water cover at low tide (Fig. 3).

Figure 3. Pen construction pens in the seagrass beds in front of Natuvu village.

Release of juveniles into the seagrass bed at Natuvu was done according to the methods recommended by WorldFish based on studies carried out in New Caledonia (Purcell & Eeckhaut 2005, Purcell & Simutoga 2008, Purcell et al. 2006a) and training received by Ms Hair at the 'Sandfish Release Techniques' Workshop in April 2008, Philippines. The experimental release was designed to look at survival and growth of two size classes of juveniles (1-3 g and >3 g). This

approach was driven primarily by the low number of available juveniles in the desired size group of greater than 3 g. Furthermore, we were releasing into a very different habitat to that used by the WorldFish Center researchers who determined that 3 g was the minimum size that should be released.

Monitoring was carried out 3 months after the release (Aug 2009) and then at approximately two-monthly intervals. Much of the monitoring was carried out by the USP postgraduate student attached to the project. During monitoring, the number of animals in each pen was counted, a skin sample was preserved to check if they were tagged, and their length and width measured. On two occasions, weight was also recorded with an electronic balance to check that the weight calculated from measurements was reasonably accurate. Monitoring continued until a cyclone destroyed the sea pens in April 2010. The mini-project was concluded at that point, although some project sandfish were retrieved and one pen rebuilt to hold up to 70 sandfish. The USP student and community plan to continue to monitor these individuals until the sandfish reach commercial size.

2.5 Training

Hands-on training was a priority throughout the mini-project.

3. Outcomes

The results are presented here against specific objectives.

3.1. Collect and maintain sandfish broodstock, carry out spawning, rear larvae and produce large numbers of juveniles of 3-5 g (Objective 1)

Part 1. Collect and maintain sandfish broodstock

All broodstock were collected by community members and/or Fiji MFF fisheries officers (Table 1).

Table 1. Broodstock collection time, place, number collected and mean weight in grams (±se)

Collection time	Location	Number	Mean weight ±se (g)
Nov 2008	Natuvu (2 collections) Nawi Island, Savusavu Yaroi, Savusavu	70 / 30 10 5	301 ± 8 / 321 ± 8 192 ± 8 857 ± 46
Dec 2009	Natuvu	33	342 ± 15
Mar 2010	Natuvu	40	453 ± 14

Attempts to maintain broodstock in a marine pond near Savusavu town were only moderately successful. Conditioning of broodstock and spawning synchrony can be more effective if the animals are kept close together. Benefits have resulted from holding groups of adults in earthen saltwater ponds before spawning, especially in old shrimp or fish ponds where the substratum is suitable for the burying and feeding requirements of sandfish. However, the Savusavu pond had never been used for farming, the sediment was quite rocky and there was no layer of nutrient-rich sediment to enhance feeding. Furthermore, the pond was exposed to regular and substantial diurnal tidal exchange with the sea. This flushing was beneficial during periods of heavy rain but reduced productivity and prevented development of algal blooms. Sandfish broodstock survived in the pond but did not grow and condition as expected, in fact average size decreased while they were held there. There were also concerns about the security of the broodstock, sandfish became more difficult to locate in the pond as the study continued. In response to these perceived problems, use of the pond was discontinued in the last six months of the project: wild broodstock were collected for spawning and then returned to the sea after spawning.

Part 2. Carry out spawning, rear larvae, and produce large numbers of juveniles of 3-5 g.

There were five attempts to produce sandfish juveniles (each involving multiple spawnings): Nov-Dec 2008, Jan 2009, Nov 2009, Dec 2009 and Mar 2010. Larvae were produced on each occasion (Fig. 4) but successful settlement only occurred in the Nov-Dec 2009 and Jan 2009 hatchery runs. In Nov 2009 some new techniques were trialled with relative success. One tank of larvae was reared using 'Instant Algae' (Reed's micro-algae concentrate, Shellfish mix) as the sole food source for larvae and this is the first time this product has been used for these species. The larvae did not reach settlement but we believe this was for reasons unrelated to the food source. None of the larvae reared using conventional live algae reached settlement in that run either, possibly because ambient sea temperatures did not rise above 26^{o}C. Juvenile production resulted only from the Nov-Dec 2008 hatchery run. About 1,500 small juveniles were transferred from a single larval tank into conditioned raceways, and 500 of these survived to 1-10 g size to be used in sea ranching trials.

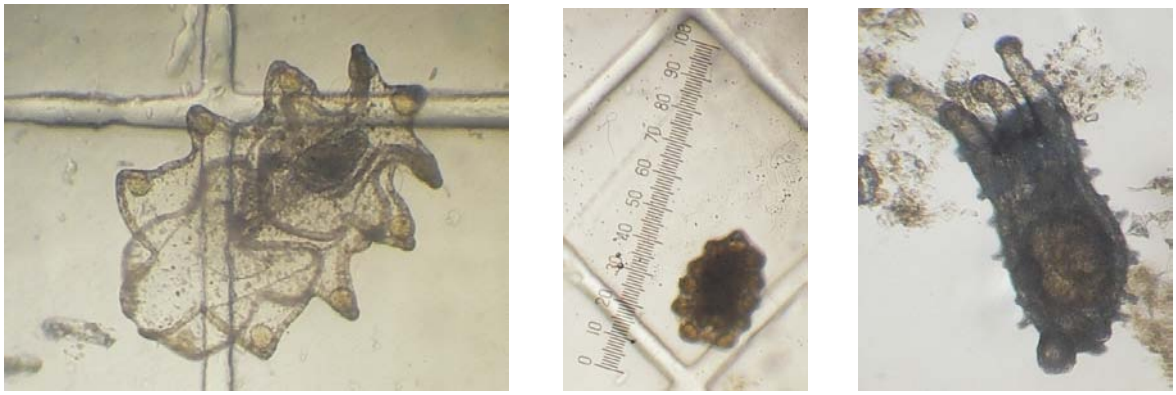

Figure 4. The final three stages of 'susu dairo' – late auricularia larvae about 10 days old (left), doliolaria larvae just prior to settlement (centre), and a settled pentactula larvae (right).

The failure to produce juveniles in subsequent production runs was due to a combination of factors, including human error, unfavourable environmental conditions and effects of cyclones. It should be noted that the Dec 2009 hatchery run was carried out successfully by the Fijian hatchery counterparts with no outside assistance, but was cut short by a cyclone.

3.2. Transfer sandfish hatchery technology to the government (MFF) and private sector (Hunter Pearls) in Fiji (Objective 2)

Hatchery technology was successfully transferred to the government (MFF) and private sector (Hunter Pearls) in Fiji. There was one targeted long-term training effort (Nov-Dec 2008) and several on-the-job training activities in subsequent hatchery runs. At the conclusion of the study, local staff were able to carry out spawning and larval rearing without external assistance. However, the lack of juvenile production meant that training in the area of juvenile grow-out was insufficient and further training effort is required in this area.

3.3. Evaluate the ease of transferring culture techniques to a pearl hatchery (Objective 3)

It was concluded that it is not technically difficult to carry out sandfish larval rearing in a pearl hatchery and hatchery staff readily learned the sandfish culture methods. It was necessary to make some physical improvements to the existing pearl hatchery (e.g. covered area where the larval rearing tanks were located, construction of raceways for juveniles, etc). There were some minor constraints associated with water supply and treatment (e.g. at some times, water could only be pumped at high tide; 1 μm water was obtained through a bag filter, inferior to cartridge filtration,)

and microalgae production (the new algal species took some time to scale up and one species, *Proteomonas*, never did grow properly). The main bottleneck to sandfish culture, however, was the overlap of production season for the two species, both species were not cultured simultaneously and we had fewer sandfish runs than desired. This was not, however, due to pearl culture being incompatible with sandfish culture but because of resource constraints (staff, water, space, time).

3.4. Evaluate the growth and survival of juveniles under sea ranching conditions in community managed *qoliqoli* (Objective 4)

A suitable release site was identified early in the project. An extensive seagrass bed on a shallow sand flat in front of Natuvu village met all the criteria for suitable habitat and the community were committed to the mini-project. The release was carried out on May 18 2009, with 105 juvenile dairo placed into each of the two 'large size' pens (Pens A, C) and 143 into each of the 'small size' pens (Pens B, D). The juveniles were "planted" in the sediment by digging a small trench with a finger, then placing them gently in it.

Survival after six months was just over 28% overall (23% and 33 % for small and large sandfish, respectively) (Fig. 5). The highest overall survival was 41%, recorded from a pen of large sandfish. Mortality (or loss) was greatest in the first three months and then levelled off. Due to the damage to pens in the later half of 2009, the six-month average is used as the survival estimate for the trial.

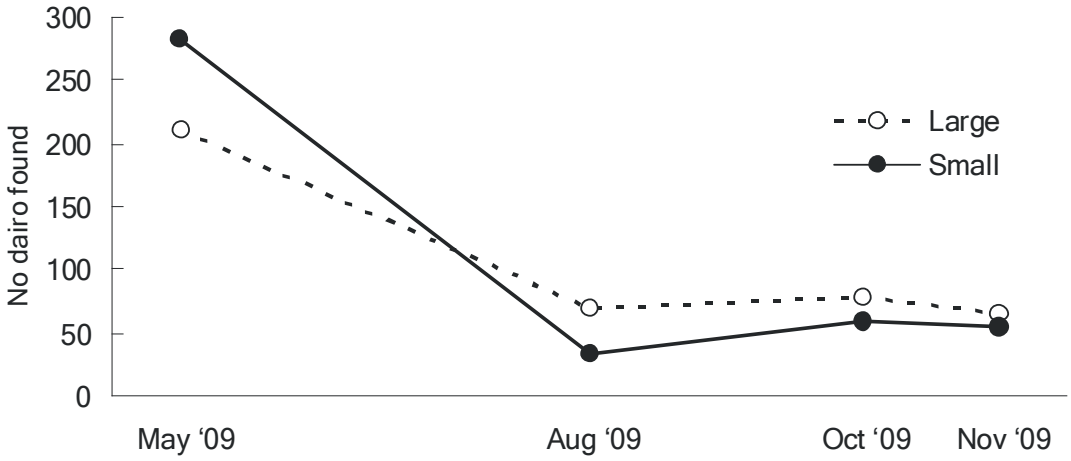

Figure 5. Survival of dairo in the four pens after six months.

Growth of hatchery-produced sandfish the study is presented in Figure 6. The last completely reliable measurements were taken eight months after release in February 2010, before Cyclone Tomas in March 2010. At eight months, average sandfish size was 165±5 g and 167±6 g for small and large sandfish, respectively (Fig. 6). Further measurements of sandfish were recorded after this time (Fig. 6) but it is impossible to be certain that only project sandfish were measured because of the extensive damage to pens. Fluorochrome marking was not able to be used to identify hatchery-produced juveniles.

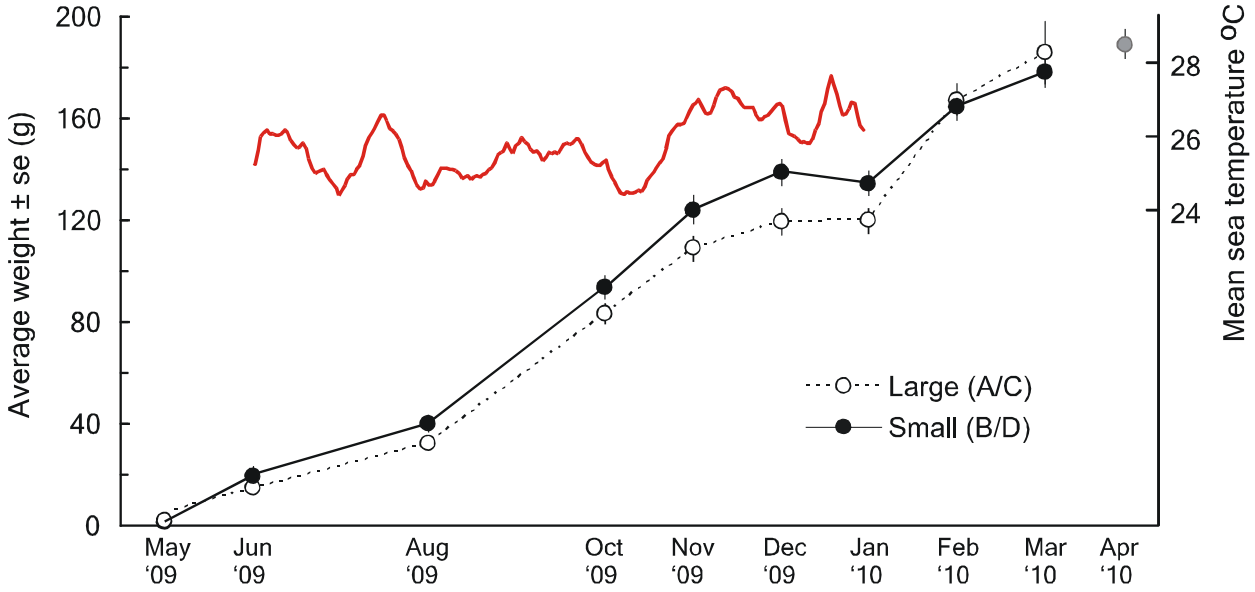

Figure 6. Eleven months growth data for hatchery produced sandfish in the sea at Natuvu. March and April 2010 are sub-samples of the sandfish recorded after Cyclone Tomas and data are to be treated with caution. The red line shows average sea temperature in the sea pens between June 2009 and January 2010.

A data logger placed in the sea pen area recorded sea temperature from June 2010 (a month after release) through to January 2011 (Fig. 6). It is difficult to draw any conclusions from the data but low temperatures in Oct-Nov 2010 and early Jan 2011 may have contributed to the slow juvenile growth observed during that period. Recall that we believe lower than normal ambient sea temperature led to failed larval production in Nov 2011.

3.5. Evaluate the growth and survival of juveniles released in MPAs within qoliqoli (re-stocking) (Objective 5)

Refer to Objective 4. Only a small number of juveniles were available for the sea ranching trial and these were released into an MPA, therefore the results are valid for Objectives 4 and 5.

3.6. Improve capacity of pearl hatchery, MFF, USP and NGO staff in sea cucumber production techniques, release and monitoring skills (Objective 6)

Sachin Deo (J. Hunter Pearls hatchery technician), Tavenisa Vereivalu (MFF senior aquaculture officer), Laisiasa Cavakiqali (ACIAR-USP postgraduate scholarship holder) and Martin Hagilmai (trainee technician from FSM) were trained in Broodstock collection, spawning and larval rearing techniques. Sachin and Tavenisa were trained in juvenile rearing techniques. Laisiasa, John Vonokula (MFF Senior Fisheries officer), Meo Semisi (FLMMA officer) and the Natuvu sandfish wardens (Manasa Levaci, Semasa Ramuacala, Tueri Julan and Tesoni Lesukinayavu) were trained in juvenile release and monitoring methods (Fig. 7).

Figure 7. Fisheries officer collecting dairo and dairo wardens monitoring ranched dairo after 3 months In August 2009 (left & centre) and after 11 months in April 2010 (right).

3.7. Scope out options in Fiji for a management framework to meet the needs of stakeholders involved in sea cucumber re-stocking/sea-ranching (Objective 7)

The mini-project did not continue to the point where substantial numbers of commercial sized adults were available for harvest and sale. Only a small number were released and these were not large enough to harvest when the study concluded. Furthermore, the community declared the area where they were released as an MPA in order to provide security for the released sandfish during the research phase. We are therefore unable to report on a management framework. If, during the next phase of this mini-project, a larger release is carried out, the issue will need to be raised and all stakeholders involved in developing a framework.

4. Impacts

4.1 Scientific impacts

The use of 'Instant Algae' greatly reduces the technical resources required for hatchery culture of commercial marine species and is potentially of enormous benefit for development of hatchery culture to support aquaculture development in the Pacific Islands region. This product was used for the first time to rear sea cucumber larvae in this mini-project. Although larvae did not progress to settlement stage on Instant Algae, the trial was moderately successful and warrants further investigation.

4.2 Capacity impacts

The study has resulted in enhanced capacity of private sector, aquaculture and fisheries technicians. Community members learned new skills and took on additional responsibilities as a result of the activities in their village. Most of the increased capacity resulted from on-the-job training but there were also some specific training activities, particularly during the first hatchery run. The proof of capacity-building was seen when local partners undertook to do spawning, larval rearing and monitoring without outside assistance.

4.3 Community impacts

Economic community impacts are unlikely since only a small number were released. However, the data generated and the implications for the future of this approach are promising in economic terms. Growth rates and survival were similar to those recorded in other areas where similar studies have been carried out (e.g. New Caledonia and Philippines). Successful sea ranching of

sandfish, if achieved, could improve food security benefits and income generating opportunities for Pacific coastal communities. The mini-project also produced positive social impacts for the Natuvu community. As part of the community involvement, four wardens were assigned to maintain the sea pens, keep sandfish secure and assist project staff with monitoring. These wardens were trained in release and monitoring skills. The mini-project has raised awareness in the village and led to the declaration of a marine protected area (MPA) and protection of sandfish stocks for the duration of the mini-project, Prior to the start of ML0801 'Culture of juvenile sandfish for sea ranching trials in Fiji', the partner community declared part of their qoliqoli an MPA and banned the harvest of sandfish. Observations suggest that sandfish populations have improved (increased size and abundance) since these measures were introduced. Sea cucumbers are known to have a beneficial ecological effect on the substratum through their feeding and burying habits. Spawning of hatchery-produced sandfish (inside the sea pens) was observed in November 2009 and March 2010, suggesting that the ranched sandfish were contributing to future stock biomass. Locals believe that other sea cucumber species have increased in number and size within the MPA.

5. Conclusions and Recommendations

Conclusions and recommendations arising from the trip are listed below.

- Due to the damage to the Hunter Pearls Wina hatchery and the sea pens at Natuvu, the mini-project was concluded in April 2010. The hatchery is expected to be back in operation later in 2010. One sea pen was rebuilt and the sandfish that are presumed to be the hatchery produced dairo will continue to be monitored by the sandfish wardens. Any data collected post Cyclone Tomas should be regarded with caution and absolute numbers not relied upon, average weights only. However, this will provide long-term data on released sandfish.
- Relatively few juveniles were produced in the study and training in juvenile care and grow-out was inadequate. This aspect of the hatchery process requires further effort.
- We did not detect any stained spicules in skin samples from juvenile sandfish released in the sea ranching trial. We believe this was due to the fact that the juveniles were stunted when they were stained prior to release. This prevents uptake of the fluorochrome into the spicules. This is another area where further training would be beneficial.
- The sandfish from the original release in May 2009 survived and grew well at Natuvu. We plan to hold another production run in the upcoming season (summer of 2010/11), release at least 2,000 juveniles of at least 3 g each and continue monitoring. This production run will be done within a new mini-project which will focus on MFF Division of Fisheries involvement and increasing capacity at Galoa hatchery, as well as continuation of the Hunter Pearls component at Savusavu. Cathy will prepare a Mini-project proposal in collaboration with Gerald Billings (Fiji MFF), Justin Hunter (Hunter Pearls) and other collaborators.

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7. Acknowledgements

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Appendix 2.9

MS0803

Improving *Pteria penguin* (winged pearl oyster) juvenile culture and mabe production techniques in the Fiji Islands

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU JAMES COOK UNIVERSITY WorldFish CENTER USP THE UNIVERSITY OF THE SOUTH PACIFIC	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Potential for *Pteria penguin* (Röding, 1798) mabé pearl aquaculture by rural coastal communities in the Fiji Islands (MS0803)**
Goal:	Improve culture and mabé production for *Pteria penguin* in Fiji Islands.
Objective(s):	The project will achieve this goal through the following objectives: 1) Develop improved methods to produce quality mabé pearl from *Pt. penguin*, with emphasis on culture depth, position and duration. 2) Determine best culture methods for juvenile *Pt. penguin* with emphasis on culture depth, stocking density, water parameter and fouling. 3) Use socio-economic surveys to determine if mabé pearl culture could be an alternative source of revenue for local coastal communities.
Project location:	Fiji Islands
Project partner(s):	USP, Fiji Pearls (Hunter Pearls)
Dates / duration:	2 years
Project description:	This mini-project was an ACIAR-USP postgraduate student project. A series of experiments were carried out to determine optimum culture depth, bead position and harvest time to produce quality *Pt. penguin* mabé. This part of the study followed on from an earlier mini-project carried out in Kiribati (on blacklip pearl oyster) and was part of a wider Pacific region study to improve mabé pearl techniques. Additionally, optimal culture methods for wild caught *Pt. penguin* juveniles were examined. This part of the study had links to a mini-project in Tonga where similar factors are being tested for hatchery-produced *Pt. penguin* juveniles. As part of the study, mabé techniques were introduced to local communities. The potential benefits from, and main constraints to, uptake of mabé production techniques by coastal communities in Cakaudrove Province was determined.
Justification:	Since mabé production is technically easier and less expensive than round pearl production, efforts to improve the mabé quality and provide increased financial return can be of benefit to coastal communities in PICs. Inefficient farming practices for *Pt. penguin* are currently a constraint to development of this industry.
Expected outcomes:	1. Optimised *Pt. penguin* mabé production methods 2. Optimised *Pt. penguin* juvenile culture methods.
Funding:	$8,300

Potential for *Pteria penguin* (Röding, 1798) mabé pearl aquaculture by rural coastal communities in the Fiji Islands

Pranesh Kishore
University of the South Pacific, Suva, Fiji Islands

1. Background:

The cultured pearl industry is a growing multi-million dollar global industry (Bondad-Reantaso et al. 2007). The blacklip pearl oyster (*Pinctada margaritifera*) is the most common species farmed in the south Pacific. Fiji has recently emerged as a pearl producing nation, with round pearl production from this species practised around the Savusavu area of Vanua Levu. Another species of pearl oyster found in this area is the winged pearl oyster (*Pteria penguin*), a species suitable for producing 'half pearls' or mabé (Passfield 1995). Mabé are half–spherical pearls are made by gluing hemi-spherical nuclei onto the inner surfaces of pearl oyster shells. They are much easier to produce than round pearls although they are not as valuable (Kripa et al. 2008). However, mabé are known for their uniqueness and beautiful colours (Haws 2002, Yamamoto and Tanaka 1997).

Wada (1973) reported that the quality of pearls depends greatly on the growth rate of oysters, water temperature, and other environmental factors. Yamamoto & Tanaka (1997) reported that around only one in every three or four mabé pearls from an oyster will be of good quality which can be sold for ~US$30. Gervis & Sims (1992) stated that the main influence on pearl quality is the culture method used for pearl oyster growth. This mini-project aimed to improve methods for mabé production by testing the effects of culture depth, nucleus position and time to harvest on pearl quality. Furthermore, because lack of knowledge of factors affecting survival and growth of *Pt. penguin* under farming conditions is an impediment to further development of this industry, a separate component of this study tested the effects of density, depth and culture method in order to optimise culture of wild-caught juvenile *Pt. penguin*.

Haws et al. (2006) reported that mabé production is well suited for coastal communities or farmers. This mini-project introduced *Pt. penguin* spat collection and mabé production techniques to two coastal communities near Savusavu. The market for mabé pearls is not well established locally in Fiji, but there is a worldwide trade. There is potential for community members to establish pearl farms since production costs are much lower than those required for round pearl production using *P. margaritifera*. The study examined the potential for mabé production and livelihood development in coastal communities in Fiji.

2. Project Description

There were two main project objectives:

1. Develop improved methods to produce quality mabé from *Pt. penguin* with emphasis on culture depth, nucleus position and culture duration; and
2. Determine the best culture practices for grow-out of juvenile *Pt. penguin* in Savusavu Bay, Fiji.

A third objective was also included as part of the ACIAR-USP Postgraduate study:

3. Determine, using socio-economic assessment tools, the potential benefits from, and main constraints to, uptake of mabé production by coastal communities in Cakaudrove Province, Fiji.

3. Project Methodology

The project was conducted in Savusavu Bay, Vanus Levu, on a commercial pearl farm operated by J. Hunter Pearls. The farm is located close to Savusavu town and is approximately 20 ha in size with a mean depth of 25 m (Fig. 1). No fishing activities are permitted at the site.

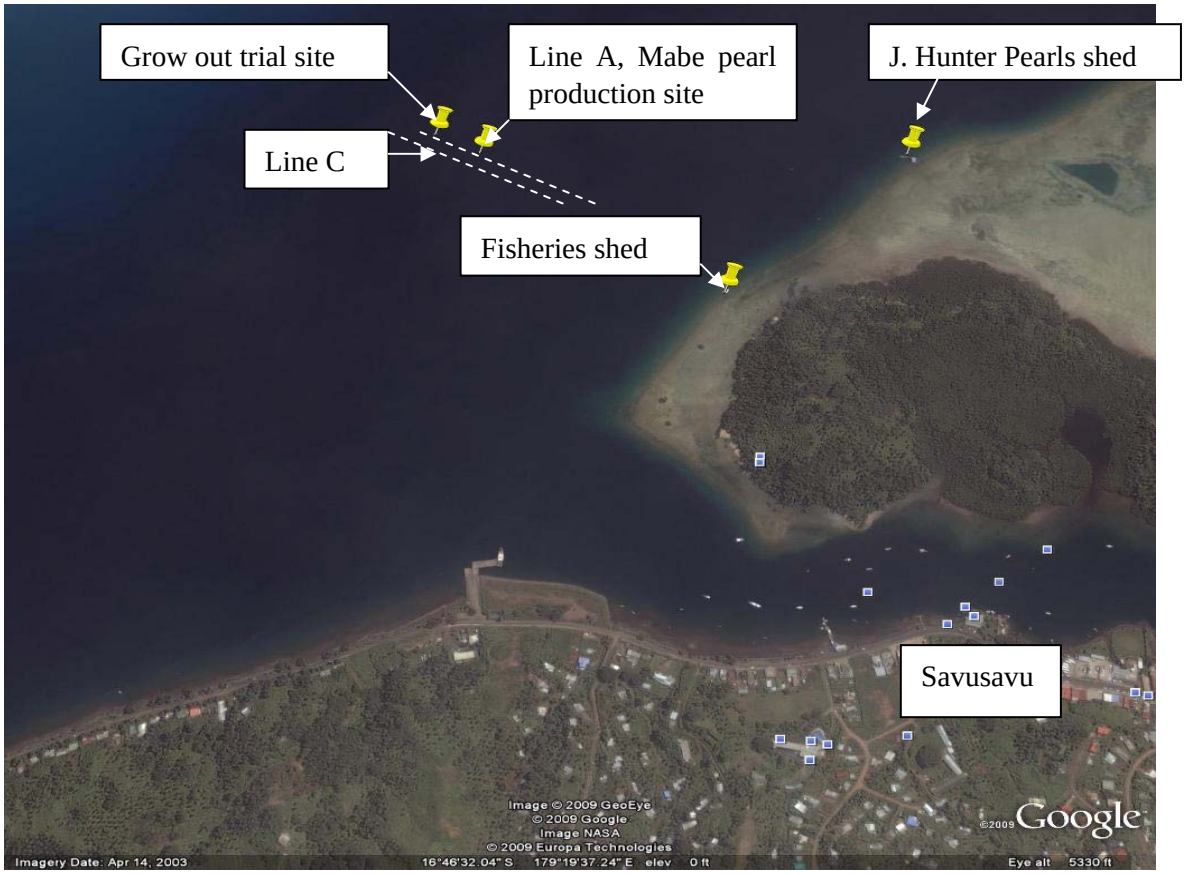

Fig. 1: Aerial view of Savusavu Bay showing sites used mabé production and grow-out of *Pteria penguin.* Source: http://www.googleearth.com

3.1 Mabe pearl production

A group of 165 *Pt. penguin* were used in the first mabé production trial of which 105 were implanted with nuclei. They had a mean dorso-ventral measurement (DVM) of 250 ± 6.5 mm and were about 3 years old. The majority of these oysters were cultured at a conventional depth (8-10 m), while the remainder were cultured at 15 m and 20 m to determine if there was any impact of culture depth on the quality of mabé produced.

A second trial using younger oysters was initiated after mortality was noted with some of the oysters used in the first trial. The oysters used for the second trial were on average two years old and had a DVM of 145 ± 4.8 mm. A total of 20 oysters were implanted during the second trial. The aim of the second trial was to determine if age could be a factor in the mortality of oysters in the first trial.

Anaesthesia of pearl oysters is often used for nucleus implantation (Ruiz-Rubio et al. 2006). Earlier research in this project showed that 1-propylene phenoxetol at a concentration of 3.0 ml/L of seawater is an appropriate anaesthetic for *Pt. penguin* which allows rapid recovery. Thus, for nucleus implantation, oysters were first anaethetised with 3 ml/L of 1-propylene phenoxetol in seawater. Five hemispherical nuclei (diameter 15 mm, height 7 mm) were glued to the inner sides of the shell valves, three on the more concave (left) valve and two on the right valve (Fig. 2) using polycyanoacrylate gel. The smaller oysters used in trial 2 were implanted with three smaller sized nuclei (diameter 8 mm, height 4 mm); two on the left shell valve and one on the right valve.

Beginning five months after implantation, three oysters were sacrificed monthly to measure the thickness of nacre covering the nuclei. This was done for a maximum culture period of nine months (i.e. samples were taken after 5, 6, 7, 8 and 9 months of culture). Mabé were carefully cut from of the shells using a high-speed diamond-cutting disk. Nacre thickness was measured at the top and base of mabé using a micrometer screw gauge (±0.01 mm) and analysed using ANOVA, as done in a similar study with *Pteria sterna* by Ruiz-Rubio et al. (2006).

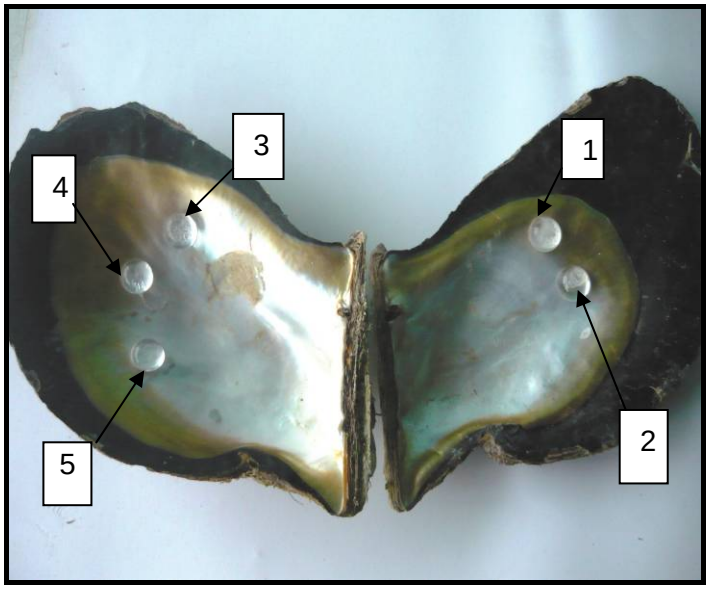

Fig. 2. Positions where the nuclei were glued for mabé production.

3.2 Juvenile *Pteria penguin* grow out trials

Pt. penguin collected from the wild using spat collectors were used in a growth trial to determine the effects of differing culture conditions. The mean DVM was 123.67 ± 8.2 mm and the mean shell thickness was 24.96 ± 3.8 mm at the start of the experiment. Oysters were housed in panel (pocket) nets with a mesh size of 10 x 10 mm, deployed from a longline at a depth of either 6 m, 8 m or 10 m. At each depth, six nets were deployed with three different stocking densities. Two nets contained five oysters (one in a pocket; Fig. 3), another two contained 10 oysters (two oysters in each pocket; Fig. 4) while another two nets contained 15 oysters (3 oysters in each of the pockets; Fig. 5). Pockets of nets were tied with a thin string at the openings to prevent entry of predators.

Fig. 3: Panel net with 5 oysters.

Fig. 4: Panel net with 10 oysters.

Fig. 5: Panel net with 15 oysters.

The growth of oyster juveniles was evaluated every month from December 2008 to April 2009. DVM was used as the major parameter to determine growth rates (Saucedo & Southgate, 2008). A Gulland–Holt plot was used to analyse the growth data for the oysters from both the trials (King, 1995). The Y-axis of the graph represented the average growth rate (mm/month), while the X-axis represented mean length/thickness. The value of the constant (*k*) represented the growth rate of the length and thickness from different culture apparatus, stocking densities, and depths. The constant (*k*) was used to determine if there were significant differences in the mean of the oyster height and thickness. Levene tests and Shapiro–Wilk tests were performed on all data for homoscedasticity and normality before carrying out parametric or non – parametric tests. The tests used were one way ANOVA and Kruskal – Wallis tests. SPSS version 13 was used for these statistical tests.

3.3 Socio-economic survey

The two coastal villages chosen for the socio-economic survey were Vatulele (16°43’12.35”S, 179º18’53.90”E) and Nacodreudreu (16°41’52.23”S, 179°13’37.63”E). Both have copra, *yaqona* (kava), fishing and dalo (taro) production as the main economic activities. Some individuals from each village had some knowledge of pearl culture as they had worked on pearl farms in the area. Household and individual questionnaires focussed on various socio-economic indicators, which revealed the current livelihoods of the villagers. The survey determined the education level, current livelihoods and expenditure per annum by the villagers. Some questions explored interest in mabé pearl culture as an alternative livelihood for the community. An economic model designed for mabe pearls (Johnston & Ponia, 2009) was used to determine the viability of mabé pearls as an alternative livelihood

for the surveyed communities. Input data for the model was obtained from J. Hunter Pearls account section and from Professor Paul Southgate.

4. Results

4.1 Mabe pearl production

As might be expected, the thickness of nacre deposited on the top and at the base of nuclei increased with increasing culture period (Fig. 6). The maximum thickness of nacre deposited on the top of a nucleus was 1.27 ± 0.05 mm and the minimum was 0.33 ± 0.05 mm while the nacre thickness at the base varied from a maximum of 1.00 ± 0.05 mm down to 0.28 ± 0.05 mm. The maximum average nacre thickness on the top and base of a nucleus was recorded in November 2009, eight months after implanting (Fig. 6). The rates of nacre deposition on the top ($F=15.39$, $p=0.00$) and base ($F=41.54$, $p=0.00$) of the nuclei were significantly different at different sampling months.

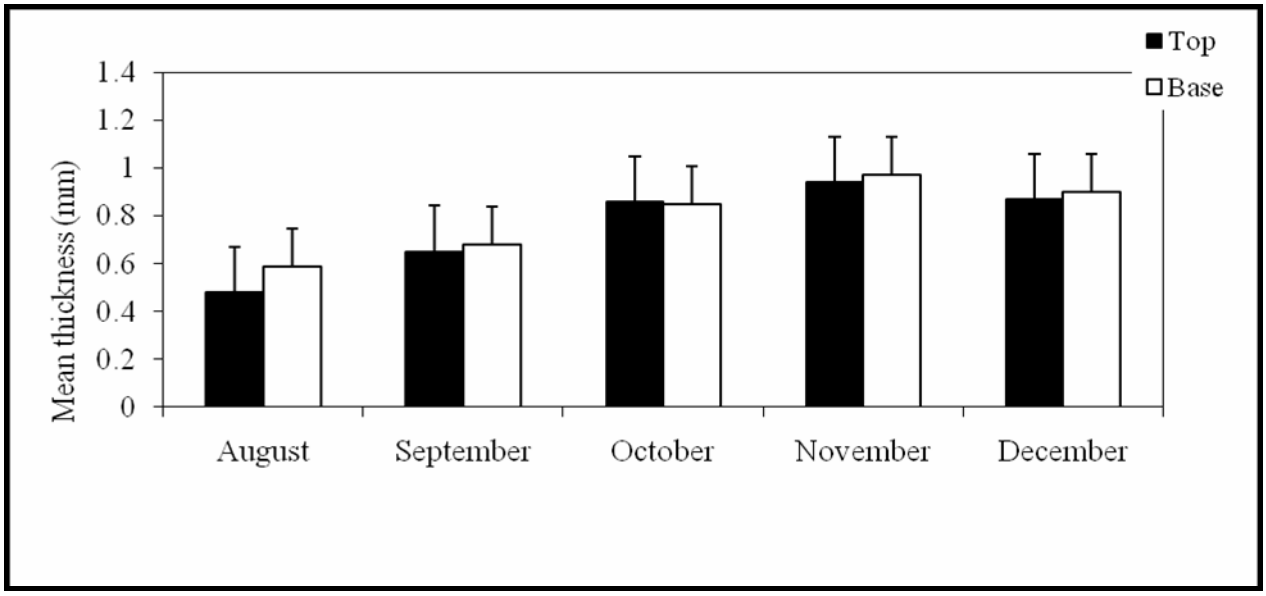

Fig. 6. Average mabe nacre thickness (mm) at the top and base of nuclei, measured monthly from five months after implantation.

The position of a nucleus influenced the quality of the mabé from *Pteria penguin*. The characteristics of mabé that developed at the various positions within the shell shown in Fig. 2, can be summarised as follows:

- Positions 1 and 2 – resulting mabé were symmetrical (or regular). However, most (89%) were metallic grey or white in colour and lacked the more desirable golden colour. Mabé with golden colours may have been obtained if the nuclei were glued more closely towards the layer of golden coloured nacre found towards the nacreous margin of the shells. All mabé formed at these positions showed commercial quality lustre with few imperfections.
- Position 3 – 65% of mabé formed in this position were dull white in colour with poor lustre. This resulted from growth of the adductor muscle to cover the nucleus. This phenomenon was first noticed in two of the four oysters sampled after 6 months.

- Positions 4 and 5 – Approximately 53% (Position 4) and 47% (Position 5) of the mabé pearls formed in these positions were asymmetrical (i.e. deposition of nacre across the nucleus was not even and the even hemispherical shape was not maintained by resulting pearls. According to Ruiz–Rubio et al. (2006), asymmetrical mabé are formed when the mantle cannot completely cover all the nuclei glued to a valve as a result of the increased shell surface. Despite the asymmetrical shapes of some mabé, professional carvers were interested in the colour, lustre and unique shape of these pearls.

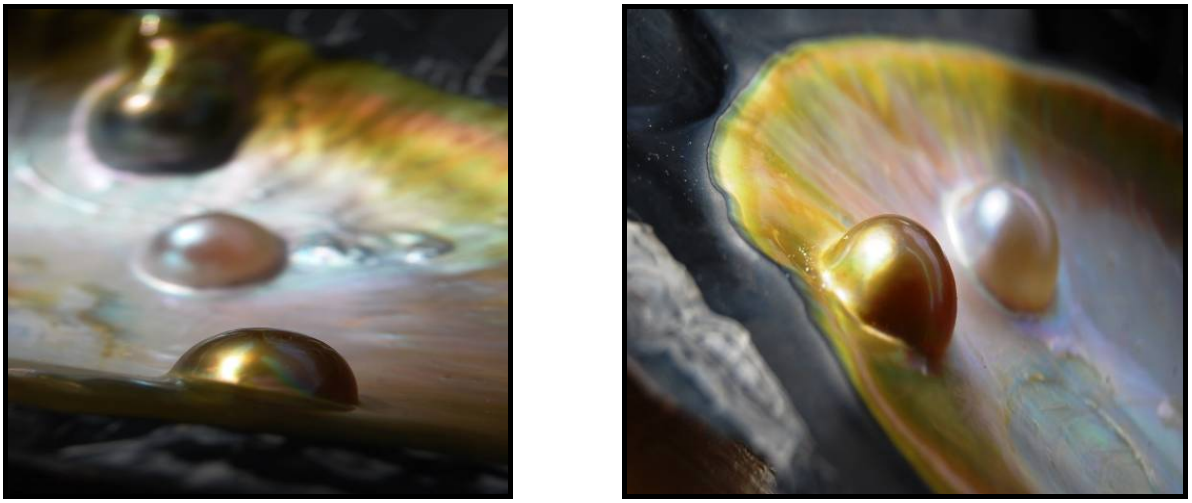

Fig. 1. Mabé pearls formed on the more concave valve (left) and on the less concave valve (right).

Mabé formed by oysters held at depths of 15 m and 20 m did not vary in size from mabé cultured at the 'normal' depth of 6 m after 10 months of culture. However, the majority of the mabé harvested from 15 m and 20 m were bright white in colour with less golden colour than those from oysters at 6 m. Mabé formed in younger oysters were generally poor in quality. This was because, as the oysters grew, the positions where the nuclei were pasted initially had shifted relative to the inner white nacreous region of the shell (i.e. their relative position shifted inwards as the shell margin extended). The band of gold coloured nacre is always restricted to the outer margin of the nacre with white coloured nacre in the centre of the shell (Fig. 7).

4.2 Juvenile *Pteria penguin* grow out trials

The Gulland-Holt plot constants (i.e. growth rate constant (*k*)) decreased with an increase in depth and stocking density. The best growth of juvenile *Pt. penguin* was at 6 m, and growth rate decreased with increased depth. Stocking density also influenced oyster growth rates.

At all depths, panel nets with a stocking density of five oysters per net showed the fastest growth rates and growth decreased with increasing stocking density (i.e. 5 per net > 10 per net > 15 per net). The growth rate of *Pt. penguin* at each depth also decreased with an increase in stocking density.

Fouling on the culture apparatus and on oysters was a major concern. Heaviest fouling was observed at 6 m depth and, as might be expected, it decreased with an increase in depth. Fouling can affect the growth rates of pearl oysters by vying for food, space, and oxygen (MacDonald & Thompson, 1985; Urban, 2000). In some cases, fouling also hindered the normal opening of valves, causing stress to oysters. However, there was no correlation between the amount of fouling and growth rates of oysters; both were highest at the shallower culture depth (6 m).

4.3 Socio-economic surveys

The surveyed households from both the villages had various forms of expenditure. These included bills, transportation costs, educational costs, organising special events and giving remittances. The revenues for the households for both the villages were derived from the sales of agricultural products, livestock, marine resources and receiving remittances. Average money saved per household was FJ$4,531.60 and FJ$1,595.50 per annum for Vatulele and Nacodreudreu villages, respectively. Mabé questionnaire data confirmed that the villagers were familiar with *Pt. penguin*. The species is common in Savusavu Bay and mainly used for consumption by the villagers. However, upon informing the villagers on the economic generation possibility, the villagers realised the benefits *Pt. penguin* had to offer. Questionnaire results showed that individuals in the active economic age group (18 to 35 years of age) from both the villages were well educated and understood the concept of mabé pearl culture.

The results from economic model indicated that a mabé pearl industry may have a cost–benefit ratio of 1:3.34, with the pay-back period or around one year for loans acquired to establish a mabé pearl venture with 10,000 oysters.

5. Impacts

5.1 Scientific

The research demonstrated how to produce high quality mabe pearls in Savusavu Bay, Fiji. Out of the five shell positions chosen for gluing nuclei, four of these position produced good quality mabe with commercial potential. There was constant nacre deposition on the nuclei and mabé sampled after six months had comparable nacre thickness at the base and top to that of a good commercial mabé. However, lustre continued to improve and the best quality mabé pearls were obtained after nine months of culture. It was found that implanting *Pt. penguin* at an age of around three years produced high quality mabé pearls of commercial value, as the oyster growth is reduced by this age.

The research showed that *Pt. penguin* grew best at relatively shallow depths (6 m) compared to greater depths (8 and 10 m). The research also revealed that a stocking density of 5 oysters is optimal per panel net. The fouling on the oysters also needs to be controlled for best growth rates of *Pt. penguin*.

5.2 Capacity impact

Employees of J. Hunter Pearls were present when the implantation process was executed. They were taught how to anaesthetise the oysters and towards the completion of the project, employees were well versed with the implantation procedure. They also set up culture apparatus at different depths, learning how to obtain maximum growth of *Pt. penguin*.

5.3 Community impact

The current average revenue earned by individuals was fairly low with a high cost of living. Results from the economic model for mabé pearl culture indicated that this operation could generate significant revenue for local coastal communities. The low associated costs and simple techniques required for mabé pearl culture present an opportunity to improve the livelihood of coastal communities. The encouraging results from the study have already prompted two existing pearl farmers in the area to establish their own mabé pearl ventures along with their normal round pearl production business. Their farms have stocks of *Pt. Penguin* and implantation of some of these oysters began in June 2010, after the techniques were taught to them. Other emerging pearl farmers have shown interest in mabé pearl culture.

6. Conclusions

Mabé pearl culture could be an alternative livelihood of the coastal communities in Fiji. The research presented here can serve as a guide to potential pearl farmers and underpin development of commercial mabé pearl production.

The study provides current and potential pearl farmers with important information on the best locations for nucleus implantation, oyster age and culture period to produce mabé pearls of high commercial value. Furthermore, the growth trial illustrated the best depth, type of culture apparatus, stocking density and other factors required for growth of *Pt. penguin*. Interested farmers now have a clear guide to mabé pearl culture, from growing *Pt. penguin* juveniles, nucleus implantation and husbandry of implanted oysters.

The socio–economic surveys indicated that mabé pearl culture offers considerable potential benefits over the existing livelihoods for local coastal communities. The interest shown towards mabé pearl culture from the respondents was overwhelming.

The project has produced biological information that would form basis for mabé pearl culture development in Fiji. Mabé pearl culture industry establishment would further complement the current lucrative round pearl industry in Fiji. It presents a great potential source of revenue for Fiji. While the study provided much needed scientific information and comprehensive economic analysis, further studies on *Pt. penguin* would be useful.

7. Recommendations

A study on hatchery production of *Pt. penguin* in Fiji needs to be carried out. Natural stocks of *Pt. penguin* stocks could be exhausted if a major mabé pearl industry was established; this has occurred with similar development in Vava'u, Tonga. Hatchery produced *Pt. penguin* spat could sustainably meet the demands of mabé pearl farmers in the future.

A trial where 2.5-year-old *Pt. penguin* are implanted should be carried out and the quality of resultant mabé pearls examined. It has been observed that *Pt. penguin* growth is reduced

by this age and mabé pearls of high commercial value could be produced. The mortality rate of the oysters after the implantation process may also be reduced.

Apart from the normal hemispherical nuclei used in this study, other shapes of nuclei could be trialled, including heart, teardrop shapes or any other shapes of interest. The commercial value of mabé pearls from these 'fancy' shapes should be compared to hemispherical shaped mabé pearls and may have increased 'novelty' value.

Juvenile *Pt. penguin* should be cultured in other types of culture apparatus (e.g. imported trays with lids, other forms of nets) to observe if there is any significant difference in their growth rates. The mesh material used to construct the panel nets used in this study was made up of multifilament material. Pocket panel nets made up of different material (imported) could be used in future to determine if the fouling rates can be reduced.

This study described the potential benefits of mabé pearl culture in Fiji. A government-assisted mabé pilot project could be initiated in a village to introduce the concept to Fijian coastal communities and which can act as a demonstration farm for others to learn from.

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Appendix 2.10

MS0804

Recruitment patterns of pearl oysters to spat collectors in Savusavu Bay, Fiji, with emphasis on the Blacklip pearl oyster (*Pinctada margaritifera*)

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU James Cook University WorldFish Center USP The University of the South Pacific	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**
Project Title:	**Recruitment patterns of pearl oysters to spat collectors in Savusavu Bay, Fiji with emphasis on the Blacklip pearl oyster (*Pinctada margaritifera*) (MS0804)**	
Goal:	To develop a reliable and efficient blacklip pearl oyster spat collection practice for Fiji that incorporates optimal targeting of spat	
Objective(s):	The project will achieve this goal through the following objectives: 1) Describe spatial and temporal variability in recruitment of blacklip (and other pearl oyster species) within three sites in Savusavu Bay; 2) Determine if there is a correlations between blacklip pearl oyster spat recruitment patterns and selected water quality variables (DO, temperature, salinity, turbidity, pH and chlorophyll); and 3) Develop a key for identification of pearl oyster spat.	
Project location:	Fiji Islands	
Project partner(s):	USP, Fiji Pearls (Hunter Pearls)	
Dates / duration:	2 years	
Project description:	This mini-project is an ACIAR-USP postgraduate student project. The student will monitor pearl oyster spat recruitment at three sites in Savusavu Bay, Vanua Levu, over a 1.5-year period. Data on water quality will also be collected. The study provides targeted research to optimise the methods used to collect spat which will help boost spat supply for the continued development of the pearling industry in Fiji and elsewhere in the Pacific Islands region. It will also add to the body of knowledge regarding the mechanisms determining the distribution of spat.	
Justification:	The main constraint to development of the pearling industry in Fiji is lack of a 'consistent supply' of oyster juveniles or 'spat'. Research is needed to improve the capacity to target valuable spat when they are available.	
Expected outcomes:	1. Optimised pearl oyster spat collection methods. 2. Increased knowledge on what factors affect pearl oyster spat distribution. 3. Identification key for pearl oyster spat. 4. Capacity building (spat collection) within USP and Fiji pearl industry	
Funding:	$9,700	

Recruitment patterns of pearl oysters to spat collectors in Savusavu Bay, Fiji with emphasis on the Blacklip oyster (*Pinctada margaritifera*)

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1. Background

The blacklip pearl oyster (*Pinctada margaritifera* L.) is found across the Indian and Pacific Oceans, The Persian Gulf and in the eastern Mediterranean Sea (Gervis and Sims, 1992). It reaches its greatest abundance in the atoll lagoons of French Polynesia and the Cook Islands and is well known in eastern Polynesia for production of the lucrative 'black pearls' (Cabral, 1989).

The cultured pearl industries of Polynesia rely on wild collected spat as a source of culture stock. They are collected with materials that are placed into the water when larvae are abundant to provide a substrate for settlement. These materials are known as 'spat collectors' The resulting juvenile oysters, or 'spat',are then removed from spat collectors and used for pearl culture. Many types of substrates have been used successfully as spat collectors including tree branches, coconut shells and, more recently artificial plastic materials such as rope and shade cloth (Imai, 1977; Iverson, 1968; SPC, 2007). Generally, dark nylon or polypropylene materials collect the highest numbers of spat (Braley and Munro, 1997). Spat collectors have been used successfully to collect the spat of pearl oyster species including *P. margaritifera, P. fucata, P. maxima* and *P. imbricata* (e.g. Beer and Southgate, 2000; O'Connor and Lawler, 2004). The accordian-style collector is commonly used in the pearling industry. It is composed of two meters of threaded, compressed polypropylene shade cloth about 12 cm wide (Fig. 1).

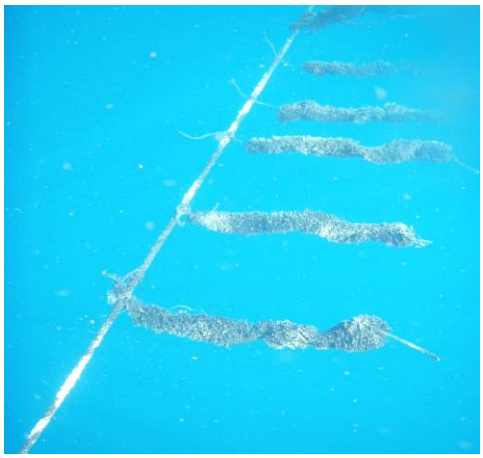

Figure 1. Accordian style spat collectors

In addition to using the most effective spat collector materials, other factors influencing spat collector success include timing their deployment to coincide with the spawning period of the target species, pre-conditioning of collectors, deployment at the correct depth (3-4 m), environmental parameters such as temperature, dissolved oxygen, salinity, turbidity and chlorophyll-a, current strength, speed and direction, maintenance of mainlines and appropriate 'soak' time to harvest of spat. The latter point is particularly important because if spat collectors are left too long then problems may include over-catch of non target species,

predation and competition for space. But if soak time is too short then the recruitment peak may be missed and the spat will be too small at harvest.

2. Project methodology

2.1 Recruitment patterns of pearl oyster spat

This study was conducted in Savusavu Bay, Vanua Levu, Fiji. Three sampling sites, Station 1, Station 2 and Station 3, were used (Fig. 2). Two were existing pearl farm locations where blacklip pearl oyster spat are regularly collected; Station 1 was situated in the vicinity of the J. Hunter Pearl farm and has been used for spat collection since the company began operation in 2000. Station 2 was located near the farm of another local pearl farmer who began spat collection in 2007. Station 3 was chosen because of high spat settlement during test plots carried out by Hunter Pearls (Fig. 2).

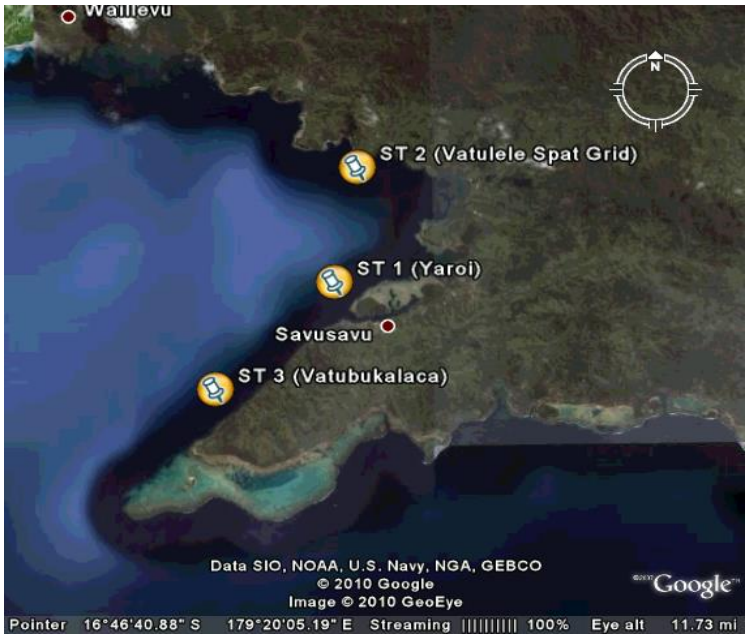

Fig. 2. Spat collector sampling stations (Source: Google Incorporated, 2010).

Accordian-style collectors were used because *P. margaritifera* juveniles have been collected in this way in this area by J. Hunter Pearls. Twenty collectors were sequentially deployed at monthly intervals at 3-4 m depth at each of the three stations and remained in the water column for periods of six weeks prior to harvest (Beer & Southgate, 2000). The first deployment occurred in November 2008 to coincide with the expected start of the summer spawning season of *P. margaritifera* (Cabral *et al.,* 1985). Consecutive deployments were made at monthly intervals until January 2010. This sampling frequency was chosen to maximize collector yield. Newly settled spat are usually too small to be observed and counted. Hence, the two week overlap (i.e. time elapsed between deployment of the new collectors and harvest of the old collectors) ensured that all settled oysters were collected. There was potential to overlook very small individuals if new spat collectors were deployed the same day that the old ones were retrieved. Oysters collected from spat collectors were preserved, labeled (collection date, time, site and harvest number), identified (see section 2.5) and counted.

2.2 Growth and survival of hatchery and wild spat in Savusavu Bay, Fiji.

This component of the study was carried out at the J. Hunter Pearls farm site and at Vatulele (ST 1 and ST 2)(Fig. 2). These are existing grow-out areas utilised by J. Hunter Pearls for both hatchery-produced and wild *P. margaritifera* spat; large spat have been observed by workers at the pearl farm site.

2.2.1 Hatchery spat growth trial

Hatchery produced *P. margaritifera* spat were obtained from the J. Hunter Pearls hatchery. A total of 100 spat, of 81-days of age, were used for the trial. The spat had a mean dorso-ventral shell measurement (DVM) of 13.5 ± 2.1 mm and antero-posterior measurement (APM) of 12.1 ± 16.7 mm at the start of the trial.

Ten spat were attached to each of ten PVC 'grids' (440 x 440 mm) using super glue (Fig. 3). The spat were attached at their dorsal end by the right shell valve so that their umbo faced upwards (Fig. 3b); this facilitated subsequent attachment of the spat by their byssus. The grids were covered with 10 mm^2 netting to exclude predators. Five grids were attached to the pearl long-lines at both Vatulele and the J. Hunter Pearls farm site at a depth of 5-7 m.

a.  b. 

Fig. 3. (a) Experimental grid (b) close-up of the grid showing attached spat.

Shell measurements (DVM and APM) of each individual spat were recorded monthly using a vernier caliper. The shell thickness, however, could not be measured due to the method employed for spat attachment. Data collection began in February 2009 and ended in July 2009.

2.2.2 Wild spat growth trial

A total of 120 wild collected spat of approximately 307-days of age, were used for the trial. The spat were divided into large- and small-size groups. At the start of the trial the large-size spat had a mean DVM and APM of 51.8 ± 5.0 mm and 53.1 ± 5.8 mm, respectively. The small-size spat had a mean DVM and APM of 37.2 ± 5.1 mm and 37.2 ± 5.4 mm, respectively.

Due to the larger size of these spat, a different grow-out system was employed to that in section *2.2.1*. Each spat was drilled at the anterior hinge area, strung through with nylon string and attached to a rope called 'centered turned knots' or (CTN) (Fig. 4). Pieces of lead were wound around the end of each CTN to hold it vertical in the water column. There were three sets of replicate CTNs for each size group at each station with 10 spat in each. The

twelve CTNs were covered with 10 mm^2 netting (Fig. 4) and attached to pearl long-lines at the two stations.

Fig. 4. CTN with attached pearl oyster spat and predator exclusion netting.

Shell measurements (DVM and APM) of each individual spat were recorded monthly from September 2009 to January 2010. Anti-predator nettings were changed and individual spat and slates cleaned (i.e. a knife was used to remove barnacles, other molluscs and algae) of fouling organisms during data collection.

2.3 Water quality data

Due to the availability of one multi-data logger, a single site was selected to represent water quality parameters in Savusavu Bay. Water quality parameters included water temperature (˚C), salinity (ppt), dissolved oxygen (mg/L), turbidity (meters) and conductivity (µs). Water quality data were collected from November 2008 to December 2009.

2.4 Statistical Analysis

The raw data from spat collectors over time (i.e. number of *P. margaritifera* spat) at the three stations were tested for normality and homogeneity of variance using Shapiro-Wilk and Levene's test (Shapiro and Wilk, 1965).

The Gulland-Holt plot was used to obtain the mean growth rate (mm/month) for the hatchery and wild spat at the Hunter farm and Vatulele (King, 1995).

2.5 Pearl oyster spat identification

Oysters collected from spat collectors as part of the spat recruitment survey were preserved and retained for future study. They were subsequently studied using a hand lens and compared to hatchery produced *P. margaritifera* spat obtained from J. Hunter Pearls hatchery and various pearl oyster identification guide books. Shell morphology was noted and close-up photos taken of the different species of pearl oysters that recruited to spat collectors during this study. These observations were used to construct a dichotomous key with reference to previous studies (e.g. Shirai, 1970).

3. Outcomes

3.1 Recruitment patterns of pearl oyster spat

Two spawning peaks were confirmed for *P. margaritifera* in Savusavu Bay. There was a major spawning peak in March-April followed by a minor peak in December (Fig. 5). The peak spawning period occurred during a peak in water temperature. A decrease in temperature favoured recruitment of the 'pest' and non-target species, *P. fucata* and *Pteria penguin*. Vatulele (Station 2) recorded the greatest number of *P. margaritifera.* However, recruitment at all three stations was significantly different.

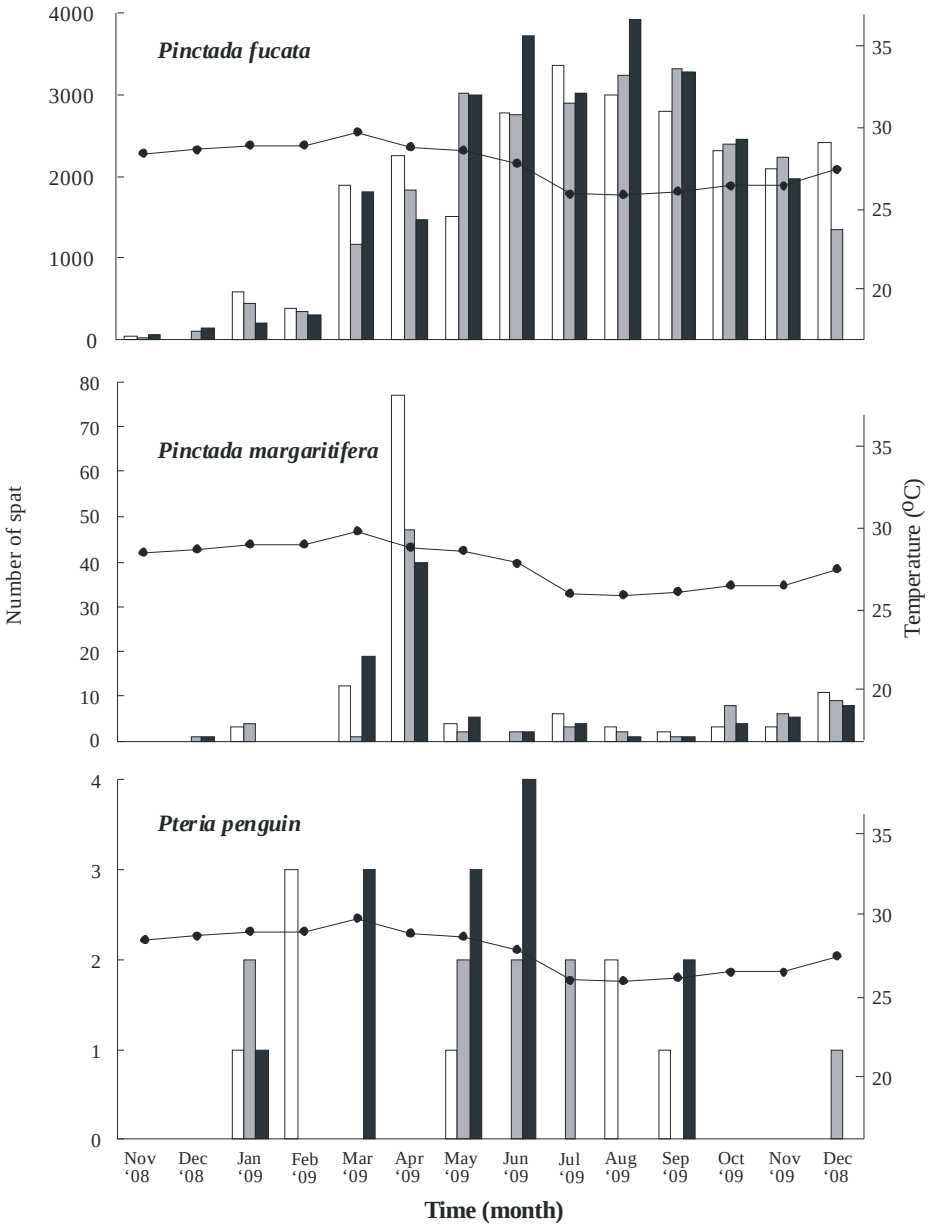

Fig. 5. Monthly recruitment of three pearl oyster species and sea temperature (°C) between November 2008 and December 2009.

3.2 Spat growth trials and survival

Growth rates of hatchery produced and wild collected *P. margaritifera* spat at the two stations is shown in Fig. 6. There were similar growth rates for hatchery produced spat at each station (Fig. 6). And these rates did not differ significantly (one-way ANOVA, $p>0.05$). There were no significant difference between mean growth rates of two size classes of wild collected spat at J. Hunter Pearls farm and Vatulele, although growth rates at Vatulele were somewhat higher.

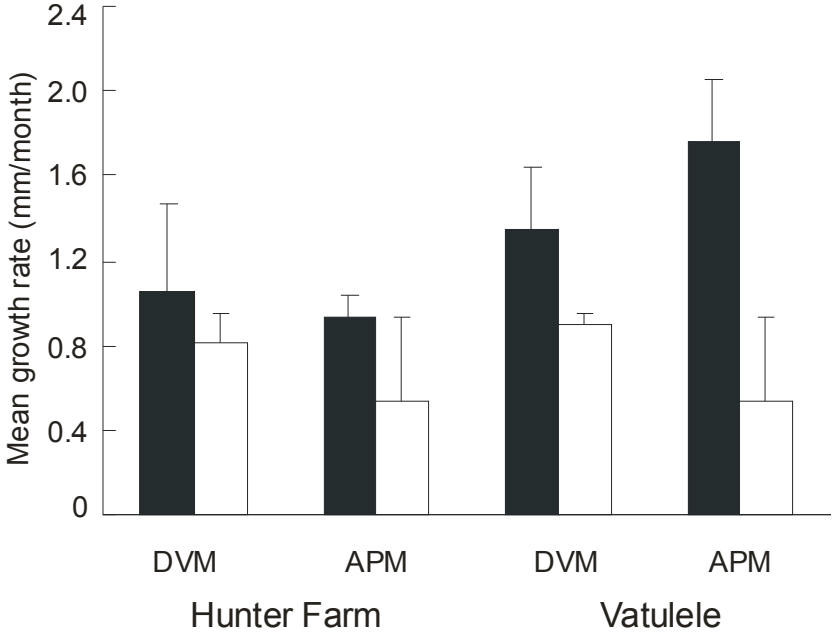

Fig. 6. Mean DVM and APM growth rates for wild collected (black bars) and hatchery produced spat (white bars) at ST1 (J. Hunter Pearls farm) and ST2 (Vatulele).

It should be noted however that direct comparisons of the growth rates of hatchery produced and wild collected spat are not possible because the initial sizes and ages of the groups was very different, and they were grown out at different times of the year.

Interestingly, the mean growth rate of spat increased with decreasing water temperature and reached a maximum during a peak in salinity (33.3 ppt) recorded in June 2009.

The J. Hunter Pearls farm site supported a better rate of survival than Vatulele (Fig. 7). Vatulele had the worst results with approximately 50% mortality after four months. Small-sized spat (i.e. hatchery spat) experienced higher mortality at both sites.

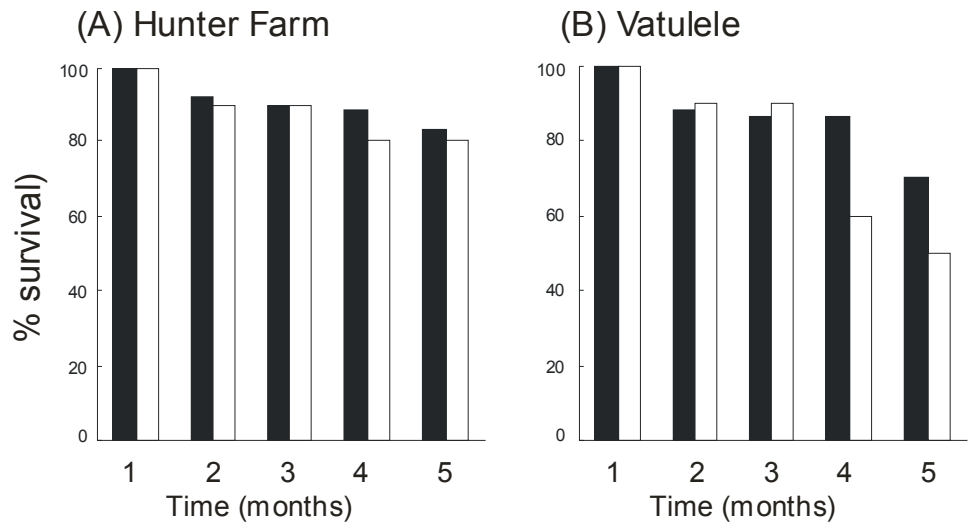

Fig. 7. Survival of wild collected (black bars) and hatchery produced *P. margaritifera* spat (white bars) at (A) ST1 (J. Hunter Pearls farm) and (B) ST2 (Vatulele).

3.2.1 Water quality

Changes in water quality parameters in Savusavu Bay over the study period are shown in Fig. 8.

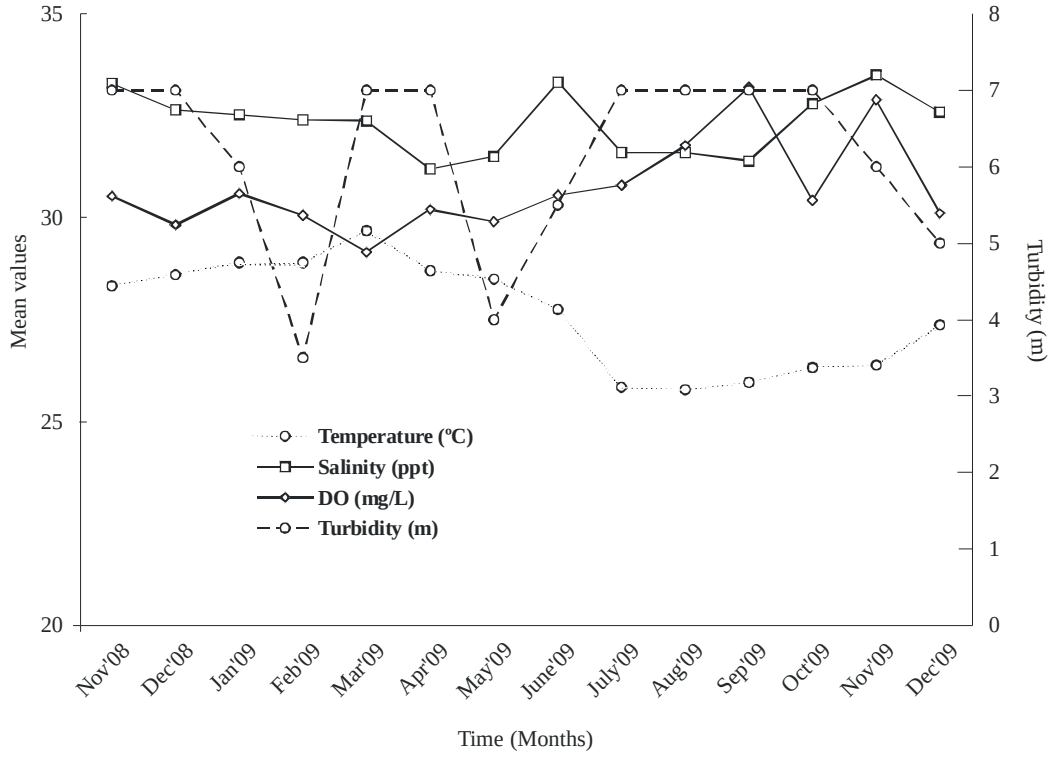

Fig. 8. Water quality data retrieved from a data logger placed in Savusavu Bay.

3.3 Spat Identification key

A comprehensive pearl spat dichotomous key was prepared. It is composed of coloured photos and easy to use steps to help identify and differentiate between *P. fucata, P. margaritifera* and *Pt. penguin* found in Savusavu Bay. This key provides a very practical method for those interested in starting up pilot plots for spat selection and collection for pearl farms in the region. The key is presented in Appendix 1.

4. Impacts

4.1 Scientific Impacts

A pearl oyster spat identification key was produced, which will be very useful for other workers in this field. Temporal and spatial data on pearl oyster spat recruitment within Savusavu Bay will help devise more targeted spat collection programmes and facilitate greater yields of target species.

4.2 Capacity Impacts

The ACIAR-USP scholarship student, Marilyn Vilisoni, enhanced her skills through this mini-project. She gained valuable experience in designing the trials, conducting the fieldwork, analysing the data and writing up the results in her MSC thesis. Workers at the J. Hunter Pearls farm also gained capacity through their involvement with this work. Development of an identification key for pearl oyster spat provides greater capacity for coastal communities to become involved in spat collection activities.

4.3 Community Impacts

This mini-project was based upon the need to design a reliable and efficient spat collection practice for commercially utilised molluscs in Fiji (with emphasis on the blacklip pearl oyster, *Pinctada margaritifera*). That is, one that incorporates the best practice for capture and handling of spat and increases productivity for Pacific pearl farms. The study identified the optimum recruitment times as April and December in Savusavu Bay and suggested the best time to deploy collectors is a month prior to these times. Although there were no significant results, there appears to be higher growth rates at Vatulele station and spat grow-out may be more successful for larger spat, although survival is higher at J. Hunter Pearls farm and smaller spat may be better started out there.

Community impacts will arise if the local community becomes involved in providing spat for established pearl farms, which would generate revenue and create jobs.

5. Conclusions and Recommendations

To maximise collection of *P. margaritifera,* spat collectors should be placed at collection sites in Savusavu Bay a month prior to the peak recruitment periods of March-April and December. The successful use of spat collectors to obtain *P. margaritifera* spat in Savusavu Bay will reduce the dependence on hatchery produced spat which is costly and time consuming and, at this stage, unreliable. Pearls produced by J. Hunter Pearls have gained international recognition for their range of colours and their quality. Pearls produced so far have resulted from wild collected oysters which provide the diversity required for a range of pearl colours that are unique to J. Hunter Pearls. Hatchery production may compromise this diversity through production of large numbers of progeny from restricted numbers of

broodstock. Rearing of these juvenile molluscs successfully into healthy adults is the next crucial step for the continued development of the pearl aquaculture industry in Fiji and the South Pacific.

Smaller spat (i.e. <40 mm) are susceptible to predators and should be covered with netting mesh size of 1mm. Different spat sizes require different mesh sizes (i.e. mesh size should be maximised for a given oyster size to maximise water flow and food delivery).

5.1 Constraints

The main constraint for this study was a delay in the release of funds to acquire equipment for the project. This impeded the deployment of spat collectors which prevented overlap of data for the recruitment experiment in September of 2008 and 2009.

Technical problems associated with a multi-data logger resulted in loss of chlorophyll-a data, which would have facilitated correlations with recruitment, growth and current data in Savusavu Bay.

The additional components of this study involving the growth of wild and hatchery spat, whose availability varied, resulting in asynchronous growth trials.

5.2 Recommendations

Chlorophyll-a studies should be carried out at the three stations to better understand the feeding mechanisms of the oysters in the farm areas at different depths. Various depths should be investigated in further studies of pearl oyster growth rate and recruitment in Savusavu Bay to help fine tune husbandry methods.

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8. Acknowledgements

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Appendix 1.

Pearl Oyster Spat Dichotomous Key (Modified after Poutiers, 1998)

1a. The shell is narrowly oblique, later expanding ventrally. The shell length is larger than the height. The posterior ear extends from the hinge and is drawn out into a wing-like expansion (Fig. 2).....2

1b. The shell is sub-quadrate in outline and laterally flattened, with ill-defined posterior auricles, not forming a wing-like expansion. The hinge length is the same or slightly larger than the DVM (Fig. 1).....3

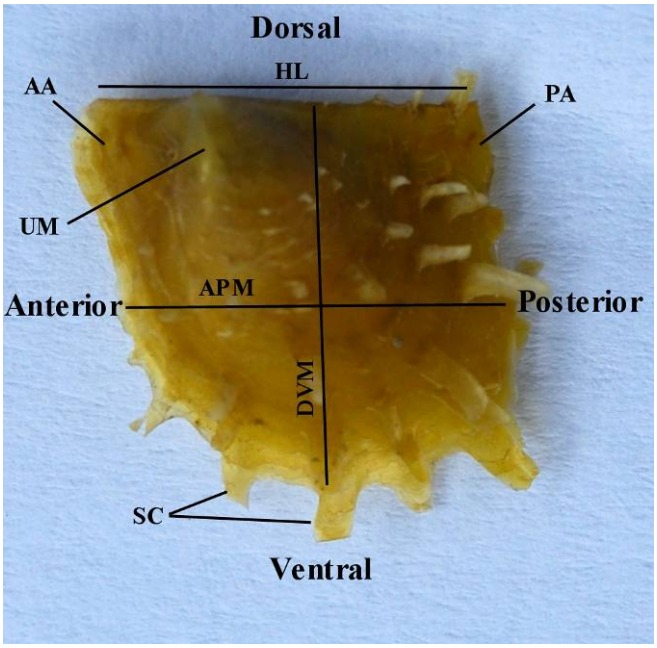

Figure 1. Left valve; exterior surface of *Pinctada*. Abbreviations: AA: anterior auricle; APM: anterior- posterior measurement; DVM: dorso-ventral measurement; HL: hinge length; PA: posterior auricle; SC: scales.

2. The shell is thin and small. The shell colour ranges from dark brown to black with white or brown radial rays (Fig. 2).....***Pteria penguin***

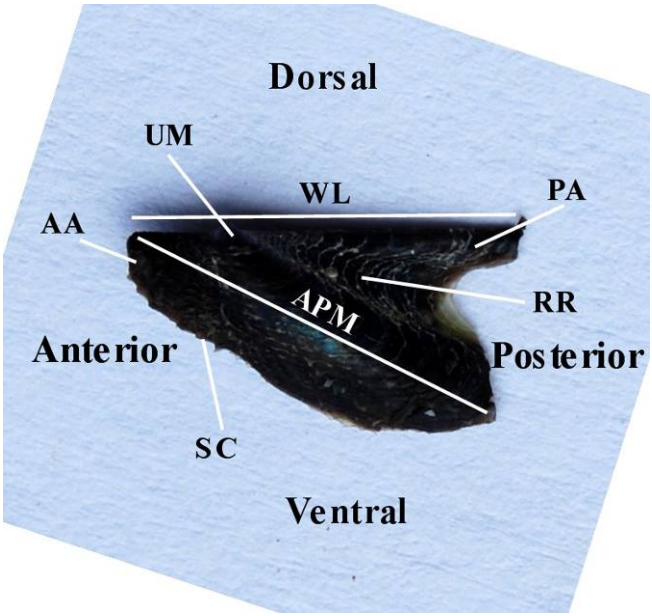

Figure 2. Left valve; exterior surface of *Pt. penguin*. Abbreviations: AA: anterior auricle; APM: anterior-posterior measurement; PA: posterior auricle; RR: radial ridges; SC: scales; UM: umbo; WL: wing length.

3a. The exterior of the shell is made up of more than one colour i.e. brown; orange-pink; orange; maroon-brown; maroon-black; dark brown and green; with white or yellow radial stripes (Fig. 3) 4

3b. The exterior of the shell is made up of one main color i.e. black; dark orange; light orange and green (Fig. 4).....4

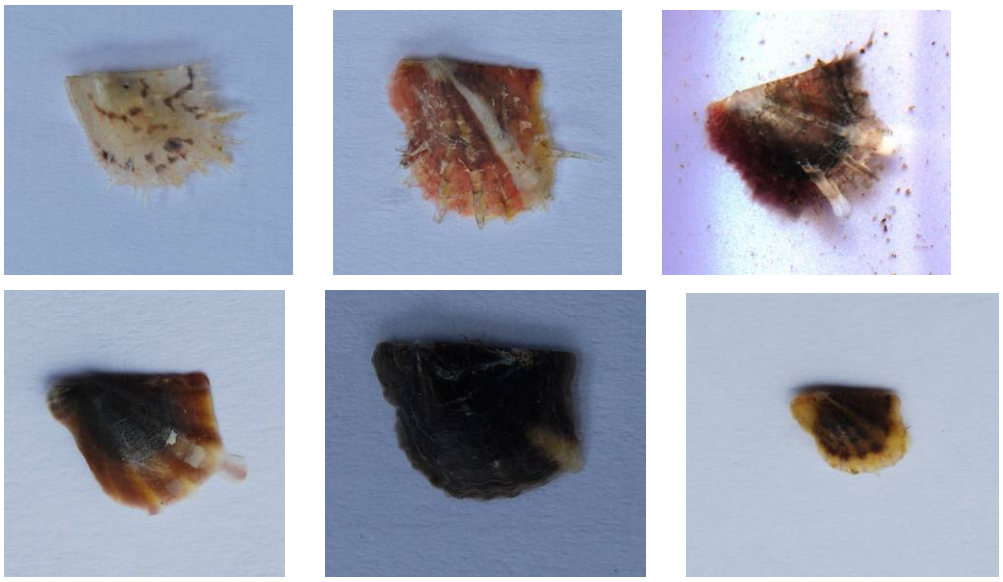

Figure 3. Exterior of spat shells which are made up of more than one colour.

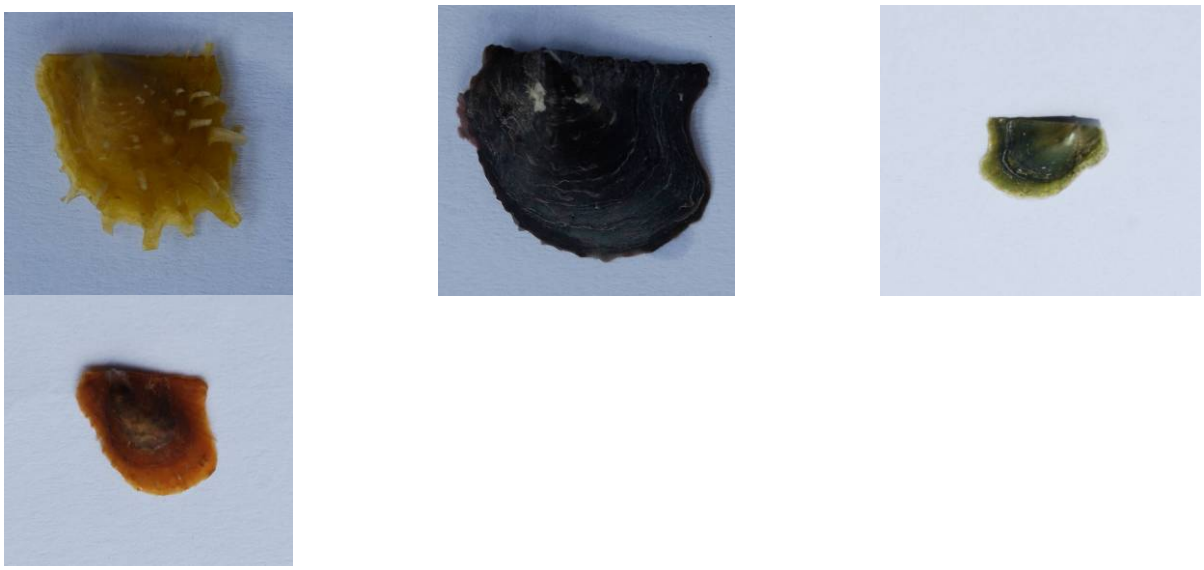

Figure 4. Exterior of spat shells which are made up of one main colour.

4a. Exterior of the shell possesses radial teeth beginning near the umbo of the left valve; at a 45 degree angle to the posterior auricle and extends until the shell edge i.e. forming the scales/ fingers (Fig. 5).....5

4b. Exterior of the shell does not possess radial teeth near the umbo of the left valve. The scales/ fingers are only present at the shell edge (Fig. 6).....6a

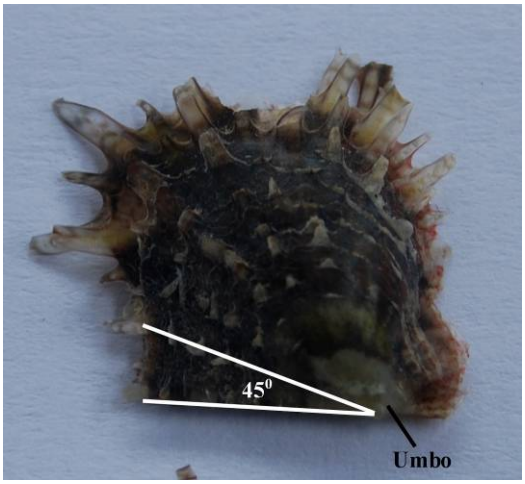

Figure 5. Exterior of left valve of four week old spat; showing 45˚angle at which radial teeth begin at the umbo.

Figure 6. Exterior of left valve of four week old spat; showing absence of scales/fingers.

5a. The scales/fingers overlap and taper at the shell edge (Fig. 7) 6a

5b. The scales/fingers overlap but do not taper at the shell edge (Fig. 8) 6b

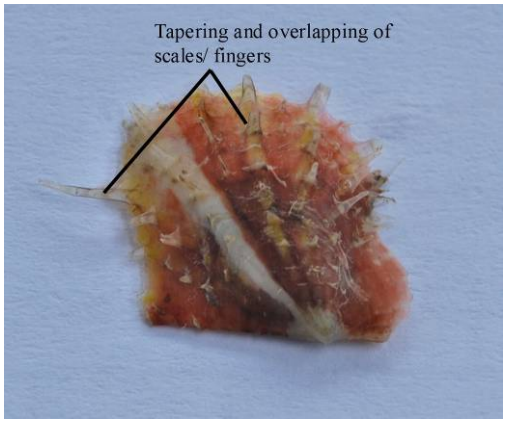

Figure 7. Exterior of left valve; showing tapering and overlapping of scales/ fingers.

Figure 8. Exterior of left valve; showing no tapering of scales/ fingers.

6a. Nacreous area is silver; pink; orange in colour with 'thin fingers' (Fig. 9) .....***P. fucata***

6b. Silver nacreous area with 'thick fingers' (Fig. 10)..... ***P. margaritifera***

Figure 9. Exterior of left valve of *P. fucata* species; showing scale tapering at the shell edge. Scales/ fingers are thin.

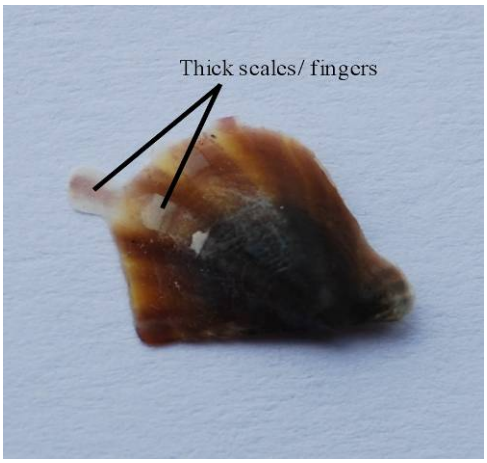

Figure 10. Exterior of left valve of *P. margaritifera* spat at four weeks. Scales/fingers are thick and are the distinguishing feature of this species.

Appendix 2.11

MS0806
Closing the life cycle of *Macrobrachium lar*, Fiji

ACIAR Pacific Aquaculture Grant: **Project Summary**	    	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**
Project Title:	**Spawning and larval rearing of the Monkey River Prawn *Macrobrachium lar* in the Fiji Islands (MS0806)**	
Goal:	To close the life cycle of *Macrobrachium lar*.	
Objective(s):	The project will achieve this goal through the following objectives: 1) culture *M. lar* and describe its larval development stages to the post-larval stage; 2) evaluate the growth and survival of *M. lar* larvae under different culture conditions of salinity and temperature; and 3) examine the feasibility of commercial-scale production of *M. lar*.	
Project location:	Suva, Fiji Islands	
Project partner(s):	USP, SPC	
Dates / duration:	2 years	
Project description	*M. lar* is highly prized as a food source in Fiji, with an estimated 170-200 tonnes purchased annually. It is ideally placed to become an important aquaculture commodity in the Pacific Islands region but it has not yet been bred in captivity. Collection of wild-caught juveniles is not sustainable as already there is evidence of declining wild stocks due to over-fishing and habitat degradation. This mini-project is an ACIAR-USP postgraduate student MSc project. The student will undertake a series of hatchery trials and experiments aimed at closing the life-cycle of *M. lar*, improving larval rearing techniques and increasing baseline knowledge about its culture requirements. It follows on from an earlier mini-project (Monoculture of the Native Freshwater Prawn *Macrobrachium lar* in Vanuatu, and Integrated with Taro in Wallis and Futuna).	
Justification	A major drawback to further aquaculture development of this species has been that the species cannot be bred in captivity. This attempt to close the lifecycle is an important step in realising its aquaculture potential.	
Adoption and extension	1. information and techniques that will allow further development of aquaculture industry involving *M. lar*; 2. a larval stage identification guide for this species. 3. increased capacity in Fiji for freshwater aquaculture.	
Budget:	AUD $7,000	

Spawning and Larval Rearing of the Monkey River Prawn *Macrobrachium lar* in the Fiji Islands

Monal Lal [1] and Tim Pickering [2]

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[2] Secretariat of the Pacific Community, Suva, Fiji

1. Background

Currently the major prawn species in culture in Fiji is the Malaysian Giant Freshwater Prawn, *Macrobrachium rosenbergii*. Other marine species such as the black tiger shrimp (*Penaeus monodon)* and the blue shrimp (*Litopenaeus stylirostris)* have been cultured in Fiji before (Pickering and Forbes, 2002) but no large-scale farms are operational at this time. *M. rosenbergii* was introduced to Fiji in 1975 and 1979 from Hawaii, with subsequent introductions from Tahiti (Kwong, 1984; Choy, 1984). Further work was carried out on this species at the Naduruloulou Freshwater Aquaculture Research Station under the Commodity Development Framework Program which ran from 1997 to 1999 (Department of Fisheries, 2004). *M. rosenbergii* is by far the most researched and highly commercialised of the approximately 200 species (Nandlal, 2005) of *Macrobrachium* that have been described worldwide, owing to its fast growth rates, large size, attractive meat quality and omnivorous feeding habit which make it adaptable to both small and large-scale farming operations (Nandlal and Pickering, 2005).

There are also a number of indigenous *Macrobrachium* species found in Fiji, including *M. australe*, *M. equidens*, *M. gracilirostre*, *M. grandimanus*, *M. latimanus*, *M. lepidactyloides*, *M. placidum* and *M. lar* (Choy, 1984). Out of these, *Macrobrachium lar,* the Monkey River Prawn (Figure 1) is the most common and widest ranging freshwater species in the Indo-West Pacific region (Choy, 1984). *M. lar* is a generalistic omnivore, and is known to consume a large quantity of plant material in its diet (Mather et. al., 2006a). For this reason, it is well suited for polyculture with native root crops such as taro (Nandlal, 2005; Mather et. al., 2006a). Due to its large size and other favourable characteristics such as being able to withstand short periods of desiccation (Carpenter and Niem, 1998), it appears to have good potential for aquaculture which warrants research being conducted on the species to assess its suitability. Indeed, an ACIAR mini-project carried out in Vanuatu and Futuna several years ago, ran grow-out trials on wild-caught *M. lar* juveniles with promising results.

A number of other reasons for investigating the potential for aquaculture of *M. lar* include:

1. The need to protect wild stocks of *M. lar* from anthropogenic threats: natural stocks of *M. lar* have declined in many places due to over-exploitation, illegal fishing and habitat modification (Nandlal, 2005; Mather et. al. 2006b).
2. It is already indigenous to the island Pacific, with a natural distribution that extends from SE Africa to the Marquesas Islands, whereas *M. rosenbergii* is naturally restricted to SE Asia, though it is being farmed as an introduced species in Fiji.
3. Disease threats: the disease status of Fijian *M. rosenbergii* is largely unknown, but viruses, bacterial disease and other problems have been reported for *M. rosenbergii* in other countries (e.g. a *Macrobrachium* Hepatopancreatic Parvo-like Virus (MHPV) and Muscle Virus (MMV, Johnson and Bueno, 2004). The availability of an alternative culture species, such as *M. lar,* would be an advantage for the local prawn culture industry should a serious disease concern arise in the *M. rosenbergii* population. Given that *M. lar* is native, healthy stocks could easily be

sourced from wild stocks provided that they remain unaffected by disease from cultured *M. rosenbergii* stocks.

M. lar is highly prized as a food source in Fiji, with an estimated 170-200 tonnes purchased annually (Ponia, 2004) and is ideally placed to become an important aquaculture commodity in the Pacific Islands region. A major drawback to further development has been that the species has not been successfully bred in captivity. There have been four documented attempts at closing the life cycle of *M. lar*: by Kubota (1972) in Hawaii who managed to rear larvae up to Stage V; by Atkinson (1977) in Hawaii up to Stage XI; by Takano (1987) in Fiji; and (Nandlal, 2010) in Fiji up to Stage VII. Research carried out by (Nandlal, 2010) identified requirements of *M. lar* culture in Fiji, providing a benchmark for this study.

2. Project Methodology

Research for this project was carried out as part of a Master of Science Degree for the project principal researcher (Monal Lal). All experimentation was carried out at the Seawater Laboratory of the School of Marine Studies of the University of the South Pacific in Suva, Fiji Islands.

2.1 Larval rearing trials

Twenty separate replicated trials were carried out in 1,000 L polyethylene larval rearing tanks (LRTs) in three phases where larvae were hatched and reared at increasing salinities to maxima of 20, 25 and 30 ‰ respectively. The purpose of these trials was to determine the characteristics and performance of the larvae under laboratory culture conditions and to make observations which would lead to the development of a culture method that would be successful in producing post-larvae (PL) of *Macrobrachium lar*. Subsequent trials were progressively refined using information gained from previous unsuccessful trials. Basic culture parameters such as salinity, temperature, aeration volume, photoperiod, average larval development and survival and feeding etc. were recorded and varied for each trial.

2.2 Larval development observations

Concurrently during each culture trial, observations on the development of the larvae after hatch from the egg were carried out at regular intervals. The average size (carapace and total lengths) and morphological characteristics of the larvae were noted as the larvae developed and the data gathered used to identify the different developmental stages the larvae pass through before they metamorphose into post-larvae. This information was used to produce a simple guide for the identification of the larval development stages of *M. lar*. The purpose of the guide was to provide a rapid means of identifying live larval specimens during a culture run for the scientist/hatchery operator, without incorporating too much anatomical detail.

2.3 Culture conditions experimentation

The findings of the larval rearing trials described earlier were used to devise a series of experiments to determine optimal ranges of salinity and temperature for culturing the larvae of *M. lar*.

2.3.1 Salinity tolerance tests

A two-phase approach was taken to determine salinity range optima for *M. lar* larvae by way of short-duration salinity tolerance tests. The first phase of the investigations was termed ‘coarse-resolution tolerance tests’, whereby larvae of different developmental stages were acclimated to four different test salinity regimes viz. 0, 10, 20 and 30‰, to determine the proximate salinities which produced optimal survival and growth. The second phase of investigations was termed ‘fine-

resolution tolerance tests' and were based upon the results of the coarse-resolution phase. These tests exposed larvae of the same developmental stages as those in the previous phase to a range of test salinities in 5‰ increments bordering the best test salinity from the coarse-resolution phase. Survival and growth (larval developmental stage increase) of stage I, III, V and VII larvae were monitored in the experimental setup for 5 days using larvae acclimated from a mass-culture run.

2.3.2 Temperature optima experimentation

Three test temperature ranges *viz*. 26 ± 0.5°C, 28 ± 0.5°C, and 30 ± 0.5°C, were evaluated to determine their effect on survival and growth (Larval Staging Index) of *M. lar* larvae for test periods of 10 days each. Larval Staging Index (LSI) was calculated according to Mallasen and Valenti (2006) as follows:

$$LSI = \frac{\left(\sum S_i \times n_i\right)}{N}$$

Where: n_i = number of larvae in each stage

S_i = larval stage N = total number of larvae examined

i = 1 – 5; representing each larval stage

Treatments were replicated thrice using 60 L cylindro-conical larval rearing tanks.

3. Outcomes

The results and project outcomes are described below against the project objectives:

3.1 Culture *M. lar* and describe its larval development stages to the post-larval stage

Post-larvae (PL) of *M. lar* were produced in the USP seawater laboratory in December 2009, which may be the first time this has been achieved since larval rearing work on *M. lar* first began some 39 years ago (Kubota, 1972). A total of five PL were produced, metamorphosing 77, 78, 85, 101 and 110 days, respectively, after hatching (Fig. 1). A larval development identification guide has been developed up till the post-larval stage, indicating approximately 13 zoeal stages before metamorphosis to post-larva in this species. Simple descriptions of the larval development stages have also been made. Constraints identified in this study included a very low larval survival rate from hatch until metamorphosis into PL (0.08%) and a prolonged period over which larval hatch occurs in berried female *M. lar* broodstock.

A copy of the larval staging guide has been attached to this report as Appendix 1. Specimens of all larval stages were collected during the culture runs and lodged at the Marine Reference Collection of the School of Marine Studies, Faculty of Science, Technology and Environment, University of the South Pacific, Suva, Fiji Islands under Catalogue Number 5940.

Figure 1. Post-larva of *Macrobrachium lar*

3.2 Evaluate the growth and survival of *M. lar* larvae under different culture conditions of salinity and temperature

From the experiments on coarse resolution salinity tolerance that were carried out, it appears that completely marine conditions are optimal for the growth and development of *M. lar* larvae. The best larval survival and growth was noted at 30‰, with larvae failing to develop past the ninth zoeal stage at salinities below 25‰ (Fig. 2). The results of the coarse and fine resolution salinity tolerance tests on the growth and survival of *M. lar* larvae at stages I, III, V and VII are shown in Figures 2 and 3, respectively. Statistical analysis using Repeated Measures ANOVA and Least Significant Differences (LSD) found that the differences in growth and survival between the treatments were significant ($p < 0.05$).

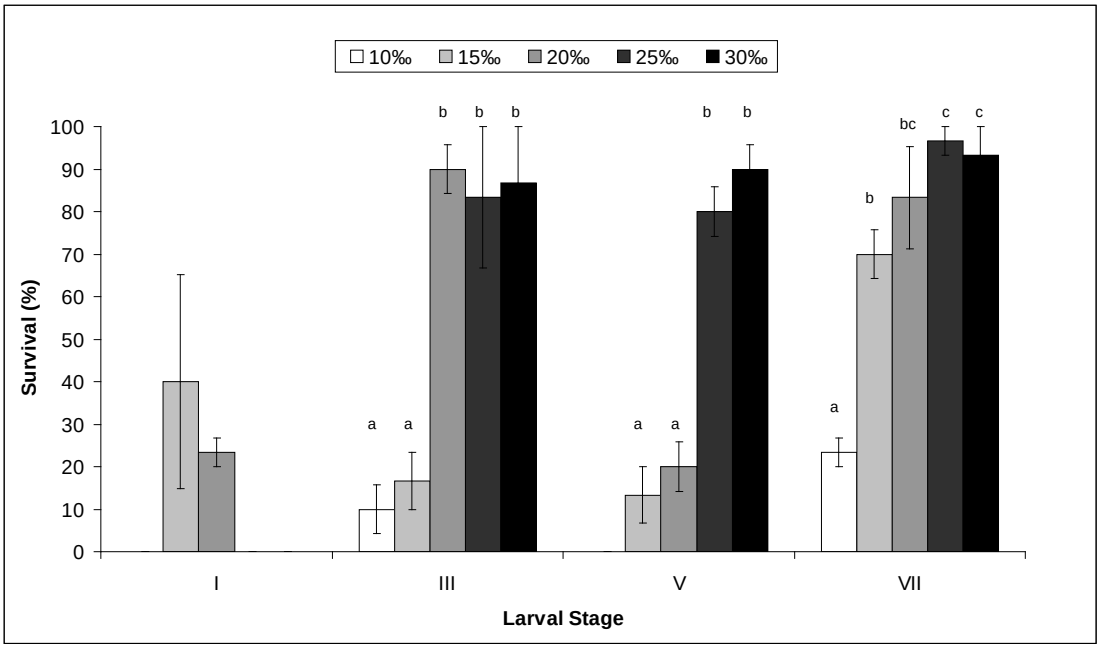

Figure 2. Effect of fine resolution test salinities on percentage survival of *M. lar* larvae (Mean ± S.E., n = 5). Superscripted letters indicate significant differences ($p < 0.05$).

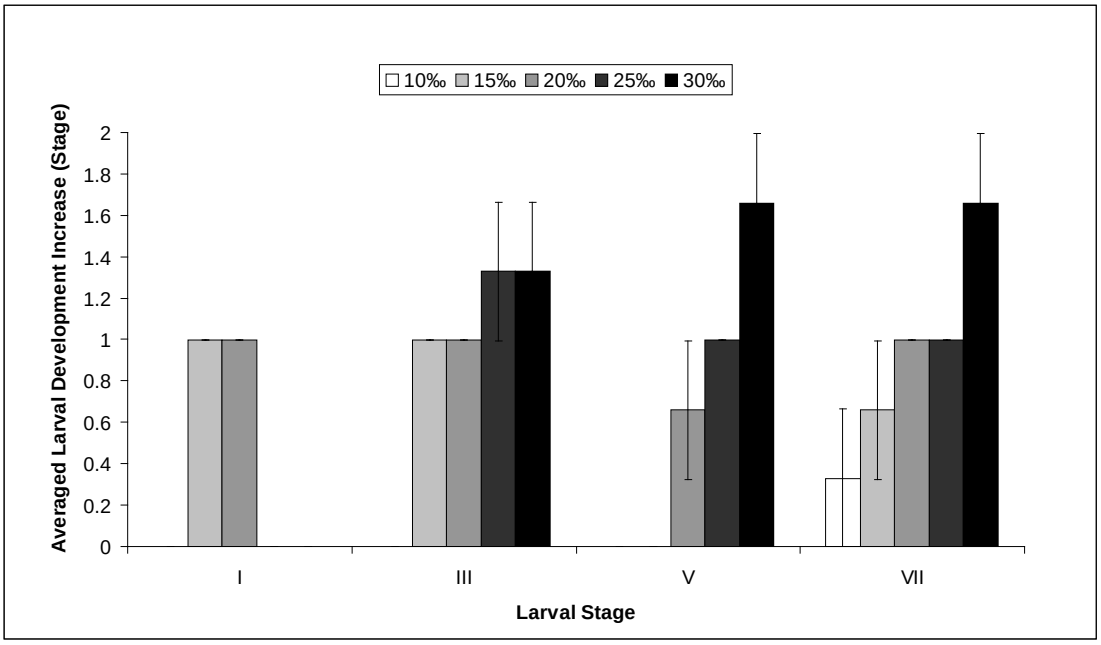

Figure 3. Effect of fine resolution test salinities on growth of *M. lar* larvae (Mean ± S.E., n = 5).

The results of the temperature experimentation indicate that growth and development of the larvae up to the fifth zoeal stage are faster at 30°C when compared to larvae cultured in the other experimental treatments at 26°C and 28°C (Figs 4 and 5). Analysis using Repeated Measures ANOVA and *a posteriori* One-Way ANOVA testing between treatments at sampling intervals found that the differences in growth and survival between the treatments were significant ($p < 0.05$) from day 6 of culture onwards.

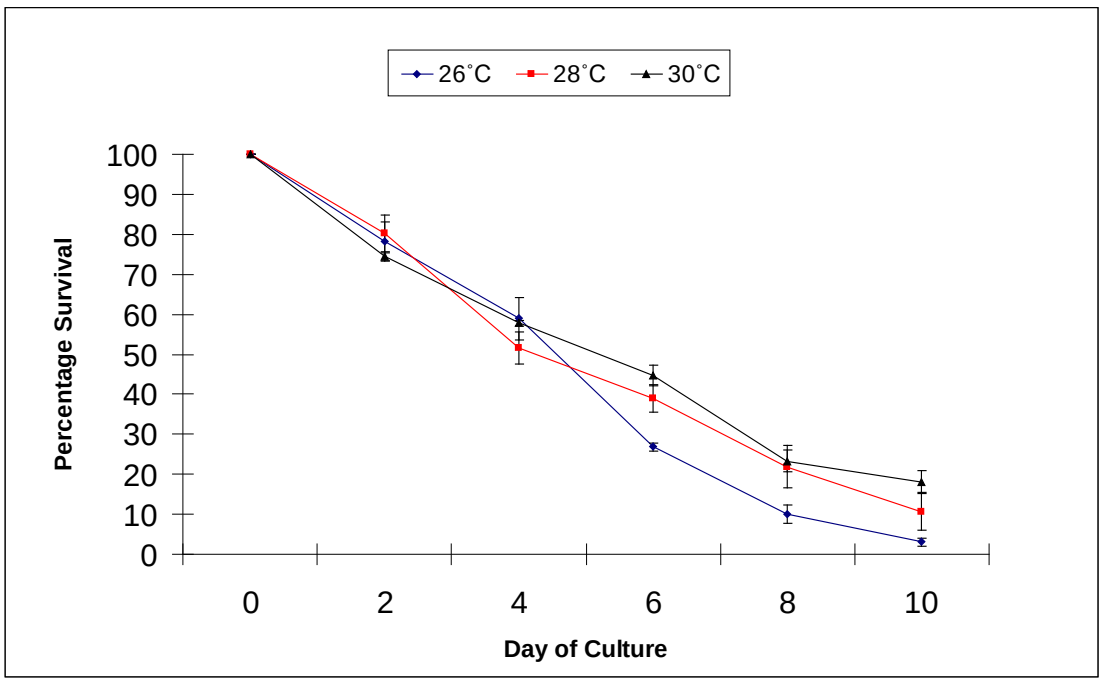

Figure 4. Effect of treatment temperatures on larval survival (Mean ± S.E., n = 3).

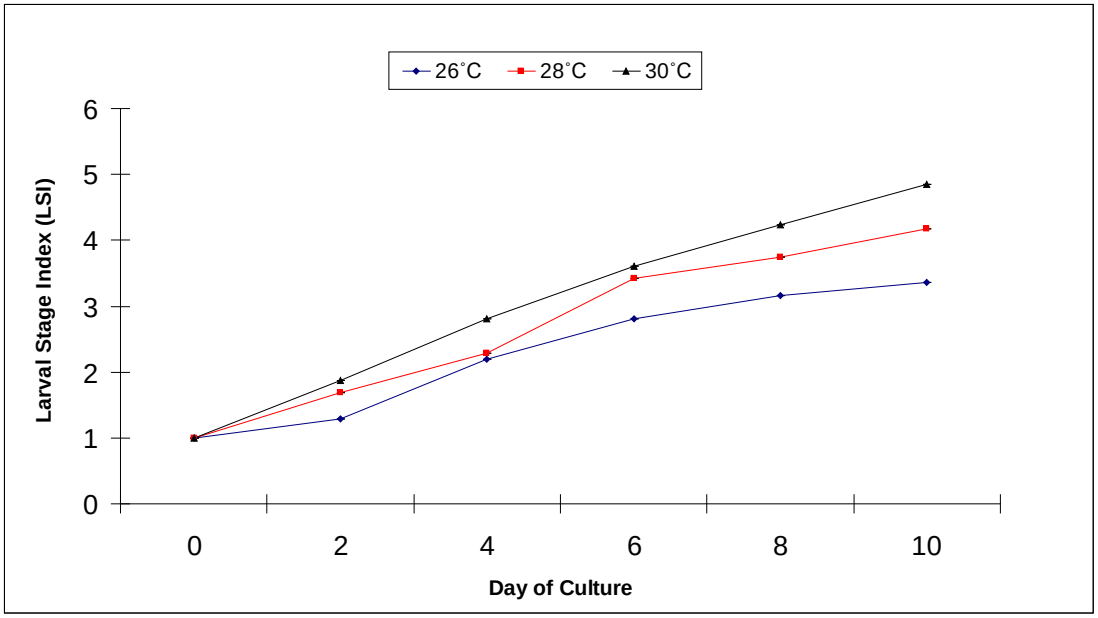

Figure 5. Effect of treatment temperatures on larval growth (Mean ± S.E., n = 3).

3.3 Examine the feasibility of commercial-scale production of *M. lar*

The results of the current study are a significant achievement for *M. lar* research as larvae have been successfully reared in captivity from eggs through to the post-larval stage. The success of this study can be attributed in part to the development of a suitable feed that appears to better meet the nutritional requirements of the larvae, in addition to culturing it at its preferred salinity level in an appropriate rearing environment (see Lal, 2011).

There is scope for much more research into *M. lar*, and the work done here is an important step towards further developing and refining techniques for its culture. Among the constraints identified in this study were a very low larval survival rate (0.08%) until metamorphosis into PL and a prolonged period (see Lal, 2011) over which larval hatch occurs in berried female *M. lar* broodstock, both of which will need to be addressed by future research efforts. Overall, the findings of this study show that *M. lar* larval performance compares very poorly with *M. rosenbergii*, which can routinely reach post-larval stage in only 20–30 days and with 20–50% survival of large batches.

Among the opportunities identified for further research into *M. lar* larviculture was the possibility that larvae of this species may require a higher proportion of vegetable matter (via biofloc) in their diet, and that this may reduce the time to reach PL stage. This may lead to less *Artemia* nauplii being required as live feed, which would greatly reduce hatchery operating costs. Nauplii production for *M. rosenbergii* culture makes up a large proportion of hatchery operating expenses.

Further research is required to better understand optimal culture conditions required by the larvae of *M. lar*, especially with regards to larval feeding in order to reduce duration of the larval phases. As an example, significant decreases in instar duration and increases in survival rates were observed in this study once the optimal target culture salinity of 30‰ was identified and mass cultures of larvae were maintained at this salinity compared to previous trials where the target culture salinity was set at 20 and 25‰.

The primary issues which remain to be resolved if commercial-scale culture is to be made feasible are improvement of larval survival and decreasing development time. Larval nutrition is likely to play a crucial role in this regard. Further work with incorporating biofloc into the culture system and trialling micro-encapsulated feeds may yet prove that large scale larviculture for this species is possible. For the short and medium-term, the capture of wild juveniles will have to be relied upon for developing the culture of *M. lar* in ponds. However, it may be premature to discontinue efforts to understand the larval requirements of this species as they may lead to successful mass-culture techniques through which production of sufficient numbers of PL for pond-stocking could be realised.

4. Impacts

4.1 Scientific impacts

As a result of the research carried out as part of this mini-project, the technical feasibility for production of *M. lar* PL in the laboratory has been demonstrated. This is a significant achievement as this has previously not been able to be reported by other researchers who have worked on the larval rearing of this species in earlier studies.

Another achievement of this project has been that baseline salinity and temperature parameter requirements for the larvae have been established, along with a technique that has proved itself capable of producing PL in the laboratory. This preliminary information will be of much use for further research into mass larval rearing of this species.

4.2 Capacity impacts

Specific training was provided to the principal researcher over the course of the project on how to adapt the Rua Cell System of greenwater larviculture to culture larvae of *M. lar* by senior JICA volunteer Mr. Tomohiro Imamura. As a result of this training, there is capacity in-country for further research work on *M. lar* larviculture.

4.2 Community impacts

This project has had no community impacts that are able to be reported. However, if routine hatchery production of this species can be achieved, then there would be important community impacts through the availability of cultured *M. lar* PLs for pond farming. The environmental advantages of using an endemic prawn species were outlined in the introduction. Features such as the lower protein requirements make this a desirable species to farm in the Pacific context. This mini-project has made an important contribution towards the development of this species as an aquaculture commodity.

5. Conclusions and Recommendations

5.1 Conclusions

The primary goal of the research, which was to rear larvae of *M. lar* from hatch through to metamorphosis into post-larvae, has been achieved. Data on the salinity and temperature requirements of the larvae have also been collected, and will be of use in further investigations on the larviculture of this species. It is now apparent that the larvae of *M. lar* develop through approximately 13 zoeal stages at a salinity that needs to be gradually increased from either 0 or 10‰ up to a maximum of 30–35‰ for the duration of culture. A temperature of 30^{o}C appears to be optimum for growth and development.

Mass culture of the larvae of this species unfortunately will require more research in order to improve larval survival rates and shorten larval development times in order for a commercial-scale hatchery operation to be economically viable. For the short to medium term, capture-based culture methods appear to be the only alternative for small-scale culture of *M. lar* in ponds.

5.2 Recommendations

A number of areas for further research have been identified as a result of the work carried out for this project. These are outlined below:

- Improve larval survival rates up to PL to a level where commercial-scale production is feasible. The current study recorded an overall survival of 0.08% to the PL stage, which will need to be improved significantly to compare with survival rates of *M. rosenbergii* larvae which average upwards of 20 to 50%.
- Shorten larval development time to compare with *M. rosenbergii* larvae. This study recorded the first and last PL produced metamorphosing on day 77 and 110 of culture, respectively. With *M. rosenbergii*, the first PL are usually seen between day 20 and 25 with all surviving larvae metamorphosing into PL by day 35 and 40 of culture. If development time could be reduced by half, this would compare well with the performance characteristics of *M. rosenbergii* larvae.
- A key to improvement of larval survival and development duration may involve larval nutrition. Investigations of the importance of biofloc in the diet of the larvae are warranted, along with studies on the nutritional requirements of the larvae. Observations made during the current study showed that larvae had a distinct preference for biofloc over *Artemia* nauplii as a live food item. If this is able to be experimentally proven, it will imply cheaper hatchery operating costs for *M. lar* larviculture over *M. rosenbergii*, as less *Artemia* will be consumed and biofloc are able to be produced cost-free in the larval rearing tanks.
- Fine-tuning of the culture environment salinity and temperature parameters are also worth investigating, along with attempting to grow the larvae in a clearwater system. Further work on the salinity requirements of the larvae will identify if there is an optimal regime by which the salinity of the culture medium should be increased to maintain maximal larval survival and growth. Successful culture of larvae in a clearwater system will demonstrate if the nutritional requirements of the larvae are sufficiently understood to allow culture in a system which does not contain additional sources of live feed as a greenwater system does.

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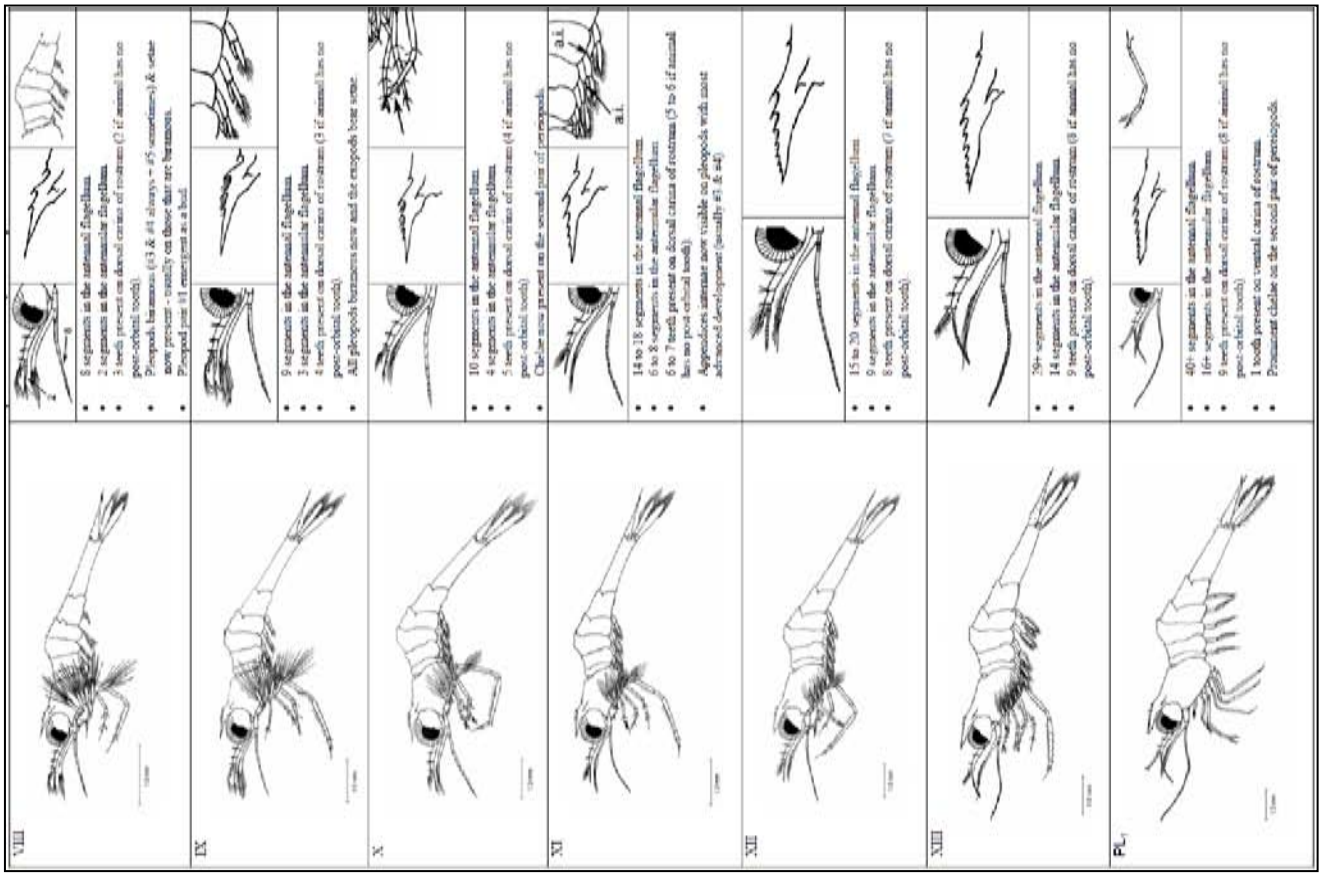
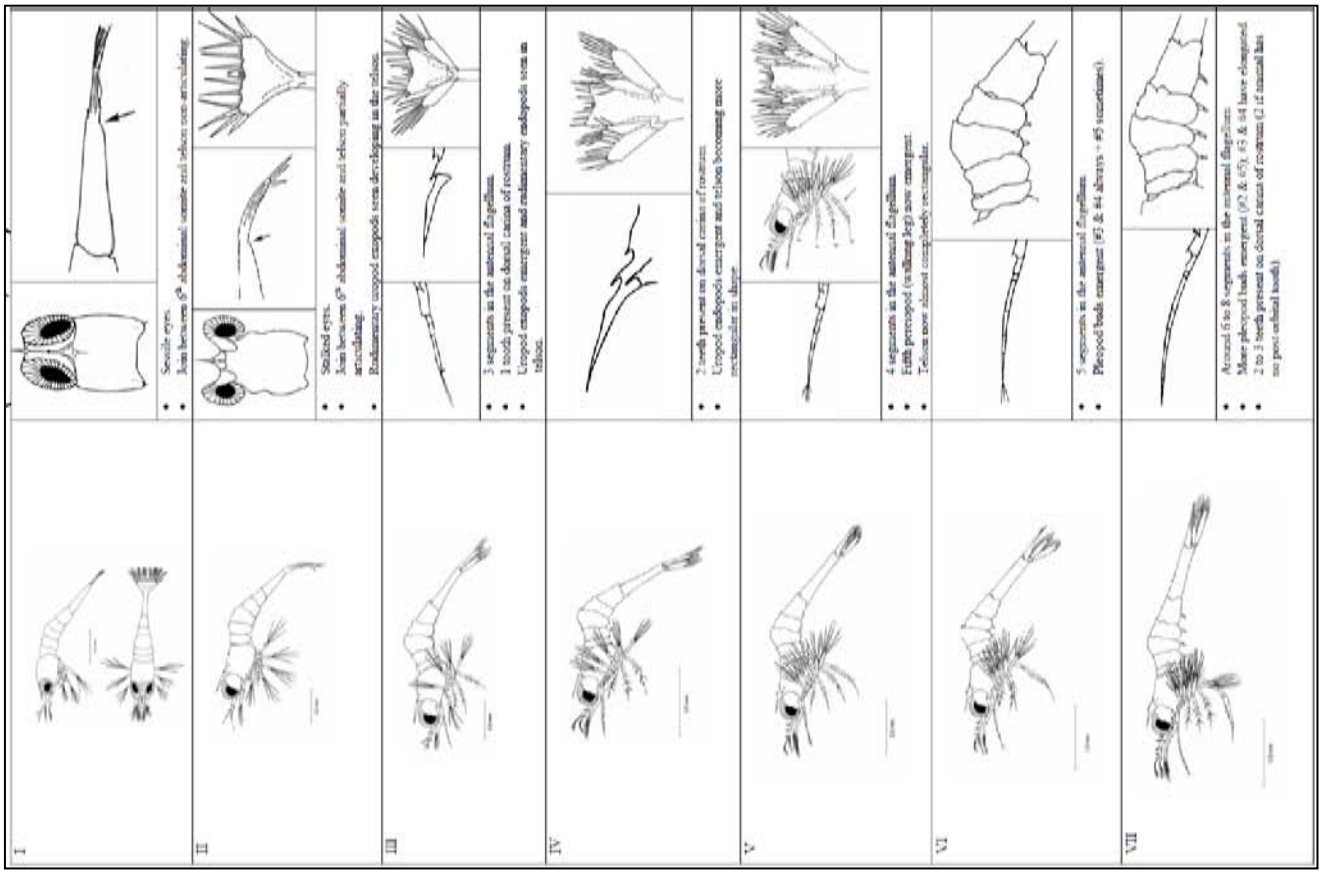
Appendix 1: Staging Guide for the larvae of *Macrobrachium lar* (Fabricius, 1798)





Appendix 2.12

MS1003

Evaluation of different substrata to enhance freshwater prawn post-larvae production, Fiji

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU James Cook University WorldFish Center USP The University of the South Pacific	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Evaluation of different substrates to enhance freshwater prawn post-larvae production (MS1003)**
Goal:	Investigate the effects of introducing different substrates with various physical characteristics as a culture system enhancement for freshwater prawn production in Fiji.
Objective(s):	The project will achieve this goal through the following objectives: 1) Evaluate survival and growth of freshwater prawn post-larvae (PL) using different culture substrates. 2) Investigate the best substrate based on colour, mesh size, texture and orientation to obtain the best surface distribution possible. 3) Determine optimum PL/juvenile prawn stocking density using culture substrates.
Project location:	Suva, Fiji Islands
Project partner(s):	USP, Division of Marine Studies
Dates / duration:	18 months, starting March, 2010
Project description:	A method to reduce production costs is to increase stocking density at the nursery and grow-out phases (increase production per surface area), but this practice very often sacrifices survival and growth. Culture systems that maximise production by increasing survival and growth rate facilitate the commercial viability of prawn hatcheries and nurseries. This study of investigating the effects of artificial substrates for freshwater prawns is a first for Fiji.
Justification:	The cost of producing prawn PL is very high, thus new technologies are required to decrease production costs by enhancing production.
Expected outcomes:	1) Increased freshwater prawn PL culture performance. 2) Knowledge of the best substrate for PL settlement. 3) Improved industry and livelihood opportunities in Fiji's prawn industry.
Funding:	$6,500

Evaluation of different substrates to enhance freshwater prawn post-larvae production

William Camargo and Chillion Panasasa
University of the South Pacific, Suva, Fiji Islands

1. Background:

The giant freshwater prawn *Macrobrachium rosenbergii* (De Man 1879) is a commercially important species in several South Asian and South Pacific countries, Northern Oceania, and Western Pacific islands, both as a food item for local consumption as well as a valuable export product. Aquaculture of *M. rosenbergii* is a growing industry in Pacific Island countries. The GFP was one of the first species to become scientifically known, the first recognisable illustration appearing in 1705 (New, 2002). Species of the freshwater prawn genus *Machrobrachium* are distributed throughout the tropical and subtropical zones of the world (New, 2002). They are found in most inland freshwater areas including lakes, rivers, swamps, irrigation ditches, canals and ponds, as well as estuarine areas. Most species require brackish water in the initial stages of their life cycle, although some complete their cycle in inline saline and freshwater lakes (New, 2002).

Freshwater prawn farming is an important aquaculture industry in many Asian countries, which contributes over 98% of the global freshwater prawn production (Asaduzzaman, 2009). Fiji has a strong domestic market demand (approx. 700 t/yr) for penaeid shrimp (retail price US$14–17/kg), but only 100 t/yr can presently be provided by local sources and the remainder is imported from overseas (Pickering and Chim, 2007). The local supply from the natural population is quite small and is estimated to be less than 500 t/yr. The local market price for freshwater prawn was previously less than FJ$20/kg, but currently fetches around FJ$25-30/kg (Fiji Islands Trade and Investment Bureau, 2009). However, aquaculture in Fiji is still at its infancy (less than 10% of the value of all fishery exports) and this is expected to increase. The major obstacle that Fiji faces is the lack of adequate numbers of post-larvae (PL) to supply the ever-increasing demand from existing and new freshwater prawn farmers. The grow-out sector of the industry depends entirely on hatchery-produced PL and the primary problem facing this emerging industry is the unavailability of post larvae (Nandlal and Pickering, 2005).

Therefore it is vitally important to work out ways as such to increase the sustainability and yield of the fresh water prawn industry in Fiji as well as other Pacific countries. In aquaculture, substrates have been used for improving production of the cultured species and water quality. Various types of materials such as halved plastic bottles, bamboo, fire wood, water hyacinth, bamboo mat, nylon netting, PVC pipes, plastic sheets (Shrestha and Knud-Hansen, 1994; Tidwell et al., 1998) and custom designed materials like Aquamats™ (Bratvold and Browdy, 2001) have been used as substrate. The aim of this study was to evaluate the growth performance of the *M. rosenbergii* PL using a natural culture substrate and to investigate the best substrate position to obtain the optimum surface distribution possible in order to increase PL production.

2. Project Methodology

2.1 Experimental design

A total of nine glass aquaria (68 x 43 x 36 cm or 1.083 m^2) were used to evaluate the effect of natural substrate (potato sack) material on *M. rosenbergii* PL performance (growth and survival) and feed conversion ratio (FCR) over a 51-day culture period. To increase the surface area available for prawn PLs, galvanized wire racks (each 32 x 23 cm or 1.17 $m^{2)}$ with 5 layers of potato sack material were placed in tanks as experimental units. Treatments in the experiment were: vertical (n=3 racks); horizontal (n=3 racks) and control (n=3, no racks). Each tank was stocked with 36 PLs. The initial average PL weight and carapace length was recorded for 100 PLs from the same batch but not used in the experiment (to avoid stressing experimental animals).

At the end of the experiment all animals were collected from each aquarium for final weight and carapace length determination. The weight was determined with an analytical scale and carapace length was measured with an electronic vernier-caliper. Remaining animals were counted and survival expressed as percentage.

Temperature (^oC) and dissolved oxygen (DO, mg/L) were measured daily, and were maintained between 25–28°C and above 6 mg/L, respectively. Continuous aeration was supplied. A 20% water exchange was done on a daily basis to maintain good water quality. The PLs was fed to apparent satiation with pelletised feeds (35% protein from Pacific Feeds Ltd, Fiji) four times a day (09:00, 11:30, 14:30 and 16:30) according to Arnold et al. (2005).

No experiments were undertaken to determine the best substrate colour, mesh size or texture or investigate optimum stocking density.

2.2 Statistical Analysis

Raw data was analysed via normality and homogeneity of variance. Sample distributions violating assumptions were log-transformed before analysis. Data expressed as percentages (e.g. survival), were arc sine-transformed before analysis. Data on growth performance (total carapace length and weight) and survival were subjected to one-way analysis of variance (ANOVA) followed by a comparison of means using the least significant difference (LSD) test. All differences were regarded as significant at $P < 0.05$.

3. Results

After the 51-day culture period, only the PL in the control treatment (no substrate) presented a significant ($P<0.05$) increase in weight (0.29 ± 0.07 g) and carapace length (12.84 ± 0.69 mm) (Table 1, Figures 1 and 2), although carapace length data should be treated cautiously when comparing growth rate of animals since carapace length can give uncertain results if the rostrum has been broken during handling. The vertical substrate treatment showed the least increase in weight and length.

The highest survival rate was recorded from the horizontal substrate treatment, followed by the control (no substrate) and finally the vertical substrate treatment, which was significantly lower than the other two treatments (Table 1, Figures 1 and 2).

FCR values ranged from 5.8 (control) to 13.4 (vertical substrate).

Table 1. Final mean weight, carapace length and survival of *M. rosenbergii* cultivated in the presence of three different treatments (H: horizontal, V: vertical and C: no substrate). Different superscript letters in each row represent significant differences among means.

Production parameters	Horizontal	Vertical	No substrate (control)
Final weight (g)	0.17 ± 0.02[a]	0.15 ± 0.05[a]	0.29 ± 0.07[b]
Final length (mm)	11.31 ± 0.70[a]	11.28 ± 0.07[a]	12.84 ± 0.69[b]
FCR	10.7 ± 1.7[a]	13.4 ± 6.0[a]	5.8 ± 2.0[b]
Survival (%)	68.5 ± 8.5[b]	15.8 ± 9.3[a]	31.5 ± 7.0[b]

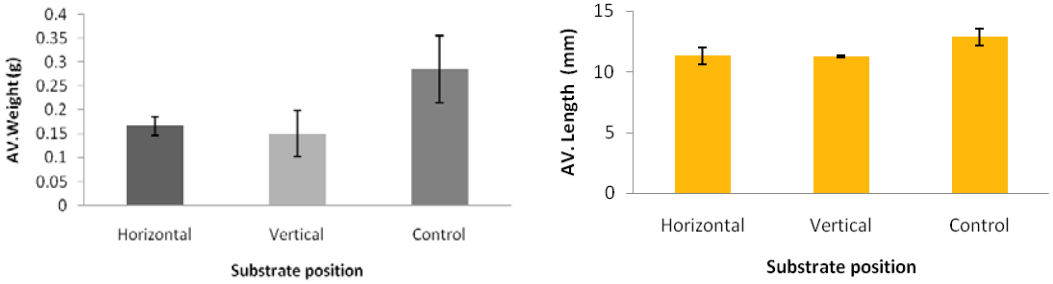


Figure 1. Final mean weight and carapace length of *M. rosenbergii* cultivated in the presence of three different treatments (H: horizontal, V: vertical and C: no substrate).

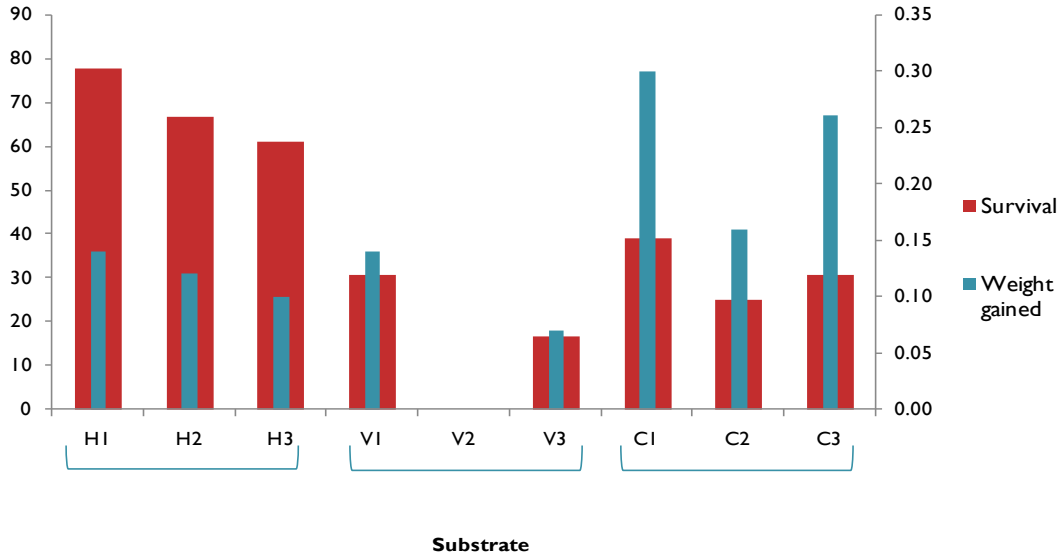


Figure 2. Weight gained and survival of *M. rosenbergii* cultivated in the presence of three different treatments (H: horizontal, V: vertical and C: no substrate).

All water parameters for *M. rosenbergii* during the 51 days that the experiment lasted were within permissible levels (temp. 22–26^{o}C, DO>6 mg/L). Ammonia and nitrite both were both close to 0 mg/L, well below the toxic level that would be harmful to the prawns.

4. Impacts

4.1 Scientific

There were no scientific impacts from this study.

4.2 Capacity impact

The study has resulted in enhanced capacity of the USP student who undertook the Associate Diploma and ran this experiment reported on here. Following this mini-project, Chillion was awarded an ACIAR-USP post-graduate scholarship to undertake a Master of Science degree at USP.

4.3 Community impact

Improvement in *M. rosenbergii* PL growth and survival through the use of substrates in nursery culture will have important community impacts if production can be increased. This research is a first step to developing improved culture techniques in Fiji and supporting further development of this industry.

5. Conclusions

The addition of substrates showed mixed results in terms of the survival and growth (carapace length and weight gained) in *M. rosenbergii* PL. The average final PL weight and carapace length in the control treatment (no substrate) was significantly greater than treatments with extra surface area (horizontal and vertical substrate). In terms of survival, almost 70% of prawn PL raised in the horizontal substrate survived, significantly more than either the (vertical (~16% survival) and control (slightly more than 30% survival). This implies that addition of substrate has benefited survival the prawn PL by increasing the surface area, but only in positioning it horizontally. Our results corresponds to the study reported by Sandifer and Smith (1977) where the addition of substrate in nursery tanks allowed prawns to utilise the entire water column and reduced mortality.

The likely cause for this increase in weight and length on the treatment without substrate was probably due to cannibalism, since no shelter was available for prawns to hide during moulting. Bigger prawns tend to attack the smaller and weaker individuals when there is not enough food and this behaviour was commonly displayed during the experiment. This is further supported by Arnold et al. (2006), who state that the addition of substrates provide refuge for shrimp to escape cannibalism from other post-larvae. The primary benefit of substrate, therefore, is to allow prawns to physically separate themselves from each other, thus reducing prawn-prawn interaction and stress (Tidwell and Coyle, 2008). Where there is insufficient shelter the weaker PLs, especially the newly moulted ones, are more vulnerable to attack and this led to the increase of the final weight and carapace length of the few remaining in the control treatment.

For the FCR, the observed values from every treatment were very high compared to values reported in the literature. Although it must be noted that the reported values in the literature

correspond to the grow-out and not the nursery phase, which requires higher feed intake (near 20% BW). According to Tidwell et al. (1999), FCR is improved by the addition of substrate, probably as a result of increased surface area for periphyton production and increased availability of natural food. However the data in this study does not support this statement, since the FCRs were all lower for prawn PL raised with no substrate.

Numerous studies have shown that the effect of adding substrate in prawn culture can benefit *M. rosenbergii* post larvae culture. Most of the studies carried out by other researchers focused on raceway and pond production. A major shortfall in the current experiment was the use of indoor aquaria, which were not exposed to sunlight and contained a low volume of water compared to raceways and ponds. This is one of the reasons why the development of periphyton was not evaluated unlike other substrate experiments that are carried out in open ponds that are exposed to sunlight as a source of energy.

The main goal of the experiment was to evaluate the influence of substrates on *M. rosenbergii* PL growth performance, it can be concluded that none of the treatments were able to achieve high survival and increased growth, indicators of good growth performance. The significant increase in survival in the horizontal substrate treatment was, however, promising. Other settlement materials could be trialled in order to investigate ways to increase both growth rate and survival rate to help improve production.

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Appendix 2.13

MS1006
Large scale sandfish sea ranching trial, Fiji

ACIAR Pacific Aquaculture Grant: **Project Summary**		**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Large scale sandfish sea ranching trial, Fiji (MS1006)**
Goal:	Produce a large number of juvenile sandfish at MAFF Galoa and Savusavu and release for sea ranching trial at Natuvu.
Objective(s):	Specific objectives are to: 1) Transfer production and pond grow-out technology to MAFF aquaculture officers at Galoa hatchery, Viti Levu; 2) Determine survival and growth of juvenile sandfish from a large scale release into a protected marine habitat (Natuvu *qoliqoli*); and 3) Determine the feasibility of sea ranching of sandfish as an economic activity in Fiji.
Project location:	Suva and Savusavu, Fiji.
Project partner(s):	Fiji Ministry of Agriculture, Fisheries and Forests, J Hunter Pearls
Dates / duration:	One year, starting September. 2010
Project description	This mini-project follows and builds on the experience of the previous mini-project ML0801. In that study, broodstock management, spawning, larval rearing, juvenile grow-out and sea ranching techniques were successfully transferred to Fiji government and private sector project partners. Results showed relatively high survival and growth of juveniles released into seagrass beds at Natuvu village *qoliqoli* MPA. However, the large scale release did not occur. This is a follow-on effort to introduce production at a second Fiji hatchery (MAFF government shrimp hatchery) and to attempt the large-scale release to gain a better idea of the economic feasibility of this activity.
Justification	Results from the previous mini-project were promising but due to low production (partly as a result of cyclones and other problems), the large scale release never eventuated. In order to properly evaluate sea ranching activities, a large release is desirable.
Expected outcomes	1. Increased capacity of MAFF aquaculture officers. 2. Gain knowledge of the economic feasibility of this activity. 3. Improved industry and livelihood opportunities in Fiji.
Funding sought:	$7,000

Large scale sandfish sea ranching trial, Fiji

Cathy Hair[1] and Teari Kaure[2]

[1] James Cook University, Townsville, Australia
[2] Fiji fisheries Department, Suva, Fiji

1. Background

This mini-project follows on directly from and builds on the experience of a previous, related mini-project *Culture of juvenile sandfish (*Holothuria scabra*) for restocking and sea ranching trials in Fiji*, which ran from May 2008 to April 2010 (Hair et al. 2011a). In that study, Fijian government and private sector partners successfully collected mature sandfish (*Holothuria scabra* or dairo) and spawned them at a blacklip pearl oyster hatchery at Savusavu, Vanua Levu. Larvae were raised to settlement stage on several occasions — however, very few larger juveniles were produced. Subsequently, only one modest experimental release was made into the wild at the village of Natuvu. The release was not sufficient to test the economic and practical feasibility of sea ranching. It did, however, produce valuable information on survival and growth of hatchery produced juveniles in sea pens. The results compared favourably to those from other countries where juveniles have been released (e.g. New Caledonia, Philippines).

In addition to the promising trial results, the mini-project established close links with Fiji MAFF aquaculture and fisheries research officers, J Hunter Pearls hatchery technicians, a local NGO (Fiji Locally Managed Marine Areas, FLMMA), University of the South Pacific (ACIAR- USP post graduate student), local government officers (CYMST) and community members. Natuvu village, Wailevu, declared part of their *qoliqoli* (traditionally managed fishing area) as a marine protected area (MPA) and banned fishing of dairo over an even wider area. They were closely involved in all aspects of the study and four men from the community were trained to maintain and provide security for the sea pens, and assist in monitoring survival and growth of the sandfish. The same project partners participated in this follow-on mini-project.

As mentioned, most of the hatchery produced sandfish in the first phase did not reach juvenile stage. This was due to several factors, including lack of experience in Feb 2009, low sea temperatures in Nov 2009, and damage from two cyclones in December 2009 and April 2010. Low numbers of sandfish reaching juvenile stage had two impacts on the project: (1) project partners did not receive sufficient training in juvenile rearing; and (2) the planned large-scale release was not carried out.

This follow-on mini-project aimed to produce more juveniles and conduct the large scale release at Natuv. Production was done for the first time at MAFF Galoa shrimp hatchery, where MAFF aquaculture officers were trained. This MAFF facility also has ponds which will be very useful for holding broodstock and bag nets for juvenile grow-out.

Specific objectives of the mini-project were to:

1. Transfer production and pond grow-out technology to MAFF Fisheries aquaculture officers at the government shrimp hatchery at Galoa.
2. Determine survival and growth of juvenile sandfish from a large scale release into a protected area.
3. Determine the feasibility of sea ranching of sandfish as an economic activity for Fijian (and other Pacific) coastal communities.

2. Materials and Methods

2.1 Hatchery facilities

The Government shrimp hatchery (Fig. 1) at Galoa was used for the production run and training. The hatchery is located about an hour's drive from Suva. The hatchery is primarily set up for shrimp (*Penaeus* spp.) production, although giant freshwater prawn (*Macrobrachium rosenbergii*) is also produced at the facility. From previous visits, we knew that all of the basic facilities were in place for sandfish production, with the exception of microlagae culture capacity. Fisheries agreed to renovate the old algal culture room in preparation for this mini-project. Otherwise, some minor systems modifications were required and some specialised pieces of gear brought in to facilitate the production run.

Figure 1. Fiji Department of Fisheries shrimp hatchery at Galoa. Shrimp pond in foreground, staff housing and offices on right, seawater reservoir tank and hatchery on left.

Production of juvenile sandfish at Galoa used the following hatchery resources:

- A flat bottomed spawning tank. A 1000 L green plastic "Rotomold" tank was purchased and fitted with a central standpipe to control water depth and facilitate quick water changes. A 90 µm screen placed over the standpipe allowed flow-through at night, when broodstock were unattended
- A water heater to heat a bin of seawater to provide water for the temperature shocks (spawning induction)
- Larval rearing tanks. Five conical based fiberglass tanks of 500 L volume and two flat-bottom plastic tanks of 1000 L volume were used for larval rearing (Fig 2a,b)
- UV-treated 1 µm filtered water for spawning induction, egg washing and water exchange in larval rearing tanks
- Larval and early juvenile feeding. The Galoa hatchery did not have the algal culture unit prepared in time for the project but did have an air conditioned room with fluorescent lighting. Carboys of *Chaetocerus muelleri, T. iso* and *Nitzschia closterium* were supplied by USP. And kept in the room for up to three days (Fig. 2c). A bottle of Reeds Mariculture Instant Algae® was on hand as an emergency food supply. The Instant Algae product called Shellfish Diet 1800® is composed of a mixture of

Isochrysis (30%), *Tetraselmis* (20%), *Pavlova* (20%) and *Thalassiosira weissflogii* (30%) (manufacturer's information, http://www.reed-mariculture.com/)

- A compound microscope for monitoring larval development and estimating algal density.

Several smaller pieces of specialised gear were brought from Australia or sourced in Fiji. These included settlement plates, egg washing bags and transfer screens.

(a)

(b)

(c)

Figure 2. Galoa hatchery facilities: (a) Conical based 500 L tanks; (b) Flat based 1000 L tanks; and (c) Carboy of microalgae in the algal room.

Ponds, which were available at the site, can greatly increase the ease and capacity for grow-out of juveniles. Fisheries also agreed to prepare one of the three ponds for sandfish. The pond base required a layer of about 10-15 cm of sand and the capacity for water exchange.

2.2 Broodstock acquisition

Mature sandfish broodstock were sourced from the seagrass beds at Natuvu. Local divers collected the sandfish on a rising tide in the afternoon (Monday 1 Nov) and left in a hapa net in the sea. On the high tide at around midnight, these were retrived, packed in plastic bags containing seawater and oxygen (1:2 ratio) and transported in eskies. The community was paid to collect the broodstock, with the agreement that they would be returned after the hatchery activity. This was in order to respect the current ban on their harvest. A total of 55 sandfish were collected, mean weight was 395 g (±17 se). The largest individual was over 1 kg, the smallest was 235 g. Early the following morning, the

broodstock were transported to Nabauwalu where they were repacked with fresh seawater and oxygen before going by ferry to Natovi and thence by car to Galoa.

2.3 Spawning

Sandfish can be induced to spawn by subjecting them to various stresses. These include:

- Transport to the hatchery by car and ferry
- Dry treatment – sandfish are left for 20–30 minutes in a drained tank
- Warm water bath – sandfish are left for 1 hour in water 5^{o}C above ambient
- Cool water bath – sandfish are left for 1 hour in water 5^{o}C below ambient, and
- *Spirulina* bath – sandfish are left for 1 hour in water with 30 g of blended *Spirulina* added.

The initial stress was that of transport from Natuvu to Galoa (about 16 hours). This resulted in a spawning late on Tuesday 2 November. Eight males and at least two females spawned. Three 500 L conical tanks were stocked at 0.3 eggs/mL, and one 500 L tank at a higher density (0.6-1 eggs/mL).

Seven more inductions were carried out over the following 8 days, each using 30-35 sandfish. All attempts involved drying, warm water and *Spirulina* bath, except attempt 6 which also used the cold treatment. This attempt resulted in one male spawning but nothing else. After changing 20 of the 30 broodstock, the seventh attempt on 10 Nov was successful, with ten males and four females spawning (Fig. 3).

Figure 3. Sandfish spawning.

Project staff monitored the spawning and removed broodstock from the tank when it was over. An hour later, eggs were siphoned from the spawning tank and washed carefully in UV treated-1 µm filtered water to remove excess sperm and minimise the incidence of polyspermy. Several million fertilised eggs were produced. Two 500 L conical tanks and two flat-bottom 1000 L tanks were stocked at 0.3 eggs ml^{-1}. Over one million eggs were stocked, the rest discarded. Three 500 L tanks from the 2 Nov spawning were retained as these larvae were already advanced.

2.4 Broodstock maintenance

The Natuvu broodstock were kept in a concrete tank with 10 cm of sand in the base (Fig. 4a). At least half the water was replaced every second day. They were fed every other day on either shrimp pellets, *Spirulina* or shrimp flakes (dissolved in water and added after the water change). The sand was replaced every 2 weeks. After the sandfish had been in

the tank for 4 weeks and the second sand change was carried out, about 30 of the 55 sandfish spawned with the handling and water change (Fig. 4b).

(a)  (b) 

Figure 4. Sandfish broodstock holding tank: (a) Teari with broodstock, and (b) sandfish spawning in the holding tank after a water change after being held together for approximately one month.

Broodstock were meant to be returned to Natuvu after the hatchery activity. Instead, they were transferred to the pond to await transport back to their origin. They were still at Galoa when the pump broke and pond conditions deteriorated. All broodstock died.

2.5 Larval rearing

Larval rearing followed the techniques recommended in hatchery manuals written by Agudo (2006) and Duy (2010). A total of four 500 L tanks were stocked from the first spawning event (2 November). Two 500 L tanks and two 1000 L tanks were stocked from the second spawning event (10 November). All larvae from the first spawning died. From the second spawning, we obtained late auricularia larvae in all tanks, doliolaria larvae in three tanks and settled early juveniles in the two 1,000 L tanks (Figs 5a,b,c, Table 1). By day 20, many small juveniles were clearly visible in the two remaining tanks.

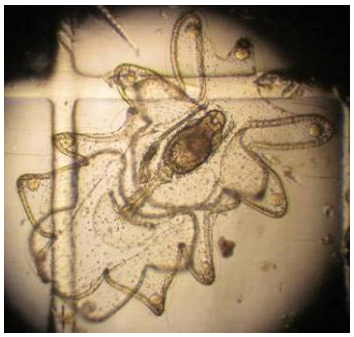
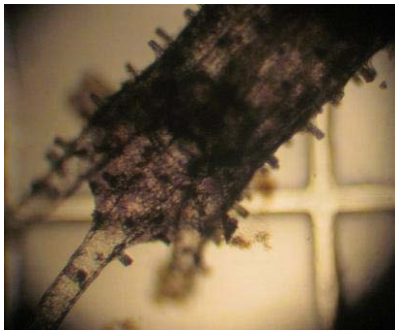
(a)  (b)  (c) 

Figure 5. Two late larval stages, (a) auricularia) and (b) doliolaria, and (c) early juvenile stage of sandfish produce at Galoa.

Two types of settlement plates were used: flat perspex plates imported from Australia; and corrugated plastic roofing material (Duy 2010). Plates were painted with a light coating of *Spirulina* paste. They were added to the tank on Day 12, the day after the first doliolaria

was observed. At this time, small amounts of Algamac 2000 and *Spirulina* were included in the diet.

Inadequate quantity and low quality of microalgae was a constraint throughout the run. To make up for the shortfall in live feeds, a commercially available algal concentrate, Reeds Mariculture Instant Algae® (Shellfish Diet 1800®), was used. Most of the live microalgae was fed preferentially to the two 500 L conical tanks (tanks 1 and 2). Diet composition and larval development for each tank is summarised in Table 1.

Table 1. Summary of diet and larval tank performance (November 10 spawning).

Tank	Volume	Feed	Larval development
1	500 L (conical)	60% microalgae 40% Instant Algae	Good development and density of larvae to mid auricularia, thereafter no growth and crash day 10.
2	500 L (conical)	60% microalgae 40% Instant Algae	Good development and density of larvae to late auricularia, doliolaria observed on day 11. Aeration problem and crash on day 14.
3	1000 L (flat)	10% microalgae 90% Instant Algae	Good development and density of larvae to late auricularia, doliolaria observed on day 11, settlement of pentactula by day 14. Many early juveniles day 20.
4	1000 L (flat)	40% microalgae 60% Instant Algae	Good development and density of larvae to late auricularia, doliolaria observed on day 11, settlement of pentactula by day 14. Early juveniles by day 20.

2.6 Pond preparation

The smallest pond (Pond #3, approx. 40 x 20 m) was prepared as a dedicated sandfish pond. Local village contractors laid fine sand over the base of the pond to prepare it for adult broodstock as well as juvenile grow-out in the future. Sandfish require about 10–15 cm of sand but there was probably less than this as it was a difficult and time-consuming task. We ran out of time and funds to complete adding sand to the pond base during the run.

Three bag nets (2 m wide x 2 long x 1 m deep) were installed in the pond in early December (Fig. 6). These nets were left to be conditioned for 10–14 days in order to allow an algal biofilm to develop on the sides and base to provide food and also reduce the mesh size to minimise escape of small sandfish.

Figure 6. Setting up bag nets in the Galoa pond in readiness for juvenile sandfish transfer.

2.7 Pond grow-out of juveniles

The juveniles were transferred to hapa nets in the pond once they reached at least 5 mm length (at around 30–40 days old). A spray solution of 1% KCl was used to detach juveniles from the sides and base of the two 1,000 L tanks and they were siphoned into screened trays. On December 20 and 22 (approx. 40 days after spawning), an estimated 5,300 small juveniles were transferred into three bag nets.

The juveniles were sampled on 10 January 2011. Twenty individuals from each bag net were weighed (to the nearest 0.1 g) and measured (to the nearest mm) (Table 2). Salinity and temperature of the pond were recorded as 28 ppt and 29.5^{o}C, respectively.

Table 2. Length (g) and weight (g) of juvenile sandfish (*n*=20) in hapas at Galoa, 10 Jan 2011.

Hapa #	Length (±se) (mm)	Length range	Weight (±se) (g)	Weight range
1	21.3 (±0.9)	12 – 29 mm	0.68 (±0.09)	0.1–1.5 g
2	20.5 (±1.5)	9 – 34 mm	0.42 (±0.08)	0.1–1.6 g
3	23.6 (±2.0)	13 – 43 mm	0.76 (±0.17)	0.1–2.6 g
Mean	**21.8 (±0.9)**	**9 – 43 mm**	**0.62 (±0.07)**	**0.1–2.6 g**

Water flow was maintained in the pond until mid December when the main seawater pump broke down. A small submersible pump was soon set up but water exchange in the pond was thereafter low and there was heavy rain through late December 2010 and early January 2011. Water flow into the hapa nets where the juveniles were kept was minimal and they were likely stressed by the salinity drops and poor circulation. The small pump was removed after January 17 and no further water exchange occurred. When the juveniles were checked on January 19, they were all dead.

2.8 Training

Training was carried out primarily through practical hatchery exercises. Two manuals, 'Sandfish Hatchery Techniques' (Agudo 2006) and 'Seed production of sandfish in Vietnam' (Duy 2010), and demonstration DVDs were also used to augment the hands-on learning. Ms Teari Kaure (Fisheries aquaculture trainee) was fully trained in sandfish culture methods. Hands-on experience was gained in the following areas:

- broodstock handling and maintenance
- spawning induction, spawning and fertilised egg management, (i.e. recording, egg washing, egg density estimates and larval rearing tank stocking)
- larval tank management and larval rearing through to settlement
- preparation and use of live microalgae and commercial algal concentrates as larval feeds (i.e. Instant algae)
- preparation and use of coated settlement plates
- post-settlement tank management for pentactula and juveniles.

Emori Ganilau (Department of Fisheries aquaculture officer) was the key staff member responsible for pond preparation and management. Both Emori and Teari were trained in:

- Preparation of the pond for holding sandfish adults;

- Hapa construction and management;
- Water management during heavy rainfall (salinity management).

2.9 Natuvu Village Outcomes

Due to the loss of all juveniles and broodstock at Galoa, no broodstock or juvenile sandfish were returned to Natuvu village. This was a disappointing outcome for them. However, the possibility of the research being unsuccessful has been explained prior to commencement of the study and the community was very understanding.

4. Impacts

4.1 Scientific impacts

The use of 'Instant Algae' was tested more comprehensively in this study. Recent simplification of hatchery techniques (developed in Vietnam and Philippines) led to larvae being reared on *Chaetocerus* alone, rather than a cocktail of several microalgae. This mini-project went one step further to rear larvae predominantly on 'off-the-shelf' algal products.

An article was published in the SPC Beche-de-mer Bulletin (Hair et al. 2011b), describing the first successful hatchery culture of sandfish on a diet that was not exclusively live microalgae. Indeed, the results indicate that sandfish larvae can be reared almost entirely on Shellfish Diet® without compromising their growth or survival. This finding has important implications for future developments in hatchery culture technology for sandfish and tropical sea cucumber generally.

4.2 Capacity impacts

The study has resulted in enhanced capacity of aquaculture officers in the government sector. The ACIAR-USP post-graduate scholarship Masters student assisted with the hatchery work and conducted experiments using the juveniles. Most of the increased capacity resulted from on-the-job training.

Natuvu community members consulted with Fiji Fisheries and increased their capacity in community-based fisheries management (see below).

4.3 Community impacts

The success with instant algae to rear sandfish has significant community impact as it greatly reduces the technical resources required for hatchery culture of commercial marine species and is potentially of enormous benefit for development of hatchery culture to support aquaculture development in the Pacific Islands region. It may allow, in the future, production of juveniles for sea ranching to occur in remote areas.

The mini-project had further, unforeseen, community impacts. Curryfish, a medium-value sea cucumber species, were collected in late 2010 from the MPA that was created during the first ACIAR sea ranching mini-project. The harvest of curryfish was processed into beche-de-mer (Fig. 8) and the proceeds funded a community hall (disaster evacuation centre), and contributed to the local school and church, as well as other community needs. The MPA was closed to fishing again after the harvest and sandfish remained protected. The community intends to manage their MPA in collaboration with Fiji Fisheries

in ways to ensure continued benefits from sandfish and other commercially-valuable species.

Figure 7. Project closing ceremony, Natuvu community hall.

Figure 8. Processed curryfish.

5. Discussion and recommendations

As with any new production activity, a number of problems were encountered during the training and larval production. The live microalgae supply was insufficient in quantity, quality and species variety. There were very limited facilities at Galoa for microalgae production. This led us to rely on a commercially available algal concentrate, Reeds Mariculture Instant Algae® (Shellfish Diet 1800®)), an untested diet. Fortuitously, the lack of live microalgae led to a breakthrough in rearing techniques as we found that the larvae raised on this product outperformed the larvae raised on the poor quality live feed. More research is necessary but this finding has major implications for further developments in hatchery culture technology for sandfish and tropical sea cucumber generally.

Broodstock were brought from Natuvu at considerable expense and effort. There were two important reasons why this was considered of benefit:

(i) Genetic considerations. Any juveniles produced at Galoa were to be returned to the Natuvu *qoliqoli* as this community were project partners since the first mini-project.

(ii) A known source of broodstock. Sufficient numbers of large broodstock were available at this location. Many other areas have small-sized or low numbers of large sandfish.

Unfortunately, the broodstock were not returned to their origin as planned but died as a result of poor husbandry (exacerbated by equipment failure). Broodstock care and maintenance should be improved if broodstock are to be kept at the Galoa hatchery for extended periods.

It was further recommended that the Fiji Department of Fisheries develop a functional microalgal production facility, make modifications to the larval rearing system (including tanks and water supply), improve the sandfish pond and train more staff if they wish to further develop Fiji's sandfish production capacity.

Importantly, this mini-project successfully demonstrated that juvenile sandfish can be produced at the government shrimp hatchery at Galoa. Furthermore, Fiji is extremely well-positioned for production and grow-out of sandfish. It now has an equipped hatchery with production capacity and one fully trained staff member. It has a dedicated pond for broodstock holding and juvenile grow-out. There is ample suitable sea ranching and restocking habitat throughout the Fiji Islands. Broodstock are available in some areas. It has a well functioning traditional marine resources management system, which is supported by government and NGOs such as FLMMA. There are many remote island groups with suitable habitat that would be able to benefit from this technology.

6. Acknowledgements

Gratitude is extended to the Fisheries Department of Savusavu for support in activities in Natuvu village and other logistics (in particular Joji Vakawaletavua and Wane Vonokula). Special thanks also to the Natuvu village chief, dairo divers and community for their help in providing broodstock and their gracious hospitality. Tavenisa Vereivalu, Anand Prasad, Emori Ganilau, Orisi, Naduroloulou and Nabawaulu Fisheries officers provided support during the project. I would like to acknowledge the assistance provided by Laisiasa Cavakiqali of USP in producing microalgae for the larval run. Lastly, thanks to the Galoa village pond contractors (Koro and Semisi).

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Vanuatu

(Appendixes 2.14 to 2.15)

Appendix 2.14

MS0801
Clown fish culture, Vanuatu

ACIAR Pacific Aquaculture Grant: **Project Summary**		**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Clown fish culture in Vanuatu (MS0801)**
Goal:	To produce and supply the sought-after, valuable ornamental fish *Amphiprion melanopus*
Objective(s):	Specific objectives are to: 1) produce cultured clownfish fingerlings, using existing hatchery facilities in Vanuatu; 2) develop simple and cheap ocean grow out systems that are appropriate in the village context (including cage design and nutrition) to rear clownfish to market size; and 3) ensure that the products are economically viable and well accepted by the aquarium trade.
Project location:	Vanuatu.
Project partner(s):	Vanuatu Fisheries Department, JICA The Grace of the Sea, Reef Life Ltd
Dates / duration:	June 2008 –June 2010 (2 years)
Project description	There is increasing global demand for aquarium fishes. Over ten PICs are currently involved in the aquarium fish trade which provides a significant source of livelihood in both rural and suburban areas of these nations. Clown fishes are one of the most popular and sought after marine aquarium fish in Vanuatu. They are caught by professional divers and sold to export companies. In Vanuatu the number of clown fishes caught from the wild per year is 5–10,000 pcs. Hatchery production of some clownfish species is now routine and will be used as a basis for this project using existing VFD hatchery facilities. Hatchery produced juveniles will be cultured in floating cages maintained by village communities/families based on the current practices of holding wild collected aquarium fishes in nets in shallow reef areas prior to distribution. This project will transfer technology for hatchery culture of clown fishes, develop methods for grow-out of juveniles, and provide opportunities for livelihood income.
Justification	Clown fish culture may: (1) provide alternative livelihood to coastal communities and (2) reduce the pressure on wild stock of these species.
Expected outcomes	1. Increased capacity of VFD aquaculture officers. 2. Gain knowledge of the economic feasibility of this activity. 3. Improved industry and livelihood opportunities in Vanuatu.
Funding sought:	$15,000

Clown fish culture in Vanuatu

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1. Background

The trade of aquatic organisms for home and public aquariums, and water gardens, along with associated equipment and accessories, has become a multi-billion dollar industry known as the aquatic-ornamental industry (AOI) (Larkin 2003; Wabnitz et al. 2003). On the whole, the most recent estimated value of the AOI was in the vicinity of 15 billion US dollars (Wittington and Chong 2007). Within the AOI, among a myriad of aquatic organisms traded, freshwater and marine fish species are the most popular and dominant groups (Lecchini et al. 2006). And on a unit weight basis, ornamental fish form the most valuable fisheries commodity in the world (Hardy 2003). Furthermore, demand for coral-reef species has increased in the last decade due to technical advances in captive care system technologies which have made marine aquarium care easier and more accessible to common households.

Of the estimated 1,500 to 1,600 ornamental fish species commonly traded, near half are marine (Olivier 2003; Wittington and Chong 2007), and between 90 to 99% of marine fish species traded are collected directly from the wild (Olivier 2003; Tissot and Hallacher 2003). This includes the coral reefs of Vanuatu and other Pacific nations. Continued exploitation of reefs, particularly in a destructive, poorly managed manner, has been reported to reduce the yields of both ornamental and food fish from reef fisheries, ultimately affecting the capacity of exploited reefs to recover (Rubec et al. 2001). Collection of specimens for the marine ornamental market itself has been directly linked to localised declines in several popular ornamental species (e.g. Tissot and Hallacher 2003; Shuman et al. 2005). This ultimately has flow-on effects for industries reliant on coral reefs, such as tourism.

Aside from direct exploitation, the world's coral reefs also face the severe effects of global climate change and increased impacts from anthropogenic activity, highlighting the need for multi-faceted management and recovery programs to curb reef declines and encourage recovery (Wood 2001a; Bellwood et al. 2004). As a part of effective coral reef management plans, there exists great potential for a marine ornamental reef fish captive breeding program (Wood 2001a; Zieman 2001; Tlusty 2002). Such a program could complement coral reef management through controlled releases of hatchery produced fingerlings of heavily exploited species, and supplementing or replacing the trade of wild caught marine ornamental fishes, and provide a significant contribution to scientific knowledge of reef fish biology (Wood 2001b; Zieman 2001).

In its present state, marine ornamental aquaculture (MOA) is still in its infancy, with a limited number of species being produced at an economically viable scale (Wood 2001b; Holt 2003). However, there is great potential for significant growth in this sector of the ornamental industry, owing to high product value and its significance to coral reef conservation. There are growing interests in marine ornamental aquaculture from the commercial aquarium trading industry, marine conservation and research community. However, for MOA to grow and reach large-scale success, there are two vital avenues in need of concurrent pursuit. Firstly, robust scientific experimentation needs to take place,

with a view to make results and advancements in techniques and technology freely available to the public. Secondly, these techniques and technologies need to be effectively translated to an industry setting.

The marine ornamental trade is well established in some Pacific nations such as Vanuatu, Solomon Islands, Kiribati, Tonga and Fiji, to list a few (over 10 countries are involved in the aquarium fish trade). The ornamental trade is a significant source of income that is available in both rural and (sub)urban areas of these nations, where it is estimated that over 800 households are involved full or part time in the business. The demand for cash income derived from coastal resources is increasing with current demographic trends (especially in Melanesia) while on the global aquarium market, the demand for maricultured animals grows stronger.

Vanuatu represents an ideal setting by which to implement current technologies and successes in the culture of marine ornamental species, particularly with respect to clownfishes (*Amphiprion* spp.). It also has potential to undertake studies to develop breeding and rearing techniques for other coral reef fish species. Clownfishes are highly sought after in Vanuatu. They are caught by professional divers and exported by private companies. In Vanuatu, the average number of clownfishes caught annually is between 5,000 and 10,000 pieces. In Vanuatu, the uncommon endemic colour morph of *A. melanopus* (Fig.1) can fetch US$4-5 per piece at export price (Reeflife Vanuatu Ltd. stocklist). Other clown fish species from Vanuatu also have export value: *A.clarkii* and *A.perideraion*.

Figure 1. The Vanuatu endemic morph of A. melanopus (red arrow)

An expanded list of objectives of the mini-project is as follows:

1. Construct and run a sustainable broodstock holding system adequate to elicit captive spawning in a commonly reared group of marine ornamental fishes; clownfishes (*Amphiprion* spp.)
2. Train and educate staff in everyday maintenance and husbandry of broodstock of clownfish species
3. Construct and run a larval rearing system to culture clownfish larvae past critical and sensitive early pelagic stages
4. Train and educate staff in everyday maintenance and husbandry of clownfish larvae, including hatching, feeding of live feeds and ‘greenwater’ culture techniques
5. Train staff to utilise existing infrastructure for the grow-out of newly settled clownfish to a marketable size

6. Encourage and equip staff of Vanuatu fisheries department to explore opportunities in community training for grow-out of clownfish and other ornamental species

There is currently a JICA funded Project in Vanuatu called 'Grace of the Sea', located at the Vanuatu Fisheries Department (VFD), in Port Vila. This project aims, amongst other things, at providing alternative livelihood to coastal villages in Vanuatu. They currently produce clam spat and train villagers to on-grow them. The clownfish project will be run in harmony with the clam project (optimising resource people, sites, sharing costs etc.)

2. Materials and Methods

The project will have a 2-year life span. During the first year, the focus will mostly be on hatchery techniques and fingerling production at the VFD hatchery in Port Vila. If sufficient fingerlings are produced the village grow out experiments will be conducted in the second year in Mangaliliu village, on the north coast of Efate.

2.1 Hatchery

VFD has facilities that are suitable to run a small scale aquarium fish mariculture project. Their newly renovated hatchery (JICA) has a laboratory, a set of raceways/production units and access to open ocean sites with boats. A lot of equipment can be used for the project such as tanks, pipes/hosing, net material, glassware and monitoring equipment. The station has trained technical staff that will be able to assist in day to day husbandry work for this project.

Two trips will be undertaken by the SPC aquaculture officer for this part of the project. The first trip (June 2008), will aim at setting up the hatchery, collecting broodstock, and developing optimum feed for broodstock maturation. The second trip should be undertaken after the broodstock have produced the first batch of eggs, when larval culture expertise is needed (expected September/November 2008) (details of larval culture provided in annex). During this time, training will be provided by SPC Aquaculture officer. VFD/JICA staff should then be able to run the next larval batch through to juvenile stages as formed pair of clownfish can spawn every two weeks.

2.2 Village grow-out

The grow out site was planned for the reef near a community on the north coast of Efate. There will be a single trial site in nearby Mangaliliu village where there is already a giant clam grow out station and where aquarium fish collection companies have licenses to operate. VFD fisheries staff will be in charge of introducing the clown fish grow out project there and selecting key operators in the village, prior to the initial trials. Once juvenile clownfish can be produced routinely from the hatchery, the VFD Aquaculture Officer and JICA staff will introduce floating cage farming techniques to the community. Initial trials will determine growth and survival of clownfish in the simplest possible cage set up. Low cost, readily available feed will be identified at that stage, together with the villagers (e.g. minced shrimps, fish or crushed shell fish).

VFD and JICA will monitor survival and growth of the village cage clownfish on a monthly basis during the 3-5 month grow out period and will provide on the job training to interested villagers. Regular weekly/fortnightly visits will also aim at ensuring fish are in good conditions and the trials are being looked after. An exporter (Reeflife Vanuatu Ltd.) has also expressed interest in grow out trials and will possibly do so in Pango, near Vila, at his own expense. The project will have access to his growth and survival data. The area is five minutes away from the VFD hatchery. This exporter will also supply broodstock and buy fish from the community when they reach commercial size.

2.3 Broodstock acquisition and maintenance

Broodstock of three commercially valuable species (*Amphiprion melanopus, A. clarkii, A. perideraion* and *A. percula*) were used in the mini-project. Acquisition was from wild capture, and purchase from local and overseas aquarium dealers. Broodstock were maintained in purpose-built aquarium systems in the VFD hatchery.

2.4 JCU expert advisor

In the months leading up to the project improvements, the consultant (Jonathan Moorhead) was briefed on the state of the broodstock system and a plan devised to rectify ongoing water supply problems using a recirculating system. Materials required included a foam fractionator rated to the system requirements, a pump large enough to supply flow to the broodstock tanks and allow for expansion of the system later on, biological media for the construction of a biological filter, and bag filters for simple mechanical filtration. This equipment was purchased in Australia and brought by Jonathan, to ensure that all critical materials needed for project improvements were on hand from the outset. Additional plumbing supplies and sundries were sourced locally in Port Vila.

3. Outcomes

3.1 Hatchery

In 2008 work began to set up a small clownfish hatchery system at the Vanuatu fisheries department facility located in Port Vila, Vanuatu. A functioning broodstock holding system was constructed (Fig. 2). However, inherent problems with water flow to the system resulted because the existing water supply (pumping from a tidal well previously set up by the JICA group for the culture of tropical clams) meant that daily maintenance on the clam system altered water flow to the broodstock system, sometimes cutting off water flow altogether. This resulted in rapid deterioration of dissolved oxygen levels and water quality, and thus the death of a majority of broodstock. In response to this an independent hatchery system was set up, including installation of a separate water system from the giant clam hatchery. Further constraints were that water quality in the well was very poor and loaded with sediments resulting in frequent (and expensive) water filter replacement.

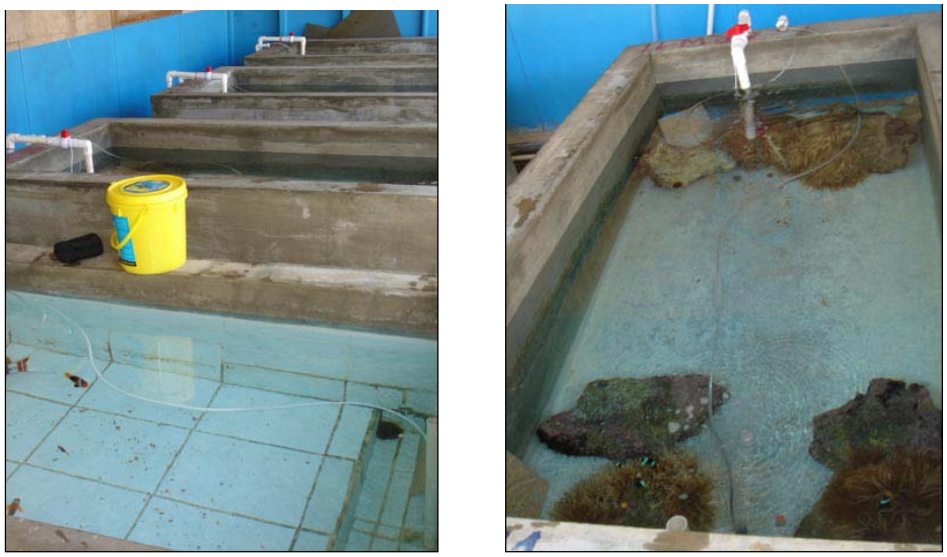

Figure 2. Initial hatchery set up for clownfish

With assistance from the Vanuatu staff, Jonathan modified a fibreglass tank available at the facility to be utilised as a sump for the improved broodstock system. The sump was moved into the broodstock room, positioned next to the broodstock tanks and a manifold system plumbed in, to supply water to each of the broodstock tanks. Within the sump, three bio-towers were constructed to hold the biological media and a spray bar directed a constant flow of water over them, via the pump. The simple 'plug-and-play' foam-fractionator was also placed into the sump, and appropriate training given by Jonathan concerning its operation, cleaning and maintenance.

The changes Jonathon instigated are summarised below:

- A recirculating system specifically for the broodstock clownfish system was constructed to eliminate water flow issues relating to the unreliable tidal well water supply
- Biological filtration and foam fractionation was implemented as a part of the recirculating system to ensure water quality is maintained within adequate bounds for the breeding of marine ornamental clownfish
- An outdoor system was also implemented to increase the number of broodstock that could be maintained and to compare to the indoor recirculating system in terms of ease of care and eliciting successful spawning. This system was implemented in existing tanks that experienced few if any water supply problems.
- The old broodstock holding system was deconstructed, cleaned and re-implemented to make better use of tanks and accommodate the recirculating system Fig. 3).
- A small 3-tank larval rearing system was also constructed (Fig. 4).

Figure 3. Improved hatchery set up for clownfish, showing recirc tank in foreground and individual, insulated broodstock pair holding tanks in background.

Figure 4. Larval rearing system.

3.2 Broodstock acquisition and maintenance

From 2008–2009 clownfish broodstock were collected from the wild, purchased from local collectors, and mating pairs of *A. percula* were imported from Solomon Islands (to increase chances of mating and to work with the species that is highest in demand). Due to water quality and other maintenance problems, many of the broodstock died. In 2010, during Jon's visit, broodstock were bought from a local collector and were captured from the wild to replenish stocks that had died earlier in the project.

Each broodstock tank was given a standard type hide used with success at JCU, Townsville for the rearing of marine ornamental clownfish (Fig. 5). This change produced instant results. Broodstock behaviour ceased being skittish and stressed. These particular hides were also sturdier and did not require regular adjustment and re-positioning in the tanks compared to when tiles were propped up against the tank walls.

Figure 5. Original tile clownfish hide in tanks (left), and JCU-style hide added in 2010 (right).

Anemones were also collected from the wild to place in tanks with the clownfish broodstock pairs. Four large carpet anemones and > 30 bubble anemones were collected (Fig. 6).

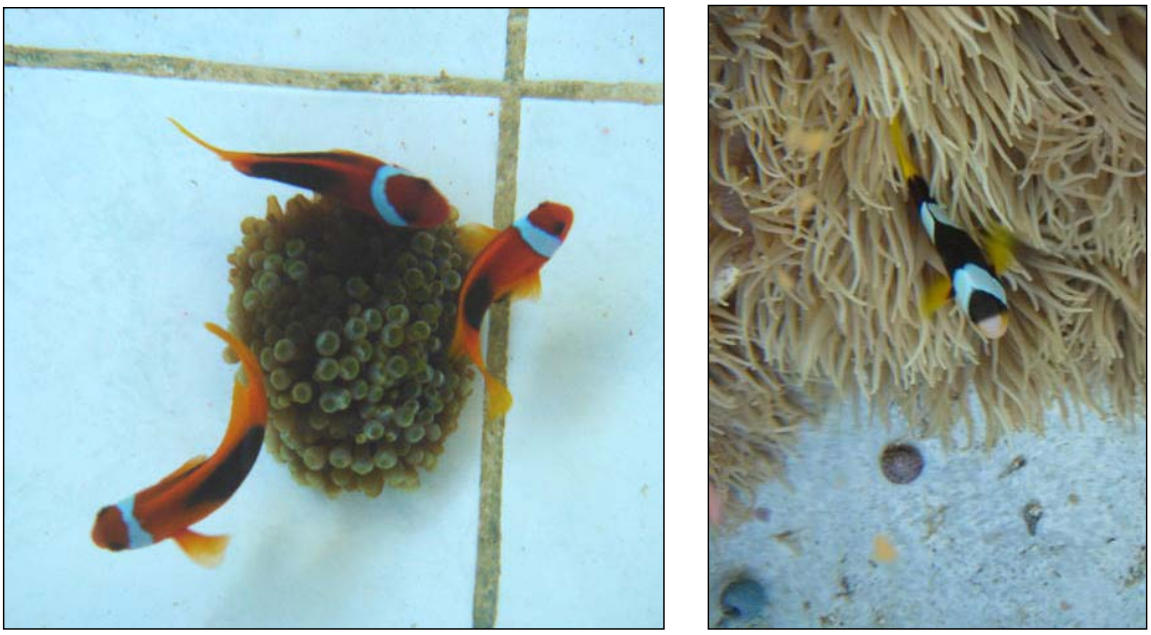

Figure 6. Clownfish broodstock maintained at VFD hatchery: *A. melanopus* with a bubble anemone (left) and *A. clarkii* with a carpet anemone (right).

Staff were provided a protocol to follow for regular broodstock maintenance. The trainers emphasised several critical areas requiring careful monitoring. Husbandry methods changed from poor broodstock monitoring to careful observation of broodstock behaviour and condition. Improvements were made to feed supply and feeding practices were improved.

3.3 Clownfish larval rearing techniques

The lack of spawning meant that the VFD staff were not able to undergo training in larval rearing and juvenile grow-out of clownfish. However, a large clutch of eggs was collected from the wild in 2010 during Jon's visit. Although these eggs died after Jon and Antoine left, the staff were exposed to the appearance of clownfish eggs and their appropriate care and artificial incubation.

3.4 Training

VFD staff were trained in a range of techniques and acquired new skills through the project:

- Maintenance of the hatchery system
- Making fish feeds and feed management
- Collection and culture of wild copepods based on available resources
- Protocol for larval feeding.
- Regular maintenance of the broodstock, with emphasis on careful monitoring of broodstock behaviour and condition.
- Care and artificial incubation of clownfish eggs.

4. Impacts

4.1 Scientific impacts

There were no scientific impacts from this mini-project.

4.2 Capacity impacts

With training provided by Antoine and Jonathan, staff at Vanuatu fisheries department had exposure to the construction of a system that better meets the needs of clownfish broodstock. With the experience of Jonathan Moorhead in the area of marine ornamental aquaculture, the staff were given on-the-job practical and theoretical training regarding husbandry of clownfish (Fig. 7). The comfortable work environment and interest in the project encouraged learning, and made the training and theory beneficial to the staff. This included basic broodstock food handling and storage, broodstock behaviour (and the importance of taking the time to pay attention to it), to their first exposure to what clownfish eggs look like, and how to incubate them artificially. It was clear that staff were keen to work and showed dedication to the project, and thus absorbed the theory they needed to explain why they need to do things in certain ways and what to look out for.

The response to training was very positive and fostered immediate change and improvement of techniques, skills and protocols. It appeared that the main barrier to success at Vanuatu fisheries was knowledge of theory behind the culture of ornamental clownfishes. The provision of this knowledge (both from the experience of Antoine and Jonathan and the book resource Jonathan brought) both allowed staff to see why the project had not been successful to date and equipped them with the ‘why’ so they could tackle the ‘how’. It was clear that some staff displayed distinct husbandry qualities and genuine care for the fish, and eagerness to learn how to look after the fish better. With the implementation of a clear protocol and now equipped with the knowledge of why this protocol is important to follow, I believe this project will progress. Staff competency and skills undoubtedly improved in the week of training.

Figure 7. Staff capacity building: training in collection of plankton using a light at night (left) and feed preparation (right).

4.3 Community impacts

There were no community impacts from this mini-project. Since no clownfish spawned, there were no juveniles available for the community grow-out activity.

5. Discussion and recommendations

As with many forms of aquaculture, technology can take more time than anticipated to be efficiently developed. In this project, most of the project time was allocated to developing suitable set ups for the breeding of clownfish. Thus, subsequent objectives related to rearing clownfish juveniles and village grow-out trials could not be met.

Marine ornamental aquaculture is a means towards supplying aquarium fish to the global trade and we feel that it would be beneficial for Pacific source countries to be involved in this process. MOA usually develops in western countries, near markets or in Asia where production costs are low. Unfortunately, this means that Pacific island countries lose market on the export of their own species, since other companies can now breed them overseas. That is the case for clownfish, where most species are being bred outside of source countries at a large scale and a low price.

We feel that Vanuatu could still be a very good case study to demonstrate the viability of cultured ornamental fish from the Pacific region. It has many advantages, including:

- Existing aquarium trade and market for these species
- Environmental pressure leading exporting companies to develop alternatives to wild capture
- Availability of broodstock
- Ease of access to farming site
- Shore-based hatchery

However for such a project the presence of a private entrepreneur with a business vision would have been likely to result in more success. Visits by JCU and SPC advisors were too spaced out to ensure continuity in the progress of the project.

The positive side of the project is that VFD staff were exposed to handling new species, new systems and gained training in husbandry of clownfish. There are two options for the future of this work: (1) continue the project with a more consistent expertise (Vanuatu based trainee/intern) and more regular advising trips: for this purpose, extra funding need to be sought; or (2) Abandon the project as it is and be satisfied by the amount of training and novelty that has been provided. In both cases, a closer involvement with private sector should be developed.

6. Acknowledgements

Gratitude is extended to the Vanuatu Fisheries Division for use of their facility, equipment and staff time. Thanks to Reeflife for providing clownfish broodstock and to Grace of the Sea project for equipment and expertise. In particular, thanks to the aquaculture team at VFD—Lency Dick, Roderick, Andrew, Jayven Ham and Jeremy—for continuous assistance, will to succeed and positive energy.

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Appendix 2.15

ML0901
Study of *Macrobrachium lar* capture and culture techniques in Vanuatu

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU James Cook University WorldFish Center USP The University of the South Pacific	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Domestication of Freshwater prawn *Macrobrachium lar* in Pacific Island Countries: Study of *M. lar* capture and culture techniques in Vanuatu (ML0901)**
Goal:	To achieve the domestication of *M. lar* in the island Pacific, as a basis for small-scale aquaculture using techniques accessible to rural households or small businesses
Objective(s):	1. Determine the best places, times and methods in Vanuatu for capture of juvenile prawns for pond stocking; 2. Determine the best feeds that are locally available and affordable in Vanuatu; 3. Determine the best pond design and pond management regime for *M. lar* grow-out; and 4. Improved knowledge of *M. lar* larval dispersal and re-colonisation abilities from genetic structure of *M. lar* populations in Vanuatu.
Project location:	Efate Island and Santo Island, Vanuatu
Project partner(s):	Vanuatu Department of Fisheries, Sarete Village (Santo)
Dates / duration:	1 year, beginning from March 2010
Project description	Three techniques of juvenile prawn collection will be compared, along with different places and times of collection, to find out how, where and when it is best to obtain prawns for pond stocking, and what type of prawns appear in catches (in particular, what proportion may be *M. lar*). Pond trials of culture to harvestable size will be conducted to compare different feed types, and different culture conditions, e.g. stock density. Adult prawns will be collected from four sites across Santo and Efate for genetic analyses to gain insights into connectivity between prawn populations at different locations within Vanuatu.
Justification	Diversification of aquaculture commodities that can be commercialised in the insular Pacific will benefit rural households and small businesses.
Expected outcomes	1. More efficient and sustainable means to collect juvenile *M. lar* for pond stocking *2.* Feeds specifically tailored for *M. lar* *3.* Pond culture methods specifically tailored for *M. lar* 4. Population connectivity data to inform sustainable management of juvenile prawn capture from the wild for culture in ponds.
Funding sought:	**AU$38,800**

Domestication of Freshwater prawn *Macrobrachium lar* in Pacific Island Countries: Study of *M. lar* capture and culture techniques in Vanuatu

Tim Pickering[1], Sompert Gereva[2], Glen Alo[2] and Michael Sharp[1]

[1] Secretariat of the Pacific Community
[2] Vanuatu Division of Fisheries, Vanuatu

1. Background

The indigenous freshwater prawn, *Macrobrachium lar* (Fig. 1), is an iconic species among Pacific island countries (PICs), where it is of high commercial and cultural value. This species constitutes locally-important artisanal and subsistence fisheries which, in many places, have become depleted due to growth over-fishing and to habitat or water-quality degradation in rivers.

Figure 1. Freshwater prawn, *Macrobrachium lar*.

An earlier ACIAR mini-project "Monoculture of the freshwater prawn, *Macrobrachium lar,* in Vanuatu and integrated prawn-taro farming in Wallis & Futuna" produced baseline data on growth of *M. lar* in monoculture at Sarete village on Santo, and in integrated farming of *M. lar* with swamp taro on Futuna, and demonstrated that capture-based culture of *M. lar* in Pacific island countries as a protein source and for income generation was technically feasible. That preliminary investigation recommended that there be a larger follow-on study to fine-tune the culture methods.

The Secretariat of the Pacific Community (SPC) subsequently prepared a regional strategy for *M. lar* domestication that encompassed further capture and growth trials, larviculture research to close the life-cycle (the subject of a separate mini-project), genetic analysis to study larval dispersal, trials of feed formulations, marketing, and training and extension. This mini-project addresses some of the research priorities identified in the regional strategy, in particular to refine juvenile capture techniques, culture methods, and feeds for *M. lar*. After reviewing the regional strategy for *M. lar* and the national priorities in Vanuatu, SPC and Vanuatu government counterparts jointly agreed upon five main areas for follow-up research:

1. Improve techniques for capture of juvenile prawns
2. Identify the best feeds for *M. lar* prawn culture
3. Identify the best culture system and management regime for *M. lar* grow-out
4. Study the connectivity between populations of *M. lar* within Vanuatu, to underpin sustainable management of juvenile capture for aquaculture

5. Determine the socio-economic impact of capture-based aquaculture of *M. lar*.

2. Project Methodology

The overall goal of this project was to achieve the domestication of *M. lar* in the island Pacific, as a basis for small-scale aquaculture using techniques accessible to rural households or small businesses.

The project objectives were:

1. Determine the best places, times and methods in Vanuatu for capture of juvenile prawns for pond stocking
2. Determine the best feeds that are locally available and affordable in Vanuatu
3. Determine the best pond design and pond management regime for *M. lar* grow-out, in particular any significant variations needed from standard methods published for *M. rosenbergii*
4. Investigate *M. lar* larval dispersal and re-colonisation abilities using genetic evidence for structure for *M. lar* populations in Vanuatu, and
5. Determine what socio-economic impact *M. lar* culture may have upon household income or nutrition in rural SanMar province (SanMar is comprised of Santo and Malekula Islands).

2.1 Capture places, times and methods

Four sampling methods were employed to determine the best habitats or site characteristics for capture of *M. lar* of a suitable size for pond stocking. Also, to investigate the best time to sample (i.e. seasonal, lunar and diurnal abundance). The methods were: (1) a bottle-trap (Fouilland and Fossati, 1996); (2) hand dip-nets (Fig 1a); (3) large push nets (hapa) (Fig. 1b); (4) a stream-bed draining technique implemented by constructing a temporary dam. Trials were conducted in day- and night-time, and at different phases of the moon. Once the best method was identified, regular monthly sampling was conducted at a fixed sampling station to build up a picture of any seasonal trends in juvenile prawn abundance.

a.  b. 

Figure 1. Prawn capture methods: (a) hand scoop-nets (foreground) and drag net (background), and (b) stream diversion by constructing a log & gravel dam.

2.2 Locally-available feed sources

Growth trials of *M. lar* in monoculture in Vanuatu were carried out in small (less than 10 m long x 5 m wide x 1 m deep) ponds at Sarete and at Vunaspef villages in Santo (Fig. 2). Prawns were

transported from the collection site to grow-out sites in buckets with battery-powered aerators to reduce stress. In separate trials two locally-available diets were each compared against a benchmark (or 'control') feed consisting of commercial, formulated *Macrobrachium* feed (Pacific Feeds pellet imported from Fiji) provided according to standard methods for daily food ration (Nandlal and Pickering, 2005). The two local feeds were (i) 'on-farm feed' consisting of a mix of plantation foodstuffs like grated coconut, raw taro, breadfruit, pawpaw, banana, and cooked kitchen scraps, and (ii) 'local pellet' formulated from locally available ingredients (40% meat meal, 40% cassava, 10% copra meal, and 10% giant African snail meal), using a hand mincer and sun drying. A feed sample was submitted to DEEDI lab in Queensland for proximate analysis. Cage culture was also carried out using commercial pellets and on-farm feeds.

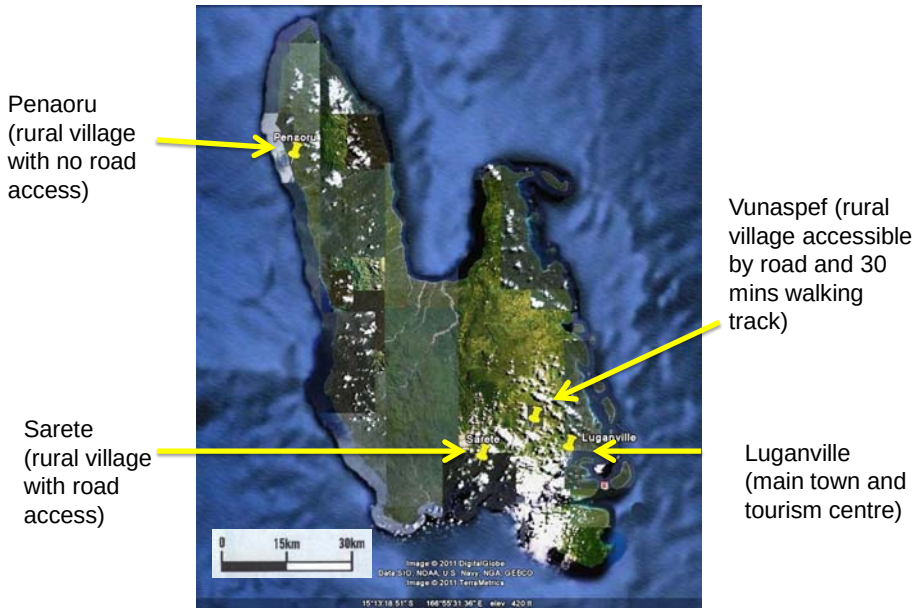

Figure 2. Map of Espiritu Santo showing study sites.

Prawns were sampled monthly for estimation of average body weight, and at the end of the trial they were harvested, counted and weighed.

2.3 Culture system design and management

By observation, and from data for growth and survival during the culture cycle, comparisons were drawn between *M. lar* and *M. rosenbergi* with respect to behaviour, diet and culture conditions. It was already known that a tendency for *M. lar* to climb out of culture ponds must be countered by erecting a plastic-sheet barrier around the pond. Other questions related to aggressive interactions or cannibalism in a pond environment that might affect stock density, and about requirements regarding pond water depth or provision of shelters. Cage culture was trialled as a lower-cost alternative to pond construction because most ponds in Santo need to be dug by hand.

2.4 Population connectivity

The ability of *M. lar* to re-establish populations in juvenile collection sites needs to be investigated to ensure that capture-based culture can be environmentally sustainable. Micro-satellite markers are now available for *M. lar* that can be used to detect whether there is any structure in natural populations that might be a consequence of limited larval-dispersal abilities. This research tool can

be applied to the sustainability question, because it can establish what connectivity exists between *M. lar* populations on different islands of Vanuatu. Adult *M. lar* were collected from four river catchments within Vanuatu (*n*=70). A pleiopod from each prawn was preserved in 70% ethanol for genetic analysis at the Faculty of Science and Technology Queensland University of Technology (FST QUT). The river catchments chosen were from east and west Santo, and east and west Efate, in order to investigate whether there is any structure to the *M. lar* population at two geographical scales (intra- and inter-insular).

2.5 Socio-economic impact

Any new livelihood must be integrated with existing livelihoods and lifestyles if it is to be adopted. To assess whether prawn farming can benefit rural SanMar communities, questionnaires were conducted in households with and without engagement in prawn farming. To find out how prawn farming might provide a livelihood opportunity, we made an economic assessment of the prawn business under two scenarios: (i) selling prawns in Luganville, and (ii) selling prawns in Port Vila.

3. Outcomes

3.1. Capture places, times and methods

More *M. lar* were caught at coastal sites than inland sites (Fig. 2). In Santo, there are many short (<2 km) spring-fed streams among coastal coconut and taro plantations, into which *M. lar* recruit but cannot migrate to the mountains, so appear to accumulate *M. lar* readily. On the other hand, Vunaspef is more than 10 km inland and the local creeks feed into a major river. People here were unable to collect enough juveniles for pond stocking, so instead they were collected at Sarete and transported by road to Vunaspef.

Hand scoop-nets, drag nets (hapa), and bottle trap collection techniques were either very laborious (nets) or did not capture many prawns (bottle traps), and they caught a large amount of non-target prawn species. The most effective technique was ‘stream diversion’ whereby a spring-fed stream was diverted temporarily from its natural course, and a net was placed in a pool of the drained stream-bed (Fig. 1b). Over the course of 5-6 hours, prawns followed the draining water down into this net. In addition, *M. lar* exhibit a strong climbing behaviour not shown by other prawn species (Fig. 3) , so it was easy to thus ensure 100% catches of *M.lar*. Between 200–400 prawns could be caught in a single stream diversion fishing session, enough to stock a small pond or cage.

Figure 3. *M. lar* showing their characteristic climbing behavior

According to our catch data and observations, and the observations of prawn fishers at Sarete:

- The hot, wet season (October–April) is the *M. lar* recruitment season
- 2–3 days after heavy rain is a good time for collection
- New-moon phase is slightly better than full-moon.

Juvenile *M. lar* of pond-stockable size (0.5–8 g body weight) were captured all year round using the stream-diversion method at the same location near Sarete. However there were seasonal peaks in Nov-Dec and Mar-Apr (Fig. 4).

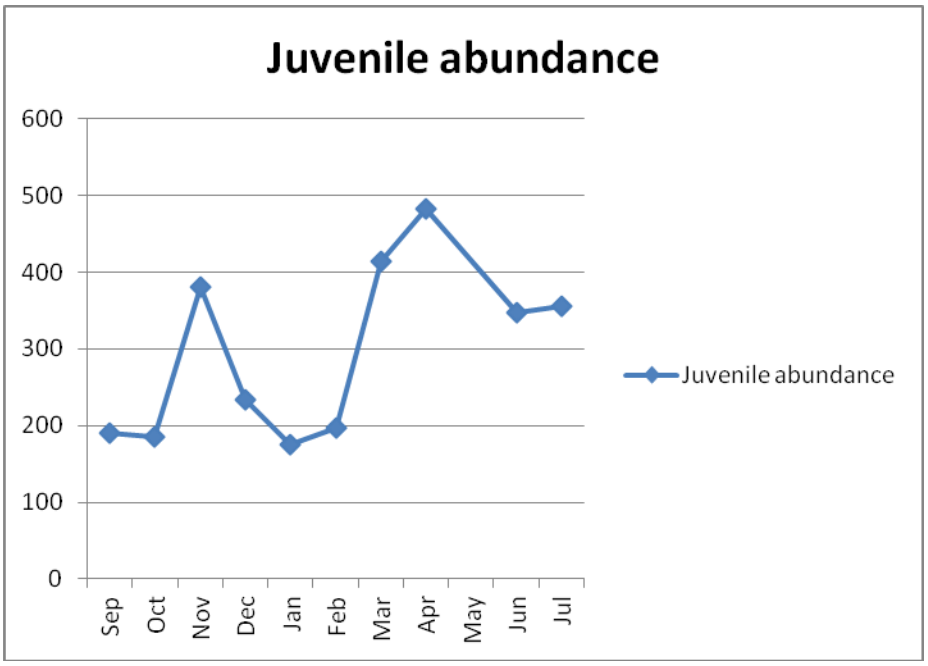

Figure 4. Monthly abundance of *M. lar* juveniles (0.5–8 g) caught by the stream diversion method at the Sarete site.

A prawn farmer at Belmoli (southwest Santo) developed a technique to divert a waterfall on his land and then use a 50 m length of 50 mL polyethylene pipe to siphon out each of the waterfall pools to collect the juvenile prawns. He also uses a 'refuge pond' technique whereby water is diverted through a shallow, man-made pond provided with palm leaves for shelter and grated coconut for food over several days, then the water is cut off and the pond drained to capture the prawns attracted by the coconut. Both methods are effective in supplying sufficient juveniles for pond or cage stocking.

There was seasonal variation in juvenile prawn catch, however there was no trend toward depletion through time as a result of repeated monthly samplings at the same site. At one point (in January 2011) the catch at the scheduled sampling time was zero, and then it was learned that some youths had carried out clandestine chemical fishing in the study site stream. However, when the sampling was repeated two weeks later to estimate recovery from this poisoning event, the catch of prawns (including adult sizes) was back to normal.

3.2 Best locally-available feed sources

There was little difference in prawn growth rate between the three diets tested pair-wise in two trials, namely:

(i) formulated *M. rosenbergii* prawn pellet made by Pacific Feeds Ltd in Fiji, compared with on-farm feed consisting mainly of plantation vegetables, fruits and grated coconut, in ponds at Sarete (Fig. 5), and

(ii) Pacific Feeds Ltd commercial pellet from Fiji, compared with a pellet formulated locally from meat meal, snail meal, copra meal and cassava ingredients, in ponds at Vunaspef (Fig. 6).

Within each experiment, between-pond differences accounted for more of the variation in growth rate than did feed type. Fiji commercial pellet did give slightly better results, however this feed is costly whereas on-farm feed requires no cash inputs by the farmer. The results of the trial were compromised somewhat when prawns from Pond 4 were harvested and eaten before the experiment concluded and by pond seepage in Pond 2. For these reasons the experiment is currently being repeated in two ponds, one each for Fiji pellet and on-farm feed. So far, after two months, these ponds are providing further confirmation of the overall trends shown in Figure 5.

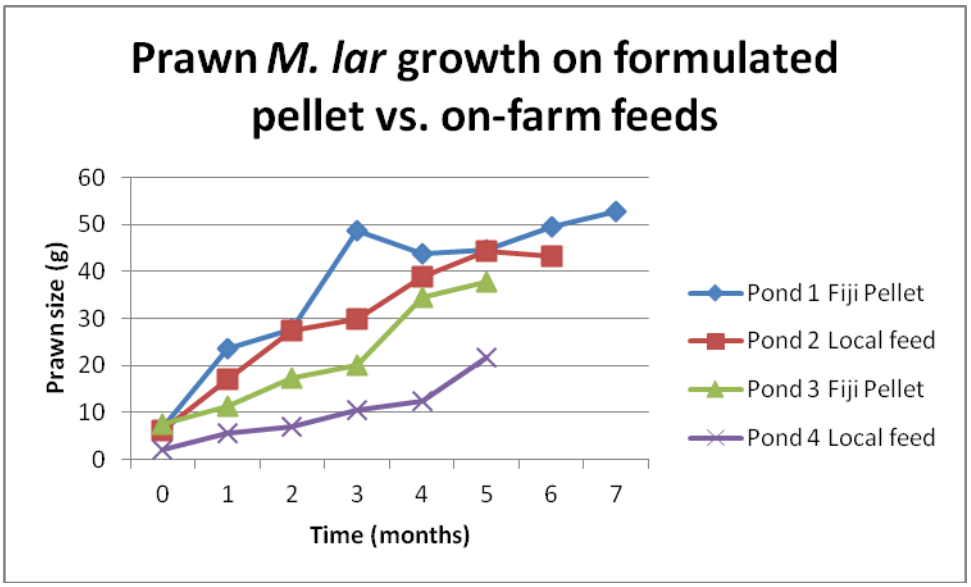

Figure 5. Prawn growth (g) over 7 months for *M. lar* fed a commercial Fiji pellet vs on-farm feed.

Yield and survival from Pond 1 (Fiji pellet) was higher at 4.8 kg and 85% (213 harvested from 250 prawns stocked) respectively, compared with Pond 2 (local feed) at 2.8 kg and 57% (142 harvested from 250 stocked). Seepage problems with Pond 2 resulted in the water level falling quite low at times, so the difference may not be attributable solely to difference in diet. All prawns were sold in Luganville at VT1000 per kg.

The experiment to compare commercial *M. rosenbergii* prawn pellet with a local pellet (Fig. 6) was still in progress at the time of reporting. Results at that time, however, indicated no difference in growth rate due to pellet type. There is a significant difference in the cost of these feeds, however, with the commercial pellet being much more expensive than the local version.

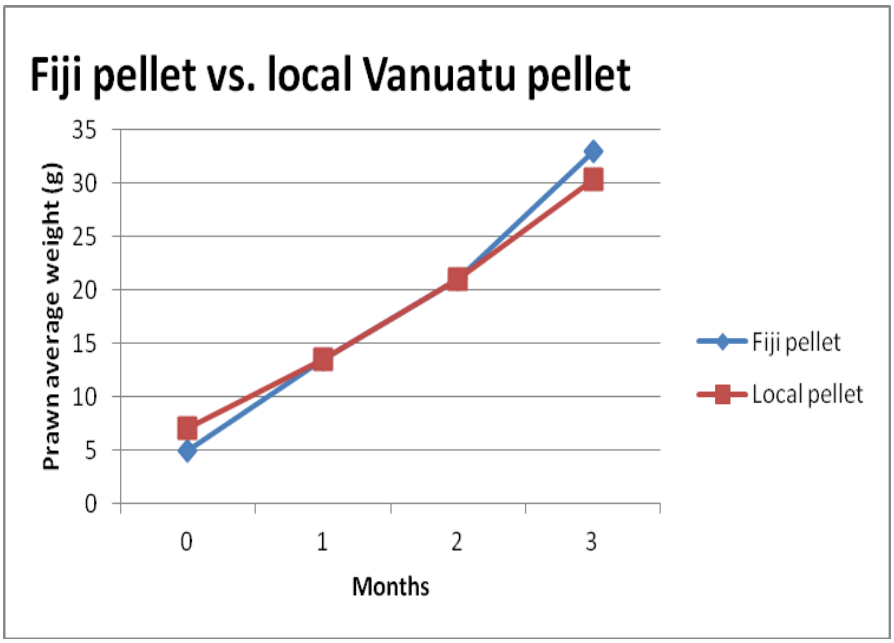

Figure 6. Prawn growth (g) over 3 months for *M. lar* fed a commercial Fiji pellet vs a locally formulated pellet produced in Vanuatu.

When Sarete ponds 1 and 2 were harvested it was noted that a high proportion of prawns were in berry and that the sizes of berried prawns was generally quite small. All prawns from this first harvest were weighed and their reproductive condition noted (Fig. 7). The sizes formed a bi-modal distribution with smaller sizes dominated by females, as has been observed for *M. rosenbergii* in pond culture. An apparent resilience of *M. lar* to fishing pressure is demonstrated by this very small size of first maturity in female *M. lar* prawns, with sizes as small as 3 g found to be in berry. In net and spear fisheries for these prawns, sizes smaller than 8–10 g are not usually harvested.

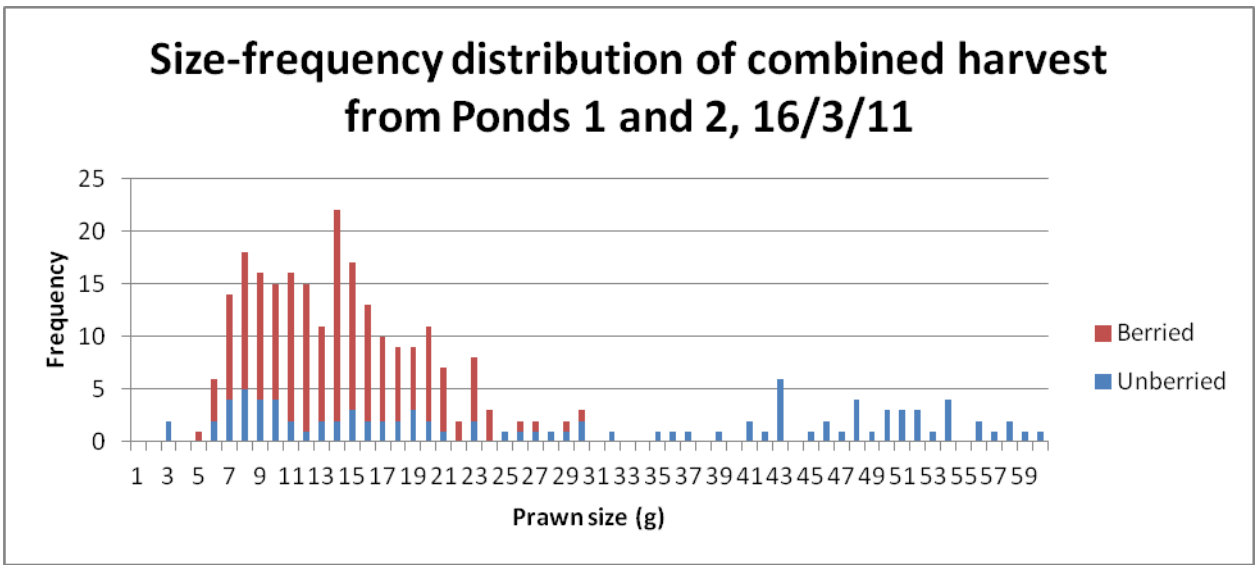

Figure 7: Size distribution (g) and reproductive condition of *M. lar* harvested from two ponds at Sarete.

2.3 Culture system design and management

A key research question is to what extent the culture system for *M. lar* may need to differ from those typically used for *M. rosenbergii*. The latter species is limited by behavioural interactions to stocking densities of around 6–7 ind/m^2. However *M. lar* is more gregarious and stocking of up to 25 ind/m^2 may be possible. Ponds can be shallower (around 50 cm depth) and water may be clear (high water flow and no plankton bloom) provided that abundant shelter is provided (Fig. 8).

Figure 8. Typical pond suitable for *M. lar* culture.

The communities interested in *M. lar* culture are often remote, where machine diggers are not available. Also, floods or droughts can adversely affect pond culture of prawns. For these reasons, cage culture in streams is now being trialled as an alternative to hand-dug, earthen ponds (Fig. 9). A replicated trial of *M. lar* prawns in cages, to more accurately establish growth in cages when fed on two feed types, is still under way at Sarete. Initially cages were placed inside experimental ponds with water inlets splashing down upon them. Build-up of lime deposits clogged the mesh and restricted water flow however, so cages were re-located to a flowing-stream site at Sarete where prawn growth is still being monitored.

Figure 9. *M. lar* cage culture in streams: a low-cost bamboo prawn cage (left) and experimental cages from Santo (right).

The concept of cage culture is sufficiently attractive that over a dozen farmers have already adopted it and have made commercial harvests. Growth of prawns appears slower and more variable than in ponds, depending upon location and/or feeding regime, with harvestable prawns produced in 6–12 months (Fig. 10). Sizes of farms and yields of prawns, along with income from each harvest, are shown in Table 1.

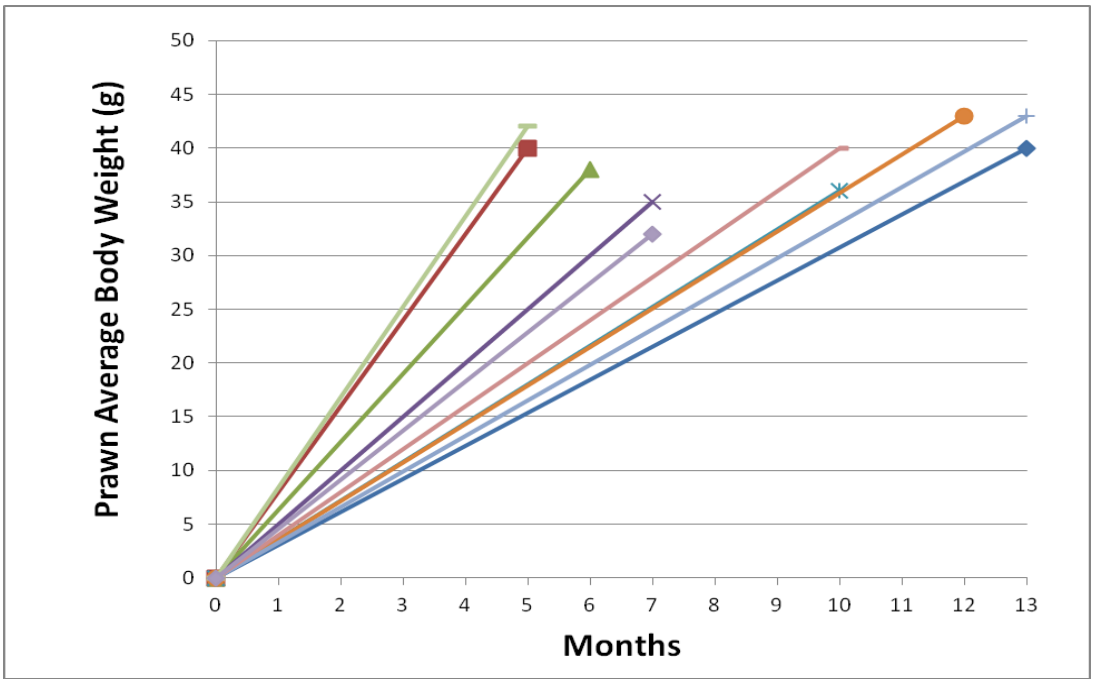

Figure 10. Growth of *M. lar* in artisanal cage culture in Santo, based upon records of individual farmer's final-harvest weights and culture times during 2010.

Table 1. Profiles of artisanal prawn farms now established and operating in Vanuatu

Prawn production

Farm	Village	Pond area (m^2)	Culture period (months)	ABW (g)	Harvest Weight (kg)	Price per kg (USD)	Net income per pond cycle (USD)	Production (kg/ha/yr)
1	Penoru, NW Santo Is.	96	13	40	15	$10.55	**$158.25**	1693
2	Penoru	33	12	40	8	$10.55	**$84.40**	2424
3	Penoru		6	38	5	$10.55	**$52.75**	
4	Penoru	6	7	35	6	$10.55	**$63.30**	5833
5	Penoru	12	7	36	4	$10.55	**$42.20**	1944
6	Petawat	18	10	43	18	$10.55	**$189.90**	8333
7	Penoru	24	12	43	10	$10.55	**$105.50**	4167
8	Pemoli	450	10	40	63	$10.55	**$664.65**	1167
9	Sarete, S. Santo Is.	150	5	42, 54	10	$10.55	**$105.50**	278
10	Green Hill, Tanna Is.	10	7	32	12	$9.50	**$114.00**	7000

Stocking density can be 15–25 ind/m^2 (c.f. *M. rosenbergii* <8 ind/ m^2)

A replicated trial of *M. lar* prawns in cages, to more accurately establish growth in cages when fed on Fiji commercial pellet versus on-farm feed, is still under way at Sarete. Initially cages were placed inside experimental ponds with water inlets splashing down upon them. However, build-up of lime deposits clogged the mesh and restricted water flow, so cages were re-located to a flowing-stream site at Sarete where prawn growth is still being monitored. Results so far are shown in Figure 11.

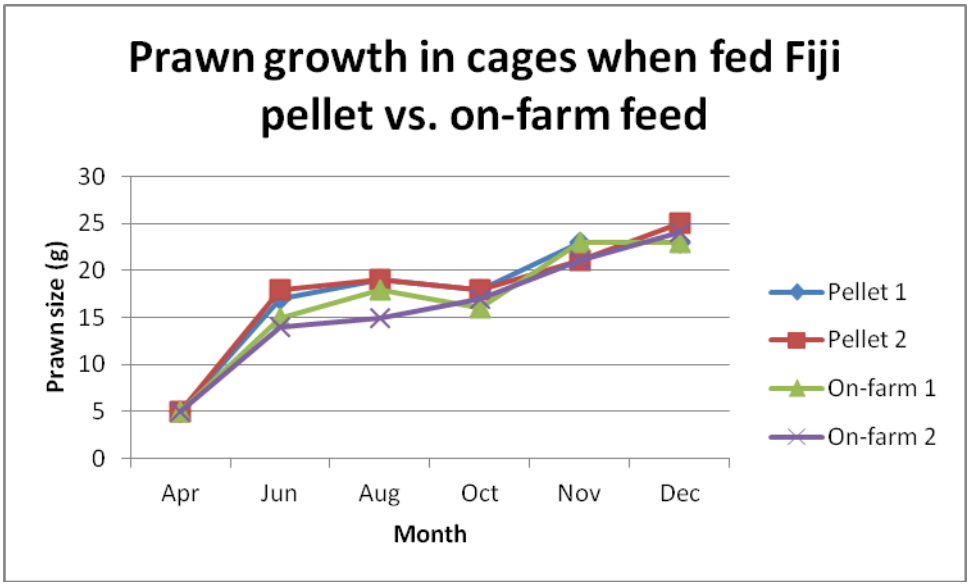

Figure 11. Growth of *M. lar* grown on two diets in experimental cages. The cages were re-located in September 2011 from inside earthen ponds to a flowing stream site at Sarete.

2.4 Population connectivity

Seventy prawns per site were collected from Rentapao River in Efate, north Efate, southeast Santo and south Santo near Sarete. The samples were taken to FST QUT for genetic analysis in late 2010, however the analyses were still pending at the time of writing (end of 2011).

2.5 Socio-economic results

A preliminary survey of ten households from Sarete and Penaoru villages, seven of whom are engaged in prawn farming activity, showed trends for income and expenditure (Figs 12 and 13). Half of household income (average 7–8 people per household) goes on food, and families invest heavily in education with a further one-quarter being spent on schooling. Copra and kava are the main income earners, however prawn sales can account for amounts similar to those earned from vegetable gardening, cocoa or cattle. Prawn sales can contribute US$155 per year (or 15%) to the average household income of US$1,040. This figure is less than the official United Nations 'poverty line' of US$455 per person. Fortunately, they have a strong subsistence food production sector. Survey questions related to the food items consumed by the average household (Fig. 14), finding that household diets are largely vegetarian, with tinned fish eaten on average about three times a week (one 1 kg tin among four people). The main locally available 'fresh-fish protein' for inland communities is *M. lar* from river fisheries.

The level of ownership of household possessions indicated that the socio-economic status of all surveyed households is very low (Fig. 15).

This sample size of surveyed households is small. However, the same questionnaire will be implemented at additional households during planned community visits by Vanuatu Department of Fisheries for prawn training workshops.

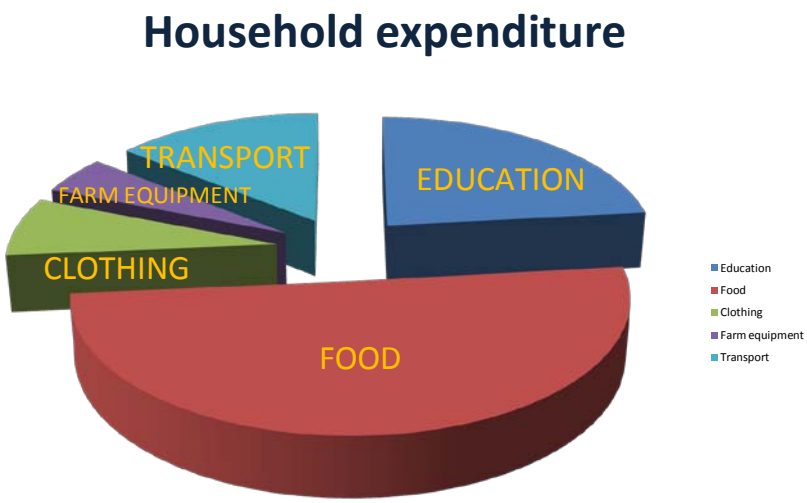

Figure 12. Major items of household expenditure by rural village households in Santo

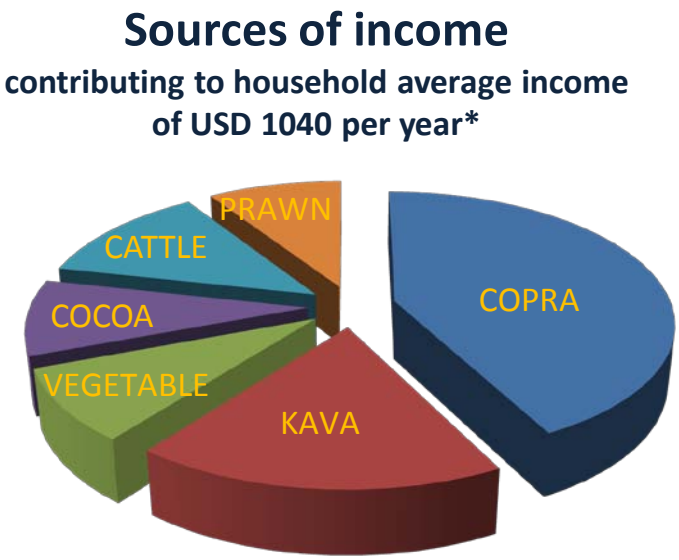

Figure 13. Major sources of household income by rural households in Santo when engaged in prawn farming

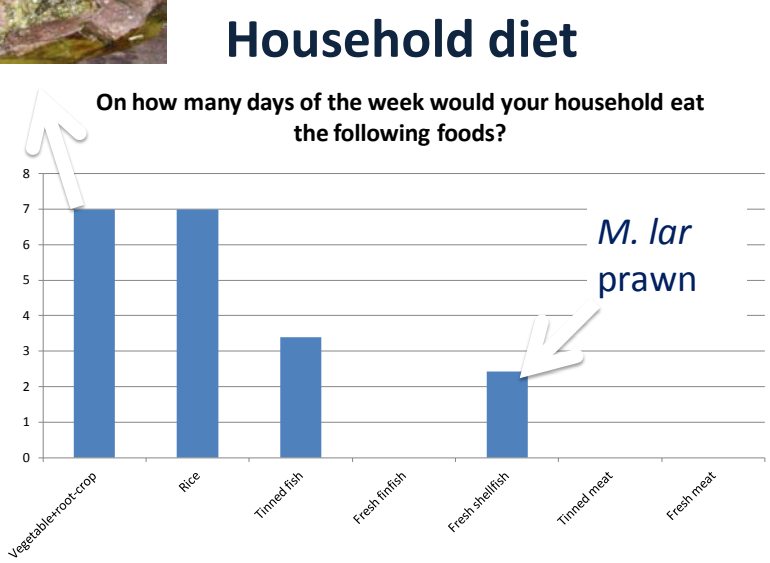

Figure 14: Questionnaire results for main food items in household diets.

Possessions

Does your household have any of the following items?

100% response: “NO”

Item	YES/NO
TV set	NO
DVD player	NO
Radio	NO
Washing Machine	NO
Gas Stove	NO
Refrigerator	NO
Flush toilet	NO
Boat or canoe	NO
Outboard motor	NO

Figure 15. Survey results in rural Santo for ownership of household items indicative of general socio-economic status

An economic analysis was made of pond production (Table 2) and cage production (Table 3) of prawns at Sarete, based on an assumption that prawn growth and survival in both systems is similar. This may need to be further refined as more definitive cage-culture results become available, and preliminary indications are that growth in cages may in fact be slower. The analysis was further split into comparison of two marketing opportunities, these being Luganville which is currently the targeted market (VT1,000 per kg), and Port Vila which is the more lucrative market (VT2,000–2,500 per kg).

Table 2. Estimated economic analysis of pond production of *M. lar* over a 3-year life cycle, based on project results to date.

	Luganville	Port Vila
Gross profit (US$ per kg)	$724.87	$1,574.87
Gross profit (US$ per cycle)	$99,325.00	$215,796.00
Gross profit (US$ per annum)	$198,650.00	$431,593.00
Cumulative net present value (NPV) (US$)	$394,013.00	$973,307.00
Internal Rate of Return (IRR) (%)	190.55%	428.67%
Value added ratio (US$ per annum)	$258,650.00	$491,593.00

Table 3. Estimated economic analysis of cage production of *M. lar* over a 3-year life cycle, based on project results to date.

	Luganville	Port Vila
Gross profit (US$ per kg)	$663.49	$1,513.49
Gross profit (US$ per cycle)	$62,700.00	$143,025.00
Gross profit (US$ per annum)	$125,400.00	$286,050.00
Cumulative net present value (NPV) (US$)	$287,851.00	$834,150.00
Internal Rate of Return (IRR) (%)	520.31%	1191.32%
Value added ratio (US$ per annum)	$174,000.00	$334,650.00

The results indicate that both pond and cage production systems are financially and economically viable, whether marketing to Luganville or Port Vila. The current situation of marketing to Luganville is indicative that the enterprise is financially profitable and economically viable. A positive NPV, an IRR greater than 10% (the discount rate) and significant value added contributions to the domestic economy are indicative of an economically viable project over a 3-year period. The enterprise is even more viable if prawns are marketed in Vila, even after allowing for the cost of air freight.

In the situation of an equivalent private enterprise, the value added ratio, being the gross profit plus the cost of labour, could be split among the manager and a single employee. In breaking this down in terms of hours of work involved per annum for pond production, this equates to an hourly income of VT646 (shared between two people), which is more than triple the minimum wage in Vanuatu. Similarly, breaking this down in terms of hours of work involved per annum for cage production equates to an hourly income of VT537 (shared between two people), which is approximately double the minimum wage in Vanuatu. Therefore, this production system is not only financially and economically viable, but it also provides significant employment opportunity.

4. Impacts

4.1 Scientific impacts

This follow-on project has confirmed the findings of the earlier ACIAR funded 2005 mini-project "*The Monoculture of the freshwater prawn, Macrobrachium lar, in Vanuatu and integrated prawn-taro farming in Wallis & Futuna*" implemented by SPC and Vanuatu Dept. Of Fisheries, which produced baseline data on growth of *M. lar* in monoculture on Santo and in integrated farming of *M. lar* with swamp taro on Futuna Island, and demonstrated that small-scale capture-based culture to produce *M. lar* in Pacific island countries for income generation is technically feasible.

It has now been further demonstrated that the Pacific's largest indigenous prawn *M. lar*, in both pond and cage culture, can grow and survive at rates comparable to those of the non-indigenous giant Malaysian freshwater prawn, *M. rosenbergii* .

4.2 Capacity impacts

Based on research results to date, Vanuatu Dept. of Fisheries conducted field days to promote prawn capture-culture techniques in NW Santo, Malekula Is. and Tanna Is. These regular training workshops are now being held by Fisheries Department, some in very remote places in the interior of islands, to train interested farmers in prawn pond construction and management. Three such workshops were held in Malekula during 2011: further workshops are planned for SanMar province in 2012. Funding support for these workshops has been obtained through the AUSAID Technical and Vocational Education and Training (TVET) capacity-building project in SanMar province.

Research outputs have been incorporated into the curriculum of a training module on prawn farming, written by Aquaculture Officer Glen Alo, which is now accredited by the Vanuatu National Training Council (VNTC) and offered through the Vanuatu Agriculture College to tertiary students enrolled in Certificate of Agriculture who intend to take up agriculture as a career. Module candidates are required to construct and manage a prawn farm in a village situation for an extended period, where they are assessed in competency-based learning.

Four module candidates in 2010–2011 were attached to this project, and assisted to manage the ponds and cages. Based upon his training and experience, one of these candidates has now been offered a post as Aquaculture Technician based at the Northern Office of Vanuatu Department of Fisheries.

The project's Country Leader, Sompert Gereva, is continuing with post-graduate studies on *M. lar*. In 2011 he enrolled in the Masters program within the QUT School of Sciences and Technology.

The Aquaculture Section leader of Vanuatu DoF, Lency Kukan, and a USP-ACIAR scholarship Masters student aligned to this mini-project Laura Williams, were supported to attend a training workshop in Noumea on identification of freshwater prawns, to ensure that prawns targeted by this capture-based culture research are indeed *M. lar*, and to be able to identify any other prawn species appearing in catches.

4.2 Community impacts

Household-level commercial projects of small-scale capture-based pond and cage culture of *M. lar* are now self-sustaining, and are contributing to poverty alleviation in remote rural villages in Vanuatu. At the end of 2010 there were 12 prawn farmers, and by the end of 2011 this had increased to 16 farmers.

Preliminary socio-economic survey results indicate the following positive impacts:

- Prawn farming is making a very useful addition to household income (15% on average)
- Prawn farming makes a good sideline activity to diversify agricultural production, but does not hinder other types of production

Negative socio-economic impacts of prawn farming may include:

- Land disputes can arise when communally-owned tribal land is used by individuals for cash income
- Disputes can arise in some places over access to river sites favourable for collection of prawn juveniles

- There can be some stealing of prawns from ponds in the night by hungry youths.

The possibility of negative environmental impacts can be ameliorated by the following characteristics of *M.lar* capture-based culture:

- Methods that use *M. lar* climbing behaviour to separate them from other fauna can result in better than 90% *M. lar* catch composition
- It is hard work to catch *M. lar* in the 'hundreds', and not practicable to get them in the 'thousands'. This will limit commercial engagement to small-scale low-impact aquaculture activity among impoverished communities with few alternative income sources.

5. Conclusions

M. lar has a wide-spread geographical distribution, and is indigenous to many Pacific Ocean and Indian Ocean islands where *M. rosenbergii* is not naturally present. However, *M. lar* has not previously been considered a species with aquaculture potential, because:

- Past efforts to raise larvae to post-larval stage in captivity have not been successful (but see the report of mini-project MS0806 'Closing the life cycle of *Macrobrachium lar*, Fiji' by Monal Lal)
- Adult show strong climbing behaviour—they can escape from ponds unless fenced-in by plastic sheeting, and
- The species had been poorly researched—there was little information available on culture conditions or dietary requirements.

Findings from this mini-project lend support to domestication of *M. lar* for small-scale aquaculture. For example:

- *M. lar* grows quite rapidly to a marketable size
- *M. lar* has widespread acceptance and fetches a good price in Pacific islands domestic markets
- *M. lar* is a tough, hardy and gregarious species that can be cultured either in ponds or in cages
- *M. lar* is quite herbivorous when compared to *M. rosenbergii*, with lower dietary protein requirements and will accept on-farm feeds
- *M. lar* grows well in culture systems constructed of low-cost materials
- *M. lar* can be cultured at higher stocking density than *M. rosenbergii* (i.e. 10 – 15 ind/m^2)
- *M. lar* survives out of water for up to 10 hours, so does not need to be immediately iced pond-side at harvest
- In some locations, availability of small juveniles is sufficient to support capture-based culture as a small-scale household-level activity
- Prawns are a small-volume high-value commodity – easier to bring out to market when transport is scarce or expensive (e.g. by air) than bulk commodities like copra, cocoa, etc.

This project has demonstrated that *M. lar* dietary requirements are flexible and can be very low-cost. There is so far little difference, in either cages or in ponds, between feeding on expensive, commercial *M. rosenbergii* pellet compared with a locally formulated pellet, or with on-farm plantation fruits, vegetables or kitchen wastes like grated and squeezed coconut. These latter feeds require little or no cash outlay by farmers. Prawn growth may be slower (35 g in 6 months) on the lower cost feeds and in cages, but nevertheless is acceptable. Any slow-down in growth

rate is amply compensated-for by the saving in cash outlay by the farmer for feedstuffs. This needs to be verified by follow-up studies in replicated experimental systems. *M. lar* appear to readily reach a size of around 40 g within 3–5 months (depending on diet) after which growth levels off (regardless of diet). This does not affect marketability since a 40 g prawn is generally regarded as a good-sized prawn (anything > 20 g can be sold). However, it does suggest that the best farming strategy may be to harvest early as there is no benefit in keeping prawns for longer in order to grow them larger than 40 g.

The main draw-back of *M. lar* culture is obtaining sufficient number of wild juveniles for pond or cage stocking. The range of places where this can be readily accomplished may not be very wide-spread, depending upon available habitats and site characteristics. Even so, some sites and techniques have been identified whereby juvenile collection for prawn farming at household-farm scale is practicable. The best collection sites were small, drainable streams or pools which are not too far from the coast and are relatively short, i.e. where *M. lar* can recruit but cannot disperse to far-flung inland locations. While there appears (within the limitations of a single-year study) to be a distinct seasonality in juvenile recruitment, they do appear to recruit all year round. The climbing tendency of *M. lar* makes separation from related taxa quite easy.

In conclusion,

- Farming of *M. lar* can contribute useful additional cash income to Santo rural households
- A capture-based culture method has been developed which is commercially successful and appears to be environmentally sustainable
- It will never be a huge industry, nor will it replace subsistence or commercial agriculture as the main livelihood (except in a few cases), because of limitations on juvenile supply for pond or cage stocking
- To provide even small additional income to people whose income is already low can make a positive socio-economic impact
- This capture-based culture technique is now ready for delivery to other parts of the Pacific, subject to finding suitable sites where collection of juveniles is practicable. This could be the subject of follow-on projects in these other places.

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SPC Aquaculture Action Plan 2007

7. Acknowledgements

In memory of Mr. Ase Baia, the pioneer supporter of aquaculture in Santo, who provided land from his plot at Sarete Village to the Vanuatu Department of Fisheries for construction of the Sarete pilot fish and prawn farm used in this project, and who passed away at his home on 19 July 2011.

Tonga

(Appendixes 2.16 to 2.18)

Appendix 2.16

MS0807

Improved husbandry methods for the culture of juvenile winged pearl oyster, *Pteria penguin*, Tonga

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU James Cook University WorldFish Center USP The University of the South Pacific	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Improved husbandry methods for culture of the winged pearl oyster, *Pteria penguin*, in Tonga (MS0807)**
Goal:	Optimise culture methods for winged pearl oyster, *Pteria penguin*.
Objective(s):	The project will achieve this goal through the following objectives: 1) Determine the effect of various culture units on growth and survival and identify the best culture unit for nursery culture and juvenile culture; and 2) Optimise culture methods by determining the effects of depth, stocking density and cleaning frequency on growth and survival.
Project location:	Tonga
Project partner(s):	Tonga Fisheries Division
Dates / duration:	2 years
Project description:	An estimated 400,000+, 3-4 month old *Pteria penguin* spat were produced during the recent spawning trials (under ACIAR FIS 2006/172). They will be used for research that will determine optimal culture methods for this species until they reach pearl producing size. The mini-project will form part of an ACIAR-USP scholarship commencing in 2009, although data collection by a Tongan Fisheries aquaculture officer (Mr. Martin Finau) will commence in 2008.
Justification:	This is the largest successful spawning of this species in the Indo-Pacific and represents a unique opportunity to collect data on factors affecting their survival and growth under farming conditions, currently an impediment to further development of the pearl industry. The results of this research will feed-in directly to the existing pearl industry in Tonga.
Expected outcomes:	1. Optimised culture methods for *Pt. penguin* in Tonga 2. Tangible benefits to the pearl industry via more efficient culture practices 3. Capacity building (oyster husbandry) within Fisheries and the Tongan pearl industry 4. Increased mariculture research capacity within Tonga/Region.
Funding:	$18,300

Improved husbandry methods for culture of the winged pearl oyster, *Pteria penguin*, in Tonga

Martin Finau[1]

[1] Tonga Fisheries division, Nuku'alofa, Tonga

1. Background:

The winged pearl oyster, *Pteria penguin*, is traditionally used for production of half-pearls ('mabe') in Tonga for which there is an export market in Japan and elsewhere. *Pt. penguin* was introduced to Tonga in 1975 by the Tasaki Pearl Co. of Japan (Fa'anunu and Manu, 1996) and there were twenty-five small pearl farms in Tonga at the end of 2000. The industry, although small, is well organised and is represented by the Pearl Growers Association (PGA). The Tongan pearl industry is centred in the Vava'u island group and relies on natural spat collection. Spat are collected from the wild using spat collectors and grown to a size where they can be used for half-pearl production. Half-pearl culture is attractive because it uses relatively simple and affordable techniques for catching spat, for grow-out and for pearl production. Most significantly, half-pearl production does not require a specialised technician and can be achieved by local people with minimal training and/or experience.

A major impediment to the sustainability and expansion of the pearl industry in Tonga is a reliable and adequate supply of oysters. Over recent years, poor recruitment of spat has resulted in the harvesting of adult oysters from the wild, which has further impacted recruitment, and natural spat fall of *Pt. penguin* in Vava'u is now extremely limited. Further development of the pearl industry in Tonga is hindered by a lack of knowledge of the culture requirements of *Pt. penguin* and methods for optimising pearl production from this species. Research is also required to optimise culture methodology and pearl production from *Pt. penguin* as a basis for sustainable industry development.

A separate, small ACIAR Project (FIS 2006/172) is currently focused on developing appropriate hatchery culture techniques for *Pt. penguin* and the use of hatchery-propagated oysters for pearl production. As a result of a spawning activity in mid 2008, this project produced more than 400,000 settled *Pt. penguin* oyster spat at the Vava'u hatchery. This is the largest successful spawning of this species in the Indo-Pacific and represents a unique opportunity to collect data on factors affecting juvenile survival and growth under farming conditions, currently a constraint to pearl industry development. FIS/2006/172 is a small ACIAR project and lacks the funds required to support the research proposed in this application.

This mini-project will form part of an ACIAR-USP scholarship commencing in 2009, although data collection by a Tongan Fisheries aquaculture officer (Martin Finau) will commence in 2008, because the juveniles are available now. Involvement of a student who is also a Fisheries Officer in a mini-project under the ACIAR-USP scholarship scheme will enhance the current small ACIAR Project by ensuring there is a dedicated staff member on the project and enable additional data collection as part of their research topic.

2. Project Methodology

2.1 Experimental design

The mini-project was carried out primarily at Vava'u, where the Tongan pearl culture activity is centred. Experimental long-lines were established at commercial farms in the area. Another long-line (already established) at Sopu close to the Fisheries office was also used as a study site. The study employed methods used in similar studies with pearl oysters (e.g. Friedman & Southgate, 1999a, 1999b; Southgate & Beer, 2000) and consisted of a series of experiments, as follows:

1) **Experiment 1:** Comparison of different culture units (panel (pocket) net, pearl net, plastic mesh tray, see Fig. 1) on growth and survival of small juvenile *Pt. penguin* in nursery culture. Eighty four-month-old juveniles (~ 27.5 mm APM, 14 mm DVM) were cultured in replicates (n = 4) of each culture unit (n = 20 oysters in each treatment) at 5 m depth at two sites (Vaipua lagoon and Sopu) for 4.5 months, from 1 Oct 2008 to 17 Feb 2009.

2) **Experiment 2:**

   Part a: Comparison of different culture units (panel net, pearl nets, plastic mesh tray) on growth and survival of juvenile *Pt. penguin*. Nine-month-old juveniles were cultured in replicated culture units (n = 48 oysters in each unit type) at 6 m depth at three sites (Utulei, Vaipua and Sopu) for 5 months (from 17 Feb 2009 to 14 Jul 2009).

   Part b: Comparison of depth on growth and survival of juvenile *Pt. Penguin* in three types of culture units (panel net, pearl net, plastic mesh tray). Nine-month-old juveniles were cultured in replicated culture units (n = 48 oysters in each treatment) at depths of 2 m (shallow) and 7 m (deep) at Sopu for 5 months (from 17 Feb 2009 to 14 Jul 2009).

3) **Experiment 3:** Comparison of different culture units (pocket panel nets vs. ear-hanging on chaplets, see Fig. 2) on growth and survival of large juvenile *Pt. penguin.* Fourteen-month-old juveniles (~140 mm APM, 95 mm DVM) were grown in replicated culture units (n = 30 oysters in each treatment) at 5-6 m depth at three sites (Vaipua, Aneti and Sopu) for 5 months (from July to December 2009). Aneti is located across the bay from 'Utulei and was used in this final experiment because of security concerns at 'Utulei where some lines were lost during Experiment 2.

For all experiments, culture units were gently brushed clean of fouling on a monthly basis (Fig. 3). They were inspected for predators which were recorded and removed. Dorso-ventral measurement (DVM), antero-posterior measurement (APM) length and hinge length (HL) were measured at the start and end of each experiment, except for Experiment 3 where only DVM and APM were measured. Number of oysters remaining at the conclusion of each experiment was recorded to determine survival.

2.2 Statistical Analysis

Data collected during the experiments were entered onto spreadsheets for subsequent statistical analysis. Data were analysed using one-way ANOVA followed by a comparison of means using the Least Significant Difference (LSD) Test (Steel and Torrie, 1980). All differences were regarded as significant at $P < 0.05$. Survival data (%) was be transformed prior to analysis.

Fig.1. Culture unit used in Experiments 1 and 2: Panel (or pocket) nets (left); pearl net (centre); plastic tray (right).

Fig.2. Longlines with *Pteria penguin* cultured by ear hanging on chaplets (foreground) and panel nets (background) used in Experiment 3.

Fig.3. Cleaning culture units

3. Results

3.1 Experiment 1: Comparison of different culture units (pocket panel net, pearl net and plastic mesh tray) on growth and survival of *Pt. penguin* in nursery culture

After 4.5 months, mean survival of *Pt. penguin* oyster was highest in trays at Vaipua (77.5%) and Sopu (95%)(Table 1). The lowest mean survival was recorded in pearl nets (58.8% and 31.4% at Vaipua nd Sopu, respectively). The poor survival of juveniles in pearl nets was due to some of the oysters falling from the long-line and being eaten by fish and crabs. Pearl nets also recorded the highest number of fouling organisms (*Cymatium*). However, there were no significant differences ($P > 0.05$) in survival of pearl oyster juveniles in the three culture units within sites (Table 2).

Table 1. Mean (± SD) survival, antero-posterior measurement (APM), dorso-ventral measurement (DVM) and hinge length (HL) of *Pteria penguin* juveniles held in three types of culture unit at two sites for 4.5 months. Ranges are shown in parentheses and means in columns with the same superscript are not significantly different ($P > 0.05$).

Site	Treatments	Survival (%)	APM (mm)	HL (mm)	DVM (mm)
Vaipau	Tray	77.5 (± 27.2)^{a}	93.8 (± 8.0)^{a}	93.1 (± 15.1)^{a}	55.3 (± 5.5)^{a}
		(45.0 – 100.0)	(76.5 – 112.4)	(55.4 – 130.0)	(44.2 – 66.6)
	Panel nets	66.3 (± 13.8)^{a}	61.7 (± 17.8)^{b}	57.8 (± 18.1)^{b}	37.3 (± 12.5)^{b}
		(50.0 – 80.0)	(27.4 – 96.1)	(27.2 – 94.5)	(14.5 – 64.5)
	Pearl nets	58.8 (± 49.7)^{a}	80.4 (± 9.6)^{c}	75.9 (± 17.3)^{c}	46.9 (± 6.3)^{c}
		(0.0 – 100.0)	(57.4 – 98.2)	(39.5 – 112.5)	(32.9 – 57.7)
Sopu	Tray	95.0 (± 4.1)^{a}	102.7 (± 11.0)^{d}	103.8 (± 17.4)^{d}	63.3 (± 14.8)^{d}
		(90.0 – 100.0)	(75.4 – 129.8)	(64.7 – 152.5)	(45.6 – 175.1)
	Panel nets	65.0 (± 44.3)^{a}	57.0 (± 18.2)^{b}	52.7 (± 20.5)^{b}	32.6 (± 11.9)^{b}
		(0.0 – 100.0)	(25.3 - 108.9)	(19.4 – 133.5)	(13.9 – 67.4)
	Pearl nets	31.4 (± 37.6)^{a}	92.5 (± 21.1)^{a}	92.4 (± 28.1)^{a}	55.3 (± 13.4)^{a}
		(0.0 – 85.7)	(47.8 – 126.2)	(45.0 – 151.9)	(24.3 – 76.4)

Table 2. Results of comparison between two sites using Univariate Analysis with nested model, e.g. treatment nested within site (Site (Treatment)). Significance level: $P < 0.05$.

Factor	d.f.	Survival	APM	HL	DVH
Site (Treatment)	4	F=1.942 *P*=0.147	F=120.260 *P*<0.001	F=83.869 *P*<0.001	F=74.182 *P*<0.001

At Vaipua, juveniles grown in trays had the highest growth rates (Table 1, Fig. 4), significantly greater ($P < 0.05$) than juveniles grown in pearl nets and panel nets, the latter treatment had the lowest shell growth rate. Trays also produced the largest juveniles at Sopu, followed by pearl nets, while the lowest growth rates were recorded in the panel nets (Fig. 4). At both sites, juveniles in trays had significantly greater DVM, APM and HL ($P < 0.05$) and a narrower size range than oyster in pearl nets and panels. Juveniles grown in trays at Sopu had significantly greater APM, HL and DVM ($P < 0.05$) than other treatments in both sites. There were no significant differences ($P > 0.05$) between the growth rates of juveniles in panel nets at both sites; also there was no significant difference ($P > 0.05$) between the growth of juveniles in pearl nets at Sopu and trays in Vaipua. Pearl oysters

held in panel nets showed the lowest rate of growth during the experiment at Vaipua and Sopu with a mean APM of 61.7 (± 17.8) mm and 57.0 (± 18.2) mm, respectively. This treatment was covered with ascidians leaving insufficient space in the pockets for oysters to grow.

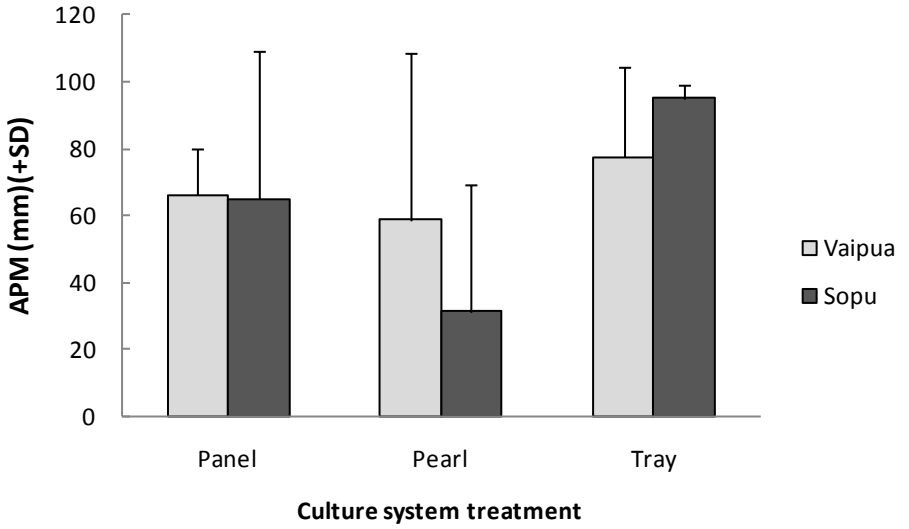

Fig. 4. Mean (± SD) antero-posterior measurement (mm) of juvenile *Pt. penguin* in three culture units at two sites.

3.2 Experiment 2, Part 1: Comparison of different culture units (panel net, pearl net and plastic mesh tray) on growth and survival of juvenile *Pt. penguin*

There were large differences in overall survival between sites (Table 3, Fig. 5) with Sopu generally having high survival in all culture units (95.8%, 100% and 93.8% for trays, panel nets and pearl nets, respectively), although there was good survival at 'Utulei in pearl nets (97.9%) and at Vaipua in panel nets (89.6%). Most other culture methods at Utulei and Vaipua did not have high survival rates. Despite quite distinct differences in survival rates between sites and treatments, there was high variability in survival within 'Utulei and Vaipua (Table 3, Fig. 5), hence no significant difference (P = 0.07) in survival between treatments within sites (Table 4).

There was no significant difference in DVM growth of the oysters at all sites and treatments (P = 0.419) (Table 4), although panel nets had the highest DVM (95.7 ± 17.3, 90.3 ± 12.9 and 94.7 ± 9.8 mm at 'Utulei, Vaipua and Sopu, respectively)(Table 3). There were, however, significant differences in APM and HL (P < 0.001 for both parameters, Table 4). Oysters in trays grew significantly less (both APM and HL) at 'Utulei and Vaipua than most other sites and treatments. Panel nets generally showed highest APM and HL values, with growth at Sopu greater than the other two sites (APM 140.5 ± 14.8, 134.5 ± 18.5 and 140.8 ± 12.9 mm at 'Utulei, Vaipua and Sopu, respectively)(Table 3, Fig. 6).

There was very high recruitment of competitive (e.g. *Pinctada* sp.), predatory (e.g. flat worms, *Cymatium* sp. and diadema) and fouling species (e.g. ascidians) at 'Utulei and Vaipua, and relatively low recruitment of these species at Sopu (Fig. 7).

Table 3. Mean (± SD) survival, antero-posterior measurement (APM), dorso-ventral measurement (DVM) and hinge length (HL) of *Pteria penguin* individuals held in three types of culture unit at three sites. Ranges are shown in parentheses and means in columns with the same superscript are not significantly different ($P > 0.05$).

Site	Treatment	Survival (%)	APM (mm)	HL (mm)	DVH (mm)
Utulei	Tray	68.8 (± 46.3)^{a,b}	107.7 (± 20.8)^{a}	97.7 (± 21.6)^{a}	71.5 (± 15.5)^{a}
		(0.0 – 100.0)	(58.5 – 142.9)	(59.0 – 137.7)	(37.6 – 100.2)
	Panel Nets	66.7 (± 44.6)^{a,b}	140.5 (± 14.8)^{c}	125.5 (± 27)^{b,c}	95.7 (± 17.3)^{a}
		(0.0 – 91.7)	(94.2 – 163.8)	(51.7 – 183.2)	(57.6 – 163.2)
	Pearl Nets	97.9 (± 4.2)^{b}	128.0 (± 19.4)^{b,c}	112.7 (± 25.2)^{a,b}	82.5 (± 11.9)^{a}
		(91.7 – 100.0)	(85.3 – 171.9)	(66.8 – 183.8)	(58.1 – 108.2)
Vaipau	Tray	31.3 (± 36.2)^{a}	106.0 (± 15.4)^{a}	95.3 (± 15.7)^{a}	70.2 (± 10.2)^{a}
		(0.0 – 66.7)	(77.7 – 134.8)	(77.5 – 136.8)	(52.8 – 87.2)
	Panel Nets	89.6 (± 12.5)^{a,b}	134.5 (± 18.5)^{c}	122.3 (± 23.5)^{b,c}	90.3 (± 12.9)^{a}
		(75.0 – 100.0)	(61.8 - 159.8)	(70.0 – 163.8)	(38.7 – 113.7)
	Pearl Nets	43.8 (± 32.2)^{a,b}	115.9 (± 24.5)^{a,b}	95.4 (± 14.0)^{a}	78.8 (± 17.7)^{a}
		(0.0 – 75.0)	(88.6 – 173.8)	(68.3 – 113.2)	(56.1 – 114.0)
Sopu	Tray	95.8 (± 4.8)^{a,b}	129.0 (± 22.0)^{b,c}	116.3 (± 22.7)^{b}	84.0 (± 14.8)^{a}
		(91.7 – 100.0)	(88.1 – 164.1)	(61.9 – 157.0)	(49.1 – 107.1)
	Panel Nets	100.0 (± 0.0)^{b}	140.8 (± 12.9)^{c}	139.9 (± 17.8)^{c}	94.7 (± 9.8)^{a}
		(100.0 – 100.0)	(106.4 - 160.2)	(97.5 – 174.0)	(67.4 – 112.8)
	Pearl Nets	93.8 (± 8.0)^{a,b}	138.0 (± 21.0)^{c}	129.4 (± 24.6)^{b,c}	91.4 (± 13.4)^{a}
		(83.3 – 100.0)	(88.7 – 174.2)	(84.6 – 176.0)	(56.8 – 121.5)

Table 4. Results of comparison among three sites using Univariate Analysis with nested model, eg. treatment nested within site (Site (Treatment)). Significant level: $P<0.05$.

Factor	d.f.	Survival	AMP	HL	DVH
Site (Treatment)	6	F=2.238	F=14.797	F=12.884	F=1.009
		P=0.07	P<0.001	P<0.001	P=0.419

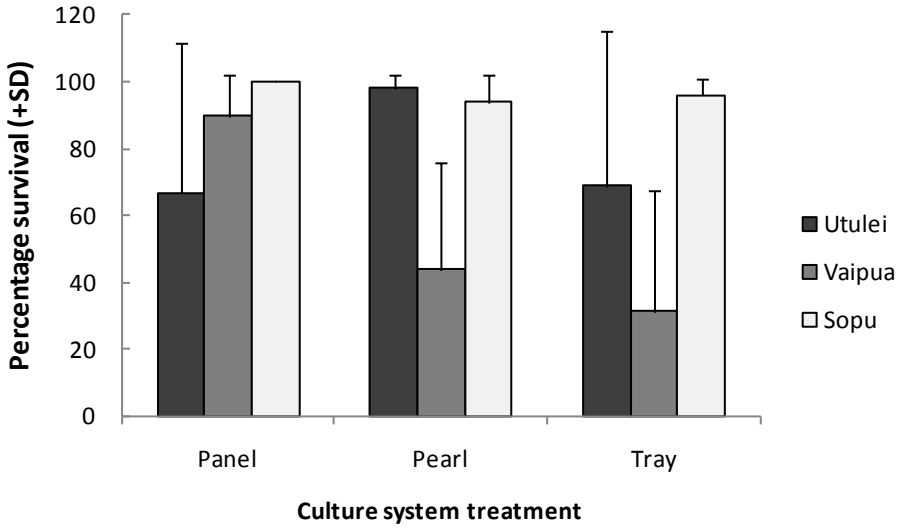

Fig. 5. Mean (± SD) survival (%) of juvenile *Pt. penguin* in three culture units at three sites.

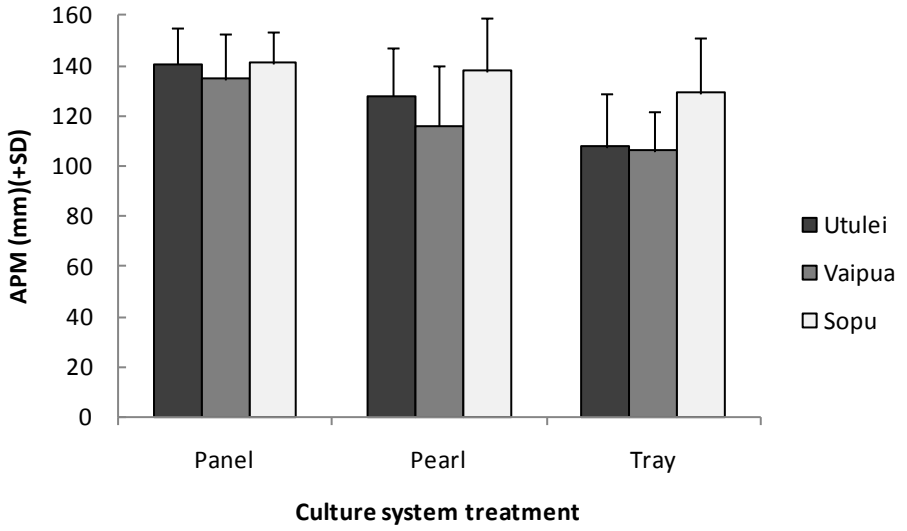

Fig. 6. Mean (± SD) antero-posterior measurement (mm) of juvenile *Pt. penguin* in three culture units at three sites.

Fig. 7. Heavy fouling (acidian) growth on a culture unit (left) and predatory *Cymatium* (right).

3.3 Experiment 2, Part 2: Effect of depth on growth and survival of juvenile *Pt. penguin* cultured in different culture units (panel net, pearl net and plastic mesh tray)

Survival ranged from around 94 –100% for all culture unit treatments in shallow or deep water at Sopu (Table 5). There was no significant difference in survival of *Pt. penguin* juveniles grown at either depth in any of the treatments (P = 0.368, Table 6).

In general, growth was higher in deep water, and panel nets in deep water had significantly higher APM and HL than the other two culture systems (Tables 5 and 6, Fig. 8). Panel nets also performed better in shallow water but not significantly so.

Table 5. Means (± SD) survival (%), AMP, HL and DVH (mm) of *Pt. penguin* juveniles grown in three culture systems in shallow and deep water at Sopu. Ranges are shown in parentheses and means in columns with the same superscript are not significantly different ($P > 0.05$).

Depth	Treatment	Survival (%)	APM (mm)	HL (mm)	DVH (mm)
Shallow	Tray	95.8 (± 4.8)^{a}	129.0 (± 22.0)^{a}	116.3 (± 22.7)^{a}	84.0 (± 14.8)^{a}
		(91.7 – 100.0)	(88.1 – 164.1)	(61.9 – 157.0)	(49.1 – 107.1)
	Panel Nets	100.0 (± 0.0)^{a}	140.8 (± 12.9)^{b,c}	139.9 (± 17.8)^{c}	94.7 (± 9.8)^{a,b}
		(100.0 – 100.0)	(106.4 - 160.2)	(97.5 – 174.0)	(67.4 – 112.8)
	Pearl Nets	93.8 (± 8.0)^{a}	138.0 (± 21.0)^{a,b}	129.4 (± 24.6)^{b,c}	91.4 (± 13.4)^{a,b}
		(83.3 – 100.0)	(88.7 – 174.2)	(84.6 – 176.0)	(56.8 – 121.5)
Deep	Tray	93.8 (± 12.5)^{a}	132.0 (± 22.4)^{a,b}	119.1 (± 22.1)^{a,b}	87.0 (± 14.8)^{a,b}
		(91.7 – 100.0)	(78.1 – 169.5)	(65.1 – 156.0)	(53.9 – 110.9)
	Panel Nets	100.0 (± 0.0)^{a}	147.1 (± 13.1)^{c}	139.6 (± 16.3)^{c}	100.4 (± 9.3)^{b}
		(100.0 – 100.0)	(95.5 - 180.0)	(110.8 – 176.0)	(73.2 – 123.9)
	Pearl Nets	100.0 (± 0.0)^{a}	131.2 (± 18.8)^{a,b}	123.1 (± 24.8)^{a,b}	86.9 (± 12.5)^{a,b}
		(100.0 – 100.0)	(94.8 – 164.4)	(87.2– 194.2)	(56.7 – 110.4)

Table 6. Results of comparison between shallow and deep water sites at Sopu using Univariate Analysis with nested model, eg. treatment nested within site (Site (Treatment)). Significant level: $P<0.05$.

Factor	d.f.	Survival	AMP	HL	DVH
Water-level	4	F=1.143	F=8.010	F=13.036	F=12.854
(Treatment)		P=0.368	P<0.001	P<0.001	P<0.001

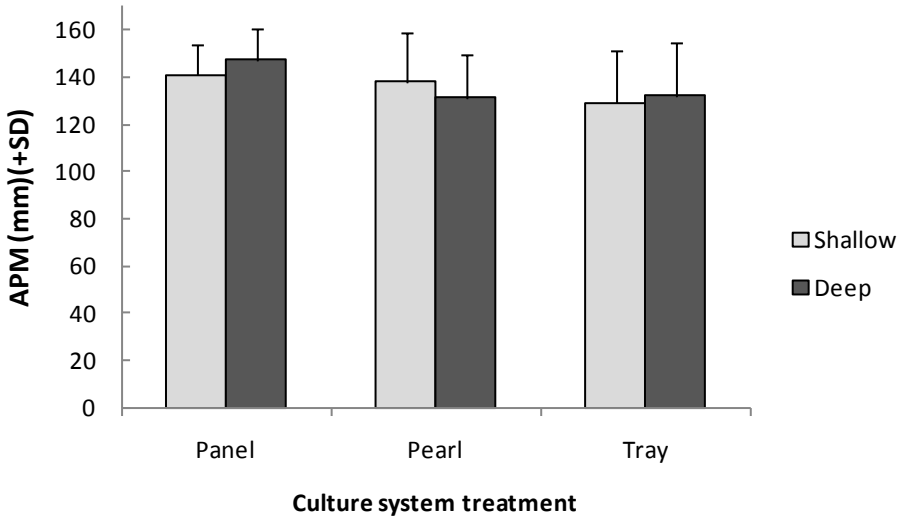

Fig. 8. Mean (± SD) antero-posterior measurement (mm) of juvenile *Pt. penguin* in three culture units at two depths: 'shallow' (2 m) and 'deep' (7 m).

3.4 Experiment 3: Effect of different culture units (panel nets, ear-hanging on chaplets) on growth and survival of juvenile *Pt. Penguin*

Survival was very high (at or just below 100%) at all sites and for both culture units (Table 7). Mean survival was around 97% in both panel nets and when cultured by ear-hanging at Aneti, but there was no mortality at all using either culture method at Vaipau and Sopu. Oyster growth (expressed as APM and DVM) did not differ significantly between the two oyster culture methods at any of the three experimental sites. Vaipau supported significantly greater APM of oyster grown in panel nets than those of oysters grown in panel nets or by ear-hanging at Sopu; however, the latter did not differ significantly from the APM of oyster grown at Aneti. Similarly, Vaipau supported significantly greater DVH than those of oysters grown at Sopu, regardless of the culture method.

Table 7. Means (± SD) survival (%), APM, HL and DVH (mm) of *Pt. penguin* juveniles grown in two culture systems at three sites. Ranges are shown in parentheses and means in columns with the same superscript are not significantly different ($P > 0.05$).

Site	Treatment	Survival (%)	APM (mm)	HL (mm)	DVH (mm)
Aneti	Ear-hanging	96.7 (± 5.8)[a]	173.0 (± 11.6)[a]	157.4 (± 29.0)[a]	120.9 (± 9.1) [a]
		(90.0 – 100.0)	(153.0 – 190.0)	(112.0 – 232.0)	(106.0 – 137.0)
	Panel Nets	96.7 (± 5.8)[a]	182.1 (± 14.2) [a]	158.8 (± 30.1)[a]	125.1 (± 9.9) [b]
		(90.0 – 100.0)	(147.0 – 214.0)	(115.0 – 206.0)	(107.0 – 148.0)
Vaipau	Ear-hanging	100.0 (± 0)[a]	178.1 (± 14.0)[a,b]	154.7 (± 25.6) [a]	124.2 (± 10.3) [b]
		(100.0 – 100.0)	(155.0 – 207.0)	(114.0 – 214.0)	(107.0 – 146.0)
	Panel Nets	100.0 (± 0)[a]	182.0 (± 14.9)[b]	145.5 (± 25.0) [b]	124.9 (± 9.0) [b]
		(100.0 – 100.0)	(158.0 – 212.0)	(105.0 – 192.0)	(109.0 – 146.0)
Sopu	Ear-hanging	100.0 (± 0)[a]	171.3 (± 9.2)[a]	na	118.8 (± 7.5) [a,c]
		(100.0 – 100.0)	(149.0 – 188.0)		(100.0 – 132.0)
	Panel Nets	100.0 (± 0)[a]	174.2 (± 8.3)[a]	na	116.1 (± 6.3) [c]
		(100.0 – 100.0)	(150.0 – 192.0)		(96.0 – 128.0)

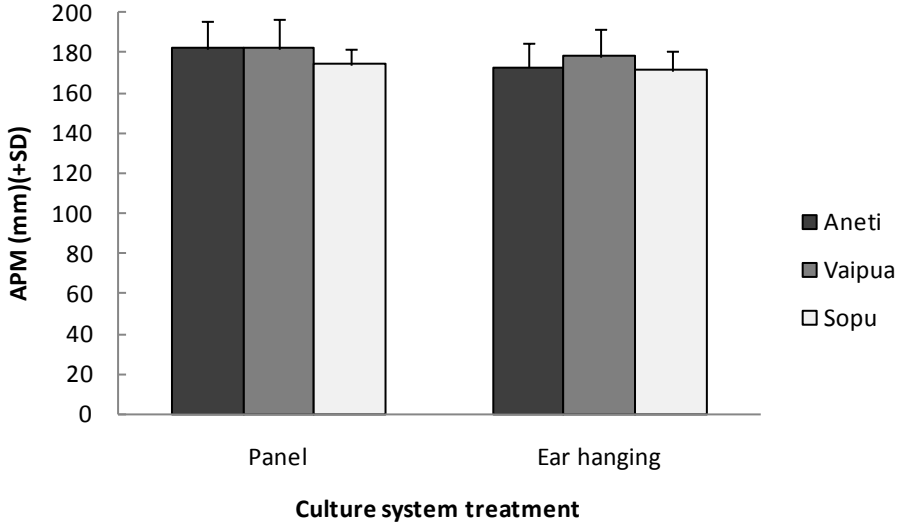

Fig. 9. Mean (± SD) antero-posterior measurement (mm) of large juvenile *Pt. penguin* in two culture units at three sites.

4. Impacts

4.1 Scientific

Information on culture methods for pearl oysters that optimise growth and survival are vital in maximising production, yield and value of an industry. This study investigated these aspects for *Pteria penguin*, for the first time, and results have been taken up by Tonga pearl farmers who have modified their farming practices as a direct result of this study. The data generated also provided a basis for (and fed into) research within another ACIAR project, FIS/2006/172[1] which aimed to further develop culture techniques for *P. penguin*. The scientific outputs of this mini-project also provide a basis for research within a larger follow-up ACAIR project, FIS/2009/057[2], which will begin in 2012 and aims to further develop pearl oyster culture methods and pearl industry sustainability in Tonga. It will also assess the potential of *P. penguin* culture as a mean of income generation in PNG. At least two publications resulting from this research are being prepared for publication in international scientific journals.

4.2 Capacity impact

This study enhanced the capacity of the Tongan Fisheries Division Aquaculture officer (Martin Finau) who ran the experiments as part of a Master of Science degree at University of the South Pacific. Other officers at the Fisheries Division and Tongan pearl farmers also gained skills in pearl husbandry and data collection in the course of assisting with the mini-project. It also built capacity within the pearl farming community at Vava'u in Tonga as a result of: (1) project research being conducted on active pearl farms with direct and hands-on involvement of a number of pearl farmers; and (2) extension of project results by Tonga Fisheries and Project personnel, and development of revised farming methods based on project results.

4.3 Community impact

Two of the experimental sites were pearl farms and two of the experiments included collaboration with pearl farmers in Vava'u. They involved project use of their culture equipment (which provided an additional experiment site) and pearl farm staff working with Fisheries staff in day-to-day activities associated with oyster husbandry. These farms benefited from the trials through being exposed to different farming techniques and being able to improve their farming techniques. Results from the study will be transferred to other farms in Tonga in order to increase survival and growth of *P. penguin*, and hence máb̃e production and income.

A Pearl Farmer Association has been formed in Vava'u and 15 farmers have already registered with the Association. The juveniles from hatchery production (2008, 2009, 2010 and 2011) under ACIAR FIS 2006/172 have been distributed to farmers that have already deployed their long-lines and culture equipment. These farmers employ the experience gained from this mini-project for their oyster grow-out.

Some people from Tongatapu and Ha'apai group have also expressed an interest in pearl farming and extension by the Fisheries department to these areas will begin soon.

[1] *FIS/2006/172: 'Winged oyster pearl industry development in Tonga'.*
[2] *FIS/2009/057: 'Pearl industry development in the western Pacific'*

5. Conclusions

Three experiments were conducted to optimise ocean-based culture of hatchery cultured *P. penguin* juveniles of different ages. Experiments were done at three sites in Vava'u and at Sopu (Tongatapu). The results of this experiment provide valuable information for improving *P. penguin* culture techniques in Tonga; they have identified the best culture methods for specific ages of oysters and better culture sites.

Generally, growth of oyster in 3-dimensional culture units, such as trays, was inferior to that of oysters in 2-dimensional nets. This conforms to the findings of similar research with other species of pearl oysters (e.g. Friedman & Southgate, 1999a, 1999b; Southgate & Beer, 2000) and is thought to result from biofouling and recruitment of predators which is greater in the former. Biofouling reduces the flow of water through a culture unit (and therefore food supply), occupies space within the culture unit and may attract recruitment of, and provide refuge for, predators of pearl oyster juveniles. Many predatory species were identified on the units including crabs, *Cymatium* sp. and flatworms. There was also very high recruitment of other oyster species especially *Pinctada* species. This study has provided valuable information on the predators of pearl oysters recruiting to culture units in Tonga, their growth rates. Although the planned cleaning frequency experiment was not carried out (due to Martin having to remain in Suva to carry out university course work), the routine cleaning carried out during the study indicated that fortnightly cleaning is appropriate; however, further research should address this on a site-by-site basis given reported spatial differences in predator composition and recruitment between pearl culture sites.

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Appendix 2.17

MS0902
Live rock and coral culture for the ornamental industry, Tonga

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government, Australian Centre for International Agricultural Research; JCU James Cook University; WorldFish Center; USP The University of the South Pacific	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** New Caledonia **Tel: +687 26.20.00; Fax: +687 26.38.18; E-mail: spc@spc.int**

Project Title:	**Live rock and coral culture for the ornamental industry in Tonga ((MS0902)**
Goal:	Teach industry stakeholders and villagers how to produce cultured live rocks and corals to augment the supply of marine ornamentals for export in Tonga
Objective(s):	Specific objectives are to: 1) Develop protocols to farm artificial live rocks and compare the performance of artificial live rock in different habitats 2) Identify suitable species of corals for farming and develop simple culture protocols 3) Facilitate technology uptake by private sector and community farms for these commodities
Project location:	Tonga
Project partner(s):	Tonga Ministry of Fisheries, Walt Smith Int. Tonga
Dates / duration:	Two years
Project description	The ornamental trade is active in Tonga, It has started in 1988 with a single exporter and had grown over the years to 5 private companies (in 2007) that export live fish, corals, rocks and other invertebrates, mostly to the USA. A quota system has limited the total number of harvests per company per year and up to 2006, the total value of this trade in Tonga was 1.2 million USD. In 2006 there was 500 tons of live rock exported from Tonga and 54 000 pieces of hard coral. Very little cultured product has contributed to this trade in Tonga so far.
Justification	In August 2008, The government has put a ban the harvest and export of both live rocks and corals. This has led two companies to close and is causing the other companies to try and catch more of the other products (fish/inverts), in order to stay afloat. The three remaining companies are currently limited to 150 pieces of hard coral per week.
Expected outcomes	1) Technology for farming live rock and coral tested and developed in Tonga. 2) Technology uptake by the private companies and development of a viable alternative to wild capture, and communities' participation through live rock and coral culture.
Funding sought:	AU$ 21,000

Live rock and coral culture for the ornamental industry in Tonga

Antoine Teitelbaum[1], Scott Mactier[2], Poasi Fale[2], Chris Turnier[3]

[1] *SPC Aquaculture Section*
[2]*Tonga Fisheries Department*
[3] *Walt Smith International*

1 Background

The global marine ornamental trade is composed mostly of wild caught products. There is, however, a trend towards culturing marine ornamental animals when possible for various reasons. These include environmental concerns, regulation restrictions on wild collection or simply attractive commercial aspects.

Corals and live rock have long been exported from the Pacific Islands region. Fiji is the world's primary supplier of live rock (e.g. 800 tonnes exported in 2001, Wabnitz et al. 2003). Tonga exported approximately 500 tonnes in 2004. In Fiji, the ornamental fish exporter Walt Smith International (WSI), have developed a live rock farming process: they 'plant' artificial rocks (cement/stone base mixed) on the reef flats as an alternative approach to wild harvesting.

The harvest of live coral has is also a booming trade in the region, with up to a million pieces exported each year. The biggest exporters are Fiji, Solomon Islands and Tonga. Wild coral harvest is subject to criticism by environmental groups. However, the impact that it may have on a coral reef ecosystem is unknown and some believe it to be sustainable (Lovell, pers comm.).

Most government bodies have expressed concerns about these practices but only a few have imposed management measures. For example, Vanuatu and Kiribati do not allow trade in wild coral, but allow the export of cultured corals. In Solomon Islands, nearly 3% -5% of total coral exports in 2007 were cultured (Teitelbaum *et al.* 2008).

The Marine Aquarium Fishery in Tonga is a fishery which has been developed over 20 years and the trade supports jobs in rural, low-income coastal areas (Fig. 1). However, the potential to damage reefs and overfish during collection means that the marine aquarium fishery has seldom been free of controversy. In 2008, Tonga imposed a sudden ban on the trade of live rock and coral as a precautionary measure. Tongan coastal communities raised their concern during consultations in regard to the harvesting of live rocks and the Government decided to ban the trade. This decision has impacted on the industry, resulting in less income for many aquarium operators because they rely on harvesting wild live corals and rocks. As a result, most of the operators increased their non-rock and coral harvest, especially ornamental fishes and invertebrates, while live rock harvest effort been shifted to Vanuatu (and other countries) as noted from their aquarium export commodities (data from the Marine Ornamental Trade Workshop, New Caledonia in December, 2008). The workshop identified a need to promote culture of live rocks and corals to replace or reduce wild harvest. WSI, one of the largest and most experienced aquarium operators in Tonga, agreed to be the industry partner for the project.

Figure 1. Aquarium product export facility in Tonga.

The mini-project aimed at trialling cultured corals and rocks in Tonga waters under various conditions. This report will detail what was trialled and how the results can be used by industry.

The specific objectives of this project were to:

1. Develop protocols to farm artificial live rocks and compare the performance of artificial live rock in different habitats
2. Identify suitable species of corals for farming and develop simple culture protocols
3. Facilitate technology uptake by private sector and community farms for these commodities.

2 Materials and methods

The Sopu Mariculture Centre was used as a project base for coral culture and manufacturing base rocks. Sopu is located on the waterfront at the western edge of Nuku'alofa (Fig. 2): the Center has more than forty 5 tonne concrete and fibreglass raceways. The land-based, flow-through aquaculture system is also utilised for giant clam culture and has an adjoining multi-species hatchery used for the cultivation of pearl oyster.

The Centre's seawater intake is situated 200 m directly off the Sopu foreshore on the edge of the fringing reef allowing access to relatively clean seawater. The seawater is unfiltered prior to

entering the outdoor system. About one third of the raceways at the facility are shaded while the rest lie in direct sunlight. Effluent water from the system is directed down a single drain and through a settlement pond prior to passing through mangroves at the edge of the reef flat.

From Sopu, experiments were either conducted on land or in the ocean. Ocean grow-out experiments were conducted at Atata Islet (west and south) and Fafa Islet (north and south). Sites near Sopu were also used for live rock experiments and some coral grow out trials. Hard coral ocean grow-out sites were carefully selected amongst locations that were close to villages and seed suitable to coral growth.

2.1 Hard coral farming

A mix of branching, encrusting and massive hard corals were chosen for the hard coral culture trial based upon their attractiveness (and potential marketability), culture history and abundance in local waters (App. 1). Most of these were branching corals *Acropora* spp. (70%) Branching *Stylophora, Euphyllia,* and *Pocillopra* spp. and massive/encrusting corals of *Favia*, *Favites* and *Montipora* spp. each made up 10% of production. All coral used throughout the trial was collected from local reefs using SCUBA or mask and snorkel.

Cultured coral mounts were made of concrete, based on the model used by WSI in Fiji. Encrusting and branching corals were all cultured using asexual reproduction, i.e. by cutting off small fragments of coral from the original wild parent colony (commonly called 'frags') and attaching them to the mounts with either synthetic adhesives or cement (Fig. 2). Once the frags were planted they were left to set in a tank overnight and then moved to an un-shaded raceway the following day. Later, some frags were kept at in raceways at Sopu while others were moved to ocean racks at the various sites. Ocean racks were made of rebar (Fig. 3).

Figure 2. WSI and Tonga Fisheries staff preparing coral frag mounts (left) and glueing an *Acropora* frag on a frag mount using cyanoacelate (right).

Figure 3.Coral culture racks.

Due to the lack of pre-filtration of sea water entering the facility, management practices were very important to the general health and survival of coral frags in the system. In particular, algae control, parasite control and sediment removal were crucial. Species' survival, growth, colour maintenance and parasite or predator vulnerability at each site were recorded in order to assess performance. Other factors such as distance from the aquaculture facility, rate of macro-algal fouling and security were also important.

2.2 Soft corals and corallimorphs

Soft coral species selection was based on their history of market acceptance and local availability. *Sarcophyton* and *Sinularia* spp. can be found very close to Sopu and on reefs surrounding Atata Island. Wild stock of corallimorphs (Zoanthus and 'mushrooms') were collected on the western near shore reefs of Tongatapu, which are characterised by a higher sediment and nutrient load compared to the outer reefs

Soft coral parent colonies were placed in plastic trays in raceways under low-medium water flow (20 L/minute flow-through). Herbivorous fish upkeep and siphoning of sediment and detritus were carried out regularly to control algal growth and maintain water quality in the raceway. Species of *Sarcophyton* were harvested on SCUBA, parent colonies were left in place and only the edge of the coral colony was harvested. Strips of the soft coral were brought back to the station and cut into 5 cm^2 pieces (Figure 4). Each piece was stuck onto a toothpick inserted in a coral mount. This allowed the cutting to heal and attach to the mount without being washed away. Later, the toothpick was removed.

Another method, used successfully in Pohnpei for the green polyp, *Sarcophyton* sp., was trialled (Ellis, 1999). Pieces of soft coral were placed on gravel and held by a tooth pick, hoping that the coral will attach to the gravel and grow.

Figure 4. Slicing *Sarcophyton* spp. for culture cuttings.

Corallimorphs (zooanthids and mushrooms) were grown on small pieces of artificial rock (refer to following section on live rock production). Small pieces of live rock were placed at the bottom of the tank and 'seeding pieces' of various corallimorphs were spread across the tank (Fig. 5). The aim was for corallimorph colonies to attach and develop on the artificial rock base.

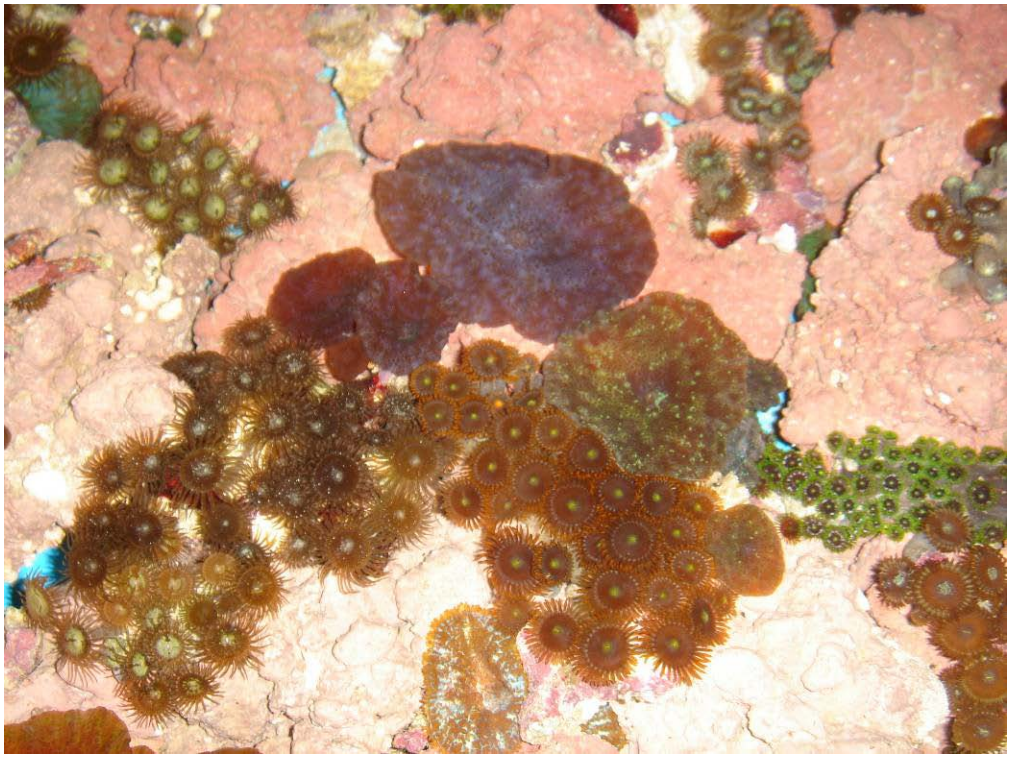

Figure 5. 'Combo' – zoanthids and corallimorphs seeded on artificial rocks.

As the corallimorph tanks were covered with shade cloth, algal growth was not a problem. Hence, ongoing maintenance was very low and the main task involved replacing pieces of rock that had sufficient corallimorph growth with new artificial rock and adding fresh corallimorph seeding pieces to the raceway. An occasional tank flush was required to remove built up sediment.

2.3 Live rock production

Artificial live rocks were made from screened beach sand, coarse sand/shells, pumice, cement, water and oxide using a cement mixer or wheelbarrow and shovel. Once the mix was made rocks were formed on a purpose-built rock-making table. The rocks were made in two parts. The first half was made straight on the sand table which was left to dry for 24 hrs and then flipped and the loose gravel from the base removed (resulting in half a rock). This process is repeated and the next half is produced by dropping wet mix straight onto the flat bottom surface of the first half. The pumice serves to reduce the overall weight of the rock, making it cheaper to ship and easier to handle. It is also less expensive to produce because the pumice takes up significant volume in the rock that would otherwise require cement and sand, the costly components. The red oxide provides the final rock with a colour that more closely resembled natural live rock covered in coralline algae. The final product is a complete and relatively symmetrical piece of light-weight artificial rock.

Once the rocks have been produced on land they were transferred to the ocean 'grow-out' or 'seeding' site (Fig. 6). The site chosen for grow-out was on the reef directly in front of the aquaculture facility at Sopu. The fringing reef here drops relatively sharply from about 1 m at high tide down to the sea floor at a depth of 12-15m and has good existing coralline algae cover, good exposure to currents and is easily accessible from the facility (at high tide only when using boat).

Figure 6. Freshly made live rock transported on a boat ready for being placed on the reef.

3 Outcomes

During the mini-project, a large number of cultured corals and live rocks were produced (Table 1).

Table 1. Quantity of product planted at each site.

Type of product	Sites	Number of products planted
Hard corals	Land nursery	1500
	Ocean nursery (crater)	1000
	Fafa islet	1250
	Atata islet	1500
Soft coral	Land nursery	200
Rocks	Reef crest at Sopu	1000
Corallimorphs	Land nursery	1000

3.1 Hard corals

High mortality (90-100%) of open-ocean cultured *Acropora* spp. occurred. The branching species, *Euphyllia glabrescens*, *Stylophora pistillata* and *Pocillopra damicornis,* did consistently well in sea racks (Fig. 7). These species thrived at the 3 sites where they were tested at the ocean nursery and Fafa north and south. No other species showed realistic potential at any of the sea sites. Over the trial period, adverse weather conditions occurred with severe impacts on the culture racks (e.g. sediment smothering the coral, broken pieces, etc). Fouling was also observed on coral frags, mostly through recruitment of bivalve species.

Figure 7. Six-month-old *Acropora* and *Montipora* grown on ocean racks.

In the land-based grow-out system, there was 80% survival of what was cultured. The success depended on to the culture species and the standard of maintenance activities (i.e. regularity and intensity). However, much of the coral that survived in the flow-through raceways was not of commercial quality (e.g. poor colour, unmarketable shape, etc). Approximately 50% of surviving corals in the land-based system were marketable (Figs 8, 9).

Figure 8. Coral frags being grown out in the raceways at Sopu.

Figure 9. A one-year-old *Acropora* cutting grown at Sopu.

Providing the management was carried out properly, an arbitrary performance category was established for each coral species according to the following criteria: survival, growth and basal attachment, colouration and vulnerability to parasites (Table 2).

Table 2. Arbitrary performance ranking according to survival growth, basal attachment, colouration and vulnerability to parasites.

Good performers	Average performers	Poor performers
Acropora Millepora *Stylophora pistillata* *Pocillopora damicornis* *Acropora macrostoma* *Euphyllia glabrescens*	*Acropora kimbeensis* *Seriatopora hysterix* *Acropora kimbeensis* *Acropora aculeus* *Acropora humilis* *Acropora cophodactyla*	*Acropora chesterfieldensis* *Favites/Favia* spp *Montipora* spp *Astreopora myriophthalma* *Acropora valida* *Acropora Secale*

Observations of coral performance during the trials clearly demonstrated the relative advantages and disadvantages of the land-based raceways grow-out system compared to coral culture in open ocean racks (Table 3).

Table 3. The observed advantages and disadvantages of culturing corals and corallimorphs in a flow through sea water system relative to open water culture.

Advantages	**Disadvantages**
A higher degree of environmental control and stability (i.e. adverse environmental conditions caused by cyclones, storms and tides have no effect on the condition of the tank).	Initial capital and ongoing operational costs are higher than if grown in the sea.
No need for to regularly tend to sea racks. This cuts out boat operation costs (fuel, maintenance, capital) and less SCUBA time required.	Water exchange in a tank is less than that of open water
The corals are only moved once between land and sea (once collected they are moved to the facility and kept at the facility), ultimately lowering exposure to adverse conditions during transport	Limits the use of potential target species: Not all species will adapt to a tank environment and water quality
Farm activities can be carried out in all weather conditions	Running filtered or unfiltered sea water will eventually result in the introduction of pests, parasites or predators (brought in through the sea water intake or on the coral itself) affecting the health, survival and overall quality of coral being produced. This will also increase labour time and costs.
Higher level of security	
Less large predators or corallivorous such as fish	

3.2 Soft corals and corallimorphs

Successful development and growth was observed in soft corals grown using the toothpick method. The soft corals grown on recycled hard coral mounts showed better growth than those grown directly on gravel. They were more uniform in size, generally larger and more organised in the culture system. It took four month for a cutting to be a regular stand alone colony (Fig. 10).

For corallimorphs (zooanthids and mushrooms) grown on artificial rock bases, over 75% of the products were marketable after nine months. A marketable state was defined by WSI staff as a piece of artificial rock having more than 60-70% of its surface area covered in corallimorph. Of the 800–1000 pieces of rock in Sopu raceways, about 600-700 pieces were ready after this time period. There was a six-month delay in growth and spreading onto the rocks for both zooanthids and mushroom pieces in culture tanks. This suggested there may be an adjustment period to the conditions of the culture system, followed by a period of growth. Shade cloth (80%) was installed over the tanks two months into the trial. This caused an increase in growth of colony and mushrooms, indicating that the nine-month duration to marketable product might be decreased in future culture activities.

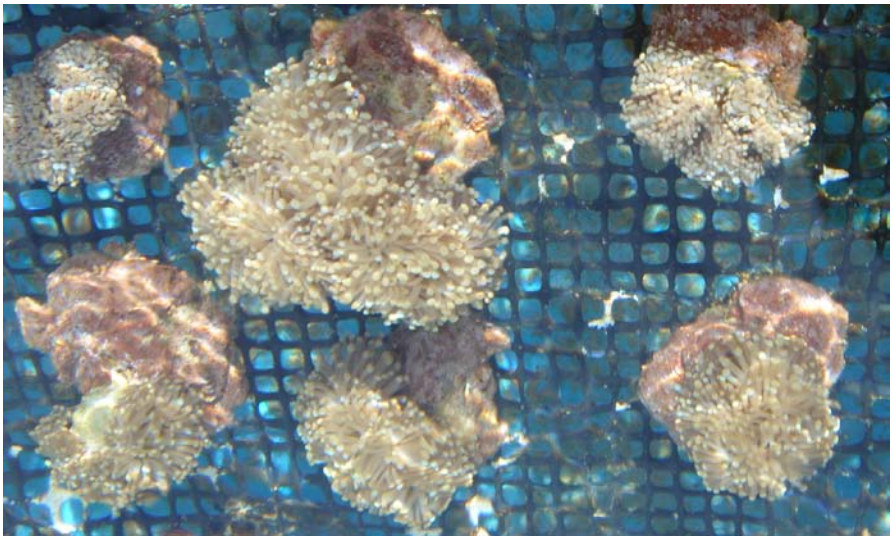

Figure 10. Few month old *Euphyllia* cuttings in the raceway at Sopu.

3.3 Rocks

Overall, the rock trials were encouraging although adverse weather conditions contributed to losing over half of what was initially seeded on the reef. However, it appears that rock could be marketed in less than a year with very good coralline coverage (red, purple, yellow or pink) on parts that weren't in direct contact with sand (Fig. 11). The rocks seeded right near by the Sopu facility were easy to work on and recover. These were placed at a manageable depth for free diving meaning SCUBA is not required (although when flipping rocks SCUBA was used). Less reliance on SCUBA means lower operational costs and reduced safety risk to workers. Although shallow areas provided desirable colours and good coralline coverage, these areas are exposed to high water movement and risk loss of pieces in case of strong winds (e.g. Cyclone René in Feb 2010). Further suitable rock farming areas have to be identified.

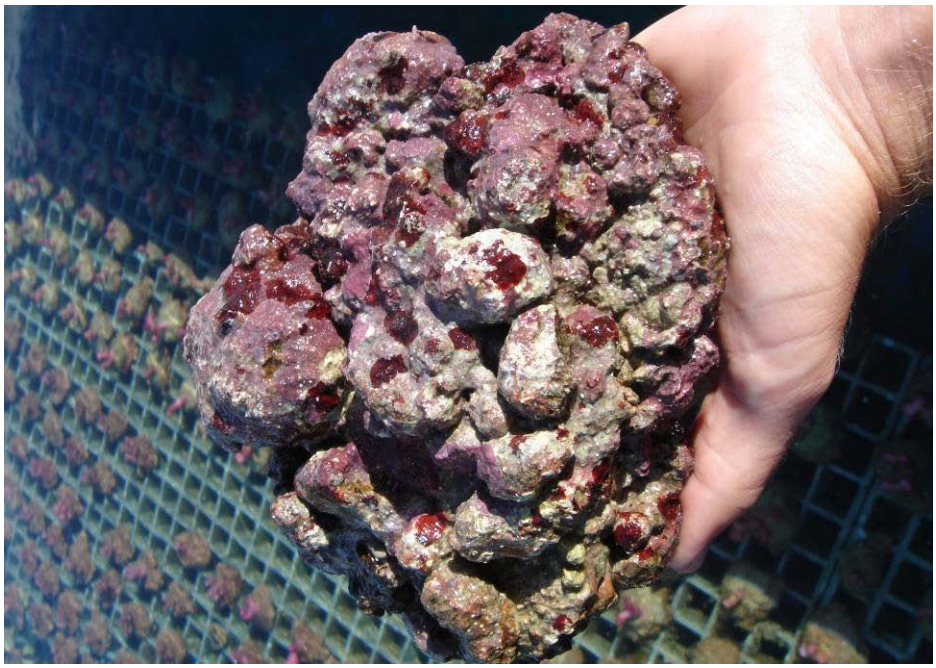

Figure 11. Artificial live rock that was cultured on the reef in front of Sopu.

4 Impacts

4.1 Scientific impacts

Although there were no scientific breakthroughs generated by this project, there were some significant advances in product manufacturing. For example, new products and new techniques that are relevant to this activity in the region were developed.

- It was found that planting several species of corallimorphs on cultured rocks was very popular with aquarium wholesalers. As a result the project trialled different coloured and sized corallimorphs planted on artificial rocks of various sizes and shapes.
- Through the live rock trials, small clams were planted on artificial rocks. This resulted in a highly attractive rock/clam cultured product that received a positive response from aquarium wholesalers.

4.2 Capacity impacts

This project allowed fisheries officer from MoF to develop extensive practical knowledge on coral farming techniques. Officers at Fisheries and WSI industry representatives all gained experience in the culturing corals under different conditions and using various species and techniques, land-based system management, sea base systems etc

4.3 Community impacts

The project had anticipated some community impact through transferring the rock and coral technology into villages. However, most of the work was carried out in collaboration with industry and government. The project team felt it was premature to spread around an activity that was yet to be proven viable and since the industry has shown signs of weaknesses following recent regulatory measures undertaken by the government. However, given the advances made in this mini-project and the relatively simple technology involved, it is envisioned that this activity has

potential to provide benefits to coastal communities. If coral and live rock culture are shown to be economically viable, the techniques could be transferred to selected communities that have access to grounds that are suitable for culture of either corals or rocks.

5 Conclusions and Recommendations

There is a question whether a land-based or sea-based farming system will produce better corals. The flow through aquaculture facility proved to be suitable for the culture of corrallimorphs and some species of hard and soft coral. The land-based facility out-performed the open ocean rack systems in the trials reported here – only a few species were successfully cultured and there were basically no marketable pieces of coral produced in one year of ocean grow-out. It was concluded that the sites were not suitable for coral culture and this was possibly the result of poor site selection. High sediment loads in the area may have stressed the corals, prevented growth and led ultimately to high mortalities. Some corals showed encouraging results at three ocean sites (i.e. the ocean nursery and Fafa north and south). If we are able to identify ocean grow-out sites with low sediment loads, they may compare more favourably with a land-based farming system.

Soft corals and corallimorphs also showed encouraging results in the land-based trials. Attractive products were obtained with relative ease as the culture of corrallimorphs under these methods is not very demanding in terms of labour. These species seemed to be more resilient to the culture conditions than hard corals. Soft corals were not the focus of this project and only three fibreglass raceways were used to produce soft corals and corallimorphs. However, they became being some of the most successful products. We suggest that this concept be expanded to other species, and that the successful 'combo' idea for corallimorphs (i.e. mushrooms and zooanthids on artificial rocks) be continued.

There is a question as to whether water should be filtered before entering the system. There were some management implications of running the sea water system raw instead of filtering the water. A major advantage was providing a supplementary food source for the corals and corrallimorphs in the form of zooplankton. In addition, not running filtration units meant less effort and costs required for filter maintenance and also possibly less electricity inputs required for running the whole system as filters ultimately increase the friction in the system and so require more power to run. However, there were also disadvantages which may outweigh the benefits. These included the compromise in coral health, survival and quality due to sediment coming into the tank and from algal growth on the tank walls and frags. A significant amount of time and labour was required for maintaining the water quality due to sediment and algal growth.

Live rock culture had technical potential in Tonga. They performed well in the sea. After a year the rocks that were survived the cyclones had good coralline cover with attractive colours. However, since only a single site was trialled, more research is needed to identify sites which have potential for producing attractive rocks in sufficient quantities to be commercial.

Land-based grow-out appears to be a more viable option until suitable ocean sites are selected and assessed properly. It is recommended that private sector explore the possibility of utilising the fisheries station for coral culture. The project team suggests that Tonga Fisheries Department prepare a template for leasing out part of the facility to private sector. Although this has been done in the past, the arrangement ceased due to contractual issues. The aquarium trade fishery in Tonga has been based on broad policies. Currently, there is an opportunity to translate these into a strategic management plan (i.e. fisheries management plan). This plan is an explicit arrangement between fisheries management authority and other stakeholders. The implementation of the plan provides ways in which the fishery is to be managed and by whom. The management plan has

been put together in consultation and cooperation with other stakeholders including government departments, tour operators, aquarium industry and fishing communities. Currently the industry is depressed because wild live rock and coral quotas were reduced. We believe that cultured ornamental can develop in Tonga through involvement of both the private sector and Government.

Overall, most products developed in Tonga such as hard corals, soft corals, 'combos' (corallimorphs on artificial rock) and cultured live rocks were new to the industry there and all were shown to have commercial potential. Throughout the experiment, several shipping trials were made and the products were well accepted in the US market. Prices are yet to be established according to the volume that can be shipped for each species. It is now up to the industry to select and ship those products in order to determine if they keep selling well on a routine basis.

6 References

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7 Acknowledgements

The project team wishes to acknowledge Tonga Fisheries officers and the Walt Smith International workers who assisted with the trials.

Appendix 2.18

MS1002
Support of pearl oyster (*Pteria penguin*) hatchery production in Tonga

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU James Cook University WorldFish Center USP The University of the South Pacific	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Support of pearl oyster (*Pteria penguin*) hatchery production in Tonga (MS1002)**
Goal:	To provide technical assistance to Tonga Fisheries aquaculture staff relating to hatchery production of winged pearl oyster (*Pteria penguin*) juveniles in support of the Tongan cultured pearl industry.
Objective(s):	The project will achieve this goal through the following objective: • Provision of technical expertise in pearl oyster hatchery production.
Project location:	Sopu (Tonga)
Project partner(s):	Tonga Fisheries
Dates / duration:	3 months
Project description	This mini-project will provide focused, short-term technical support for hatchery culture of pearl oysters in Tonga. The juveniles produced will be provided to pearl farmers in Vava'u to offset current difficulties in obtaining culture stock. The project will provide continuity between a small ACIAR project focused on hatchery production of *Pteria penguin* which finished in November 2009, and a follow-up project which will begin in July 2010. Maintaining hatchery production momentum is a crucial component of the proposed second phase project.
Justification:	Technical support of this nature is required to maintain momentum developed during a small ACIAR project in support of the Tongan pearl industry which was completed in November 2009. Two successful hatchery runs in Tonga in 2008 and 2009 produced around 700,000 spat which were used in further research to develop appropriate nursery culture and grow-out methods, and to supply pearl farmers with culture stock. *Pteria penguin* reproduces in late summer (March-May) in Tonga however the planned phase 2 ACIAR project will not begin until July 2010. Because of this additional input is required to facilitate hatchery production in 2010. This will maintain momentum and supply of juveniles to the industry.
Expected outcomes:	1. Hatchery production of significant numbers of *Pteria penguin* spat 2. Subsequent supply of oyster spat to collaborating pearl farmers in Tonga. 3. Maintain momentum for hatchery culture as a basis for phase 2 project and supply to pearl farmers. 4. Maintain existing and build new capacity within Tonga Fisheries.
Funding:	**$25,080**

Support of pearl oyster (*Pteria penguin*) hatchery production in Tonga

Paul Southgate[1] and Poasi Ngufuale[2]

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1. Background:

The winged pearl oyster, *Pteria penguin*, is traditionally used for production of half-pearls ('mabe') in Tonga for which there is an export market in Japan and elsewhere (Fig. 1). *Pt. penguin* was introduced to Tonga in 1975 by the Tasaki Pearl Co. of Japan (Fa'anunu and Manu, 1996) and there were twenty-five small pearl farms in Tonga at the end of 2000. The industry, although small, is well organised and is represented by the Pearl Growers Association (PGA). The Tongan pearl industry is centred in the Vava'u island group and relies on natural spat collection. Spat are collected from the wild using spat collectors and grown to a size where they can be used for half-pearl production. Half-pearl culture is attractive because it uses relatively simple and affordable techniques for catching spat, for grow-out and for pearl production. Most significantly, half-pearl production does not require a specialised technician and can be achieved by local people with minimal training/experience.

Fig.1. Mabe pearls in a *Pteria penguin* shell.

A major impediment to the sustainability and expansion of the pearl industry in Tonga has been a reliable and adequate supply of oysters. Over recent years, poor recruitment of spat has resulted in the harvesting of adult oysters from the wild, which has further impacted recruitment, and natural spat fall of *Pt. penguin* in Vava'u is now extremely limited. This resulted in a catastrophic decline in the number of pearl farms in Vava'u. A small ACIAR Project (FIS 2006/172) began in 2007 to alleviate this problem using hatchery culture of *Pt. penguin*. These efforts were successful and more than 700,000 *Pt. penguin* spat were produced from two hatchery runs at the Sopu hatchery in May/June 2008 and 2009. Many

of these oysters were provided to pearl farmers in Vava'u as culture stock, thus reviving the industry and increasing the number of pearl farms. On this basis, a larger ACIAR project is scheduled to begin in July 2010 with continuing hatchery production being a major objective.

Reproductive activity of *Pteria penguin* in Tonga is restricted to late summer (March-May) when hatchery production is undertaken. Because the initial ACIAR project finished in 2009 and the follow-on project will not begin until July 2010, without further input, hatchery production in 2010 will not be possible resulting in loss of momentum moving into the follow-on project and a hiatus in supply of oyster juveniles to the industry.

This mini-project had the specific aim of providing of technical expertise in pearl oyster hatchery production in order to produce juveniles for future research needs. The juveniles produced will be a crucial component of the Phase 2 ACIAR project and a production lapse would essentially negate any value to be gained from the first 8-9 months of the new ACIAR Project. They will be used in experiments to optimise husbandry practice in partnership with farmers, for experimental pearl production and, in particular, to facilitate expansion of the pearl industry in Tonga.

2. Project Methodology

Hatchery culture was undertaken at the new Tonga Fisheries hatchery facility at Sopu, Tongatapu. Necessary technical assistance was provided to Fisheries staff by a hatchery specialist from Australia (Andrew Beer) and Mr. Scott Mactier who is currently employed at the Tonga Fisheries hatchery facility at Sopu under the Australian Youth Ambassadors for Development (AYAD) scheme.

Methods for broodstock husbandry, spawning induction, larval rearing, settlement, and hatchery-based and ocean-based nursery culture of *Pteria penguin* were developed during ACIAR Project FIS 2006/172 and were adopted in this mini-project. Larvae were fed with Instant Algae® (micro-algae concentrate, Reed Mariculture, USA) as the sole food. Once they had reached the 'eyed' stage, larvae were caught on a 150 µm mesh screen and transferred to settlement tanks containing suspended settlement substrates and vigorous aeration. 'Instant algae' was fed to larvae/post-larvae in settlement tanks on a daily basis following partial water changes. Settlement tanks were maintained for 1 month before settlement substrates were transferred to an ocean-based longline adjacent to the Tonga Fisheries facility at Sopu when the oyster juveniles were 50 days old. Nursery cultures were inspected on a weekly basis when fouling was removed and cultured units were checked for predators. The juvenile oysters will be removed from nursery culture units in October 2010 and transferred to Vava'u where they will be provided to farmers.

3. Results

This earlier spawning resulted in greater spawning activity and apparently better quality eggs. Larval survival was high and development was quicker than in previous hatchery runs.

An estimated 95 million eggs were spawned which resulted in 19.5 million D-stage larvae following the 24 hour egg incubation period. Of these 15 million D-stage larvae were used for initial stocking of 6 larval culture tanks.

Larval feeding began at a rate of 1000 algae cells/mL/day and was increased as larvae grew at a rate of 1000 cells/mL/day.

Survival was high during the first 10 days of larval culture compared to the previous hatchery runs (Fig. 2) and 5.5% (857,000) of larvae initially stocked into larval culture tanks were transferred to settlement tanks between day 17 and day 25. This is a 'normal' rate of survival for pearl oyster larval to settlement.

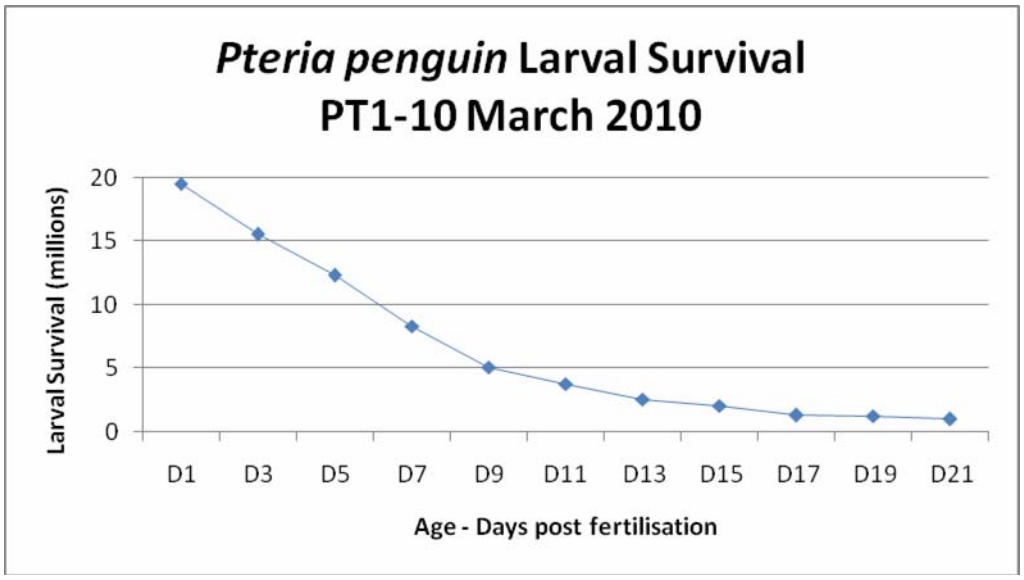

Fig. 2. Survival of *Pteria penguin* larvae during hatchery culture.

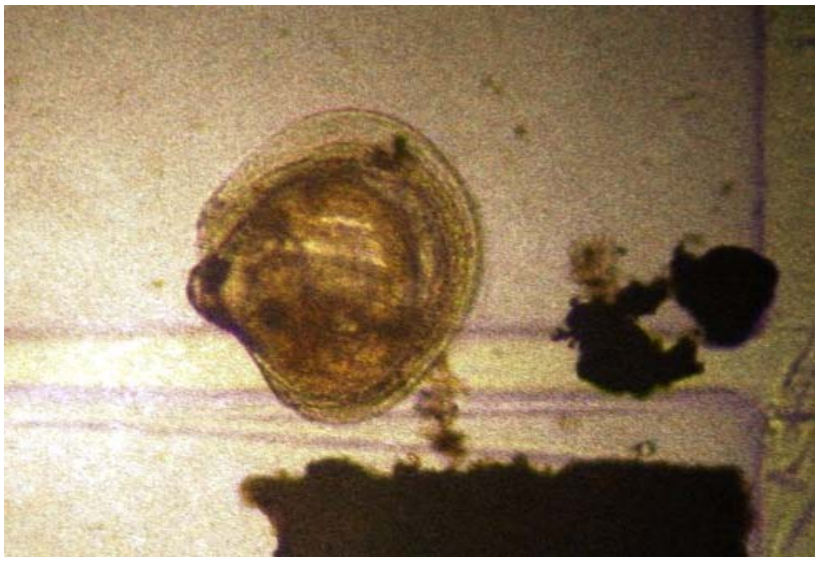

Fig. 3. *Pteria penguin* juvenile removed from spat collector in settlement tank.

Settlement substrates (spat collectors) were periodically inspected for the presence of spat/juveniles (Fig. 3) and then transferred from settlement tanks to the ocean on day 50. They were placed into plastic mesh trays and suspended to a depth of 6-7 m from a

subsurface longline (set at 5 m). On-going maintenance included: (1) monthly retrieval of culture units onto a boat; (2) opening of culture units and inspection for predators; (3) scrubbing to remove algae and other fouling; and (4) return to the water. This process involved culture units being out of the water for 5-10 minutes.

Prior nursery culture efforts with *Pteria penguin* in Tonga have been affected by predation of oyster juveniles by predatory snails (*Cymatium* spp.) and crabs. Monthly inspection, particularly the opening of culture units and removal of predators by hand, has greatly reduced predation of *Pteria penguin* juveniles in nursery culture units and supported high rates of growth and survival (Fig. 3).

Fig. 3. Juvenile *Pteria penguin* from nursery culture unit.

Prior hatchery runs in Tonga have resulted in around 23% survival between transfer from the settlement tanks to the ocean and grading. On this basis, around 200,000 spat should be collected when spat collectors are harvested in October, 2010. However, this figure is likely to be an under-estimate. Monthly inspection of nursery culture units has indicated very high survival of oysters which has probably resulted from regular internal inspection of culture units and removal of predators by hand. This has not be done in subsequent nursery culture activities.

4. Impacts

4.1 Scientific

This hatchery run was done using Instant Algae® (micro-algae concentrate) as the sole food source for larvae. Results so far confirm the suitability of this product as a food for pearl oyster larvae greatly reducing the technical resources required for hatchery culture of

pearl oysters. Given these potential benefits (which may also apply to hatchery culture of other invertebrates such as sea cucumbers and urchins) further research is justified to fine-tune and optimise methods for preparation, use and storage of this product.

4.2 Capacity impact

Two hatchery runs for *Pt. penguin* have previously been run in Tonga; one year apart and in different hatcheries. Technical capacity within Tonga Fisheries for hatchery production of pearl oysters has been further consolidated through the success of the production run conducted with this mini-project. This project will also provide training for the new AYAD position with Tonga Fisheries (Richard), who has limited aquaculture experience and no hatchery experience; he may be involved with aspects of the phase 2 ACIAR project. This project will also support capacity within the Tongan pearl industry through involvement of farmers in husbandry of resulting oyster juveniles and supply of juveniles to current farmers and those moving into the industry.

4.3 Community impact

This work will benefit the community in general through helping to increase the number of pearl farmers, a source of income and employment in many remote island areas of Tonga. The success of this (and previous *Pt. penguin* ACIAR) projects has brought optimism to the industry. The number of pearl farms in Vava'u has increased because ex-pearl farmers have now redeployed farming infrastructure in anticipation of secure oyster supply. Tonga Fisheries have also received enquiries from potential pearl farmers in other island groups in Tonga (Hapa'i and Tongatapu) as a result of increased supply of oysters.

5. Conclusions and recommendations

- The hatchery culture techniques developed for *Pteria penguin* during ACIAR research are appropriate for routine production of oyster spat in support of the Tonga pearl industry
- Instant Algae® (micro-algae concentrate) is an appropriate food source for *Pteria penguin* larvae
- Improved capacity within Tonga Fisheries (and support staff) regarding hatchery production and nursery husbandry of peal oysters will provide ongoing support for the Tongan pearl industry and expansion of this industry will have wide ranging beneficial community impacts.

Recommendations:

- Subsequent regular (at least annual) hatchery activity is required to maintain supply of oysters to the Tongan pearl industry – this should be accommodated within future ACIAR projects
- Further research with Instant Algae® may support greater survival of pearl oyster larvae and facilitate the use of this product for other species.

6. Acknowledgements

We wish to thank Andrew Beer, Tonga Fisheries staff and Scott Mactier for their inputs to this mini-project.

Solomon Islands

(Appendixes 2.19 to 2.20)

Appendix 2.19

MS0802

Rabbit fish culture and feed trials (capturing juvenile fish for food security), Solomon Islands

ACIAR Pacific Aquaculture Grant: **Project Summary**		**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18; E-mail: spc@spc.int**

Project Title:	**Cage culture of rabbitfish (Siganids) in Solomon Islands, with emphasis on locally available diets (MS0802)**
Goal:	Undertake basic farming trials of common herbivorous fish species using locally sourced diets to identify potential future strategies to address fish food security in the Pacific.
Objective(s):	The project will achieve these targets through the following objectives; 1) Culture wild caught rabbitfish fingerlings in a simple cage farming system using proven commercial diets; 2) Identify locally available sources of ingredients that can be used for fish mariculture, develop simple diets and compare growth and survival of rabbitfish using these diets. 3) Evaluate future options for marine finfish mariculture to address some of the emerging food security issues in the Pacific
Project location:	Solomon Islands
Project partner(s):	WorldFish Center, Solomon Islands MFMR
Dates/ duration:	18 months
Project description	Overfishing of coastal fisheries resources by an increasing Pacific Islands population is causing an increasing strain on this limited resource which is an important source of protein. Marine finfish farming is one option to alleviate this problem. However, some key constraints of fish diets and target species need to be addressed. More readily available and renewable sources of fish diets such as plant based ingredients or by-products need to be investigated. These diets might be applicable for fish species that are low in the food chain (rabbitfish, mullets and milkfish), which are already important sources of food and can be sold locally for cash. Their aggregating behavior as juveniles, their fast growth rates and herbivorous/omnivorous feeding patterns make them promising candidates for capture based aquaculture.
Justification	Existing wild capture fisheries are unlikely to support the nutrition demands of a growing human population. This project will provide the groundwork to develop directions for aquaculture to assist in bridging the gap for future food security demands.
Funding sought:	AU$ 20,000

Cage culture of rabbitfish (Siganids) in Solomon Islands, with emphasis on locally available diets

Antoine Teitelbaum[1] and Zelda Hilly[2]

[1] Secretariat of the Pacific Community, Noumea, New Caledonia

[2] The WorldFish Center, Nusa Tupe, Solomon islands

1. Introduction

Worldwide, rabbitfish species have long been identified as appropriate candidates for aquaculture. They are herbivorous/omnivorous, can reach commercial size in less than a year and recruit in high numbers seasonally to inshore tropical habitats. Further, they are a prized food commodity throughout Oceania.

There are two ways of securing rabbitfish fingerlings for aquaculture purposes: producing them in a hatchery or wild capture. In this project we captured wild juvenile rabbitfish (*Siganus argenteus*) for grow out trials. Several species of rabbitfishes recruit into shallow seagrass beds and mangrove areas when they are about 60 days old and show a strong aggregating behaviour. This phenomenon has been observed in the Solomon Islands and was expected to happen during the summer period (October-February).

Given their omnivorous/herbivorous nature, rabbitfish were identified as one of the few marine species available in Solomon Islands that could be fed with a low protein diet. *S. argenteus*, was the preferred target species given its size and availability, although little work has been published on this species in terms of aquaculture.

A review of available literature on this topic was carried out prior to the project and outlined the process that should be followed during the course of project. Based on previous research, the following recommendations were made for the Solomon Island grow-out trials:

- A stocking density of 30-50 fish per cubic meter. If fish are stocked once and then harvested at 200 g, there will be 6-10 kg of fish per cubic meter (assuming survival is 100%);
- Despite their herbivorous/omnivorous nature, feed should have at least 30% protein content in order to optimize growth in culture conditions;
- Feeding should be done at least twice daily to satiation;
- Trials should run for 3-8 months.

2. Project methodology

2.1 Fingerling collection

S. argenteus juveniles were caught using seine nets over at least 10 sampling attempts from seagrass beds at three different sites: Loga, Mbabanga and Rarumana (30 km to the east of Nusa Tupe). At the time of capture the fish were approximately 60-days old and measured 4-6 cm body length. They were transported live back to the WorldFish Center research station at Nusa Tupe (near Gizo, Western Province) and placed in raceways for weighing and measuring before being transferred to the grow-out systems.

2.2 Grow-out system designs

Sea cage trial

For the first set of trials (October-May 2008), nine cages were built out of mesh net available at WorldFish, with flotation provided by 120 mm PVC pipe and floats (Fig. 1). Later, nylon netting was replaced with plastic netting material (netlon).

Tank trial

For the second set of trials (October –January 2010), a land based facility was used in order to focus solely on the feed factor. Four 1-1.5 T fibre glass tanks were used for the project (Fig. 2). For the experiment, they were plumbed with a spray bar, rigged with aeration, with a 12 hour water flow-through and shaded.

Figure 1. Ocean sea cages used for rabbitfish culture trials.

Figure 2. Land-based tanks used for rabbitfish culture trials.

2.3 Feeding trials

Sea cage trial

The sea cage trial started on the 28th of October 2008 and ended on the 20th of May 2009. The following two types of feed were used for the cage trial.

(1) A locally-made fishmeal-based diet using locally available fishmeal. The feed was produced at the WorldFish station using a mincing machine (Fig. 3). It was composed of 40% fishmeal, 20% copra meal and 40% sago palm flour. The sago palm flour was used as a binder and had no significant nutritional value. Each ingredient was analysed at Laboratoire de Nouvelle Calédonie and the protein content was estimated at about 25-30%.

(3) A commercially available aquatic feed imported from New Caledonia (premium shrimp feed).

There were three replicates of each feed treatment. Fish were fed slowly, to satiety, twice a day, in the morning at 7 am and in the afternoon at 4 pm. Feed wastage was minimised as much as possible.

Figure 3. Trial diet production at WorldFish Center station, Nusa Tupe.

Tank trial

The tank trial started on the 28th of October 2009 and ended on the 25th of January 2010. Two types of feed were used for the tank trials. These were:

(1) Fresh fish. Small sized skipjack tuna were purchased from Gizo market, filleted and mashed in small pieces.

(2) Chicken feed purchased from Honiara.

Fish were fed twice a day and to satiation and feeding rations were recorded as for the sea cage trial.

2.4 Monitoring and sampling

To record growth, all fingerlings were weighed prior to stocking using an electronic scale. A mean weight for individual fish was calculated by weighing a group of 15-20 fish and dividing by the number of fish, until all fish had been weighed. Fish were weighed at the start of the trials and then

monthly for the sea cage trials and fortnightly for the tank trials. All growth data were entered into an Excel spreadsheet. For mortality data, dead fish were scooped out of the bottom of the cage, and recorded on the same spreadsheet.

3. Outcomes

3.1 Catching fish

During this study the team observed rabbitfish recruitment only from October through to January or February. During the rest of both years 2008 and 2009, there was no recruitment (Cletus Oengpepa, pers. comm.). Other fish were observed in large schools of juveniles outside this period but no rabbitfish. The other species observed schooling with juvenile *S. argenteus* were mostly small lutjanids (*Lutjanus fulvus*), other species of rabbitfish (S. *doliatus, S. punctatus* and *S. spinus*) and goat fish (*Parapeneus barberinus*)[1].

3.2 Sea cage and tank system performance

Both systems performed satisfactorily for the needs of the trials. However, there were shortcomings in both types of systems.

Sea cage trial

The original sea cage design offered optimal space and good water circulation for the fish but there were problems with escapees and suspected loss from predation. The cages were anchored in 6-8 meters of water in a marine sanctuary and larger fish were present. It is suspected that barracudas or other larger predators damaged the nets and allowed some fish to escape (or be eaten). Half way through the trial the cage material was changed to a stronger mesh and cages moved inshore where there were less large fish and thus less risk of fish loss.

Tank trial

The land based system was not designed to replicate realistic farming condition but adopted to facilitate testing the different feeds and avoid problems due to escapees and predation, along with rough weather impact on sea based system. However, fish mortality also occurred during this trial because of water pump failure.

3.3Growth

Sea cage trial

The sea cage trial ran for 174 days (28 November 2008 to 20 May 2009). Sampling was done monthly except over the December January period (Days 12-56). Fish fed with shrimp feed reached 75 g while the fish fed with locally formulated diet reached 10.2 g in 174 days (Fig. 4).

[1] The later species was briefly trialed for growth under cultured conditions in this project. It did not prove able to adapt to artificial diets or fresh fish and it proved to be a lot more sensitive to water quality than rabbitfish. Trials on this species were therefore abandoned after a few days under cultured conditions.

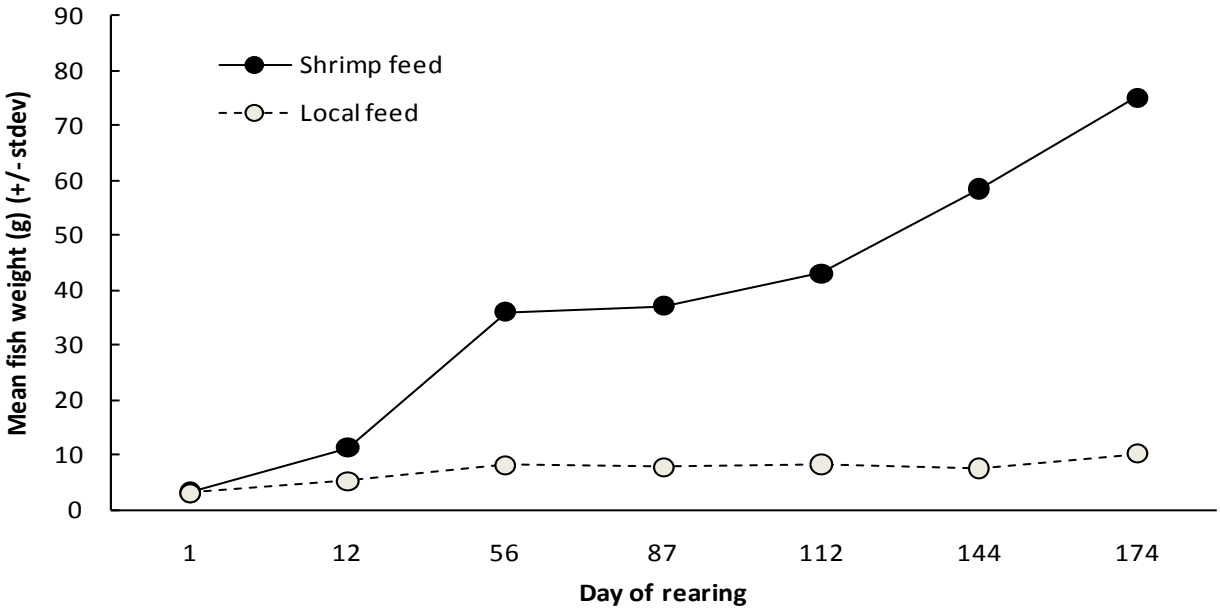

Figure 4. Growth of rabbitfish (g) (±stdev) on two diets in sea cages.

Tank trial

The tank trial operated for 89 days (28 October 2009 to 25 January 2010). Sampling was done fortnightly. All fish reached approximately 30 g at the end of the trial (Fig. 5).

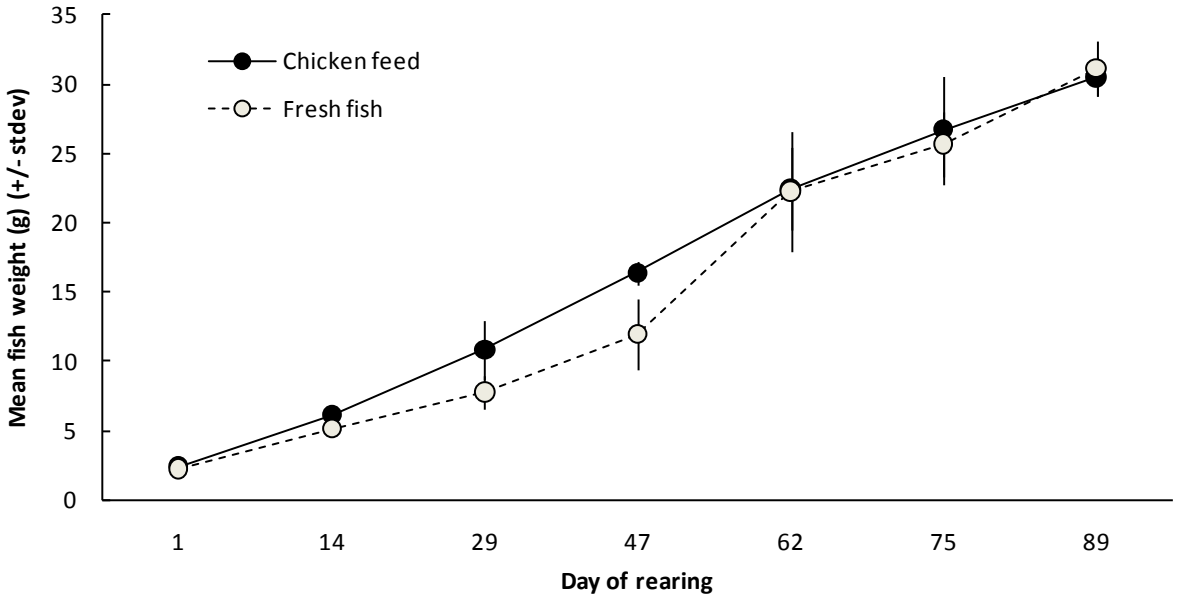

Figure 5. Growth of rabbitfish (g) (±stdev) on two diets in tanks.

By combining results from the two trials, it can be seen that all diets resulted in fish growth (Fig. 6, Table 1), although growth on the locally made diet was very poor. The highest growth was recorded by the fish fed with aquatic commercial feed. However, chicken feed and fresh fish diets also performed well.

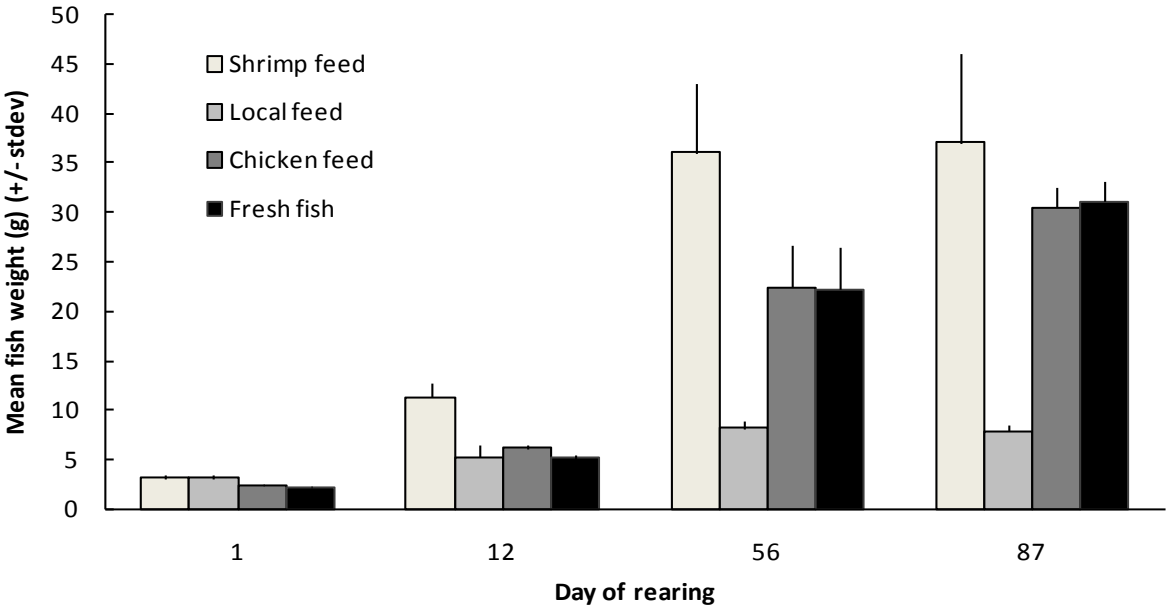

Figure 6. Growth of rabbitfish (g) (±stdev) over approximately 90 days from sea cage and tank trials combined.

Table 1. Daily weight gain (g/fish/day) and specific growth rate[2] (%/day) of rabbitfish reared on four trial diets.

	commercial feed	fresh fish	chicken feed	Homemade diet
Initial body weight (g)	3.19	2.27	2.43	3.13
Final body weight (g)	37.07	31.14	30.53	7.85
Mean daily weight gain (g/fish/day)	0.38	0.32	0.31	0.05
Specific growth rate (%/day)[2]	2.72	2.91	2.81	1.02

3.5 Mortality

Sea cage trial

Many fish escaped during the sea cage trials. This was mostly due to predators damaging the nets and creating holes by which fish escaped. In the commercial feed treatment, 5% of the fish remained after 174 days while 16.8% remained in the local feed's treatment. There was very little mortality recorded due to other factor than escapees.

Tank trial

In the tank trials there was also a lot of mortality. This was mostly due to technical problem as the pump failed twice during the trials and many fish died. In the fresh fish diet, there was 8% overall survival and 25% survival in the chicken diet treatment.

[2] Specific growth rate = Log Final body weight (g)-Log Initial body weight(g)/Time (days) x100

4. Impacts

4.1 Scientific Impacts

This was the first rabbitfish farming trial in the Pacific Islands region. It was based on capturing juveniles at the peak of recruitment out in the Solomon Islands. This study has contributed to what is known about the techniques and feeds to grow this species.

4.2 Capacity impacts

The mini-project increased research capacity of officers from both the MFMR and the WorldFish Center. Project staff were trained on all aspects of setting up a fish grow out and feeding project and handling small scale fish cage farming activities. These activities included:

- Fish identification and collection
- System design and system implementation
- Feed preparation and fish feeding practices
- Fish growth sampling
- Land based fish grow out management

4.3 Community impact

These culture trials focussed on research and feasibility of farming wild-caught juvenile rabbitfish. Thus, no direct community impacts were made. However, if rabbitfish farming using local ingredients is found to be economically feasible, then it is likely that the activity would have community impact. This activity would have most potential in areas with access to high population centres, where markets are nearby, e.g. North Malaita, Guadalcanal and Gizo.

The project showed that *S. argenteus* could be grown using locally accessible feed such as chicken feed. If sufficient fingerlings and affordable aquafeeds were available, rabbitfish farming could be attractive to private entrepreneurs in Solomon Islands.

5. Conclusions and recommendations

5.1 Fingerling supplies and suitability to aquaculture

Juvenile rabbitfish were present in the Western Province for both years of the trial (2008 and 2009) from October onwards. This suggests that the spawning season for *S. argenteus* starts in September in the Western Province of Solomon Islands. Although the techniques to catch fish were relatively straightforward, the juveniles were not abundant during the study period. Large-scale recruitment of rabbitfish (i.e. hundreds of thousands) as documented elsewhere in the Pacific, was not observed. Fish recruitment can vary enormously from year to year and this has important implications for the development of any capture-based culture industry, including rabbitfish. Unfortunately, although large numbers of rabbitfish juveniles have been observed in the vicinity of Gizo, recruitment was low during the period of this study and project staff collected barely enough fish to be able to run the trials.

5.2 System design, what is suitable to Solomon Islands?

Both systems showed their advantages and limitations. The cage system was easily built and required no running costs but the number of escapees and damage to the nets demonstrated that floating cages were high maintenance. At a larger scale, they could prove to be an expensive way

to farm fish and they could be labour intensive. Furthermore, the netting material was sourced outside of Solomon Islands and was expensive. We note that if medium scale cage farming was envisioned for Solomon Islands, there are some great sites with consistently good water quality, in sheltered area. Solomon Islands are outside the cyclone belt which is a major advantage for floating sea cage fish farms.

The tank system was useful to limit the number of factors that would influence growth or survival of rabbitfish during the experiment: (e.g. difficulty in feeding due to weather, escapees). Even though high mortality was experienced due to occasional failure of the pumping system, this system was easier to manage. Fish could be watched during feeding, and growth and mortality data were easily collected. Under commercial conditions, this system should not be recommended as has high start-up costs (capital investment in tanks, pump, etc), high running costs (fuel or electricity) and supports a comparatively lower fish biomass.

There is a third system that could be suitable for rabbitfish culture and have reasonably low capital investments and operational costs: the fixed pen method. Pens of 25-30 m² could be deployed in seagrass beds. The pens would be made out of chicken wire fencing and wooden stakes or other materials available locally. The relatively small tidal range in Solomon Islands would be an advantage for this system. To avoid thermal stratification during the extreme low tides, the pens should be built at depths of 1.5 m at low tide. Rabbitfish naturally migrate to the deeper part of the seagrass beds when the shallow parts are exposed to higher temperature especially during low tides at day. At this depth fish could be easily fed without the use of a boat. That way the fish will benefit from natural feeds present in the cage as well as other types of feed distributed in the pens. Pellets or feed that have fallen on the ground will not be wasted as they will be consumed later.

5.3 Which feed to chose?

The **commercial feed** (premium shrimp feed, priced at AU$3.00/kg) showed the best results of all four feeds. However the economics of importing aquatic feed to Solomon Island would make the development of a small scale fish farming sector not viable.

The fish fed with **farm made feed** (priced at AU$0.60/kg) grew very slowly, probably due to the quality of the protein available in the fish meal. Even though this farm-made feed is inexpensive, there is no point encouraging potential farmers to use it.

The **chicken feed** (priced at AU$1.00/kg) available in Honiara is made in PNG and distributed by a Honiara based company throughout Solomon Islands. Rabbitfish are omnivorous and the types of protein available in the chicken feed seem to have been absorbed and used efficiently.

Trash fish (skipjack tuna flesh, priced at AU$1.00/kg) is a good alternative to dried pellet feed because it is relatively cheap and abundant, and it produces a similar growth rate for rabbitfish as chicken feed. However, fresh fish is hard to preserve especially in the case of low technology fish farming scenarios where farmers would not have a freezer available. Fresh fish or other fish derived products could, however, be used on an occasional basis if dried feed was unavailable or as an additional protein source.

5.4 Overall conclusions

These two trials provided enough information to draw the following conclusion/recommendations:

- *S. argenteus* did not show good growth in these trials but related species (e.g. *S. lineatus, S. canaliculatum*) elsewhere can reach 300 g within a year under optimal culture conditions. In the present study, many factors prevented rabbitfish from achieving optimal growth but literature suggests that commercially viable growth rates are possible;

- Further research is needed to test the promising feeds from the second trial over a longer period;
- Alternative farming techniques should be trialled (e.g. fixed pen method);
- Ultimately, this activity depends on availability of rabbitfish fingerlings. Trials should continue in areas where mass recruitment of rabbitfish occurs annually, and with more consistency than recorded in Western Province, Solomon Islands. There is no point encouraging further development of this activity where juvenile recruitment is unreliable;
- The economics of rabbitfish farming based on natural recruitment and locally available diet should be assessed properly before promoting this activity. This mini-project was unable to generate data to carry out an economic analysis.

Appendix 2.20

MS0901
Mozambique tilapia grow-out trials, Solomon Islands

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU James Cook University WorldFish Center USP The University of the South Pacific	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Evaluation of the Solomon Islands strain of Mozambique tilapia *Oreochromis mossambicus* for small-scale aquaculture for food security (MS0901)**
Goal:	To assess the suitability for small-scale culture of the tilapia species/strain(s) that is already established in some parts of the Solomon Islands
Objective(s):	1) Estimate the growth rate in culture of Solomon Island Mozambique tilapia, as a benchmark for comparison with Nile tilapia varieties available for introduction from overseas; and 2) Compare Mozambique tilapia growth and FCR when fed on two locally available feed sources (i) greenwater, and (ii) greenwater plus supplementary feed using local ingredients, as a basis for estimation of economic viability.
Project location:	Honiara, Solomon Islands
Project partner(s):	SPC, Solomon Islands MFMR, Solomon Tropical Products Ltd
Dates / duration:	1 year, beginning from March 2009
Project description	The Mozambique tilapia *O. mossamabicus* already present in Solomon Islands will be bred and reared under controlled conditions in outdoor tanks for one production cycle, (1) in green water, and (2) with green water plus supplementary feed, and their estimated growth rates and food conversion ratios will be compared with literature values for both Mozambique and Nile tilapia in other places.
Justification	To assist decision-makers weigh up the benefits and risks of possible introduction of Nile tilapia to Solomon Islands, the culture potential of the Mozambique tilapia already present within Solomon borders should first be assessed.
Expected outcomes	1. Baseline growth and FCR data for Solomon Island *O. mossambicus* in small-scale culture, as a basis for comparison; 2. Scientific data that can be used to subsequently inform policy-making regarding importation of another tilapia species, *O. niloticus*, into Solomon Islands; and 3. Tilapia hatchery capacity established in Solomon Islands
Funding sought:	AU$14,488

Evaluation of the Solomon Islands strain of Mozambique tilapia for aquaculture

Tim Pickering[1], Alex Meloty[2], James Ngwaerobo[2] and Sylvester Diake Jnr. [2]

[1] Secretariat of the Pacific Community

[2] Solomon Islands Ministry of Fisheries and marine Resources, Honiara

1. Background

Solomon Islands is one of several Pacific Island countries where, owing to rapid population growth and increasingly heavy pressure on coastal fisheries and reefs, a future fish shortage is predicted (Bell et al. 2009). Inland aquaculture is one strategy recommended to address this projected shortfall in fish supply. Tilapia is one of the most suitable freshwater fish species for inland aquaculture using low-technology methods.

Mozambique tilapia (*Oreochromis mossambicus*) has been present in the Solomon Islands since the early 1960s, and is widely distributed within the country. It was intentionally introduced for release into the wild to increase freshwater fisheries production for food security purposes. Many people have become accustomed to eating it, and enjoy the taste of tilapia. Some communities depend upon it as their main source of dietary protein. For example, at Lake Tegano on Rennell Island, only one other fish species (a small goby, *Eleotris fuscsa*) is present in the lake, and the sea is inaccessible owing to rocky tracks and high surrounding cliffs. In Tikopia, people eat tilapia fished from a small lake when protracted periods of rough weather prevent fishing for marine fish.

There are already on-going attempts to farm tilapia at household level in ponds in Guadalcanal and Malaita, the two most populous provinces. People are looking to tilapia to help provide food to growing populations in urban/peri-urban or high-population rural areas, attracted by the idea of low-cost fish farming. Three-quarters of the aquaculture enquiries received from the public by the Ministry of Fisheries and Marine Resources (MFMR) and Worldfish Solomon Islands are about tilapia.

The fledgling tilapia farming sector in Solomon Islands has been slow to expand, however, due to one or more of the following factors:

- fish growth is quite slow (they need to be cultured for a year or more before harvest)
- fish food is difficult to obtain, and
- ponds are not well-constructed or managed, owing to lack of information about how to grow tilapia properly.

Internationally, Mozambique tilapia is little used for aquaculture, because it grows slowly and has an early age of breeding. Mozambique tilapia in the Pacific has little scope for improvement via selective breeding due to low genetic diversity (they are reputedly descended from just five fish, discovered in Indonesia in 1938). Nile tilapia, *O. niloticus,* is the preferred tilapia species for aquaculture, due to its faster growth and later age of first breeding. In the Pacific, Nile tilapia has already been introduced to Fiji, PNG, Vanuatu, Samoa, Cook Islands, Guam and Saipan for aquaculture in ponds or tanks.

During the formulation of the Solomon Islands Aquaculture Development Plan 2009–2014 (SPC 2009) a high priority was given to tilapia aquaculture by stakeholders. As a result, this Plan contains some broadly-worded actions to establish a tilapia aquaculture sector in the Solomon Islands:

1. Carry out an assessment of the suitability of Mozambique tilapia for small-scale community-level aquaculture for food security
2. Carry out an import risk analysis (IRA) and develop quarantine protocols for the importation of GIFT Nile Tilapia.

If, based upon the IRA and other relevant matters, a decision is made to introduce Nile tilapia, then the following actions were recommended:

3. Establish a hatchery
4. Identify trial sites for fish farming
5. Develop cost-effective local feed formulations
6. Maintain the genetic quality of adult brood stock
7. Promote awareness of the benefits of Nile tilapia and provide training in subsistence and livelihood farming methods
8. Carry out promotion and marketing of tilapia

This mini-project implements the first of these priority actions. While by international standards there may seem to be little point in assessing for culture a species that no one else is culturing, the standards of Solomon Islands may well be different. Although internationally a 200 g tilapia is a small fish, in the Solomon Islands, a 75 g fish is considered 'large' (Fig. 1). Thus, before introduction of any new species for aquaculture is contemplated, it is prudent to assess locally-available options.

In 2009, MFMR, in collaboration with Solomon Tropical Products (STP) at Ranadi, and with support by the Secretariat of the Pacific Community (SPC), established an experimental-scale tilapia hatchery in Honiara. This was used to conduct a trial of Mozambique tilapia breeding and rearing, to assess the viability of aquaculture based upon the tilapia species already present in the Solomon Islands. Follow-up trials took place in small-scale, back-yard ponds, and in a large pond at an agricultural training institution. The outcome of these assessments will be used to inform any future decision-making process about whether or not a better-performing variety of tilapia needs to be introduced to Solomon Islands.

Figure 1. In Guadalcanal and Malaita, a 12-cm-long tilapia is a 'good-sized fish'.

2. Project Methodology

The overall goal of this project was to evaluate the suitability of local Solomon Island Mozambique tilapia for small-scale aquaculture in Solomon Islands.

This goal was addressed through the following objectives;

1. Estimate the growth rate in cultured Mozambique tilapia as a benchmark for comparison with values for Nile tilapia farmed in other places; and
2. Compare Mozambique tilapia growth and food conversion ratio (FCR) when fed on two locally available feed sources: (i) greenwater, and (ii) greenwater plus supplementary feed using local ingredients, and measure growth when fed a commercial tilapia pellet, as a basis for estimation of economic viability.

2.1 Breeding and rearing tilapia in tanks

Standard methods described in Nandlal and Pickering (2004a, b) were used to set up and operate a tank-based tilapia hatchery system at the Ranadi STP base (Fig. 2). Six 1-T circular PVC tanks were set up with tilapia broodstock fish selected from holding tanks established by STP two years previously. The experimental objective was to evaluate Mozambique tilapia in tank culture, and to compare greenwater technique with supplementary feeding.

Greenwater culture was established in all six tanks (Fig. 2). Once swim-up fry were observed, the broodstock were removed. Crumbled Thai-Union shrimp pellet (38% crude protein or CP) was used as a starter mash to raise fry to fingerling size (approx. 2 g). Fingerlings were stocked in all tanks at 100 fish per tank. During the trial three tanks were maintained as greenwater tanks (Secchi value approx. 30cm) and no supplementary feed was added. The other three tanks were greenwater but also received supplementary feed at 5% average body weight (ABW) daily. The feed was pellets made from Soltai fishmeal, copra meal and mill run, purchased locally in Honiara, pelletised by hand-mincer and then sun-dried. To make 1 kg of this feed, 400 g Soltai fishmeal was mixed with 200 g copra meal and 400 g mill run, with about 5 g of cornflour added as a binder. Fish were weighed and measured monthly.

Figure 2. Tank-based hatchery system used to breed and rear tilapia fingerlings at STP

2.2 Rearing tilapia in small-scale household ponds

To assess the local tilapia under more realistic production systems, two small-scale household farms were selected for collaboration in a follow-up trial (Fig. 3). Collaboration by MFMR with backyard-scale tilapia farmers Peter Mua (Mbokonavera) and Fiona Katovai (Lunga) resulted in joint husbandry and management of pond-bred fingerlings. The goal was to find out what is the best growth that Solomon Islands tilapia are capable of when fed with formulated feed and cultured under ideal conditions. A commercial tilapia pellet (Crest pellet produced by the Goodman-Fielder Group, with 29% CP) was imported from Fiji for the trial.

The first pond trial was carried out in a triangular cement pond 4 x 4 x 4 m (7 m^2) at Mbokonivera (in Honiara). The pond was drained, cleaned and re-filled, then stocked with 35 fingerlings of 3–5 g (5 fish/m^2). The trial commenced on 23 July 2010 and ran for 6 months until 23 January 2011. The second pond trial at Lunga utilised a back-yard circular steel-cement pond of 2 m diameter (3 m^2). Thirty fingerlings were stocked in this pond (10 fish/m^2) on 30 May 2010 and the trial ran for 8.5 months until 15 Feb 2011.

During the trial, fish were fed with starter mash three times a day at a rate of 20% of ABW up to a mean size of 20 g, then 10% of ABW up to 50 g. After they reached a mean weight of 50 g they were fed Crest pellet at 5% ABW. Pond water was allowed to become green, but if the Secchi value became less than 30 cm then flow of water was increased. Fish were weighed monthly during the trial.

Figure 3. Backyard tilapia ponds at Mbokonavera (left) and Lunga (right)

2.3 Stocking and rearing tilapia in a large earthen pond

In November 2010 a large earthen pond (20 x 50 m) was constructed at Don Bosco Rural Training Centre (RTC) at Tetere (Fig. 4). The pond was dug by hand by students in lieu of school fees under the supervision of the principal, Fr. Joseph Thanh. This was motivated by the fact that the school kitchen has a monthly requirement for 1.2 T of rice, 600 kg of vegetables, and about 500 kg of fish. The pond is rain-fed and extended into the water table to avoid it ever drying-out completely. Students stocked the pond in April 2011 with many hundreds of small tilapia caught in nearby creeks and streams using mosquito-screen mesh hand-nets. Pig manure was added to the pond to encourage phytoplankton growth, and palm-oil cake (available free-of-charge) and mill run were also provided as supplementary feeds. The RTC's strategy was to keep the cost of feed inputs as low as possible. The first harvest was made using a 10 mm mesh seine net after 8 months, in late November 2011.

Figure 4. Earthen tilapia pond at Don Bosco Rural Training Centre, Tetere.

3. Outcomes

3.1. Breeding and rearing tilapia in tanks

Growth of tilapia fingerlings fed on the two diets in the six 1-T tanks was measured monthly for 5 months. After 5 months, greenwater treatment fish were 2 g ABW. Fish in tanks with greenwater plus supplementary pellet feed were 12 g ABW (Fig. 5). This level of growth compares poorly even with under-fed Nile tilapia raised under a range of husbandry competencies in Fiji (Fig. 5)(Teri and Pickering 2007).

The locally-produced pellet feed was tested for protein content and found to be at the low end of 'normal' for tilapia feed at CP of 23.4%.

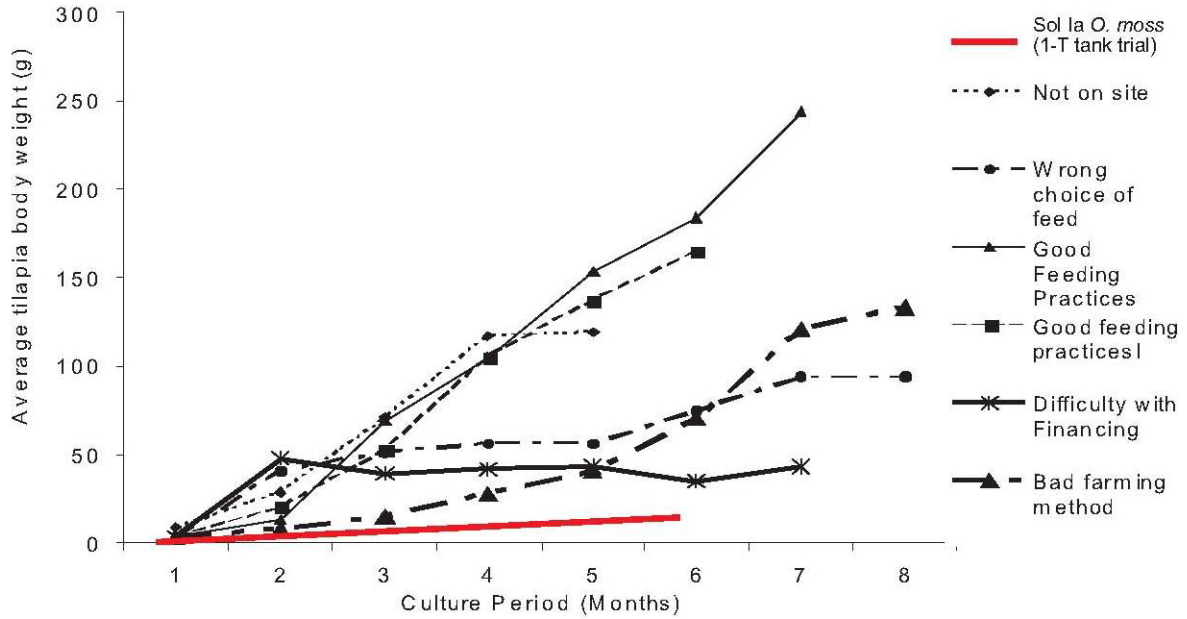

Figure 5. Mean weight (g) of Solomon Island Mozambique tilapia (red line) grown in 1 T tanks compared to Nile tilapia cultured under a range of husbandry practices in Fiji (black lines), after Teri and Pickering (2007).

3.2 Rearing tilapia in small-scale household ponds

At Mbokonavera survival after the 6-month culture period was high with 33 fish recovered from 35 stocked, plus some fingerlings which first appeared as swim-up fry at just under 3 months. ABW was 45 g (body length 14 cm) with the largest fish recovered being a male of 88 g. This was a much better result than the 12 g ABW of the tank-culture trial. The total fish harvested from the Mbokonavera pond was 1.5 kg, and 18 kg of pellet feed was given out, resulting in an FCR of 12:1. In comparison, Nile tilapia fed on the same Crest pellet feed in Fijian ponds can exceed 250 g ABW after 6 months (Fig. 6) and may have FCR in the range of 1.5:1–2.5:1. Nevertheless the Mbokonavera farm owner was impressed by the size of his Mozambique tilapia when fed on Fiji Crest pellet, and they were a source of pride to him.

The Lunga trial experienced difficulties with water quality due to water shortage for pond turn-over, and high water temperatures (up to 33^{o}C), which caused stress for fish. Stocked with 30 fish on 30 May 2010 and fed 2 kg of shrimp-pellet starter mash followed by 2 kg of Crest pellet, the result on 15 Feb 2011 was 219 fish harvested with a total weight of 868 g (ABW = 4g, FCR = 4.6:1).

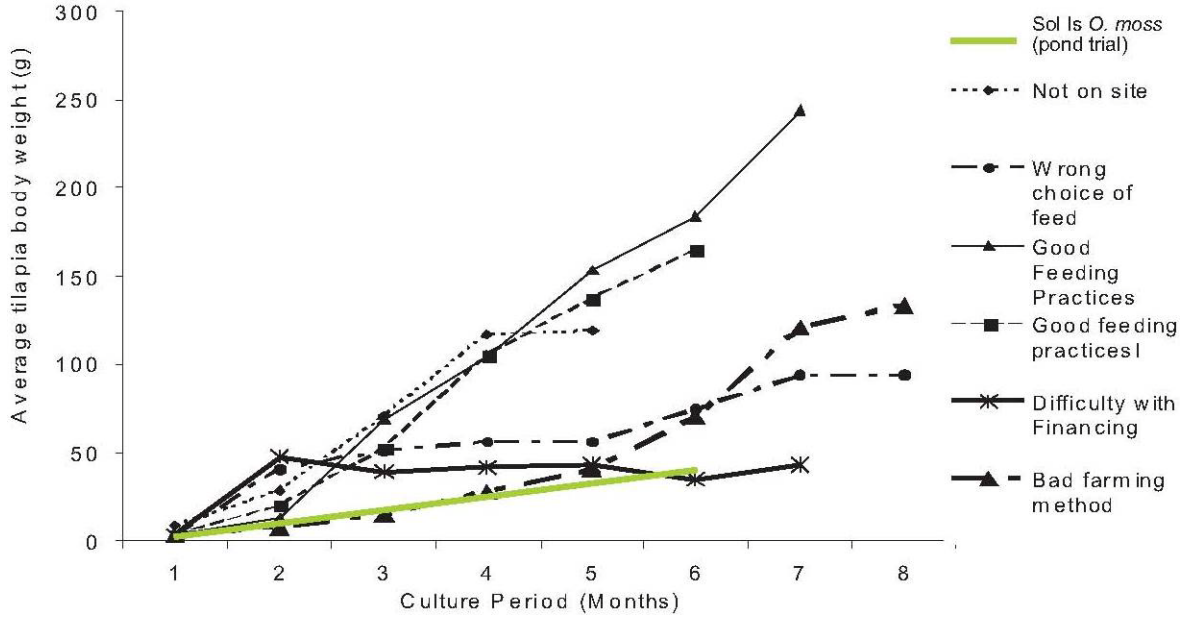

Figure 6. Mean weight (g) of Solomon Island Mozambique tilapia (green line) after 6 months of culture in a backyard pond at Mbokonavera compared with Nile tilapia cultured under a range of husbandry practices in Fiji (black lines), after Teri and Pickering (2007).

3.3 Stocking and rearing tilapia in a large earthen pond

After 8 months of culture, the RTC students harvested more than 1,000 tilapia from the pond. Unfortunately, Fr Thanh instructed that only nine fish were large enough to eat. The largest individual fish harvested weighed 50 g, however the ABW from a weighed sample of 72 fish was 15 g. Although the feed costs were indeed kept to practically nil, it was disappointing that after 8 months hardly any of the fish were big enough for eating.

4. Impacts

4.1 Scientific impacts

From this project, baseline growth and FCR data has been generated for Solomon Island Mozambique tilapia in small-scale aquaculture. This provides a basis for assessment of *O. mossambicus* suitability for aquaculture, and for comparison with the Nile tilapia cultured in other Pacific island countries.

4.2 Capacity impacts

MFMR Aquaculture Section staff received training and work experience in set-up and operation of a pilot-scale tilapia hatchery. The skills they have acquired are also applicable to operation of a quarantine facility for tilapia, should another tilapia variety be introduced in the future.

This research contributed toward a larger strategic exercise to address food security in Solomon Islands and in particular to investigate options for tilapia culture (MFMR 2010). The results from this project can be used to inform policy-making regarding importation of Nile tilapia, *O. niloticus*, into Solomon Islands. An IRA for Nile tilapia is currently being prepared for the Solomon Islands government by SPC.

The experience of breeding and rearing tilapia in a range of culture systems during this project has added to the capacity of MFMR Aquaculture Section to provide technical advice and extension support to Solomon Island tilapia farmers. Local farmers also gained new skills through their collaboration with MFMR and project staff.

4.3 Community impacts

Information generated from this project, combined with local farmer experiences and with advice from MFMR, SPC and Worldfish experts, was used to prepare and publish a tilapia farming pamphlet for Solomon Islanders, entitled *Information on the status and potential of inland aquaculture in Solomon Islands and advice on methods for improving current operations.*

5. Conclusions and Recommendations

When compared to Nile tilapia growth performance in Fiji, it is clear that the Mozambique tilapia present in Solomon Islands grows too slowly, eats too much food and breeds too early to be a candidate for aquaculture. Culture of a fish variety with such slow growth and high FCR can only be justified if feed costs can be kept to practically nil. The current price of Crest tilapia pellet in Fiji is FJ$1.28 per kg, which equates to SB$5.50 even without taking freight costs into consideration. At an FCR of 12:1 it therefore costs SB$66 to produce 1 kg of tilapia, which in the Honiara market currently sells (as a bundle of approx. 22 fish) for SB$10. Clearly, investment in high-quality formulated feed to increase Mozambique tilapia production in the Solomon Islands will not be worth it. Although cheaper to produce and acceptable as tilapia feed (23.4% CP), the locally-made pellets are also unlikely to make the activity economically viable. Soltai fishmeal has a reputation for being more like “bone meal” than fishmeal (the calcium level in this feed was 5.2%) owing to a practice of canning even the dark-meat and bloodlines at Soltai for local-market consumption. Fishmeal produced from tuna canning tends to be of ‘low to medium’ quality in terms of its proteins and amino acid profile, due to the fact that it is made from material that has been cooked. Growth performance was poor on both types of pellet feed and even lower in greenwater culture in a tank and in a large pond with natural production and supplementary feeding.

The Mozambique tilapia did respond to improvements in the quality of feed inputs through faster growth, but not to the extent that the higher costs of these inputs can be justified. Investment to grow it faster and more intensively cannot be recouped, so this variety is not a basis for an economically viable and business-like approach to farming fish. Nor could it be produced in the volumes required to make a substantial contribution to food security in Solomon Islands.

Non-commercial aquaculture of this tilapia variety for food security at a household level can be justified only if the costs of production are extremely low. This will be an attractive proposition if peoples' expectations about fish production from ponds, and the minimum size of fish regarded as acceptable for eating, remain low. The fact that some people are currently highly motivated to attempt Mozambique tilapia farming in Solomon Islands, with over a dozen farms already operating, shows that expectations are indeed being met by this species in some cases. It is worth supporting and encouraging such people to improve their farming practices as much as this species and their budgets will allow.

For tilapia farming to make a substantial contribution toward food security and livelihoods generation in Solomon Islands, use of a variety that is more suitable for aquaculture will need to be considered.

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5. Acknowledgements

Thanks go to the collaborating partners, John Volrath at STP, Peter Mua, Fiona Katovai and Don Bosco Rural Training Centre, for cooperating so freely to help implement this project.

Samoa

(Appendixes 2.21 to 2.22)

Appendix 2.21

MS1009

Village aquaculture of sea grapes (*Caulerpa* sp.) for domestic markets in Samoa

ACIAR Pacific Aquaculture Grant: **Project Summary**		**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**
Project Title:	**Village aquaculture of sea grapes (*Caulerpa* spp.) for domestic markets in Samoa (MS1009)**	
Goal:	Trial sea grape (*Caulerpa* spp.) culture in Samoa.	
Objective(s):	The project will achieve this through the following objectives; 1) Determine the feasibility of culturing of *Caulerpa* in a coastal village in Samoa; 2) Assist in development of a new income generating aquaculture industry in coastal rural communities of Samoa; 3) Increase capacity in Samoa (Fisheries officers and community members) to carry out seaweed culture.	
Project location:	Apia, Samoa	
Project partner(s):	Samoa Ministry of Agriculture and Fisheries, Fisheries Division	
Dates / duration:	June to August 2011, three months	
Project description	Growing the edible algae *Caulerpa* (sea grapes, in Samoa "*limu fua fua"*) as a village based enterprise is likely to be a suitable aquaculture activity for Samoan communities as a low level of technical expertise is required and both capital and operational costs are low. Samoa is developing plans for a more extensive sea grape project but this mini-project will test the feasibility of growing them in a village situation. In collaboration with the local expertise, a seaweed culture expert from James Cook University will share knowledge on Australian research into sea grape culture in order to develop an effective culture system for local species.	
Justification	There are limited opportunities for income generation in coastal areas of Samoa (and elsewhere in the Pacific Islands region). Sea grapes are a popular food item in Samoa and sell for $14.20/kg in the local market. However, over-harvesting has led to local shortage of the product. This project will assist in developing a new aquaculture industry in Samoa.	
Expected outcomes	1. Production of *Caulerpa*; 2. Experience gained in *Caulerpa* culture and seaweed cultivation; 3. Improved capacity among Samoan Fisheries aquaculture officers and community members; 4. Initial steps in development of a new livelihood for Samoan coastal communities, with potential for servicing a domestic market.	
Budget:	**$13,200**	

Village aquaculture of sea grapes (*Caulerpa* spp.) for domestic markets in Samoa

Nicholas Paul[1], Ulusapeti Tiitii[2], Joyce Samuelu Ah Leong[2], Clifton Sae[2], Ian Tuart[1]

[1] School of Marine & Tropical Biology, James Cook University, AUSTRALIA
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1. Background

Caulerpa or 'sea grapes' is an edible seaweed (known as 'limu-fuafua', hereafter referred to simply as limu) and a local delicacy in Samoa. Gleaning of sea grapes from reef flats at low tide is primarily done by women (Fig. 1a). The product is collected from lagoon and fringing reef areas throughout the country, usually where there are abundant algae or dead hard substrate. After collection, the sea grapes are cleaned in seawater, then ~100–200 g portions are packed inside breadfruit leaves and sold raw in bundles at central markets and roadside stalls (Fig. 1b).

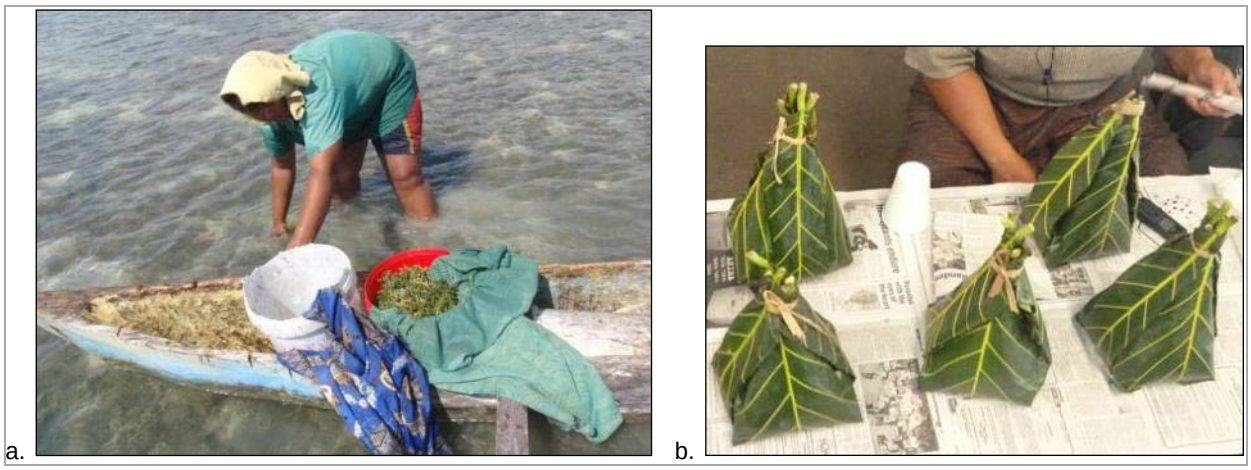

Figure 1. (a) Harvest methods for limu-fuafua (*Caulerpa racemosa* var. *racemosa*). Canoes holding harvested limu inside are pulled along the lagoon at low tide. (b) Market bundle of limu.

There are concerns that sea grapes are being overfished. Surveys show that in 2005 an estimated total of almost SAT$86,000 worth was traded and this increased to over SAT$127,000 in 2008. More fishers are targeting this resource and the bundle price has increased while the bundle size has decreased. The average price in 2005 was $5.55/kilogram, while in 2010 it was worth around $14.20/kg.

There have been no previous studies on the biology or ecology of this seaweed and there is currently no management of the resource in Samoa. Skelton (2005) identified two varieties of edible *Caulerpa* (*Caulerpa racemosa* var. *clavifera*; now var. *racemosa*: Kraft 2009) and *Caulerpa racemosa* [var. *occidentalis*?]) in Samoa. Other cryptic varieties of edible *Caulerpa* species may also exist. Samoa Fisheries Division (SFD) is developing a Japan International Cooperation Agency (JICA) project to identify the edible *Caulerpa* species found in Samoa, review the existing stocks, and introduce farming techniques that can sustain the resources and produce maximum yields from the fishery. This mini-project was not intended to replace the proposed JICA project but instead will compliment any future work by providing preliminary growth trials of limu fua fua on the main island of Upolu. This will assist in determining the scope of the JICA project and equip the community involved with skills in *Caulerpa* culture prior to the larger project.

There are five main villages which are involved with the wild harvest of sea grapes: Leauvaa; Mulifanua; Asaga, Lano and Manono-uta. Fisheries surveys indicate that the sea-grape sellers are mainly women. This study can be expected to benefit women primarily, but participation will be open to any members of the community.

This mini-project will trial low-technology culture methods developed in Australia that employ an asexual fragmentation technique to promote re-growth of seedstock, and which have proved successful for *Caulerpa lentillifera.* Successful *Caulerpa* culture may provide income generating and employment opportunities for Samoa. There is potential for the conservation and sustainability of wild stocks of this commodity to be improved through the mini-project. This mini-project did not involve any introduction or trans-shipment of new species.

2. Project Methodology

2.1 Resources

Ms Ulusapeti Tiitii (SFD Inshore Senior Fisheries Officer) has been trained in *Caulerpa* culture by Japanese contacts in Fiji and Okinawa under the Japanese International Cooperation Agency (JICA) fisheries training. Ms Tiitii was responsible for coordination of the project in Samoa, for data collection throughout the trials and for implementation of a second trial at Savaia. Eight members of the SFD (Inshore and Aquaculture teams, led by Ms Tiitii and Mr Sa'e respectively) were involved in the culture trials. SFD supplied boats and transport for the duration of the trial.

2.2 Methods

Study sites

Two sites were used for Caulerpa culture trials (Fig. 2). Leauvaa village was the site of the first growth trial for the project. This site represented one of the main producers close to Apia, where villagers harvest from the coastal lagoon. The site receives significant terrestrial runoff via adjacent estuaries, and correspondingly water turbidity was very high during the trial. In order to compare the culture system in a clear water area, a subsequent trial was conducted at a second site on the opposite side of Upolu in the village of Savaia.

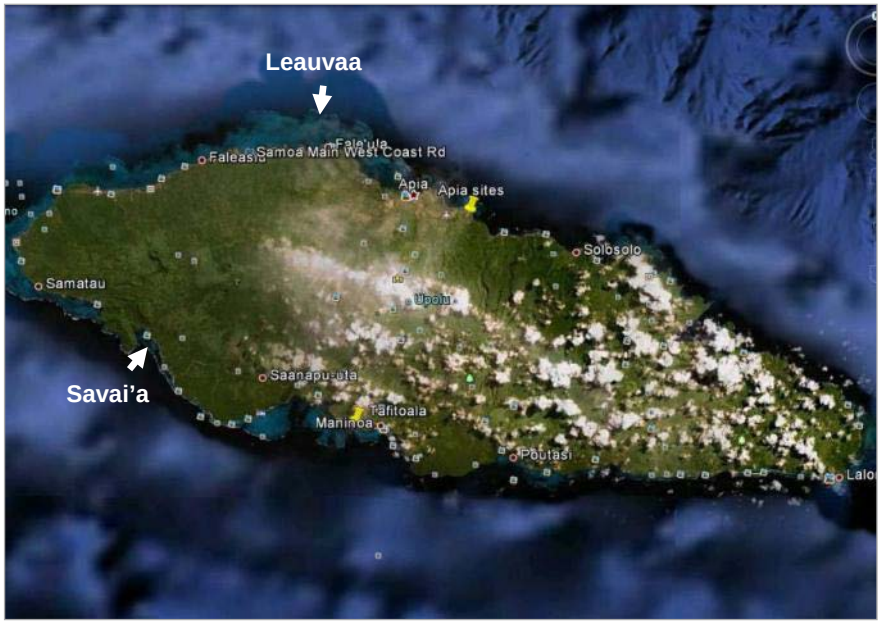

Figure 2. Leauvaa Site (Trial 1) and Savaia site (Trial 2) on the island of Upolu.

Both trials were conducted in shallow, near shore habitats, with the Leauvaa farm setting adjacent to known harvest areas of *Caulerpa* and the Savaia farm established within the community-owned fish reserve. *Caulerpa* was seen in Savaia lagoonal areas about 30–40 years ago, however, last year, fishers reported fishing only about 2–3 bundles of limu. Therefore, the *Caulerpa* biomass for growth trials at both sites was harvested from the lagoon adjacent to the trial site at Leauvaa. Both SFD officers and commercial gatherers were used to collected limu, totalling 56 kg of biomass. The majority of limu was attached to turf seaweed, primarily the coralline green seaweed *Halimeda opuntia* (Fig. 3a). This was easily freed from the turf by detaching the rhizoidal anchors. These rhizoids (hairs) were removed during the post-harvest cleaning step using a blade (Fig. 3b).

a.  b. 

Figure 3. (a) Limu fua fua is most often attached to clumps of *Halimeda;* and (b) Using a knife to remove rhizoids from harvested limu (*Caulerpa racemosa* var. *racemosa*).

The growth trials were conducted by placing harvested limu seedstock inside plastic mesh aquaculture trays at high density of 4.5–5 kg m^{-2} (Fig. 4a). Trays were suspended close to the surface at ~20 cm deep at low tide. Sixteen culture units (1 x 1 m x 50 mm deep trays) were arranged in a square plot in submerged culture in channels adjacent to the village. Because of the strong relationship between limu and *Halimeda* in the lagoon, a second treatment of the co-culture trial used 0.5 kg of *Halimeda* as a base for the limu within the tray (Fig. 4b). Experimental design for the first growth trial at Leauvaa involved 16 culture trays containing alternating treatments of *Caulerpa* monoculture and *Caulerpa-Halimeda* co-culture (Fig. 5).

a.  b. 

Figure 4. (a) Tray culture of limu fua fua (*Caulerpa racemosa* var. *racemosa.* (b) Co-culture treatment in the trial comprised of a layer of *Halimeda* (bleached tissue to left, 0.5 kg m^{-2}) with an additional layer of limu (4.5 kg m^{-2}).

Figure 5. Experimental design for growth trial at Leauvaa: treatments of *Caulerpa* monoculture (n=8) and *Caulerpa-Halimeda* co-culture (n=8).

Growth was measured as both the change in weight of the culture unit, as well as the height of new growth above the lid of the tray by sampling 5 sections of the tray. Trays at Leauvaa were stocked on the 16th June 2011, and weight was measured fortnightly over the 6-week trial period (i.e. 30th June, 14th July and 28th July 2011). Growth (change in biomass in grams) of each tray was recorded at each sample time. At the same time, the height of the limu above the tray was measured for each tray. The sampling design measured a single frond length at 5 points on the tray (centre of each quadrant and the middle of the tray) at each sample time. On the final day of the trial the length of fronds of *Caulerpa* that had grown beneath the tray was also measured, as this was observed to be a lengthy portion of the new growth.

The Savaia trial was a second site evaluation, selected as it was a "clear" water site. A subset of nine culture trays and two small clam cages were stocked with *Caulerpa* biomass from the Leauvaa site. All trays were stocked with *Halimeda opuntia* as the base (see Fig. 4b). Viability and growth of limu through the trays were evaluated after a 4–7 week period. Two trials were conducted at Savaia: after an unsuccessful first attempt, a follow-on trial commenced on 15 Feb 2012, culture trays were located within an exclusion cage of approximately 6 m long x 2 m wide x 1 m high to prevent fish grazing. The cage was then placed on a sandy substrate away from coral-rich areas, to avoid the high density of fish. Trays were weighed fortnightly and harvested at 4.5, 6 and 7 weeks after stocking.

3. Outcomes

3.1. Limu product assessment for Samoa

The project identified that two different varieties of sea grapes, both from the genus *Caulerpa racemosa,* are harvested for sale in the market: the Upolu variety *Caulerpa racemosa* var. *racemosa* (also common in tropical Australia) and the Savai'i variety *Caulerpa racemosa* var. (*occidentalis*). The Upolu variety was the primary focus of this study, as this is a common product in markets and street stalls on Samoa's main island of Upolu and has documented increases in price by SFD market surveys. On the other hand, the Savai'i variety is not consumed by Upolu residents – it appears it is not a preferred taste or texture, which could be a parochial choice – but

is instead sold directly into the tourist market at high-end hotels in Apia, the capital. The Upolu variety has a peppery taste, whereas the Savai'i variety has a more subtle aftertaste.

The two varieties are different in morphology and methods of production for market also. The Upolu variety is harvested directly from the lagoon behind the fringing reef, the attachment hairs ('rhizoids') are removed using a knife and the entire remaining thallus is packaged inside bound breadfruit leaves. The Savai'i variety has a more elongate frond (upright portion) compared to the compressed bulbs of the Upolu variety (Fig. 6a, b). Only the fronds are harvested from the fringing reef of a couple of localities (Asaga, Lano) in Savai'i, meaning that the attached horizontal portion remains on the reef and can potentially contribute to new seedstock. The Savai'i variety fronds are also packed in breadfruit leaves, but more water appears to be removed from the Savai'i product compared to the Upolu product prior to packaging.

a.  b. 

Figure 6. (a) Compressed growth form (small fronds) of the Upolu variety of *Caulerpa racemosa* var. *racemosa*. (b) Longer fronds of the Savai'i variety of *Caulerpa racemosa* (var. *occidentalis*).

3.2. Leauvaa *Caulerpa* culture trial

In the first trial at Leauvaa, two different treatments were evaluated in the tray-culture system: a monoculture of limu and a co-culture of limu and *Halimeda.* On average, 1.75 kg of limu was harvested from above each tray at the end of the trial period (Fig. 7). For seaweed culture, the production per unit area (new mass of product per square metre: $kg.m^{-2}$) is the most important measure of success as production area is scaled horizontally rather than vertically through the water column. Negative values from Day 14 onwards indicate that biomass inside the trays had degraded and, therefore, could not contribute to new growth after harvest.

New growth through the top of the trays was observed as early as 2 days into the trial (Fig. 8). However, the early growth over the first 2 weeks was not sustained, and the entire biomass inside the trays (initially 5 kg) was ultimately lost for both the monoculture and the *Halimeda* co-culture.

Average height of the limu fronds above each tray showed that the new growth reached 2 cm after a fortnight for the limu-*Halimeda* co-culture and after 4 weeks for the limu monoculture (Fig. 9). It is possible that the addition of *Halimeda* provided a more beneficial substrate initially: however, the monoculture also grew well through the tray after 4 weeks. At this time biomass became inter-twined as a mat and was less reliant on an additional substrate or anchor point. On the final day of the trial the length of fronds of limu that had grown beneath the tray were up to 7–8 cm in length (Fig. 9).

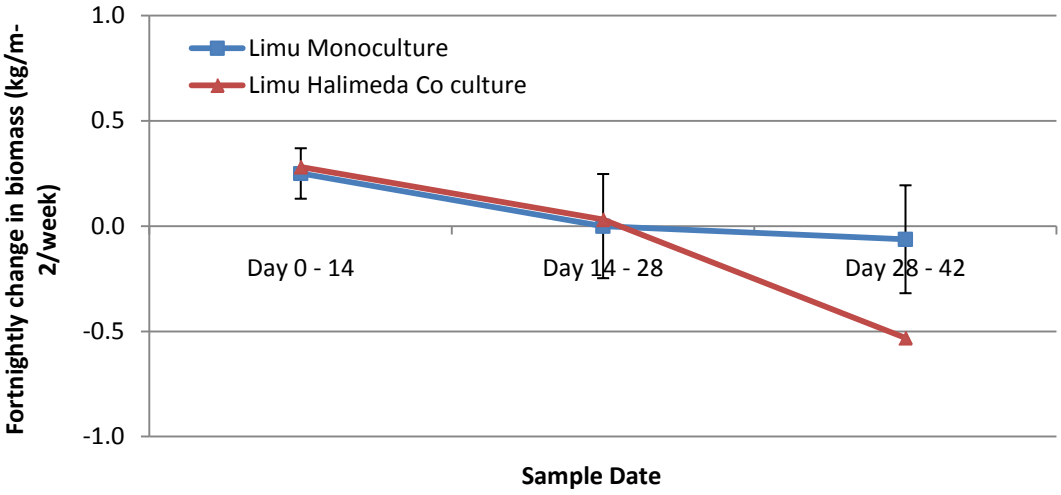

Figure 7. Fortnightly change in biomass (kg m^{-2}) of limu in monoculture and co-culture with *Halimeda* at Leauvaa.

a. 

b. 

Figure 8. (a) New limu growth protruding above the tray lid 2 days after the establishment of the culture at Leauvaa. (b) Frond height was measured fortnightly using a ruler (this image was from sampling at 2 weeks).

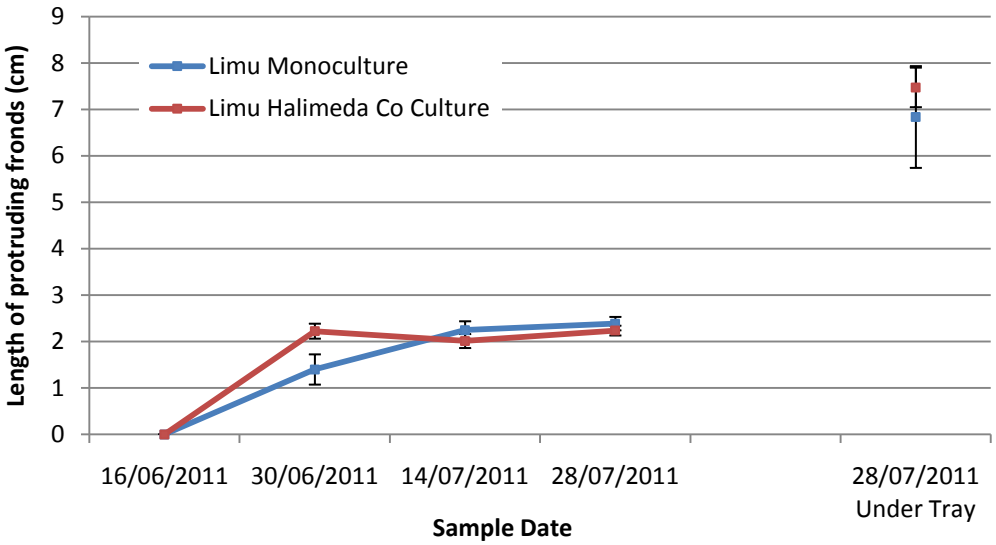

Figure 9. Growth (cm) of limu fronds protruding above (for 6-week period) and below (one sample) the culture trays at Leauvaa.

Although there was substantial amounts of sediment captured within the culture tray (see Fig. 8b), it is unlikely that this was the cause of reduced growth and degradation of the internal seedstock because wild limu stock grows well in adjacent harvest areas (~10 m away from the site).

3.3. Savaia *Caulerpa* culture trial

The subsequent trial at a 'clear' water site on the south of Upolu (the village of Savaia) with this variety was initially unsuccessful due to fish grazing—SFD staff found that there was no new growth at the end of four weeks. However, the follow-on trial in mid February 2012, produced several kilograms of new limu biomass on top of the trays (Figs 10, 11) and cages. Furthermore, new growth frond length on top of trays and cages reached 7–12 cm after 7 weeks (Fig. 12). The limu quality was also high, with a less bitter taste compared to the taste in Leauvaa.

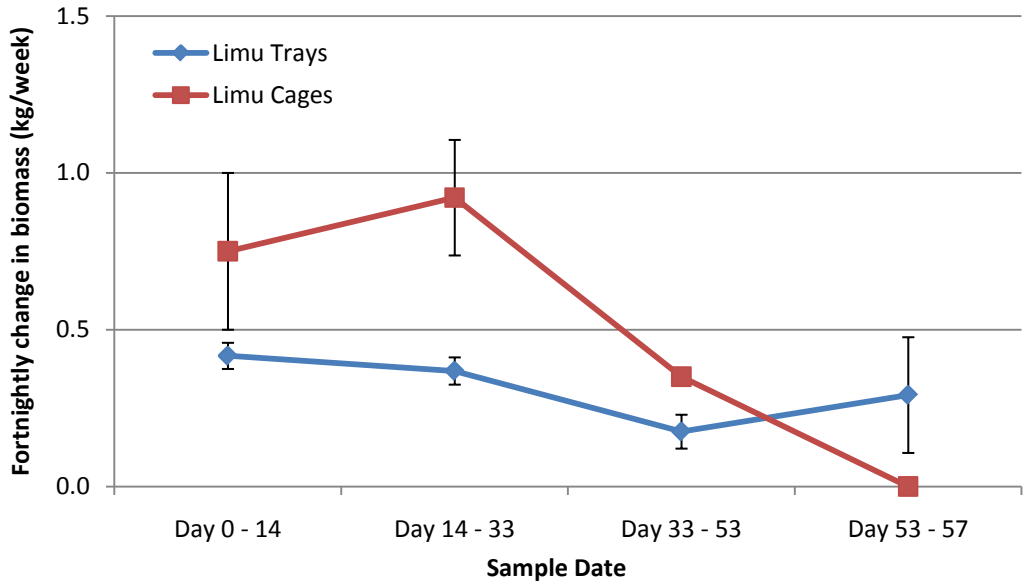

Figure 10. Fortnightly change in tray and cage biomass (kg m^{-2}) of limu in co-culture with *Halimeda* at Savaia.

Figure 11. SFD staff showing the excellent growth of limu in culture trays at Savaia.

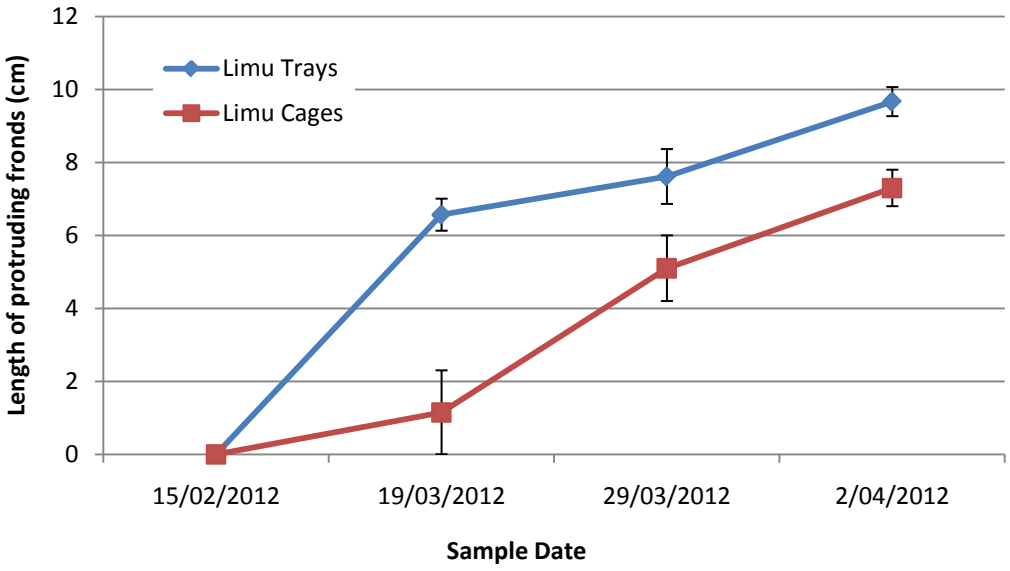

Figure 12. Growth (cm) of limu fronds protruding from the culture trays and cages at Savaia.

Harvesting of the nine trays was staggered: two trays were harvested on 19 March; one tray was harvested on 29 March; five trays were harvested on the 2 April and then left to regrow to determine their ongoing productivity after the first harvesting (Table 10). The final tray was not harvested but saved to use a display for the Agro-Show display on Savai'i Island in May.

Table 1. Limu culture results (estimated no. bundles, approximated weight and estimated value) from Savaia trial where trays were harvested at 4.5, 6 and 7 week intervals after initial stocking on 15 February 2012.

Harvest date	Approx. culture time	No. trays	No. bundles per tray	Est. weight per tray (@ 150 g per bundle)	Est. value per tray (@ SAT$14.20/kg)
19 March 2012	4.5 weeks	2	23–25	3.5 kg	SAT$51
29 March 2012	6 weeks	1	25–28	4 kg	SAT$57
2 April 2012	7 weeks	5	30–35	11-13 kg (whole tray): (4.5kg tray and lid weight; 5 kg seedstock biomass; 2.5-3.5 kg new growth)	SAT$70

4. Impacts

4.1 Scientific impacts

The mini-project demonstrated that the Upolu limu variety is unlikely to be a suitable candidate for aquaculture production in turbid water because of the inability to retain viable biomass inside the tray as seedstock for new growth after harvest. At the turbid site at Leauvaa, new growth above the tray was minimal, only 1.75 kg.m^{-2} of limu over a 6 week period. However, limu culture in the clear water environment of Savaia, proved successful. The results from Savaia were lower but still comparable with *Caulerpa lentillifera* trials in the same culture system at JCU, Townsville (Paul et al., unpublished data) which yielded between 1–2 kg m^{-2} per week whilst retaining viability of the seedstock (6 kg) within the tray.

The Leauvaa trial also compared monoculture of limu with a co-culture of limu and the green coralline alga *Halimeda*. The premise was that limu was almost always associated with and attached to *Halimeda* as a substrate in the surrounding lagoon. There was no strong evidence that this relationship was an obligate one, as the trial indicated that both monoculture and co-culture had similar growth patterns and new frond growth through the tray. However, the successful trial at Savaia also used *Halimeda* as the base, indicating that this approach is worth further investigation.

The downward growth pattern of limu in trays at Leauvaa was an interesting and unexpected finding. It revealed that the growth morphology of the limu could be manipulated to produce short, compact fronds on the upper portion and elongate fronds on the lower section. The plasticity of the limu to change morphology to suit conditions (e.g. low light conditions under the tray) could be a useful means to provide a more diverse range of products from the limu and warrants further investigation.

4.2 Capacity impacts

This mini-project allowed SFD officers to increase their knowledge in seaweed production using the technique of fragmentation as the re-growth strategy. SFD officers were responsible for management of all aspects of the trial: from site selection and sourcing seedstock through to experimental set up and monitoring for the duration of the trial. The SFD officers demonstrated their capacity to maintain the trial, measuring the important attributes of growth rates of the limu as both weight and also changes in morphology. These represent two important aspects for seaweed culture, as both the volume and the quality of the product are integral for commercial viability. Harvests were conducted at the end of the trial in a similar manner to which commercial harvests would be conducted.

Importantly, skills learned in the trial were adapted for a follow-on trial at Savaia. Initial poor results at this site were improved upon using good problem solving skills (to address fish grazing problems) and led to a successful outcome. This demonstrated an understanding of the basic requirements for culture of the limu and ability to innovate and resolve local constraints.

The SFD project leader (Ms Tiitii) consolidated the knowledge she already had with seaweed production through collaboration with Australian experts in this field. There are potential links to other larger projects on sea grapes. For example, the results of this mini-project might be used to strengthen a larger JICA-funded project on community *Caulerpa* farming or provide a basis for future ACIAR initiatives relating to seaweeds and algal products.

4.3 Community impacts

The trials at Savaia, after some initial problems with fish grazing, were a success and indicate that limu tray culture is feasible in clear water environments in Samoa. Although still needing more investigation, there is evidence that tray culture will produce sufficient new growth to support a village limu industry. During the follow-on trial, the cultured limu was distributed around the village chiefs, and the women's committee who were meeting at harvest time (Fig.13). The opportunity to view and inspect the product was timely and promoted interest in the prospects of seaweed farming.

The culture platform that was deployed in Upolu could also be used in a future trial of the Savai'i variety.

a.  b. 

Figure 13. (a) SFD staff presenting the tray of limu to the Women's Committee and (b) showing Chiefs how to harvest at Savaia.

5. Conclusions and Recommendations

In summary from above:

- Two different varieties of sea grapes are consumed in Samoa: the Upolu variety *Caulerpa racemosa* var. *racemosa* (also common in tropical Australia) and the Savai'i variety *Caulerpa racemosa* (var. *occidentalis*?). Only the Upolu variety was investigated in this mini-project.
- Different results were obtained from growing the Upolu variety of limu in tray culture. A limited amount of new growth above the culture tray was harvested (average 1.75 $kg.m^{-2}$) after a 6-week period in the turbid waters of Leauvaa. Furthermore, the seedstock of Leauvaa limu held within the culture tray (initially 4.5-5 kg) was not viable at the end of the trial. However, tray trials in clear water at Savaia yielded good growth (average 2.3 $kg.m^{-2}$ for limu trays and 5 kg for limu cages after 6 weeks), although more trials are needed to confirm that tray seedstock remains viable for subsequent culture cycles.
- Fish grazing problem was overcome by weaving a 12 m^2 cage to hold nine culture trays. Fish were observed grazed on the brown seaweed attached to the sides of the cage minimising their impact on the biomass inside. However, juveniles of about 5-10 mm length were roaming around inside with least impact.
- We tentatively conclude that the culture platform developed for the commercial sea grape *Caulerpa lentillifera* in tropical Australia is adaptable to the Upolu limu fua fua, but only under certain water quality conditions.

The positive *Caulerpa* grow-out results at a site with oceanic mixing of water suggest that further trials in other parts of Upolu would be valuable to determine the optimum culture techniques and identify criteria for successful limu tray culture in Samoa. Future trials should focus on quantifying the growth of limu in tray culture at different sites and determining the best conditions (water quality, temperature, turbidity, etc). The poor frond growth and ultimate loss of biomass within the tray in turbid water represents the most significant constraint for aquaculture production of the Upolu limu variety as it is critical to retain viable biomass within the tray as seedstock for new growth once the portions above the tray are harvested. The use of alternative culture trays or locally available materials could also be considered. SFD officers indicated that they were interested in trialling simpler methods in the future and set up more farms at suitable sites. From

preliminary trials with clam cages, it appears that other materials will also work, but are unlikely to provide as good a quality of product due a shorter length of fronds (see Figure 12).

This research is also applicable to trials using the Savai'i variety. Although it was not thoroughly investigated in the current project, the Savai'i variety appears to be an analogous product to *Caulerpa lentillifera*, the most developed aquaculture species of sea grapes fetching a high value. As stated previously, an expected yield from the low-technology culture system employed for *C. lentillifera* is between 1–2 kg m^{-2} per week (6–12 kg over the analogous 6 week trial). This provides a future benchmark for potential production of the Savai'i variety. The Savai'i variety is unique in its appearance and texture, and is well received in the local tourist market. The methods for harvest of the Savai'i product (as we understood from an SFD survey results) appears to be sustainable, as only a portion of the biomass is harvested from the fishery site. On the other hand the production practices of the Upolu variety rely on removal and consumption of the entire thallus.

In addition to tray culture, there are alternatives for aquaculture production of seaweeds that rely on sexual reproduction and settlement of propagules onto substrate for subsequent culture. This method of sexual reproduction may be the primary seeding mechanism for the Upolu variety of limu. However, this method requires a hatchery production facility for the seedstock, which is contrary to the philosophy of seaweed culture being a low tech alternative for community aquaculture at the current time. This line of investigation is therefore not recommended for limu culture in Samoa. Management of the wild stock of limu on Upolu and tray culture in suitable areas are recommended as means to regulate the commercial production of this variety.

The combined approach of managing stock and providing some aquaculture options could, in combination, prove useful for conservation of wild sea grape stocks. Additional information regarding the post-harvest treatment of the product (including removing water from the harvested biomass prior to packaging) could provide an increase in shelf-life and therefore reduce the pressure on the fishery resource of Upolu via reduced product wastage.

Recommendations

Recommendations arising from the study can be summarised as follows:

- Carry out follow-on trials of the Upolu *Caulerpa* variety to:
    - rigorously quantify growth;
    - determine the optimum culture conditions (water quality, temperature, turbidity, etc) through grow-out at a range of sites;
    - develop a list of criteria to assist in identifying alternative sites with a high chance of success; and
    - confirm that tray seedstock remains viable for subsequent culture cycles (viability of initial seedstock is a crucial factor of the sustainability of the method).
- Conduct culture trials using the Savai'i *Caulerpa* variety.
- Conduct market surveys of all cultured *Caulerpa* product.
- Investigate possible reduction in harvest of over-exploited wild *Caulerpa* stocks through:
    - use of tray culture in suitable areas as a means to regulate the commercial production of this variety;
    - optimise post-harvest treatment of the product (e.g. removing water from the harvested biomass prior to packaging) to increase in shelf-life and therefore reduce product wastage.

    - hatchery produced *Caulerpa* seedstock approach (e.g. maintaining high yielding strains for distribution to new projects or for restocking of on-going sites as required).
- Trial simpler culture methods using cheaper, locally available tray materials.
- Establish more farms in interested coastal communities.

6. References

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7. Acknowledgements

We thank the associated SFD staff (inshore fisheries and aquaculture sections) for assistance and dedication in establishing and maintaining the trial. We also thank the Samoan Fisheries Division office in Apia for welcoming and hosting the James Cook University staff members. Our gratitude is also extended to the community Chiefs and members of Leauvaa and Savaia villages for their hospitality and access to their marine areas.

Appendix 2.22

MS1010
New aquaculture facility options for Samoa

ACIAR Pacific Aquaculture Grant: **Project Summary**		**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**
Project Title:	**New aquaculture facility options for Samoa (MS1010)**	
Goal:	To assess the options and indicative costs for a new marine/freshwater hatchery in Samoa	
Objective(s):	Specific objectives are to: 1) Facilitate tour of Samoa by an expert advisor to appraise potential hatchery sites; and 2) Report on options and indicative costs for new hatchery/ies with quarantine functions.	
Project location:	Samoa	
Project partner(s):	Samoa Ministry of Agriculture and Fisheries	
Dates / duration:	April-May 2011, one month.	
Project description:	The site of the previous marine hatchery in Samoa was bought out by a hotel chain and the hatchery is no longer operational. There are currently no facilities in Samoa for the culture and grow-out of commodities for food security and income generation. This mini-project will facilitate a site appraisal by an expert advisor to select a suitable alternative hatchery sites in Samoa. The advisor will also meet with Samoa Fisheries Division managers to discuss their needs with respect to a mariculture and freshwater aquaculture facility. A report would be prepared outlining the options available, with indicative costs.	
Justification:	Purpose built hatcheries will enable larval culture and on-growing of a variety of organisms (e.g. pearl oysters, giant clam, trochus, sea cucumber, tilapia, freshwater prawn, etc). It will also include the capacity for quarantine of introduced species if desired. This project will assist in development of new aquaculture facilities in Samoa and support aquaculture development.	
Expected outcomes:	1) Expert advice on suitable hatchery site/s; 2) Approximate costs for construction of hatchery facilities; 3) Realistic appraisal of potential constraints and how to mitigate for them; 4) Support of aquaculture development in Samoa	
Funding:	$6,500	

New aquaculture facility options for Samoa

John Morrison

Morrison Designs & Advisory Service, Brisbane, Australia

1. Background:

Since the closure of the previous hatchery on Upolu, Samoa has no facilities for the culture and grow-out of aquatic species for food security and income generation. A new hatchery will enable larval culture and on-growing of a variety of marine and freshwater commodities (e.g. pearl oysters, giant clam, trochus, sea cucumbers, tilapia, freshwater prawn and so on). It will also include the capacity for quarantine of introduced species.

This mini-project will facilitate a country visit by an expert advisor, John Morrison (of 'Project Specialists') to assess potential hatchery sites in Samoa. The advisor will also meet with Samoa Ministry of Agriculture and fisheries (MAF) managers to discuss their needs with respect to mariculture facilities. This project will assist in developing new aquaculture facilities in Samoa and support aquaculture development in the country.

2. Project Methodology

John Morrison visited Samoa from 27 April to 1 May 2011. He was contracted to inspect and assess several potential marine hatchery sites on Upolu and Savaii as proposed by MAF. There had also been suggestion to assess a freshwater hatchery site but this was not required. Joyce Ah Leong (Principal Fisheries Officer, Aquaculture) and senior MAF staff met with John prior to the site inspections to discuss species of interest, the level of technology desired and to provide any other information relevant to his task. Approximately three days were spent travelling around Upolu and Savaii inspecting six proposed sites. This report provides a written assessment of each site and summary of hatchery requirements based on the needs of MAF. It includes advice on basic hatchery design and layout, and indicative costs (but not a comprehensive design with full costing).

Information generated from this mini-project will assist MAF in developing their hatchery strategy and in determining how to use funds sourced from donor organisations (e.g. FAO, AusAID) in future projects.

3. Outcomes

Site assessment

Site 1 – Mulifanua, Upolu

This site is approximately 30 minutes drive by car from the MAF offices in Apia. It is government owned land and is only a few hundred metres from the car ferry terminal.

The bay, in which the hatchery would draw its water, is quite shallow and high in particulates. The regular car ferry traffic would also affect the water quality: not only from the large vessels turning nearby, stirring up the sediments but an unknown amount and type of pollutants from these vessels could also find their way to the intake water, depending on the currents. The site is a little exposed to rough weather conditions, especially in a strong easterly or north-easterly wind, which would also elevate the sediment loads near the intake.

The capital cost of equipment and labour costs to filter the sediments would eventually cripple the viability of the entire facility. Possible pollution from the ferries and high water temperatures due to the shallow water would rule this site unsuitable.

Site 2 – Savaia, Upolu.

The villagers own this site and are already actively involved in a fish protection program with MAF, which alone is a valuable asset when considering a new hatchery site. On the day of inspection the water was clear and appeared to be of a very good quality, with excellent water flow and currents. A good current is a key element to providing a natural planktonic food source for the juvenile animals being held in grow out facilities. It appears to be well protected from most bad weather.

This fringing reef flat is not particularly deep (2-2.5 m), but the bottom is predominately a solid, old fringing reef structure. This allows the intake pipelines to sit close to the bottom without the usual hazards of sand or mud being sucked up the lines.

It is apparent that there are several freshwater springs coming up through the reef flat in some spots, which will have to be avoided when positioning the intake pipelines.

Certain areas of this large bay will be an exceptional spot to place the large numbers of juvenile giant clams during grow out phase. Given that the village is committed to their marine environment, they could assist MAF with security of the facility and animals on the reef flat. They may even provide some labour when moving the animals is required.

The proposed hatchery area is flat but is very limited in size, so if it were chosen, careful arrangement of buildings and raceways will be needed to ensure it will fit and expansion would be highly unlikely unless more land is allocated or reclaimed.

Apparently this site is where the giant clam broodstock are currently being held.

Site 3 – Savaia (200 m west of Site 2), Upolu.

This land is government owned and on the opposite side of the road from the ocean but appears to be a much larger parcel of land. It may need a raised pad to be laid prior to building, which is an added cost. However, the site is worthy of consideration.

Site 4 – Asau, Savaii.

The Fisheries department currently occupies a site and has some well established buildings available and they could be easily converted or adapted.

The seawater is clean, clear and relatively close to a reasonably deep-water channel (40 -60 m). It is also fairly protected by the outer reef shelf, protecting it from most bad weather conditions but it still has good water flow. Power is already onsite and a police station is next door in case of any security issues or breaches.

The site currently has an accommodation block, an office, a storage shed and an ice plant. The area selected for the raceways will need to be extended by building up the lower levels with rocks and backfill.

The storage shed could be converted to a small hatchery/aquaria lab without major work.

Some of the negative points identified are minor, but must be carefully considered; e.g. the more than 4 hour drive (by car and ferry) from MAF's office in Apia to Asau, which limits staff visits to at least 2 days per visit. Transporting live animals to Upolu would not be without risk and should be done only when necessary. Freshwater is apparently of low quality and fairly limited too. The site is a little limited in area, but not could be considered as a second hatchery site in the future.

Site 5 – Taumeasina, Upolu.

This site is the closest site to MAF's office in Apia, which makes it very convenient for its management, staff access, movement of animals, etc. The site is government owned and large enough for any future expansion. There appeared to be exceptional water quality nearby and the site is close to all the services required to operate a successful multi-species hatchery, with research capabilities befitting (Fig. 1). The site is on a point and is a little protected, yet has ample water flow to supply clean, fresh seawater with all the natural food supplies.

The base of the land appears to be mainly coral rubble making it ideal to support the raceways, tanks and future labs. The discharge water or any overflows from the tanks would simply be put to ground, due to the porosity of the coral substratum, the water would dissipate very quickly and safely, regardless of the nutrient loading.

Some minor issues like upgrading the access road and, sometime in the future, building a retaining wall at the water's edge is all that is really needed.

The intention is to build only single-storey buildings with a large expandable footprint, which makes this site ideal for an international standard marine hatchery. This is a highly recommended site, which should be seriously considered.

Figure 1. Right hand side of Taumeasina Point, Upolu site

Site 6 – Satitoa, Upolu.

The Samoan Slipway Company has reclaimed the land adjacent to this site, which seems to have stifled the natural currents and water flow. It is quite shallow and I believe the bay will slowly gain even more build-up of silt. Even if dredging did occur regularly, intake water to the hatchery would have to be ceased until the sediment had totally settled again and the bay was clear. It is difficult to estimate how long this would take, but it would severely hamper the operation of a hatchery. There would always be concerns of any environmental impact, whether it was by water or air.

This is not a suitable site on which to build a hatchery.

Recommendations

From the six sites on the islands of Upolu and Savaii, the most suitable place to build a marine hatchery and conduct possible future research on the local marine animals is Site 5 – Taumeasina.

If for some reason Site #5 were unavailable, either Site 3 or even 2 at Savaia would be adequate to build the hatchery, but may be limited by available land.

Asau (Site 4) on Savaii has established infrastructure already in place, which could be upgraded and modified to suit, but the distance from Apia is a major concern for staff and transporting live animals to and from it.

I would not recommend Site 1- Mulifanua or Site 6 – Satitoa to build a marine hatchery of any sort.

Facility design

The proposed facility should consist of a seawater intake system that includes optional filtration capabilities, water storage tanks, several raceways and grow-out tanks, a fully outfitted hatchery/aquaria room and accommodate certain quarantine protocols for introduced species. I understand an office, dry laboratory and toilet and shower facilities are also required in the overall grand plan.

Seawater intake system

Two high-density polyethylene pipelines draw seawater in from a deep channel; preferably over 3 m in depth that is continually flushed with fresh, clean, clear and cool seawater. The two pipelines should be secured by concrete weights chained to the pipe in position every 5 m, depending on currents all the way to the two intake pumps. These intake pumps are usually located on land, but as close as possible to the seawater without compromising their protection from the tides etc. Having two pipelines and two intake pumps, one is always redundant which assists with any maintenance or breakdown issues, when the facility is in use.

Filtration

When the seawater is pumped in from the ocean, there are two options: (a) to filter the water using two large sand filters (30-35 µm) and at least two bag filters (5-200 µm) then it is pumped into the storage tanks; or (b) bypass the filters, depending on the quality of incoming seawater, the water could then go directly to the raceway tanks and/or the Hatchery/Aquaria room. This will supply any natural foods in the seawater to the animals, but careful consideration to bypass the filters is required and raw seawater should only be used if the conditions are absolutely right. A solid timber framed roof is needed to reduce the heat from the sun and maintain the integrity of the equipment.

Figure 2. Sand and bag filters

Water Storage

There is a need to hold enough water to service the entire facility, running at full capacity for at least two hours; this should be enough time for the maintenance team to set up an emergency power source or fix any issues with the intake pumping system etc., if it breaks down. The use of polyethylene rainwater tanks is the best option and the bigger the better, as the temperature will remain more stable. Due to Samoa's climate, these tanks will require a solid timber framed portal roof to shade them from the sun to maintain the water at below 30^{o}C.

Figure 3. Covered water storage tanks at the mariculture facility on Nago Island, PNG

Raceways and grow-out tanks

The best raceways to use are the polyethylene fabricated type with dividers in each channel to segment them (Figs 4 & 5). They are made in Australia and unfortunately are very expensive, especially the numbers that will be required to rear clams at this site. There are several alternative

materials such as concrete blocks with polyethylene or fibreglass liners inside to protect the seawater from dissolving the calcium out of the concrete blocks. If a formed concrete model was used, a chemical additive is available to restrict this chemical reaction but if this chemical leaches into the seawater with the animals in it, then it could be fatal to the animals or humans (if the animals are consumed). There are some exceptional paints or membranes that are available on the market that are designed to protect the structures from corrosive or harsh liquids, such as seawater. To handle the large numbers of juvenile clams produced in one spawning, I suggest using six raceways, 10 m long x 1.5 m wide.

Figure 4: Raceway tanks at Nago Island, PNG

Figure 5: Typical raceway tanks in Darwin, Australia

Grow-out tanks are usually polyethylene or fibreglass and should be mounted at an easily accessible height for the hatchery staff or researchers. The raceway should also be at a good workable height, so the user doesn't have to bend over the tank.

This entire area should also be covered by a solid roof structure to restrict the heat from the sun affecting water temperatures and to keep out the rain. The option of using use solid colourbond iron sheets and clear 'laserlite' sheeting alternately will allow high levels of natural light over the tanks. The light levels can produce undesirably high temperatures in the hotter months of the year

so shade cloth can reduce this to the desired amount. I would also suggest the roof height be quite high to allow natural light in, but keep the rain out.

The Hatchery / Aquaria Room

This building could be constructed of concrete block or a timber framed and clad building on a solid concrete slab floor with a 1-2 degree slope towards a central drain for the waste. As noted previously, the concrete floor and about 500 mm up the wall will need to painted or sealed to protect it from the seawater. A freshwater wash-down hose is required inside for washing down. The ceiling height is most important and should be at least 2.7 m high to allow for even temperature and airflow when the room is at full capacity. The ceiling and cladded walls (if chosen) should be insulated to help maintain stable temperatures inside. A solid, double wooden door is needed to allow access of the large-diameter tanks in the room. A domestic split air conditioner is all that is required in this room for temperature control. I don't see the need for any windows in this room, as they serve no purpose. The PVC pipework around the walls that feeds the tanks should be about 2 m off the floor. The power outlets should be slightly above that at about 2.2 meters from the floor too. The ceiling lights should be plastic weatherproof fittings to cope with the environment. Reticulated air shall be accessible from anywhere inside the room. A suggested size for this room is around 7 x 5 m or 6 x 6 m.

Inside the room, it will need a small poly tank (1500 L) that is fed through a float valve from the main seawater system (outside). A small pump will draw the seawater out of this reservoir through two bag filters, one at 5 µm and the other at 1 µm, prior to entering the commercial grade UV-disinfection unit. The sterile seawater will then be piped around the room and available at each 25 mm ball valve, every 1.5 m. A small portion of this sterile seawater will return to the ocean every time the system runs. This will function as a quarantine system too. A small collection sump tank (200 L) will collect most of the water, if it is deemed to be good enough and a submersible pump delivers it back to the reservoir for recirculating again. The room reservoir should receive a full exchange of fresh seawater at least every 24 hours if seawater temperatures outside are suitable. On average of every 6 hours is usually sufficient to take care of most nutrient loads.

Power supply and equipment

The main power distribution board is to supply power from its town source to the entire facility and then feed the office, lab and toilets through circuit breakers. This board would be best mounted on the main building. RCD protection is to be included on all power outlets. This is to ensure the hatchery room is totally separate from any shared circuits. I suggest the use of seven separate power circuits, one for each wall, two pump circuits, one for the air conditioner unit and one light circuit.

Note: Do not use domestic outlets, lights or switches. Only the waterproof, industrial types should be considered.

A sub-mains board (#1) for the seawater system is fed off the main distribution board and this supplies power to the intake pumps, the system pressure pump and general-purpose lighting and power outlets outside. This sub-board shall be positioned undercover and as close as practical to the intake pumps.

I also recommend the use of surge diverters, lightning strike arrestors and earth stakes on each board to help with lightning and power surges from the local power suppliers.

Special notes

- Under NO circumstances should any metal, especially brass or copper be used near, over or in the seawater system.
- All concrete should be sealed or at least treated, if applicable.
- The air conditioner coils (both) should be sprayed with a thin layer of rust inhibitor, such as 'Innox' or 'Tectyl 151' prior to installing and every 12 months to ensure longevity of the copper coils.
- Where the concrete floor meets the walls in the Hatchery/Aquaria room, the concrete should advance up the wall about 500 mm from the floor to ensure the seawater cannot seep under the stud wall or block wall and rot timber or decay the blocks.
- In the hatchery room it is suggested that at least two power outlets be supplied on each wall.
- Concrete pads under the storage tanks are not necessary but it should be considered if funding permits.
- Standardise PVC pipe sizes to 25, 50 and 80 mm pressure pipe, and 50 and 100 mm DWV (non pressure) for return or drains pipelines.
- 100 mm DWV pipe is the preferred size used to send the high volume/low pressure air around the facility. From here, takeoffs are 25 mm low density polyethylene pipes, as used in garden irrigation.
- Inlet pipes to storage or reservoir tanks should be at the top and discharge at the bottom of each tank.
- All plastic ball floats should only be used where required. Such as storage tanks and reservoirs.
- Double union PVC ball valves are used in most positions where isolation is required.
- Fibreglass grate cover on all floor drains.
- 25 mm PVC valves only to raceways and research tanks
- ALLOW FOR FUTURE EXPANSION OF RACEWAYS, TANKS AND HATCHERY ROOMS IN OVERALL LAYOUT DESIGN.

Based on discussions with MAF senior management and with the Taumeasina site in mind, suggestions have been made with respect to the equipment and infrastructure required (Appendix 1). In addition, a preliminary design has been drawn for the hatchery if constructed at the recommended site at Taumeasina (Appendix 2). This design could be easily modified for another site if Taumeasina is not approved,

4. Impacts

4.1 Scientific impacts

There were no scientific impacts from this mini-project.

4.2 Capacity impacts

The marine facility advisor, John Morrison, travelled around the two main islands of Samoa with hatchery staff and involved them in all aspects of his assessment. Senior MAF staff also met with John to discuss how the proposed hatchery facility could meet their future aquaculture needs. This

process was capacity building for staff in terms of learning about factors to be taken into account in site selection and how to mitigate for potential constraints and gaining basic hatchery design skills. Samoa does not currently have a mariculture facility and is constrained in undertaking any culture activities until this situation changes. The site assessment contained strong justification for the preferred site (Taumeasina). Since completion of this mini-project, MAF has submitted a request to cabinet to request that this site (or part of it) be approved for a marine hatchery. The construction of a marine hatchery (at this or another suitable site) in the future, will enhance the capacity of Samoa MAF through providing capability to culture a range of marine organisms and support aquaculture development. It will also provide quarantine capability in line with recommended biosecurity precautions if new varieties or species are to be imported.

4.3 Community impacts

Development of sustainable aquaculture can help provide food security and livelihoods for communities in Samoa. However, there are currently no facilities for the culture and grow-out of suitable edible and commercial species. Although not all aquaculture requires hatchery facilities (e.g. seaweed, wild spat collection), the range of commodities and production scale are enhanced with a hatchery. Samoa has a history of village clam and trochus culture, although production of these species has ceased due to the closure of the previous hatchery. Many communities and villages on Samoa relied upon production from the old hatchery to repopulate their reefs and marine protected areas with these species. This mini-project will assist MAF in their efforts to obtain a suitable site and then seek donor funding for a new hatchery which will be superior to the old one and pave the way for future increases in the scale of production and range of possible local culture species to support community aquaculture projects.

5. Conclusions and Recommendations

The recommended site for a marine hatchery is Taumeasina, which has good physical attributes for the facility. It is also in close proximity to the MAF office in Apia, which makes it convenient for staff access and more cost-effective in the long term. A hatchery design and list of equipment needed has also been provided. This provides a valuable source of information to MAF with which to plan for future aquaculture activities and to base funding applications upon.

6. Acknowledgements

Thanks to officers of the Samoa Ministry of Agriculture and Fisheries for assistance with the site assessments and for valuable help in logistical arrangements for John Morrison's trip.

Appendix 1. Suggested equipment and infrastructure requirements.

Seawater System

Equipment	No. Reqd.	Approx. cost in AUD$ + GST	Local only (SAT)
Amiad 63mm Poly Footvalves	2	A$75 each	
63mm PN6.3 Polyethylene Pipelines x 100m	2	A$520 each	
63mm Polyethylene Comp. Fittings – (2 x joiners, 4 x flange joints)		A$28 each & A$64 each	
25mm, 50mm, 80mm PVC pipes & fittings	Approx. only	A$1500	
25mm PVC Dble union valves	20*	A$40 each	
50mm PVC Dble union valves	20*	A$80 each	
Davey PM 450 or OngaSeabass22 Intake Pumps (single phase)	2	A$1200 each	
Waterco Multi-cyclone filter	2	A$490 each	
Large Davey F32 or Onga P233 Sandfilters	2	A$1490 each	
Waterco C75 Bag Filters	2	A$750 each	
Poly storage tanks to hold at least 60,000 L – 6 x 10,000 l or 3 x 20,000 l or 2 x 30,000 l		>	$10000.00 **
Davey PM 250 or OngaSeabass 9 pump - plus spare	1 + 1	A$840 each	
Raceways (10 x 1.5 m) – depending on construction material used	6	>	$10000.00 **
Round tanks (1000 L)- Could use existing tanks	3	>	$1215ea **
More water tanks			
Sub total		A$14,794	SAT$21,215

* Estimated number only ** Local supply only

Hatchery/Aquaria Room

Equipment	No. Reqd.	Approx. cost in AUD$	
Small reservoir tank (1500 L)	1	>	SAT$2865**
Davey PM250 or OngaSeabass 7 pump – plus spare	1 + 1	A$800 each	
Waterco C50 Bag filters	2	A$700 each	
Waterco C50 & C75 filter bags	20	A$18 each	
Commercial grade UV sterilizer – plus spare tube and quartz sleeve	1	A$3800	
Small collection sump (200 - 300 L)	1	A$380	
25mm, 50mm,80mm PVC pipes & fittings	Approx. only	A$3000	
Tsurumi TM Series submersible pump c/w float switch – plus spare	1 + 1	A$1830 each	
Small facility air blower – plus spare	1 + 1	A$800 each	
Float valves, tank level indicators, flow switches, pressure gauges, F30 press. sw	Approx. only	A$1500	
Estimated electrical equipment	Approx. only	A$5000	

Total for Samoan supplied equipment		SAT$24,080 (**)
Total for Australian supplied equipment	A$37,094	= SAT$88,642
Estimated Total in Samoan Tala		**SAT$112,722**

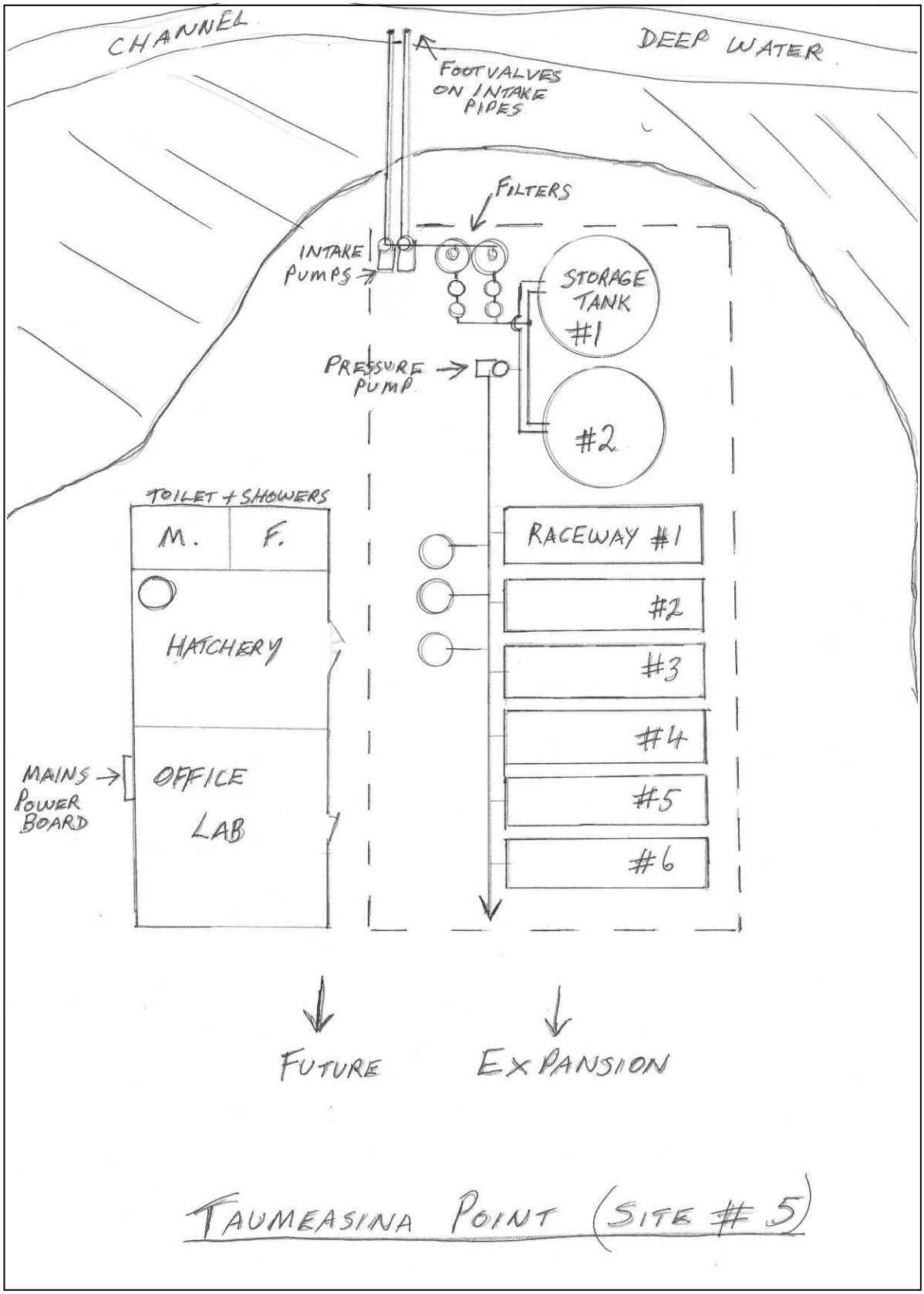
Buildings and Roofed Areas

Designated Area	Material	Cost
Portal roofing over seawater intake pumps and storage tanks	Timber frame and colourbond roofing	SAT$
Portal roofing over raceways and open tanks	Timber frame with clear laserlite and colourbond roofing	SAT$
Hatchery room, Office/Lab & toilet/shower	Concrete block with colourbond roofing	SAT$

Estimated total cost to build infrastructure	**SAT$??**

Note: MAF final design will determine the amounts above!

Appendix 2. Proposed hatchery design for Taumeasina (Site 5).



Kiribati

(Appendix 2.23)

Appendix 2.23

MS0904

Survival and growth of hatchery produced white teatfish (*Holothuria fuscogilva*) juveniles in the wild, Kiribati

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU JAMES COOK UNIVERSITY WorldFish CENTER USP THE UNIVERSITY OF THE SOUTH PACIFIC	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Growth and survival of hatchery produced white teatfish (*Holothuria fuscogilva*) juveniles in the wild (MS0904)**
Goal:	Investigate the growth and survival of hatchery produced white teatfish juveniles released in the wild in a variety of microhabitats
Objective(s):	Specific objectives are to: 1) Investigate survival and growth in different inshore marine habitats; 2) Trial pond culture; and 3) Build capacity of Kiribati aquaculture officers.
Project location:	Tarawa and Abaiang, Republic of Kiribati
Project partner(s):	Kiribati MFMRD
Dates / duration:	Eight months (Dec 2009 to July 2010)
Project description:	Kiribati Fisheries have released many thousands of juvenile white teatfish produced under their successful culture program. However, very few large individuals have been recovered from these releases and the commercial fishery has not shown any signs of recovery. Research into the best release methods to ensure optimum survival and growth of the hatchery produced juveniles is needed. An earlier mini-project found that dark coloured surfaces such as hard reef substrata with epilithic algae, and certain sea grass, may allow the juvenile phase to be camouflaged and provide protection from predation. These habitats may be more suitable than sand or coral rubble for releasing juveniles for restocking. Ponds may also be a suitable (and safer) place for grow-out. The mini-project will conduct a release experiment in Abaiang, Kiribati using 500 juveniles (approx 5 cm length) that are currently being held at Tarawa hatchery.
Justification:	Kiribati Fisheries has invested considerably in hatchery techniques and is the only PICT to successfully culture this sea cucumber species. In order to realise the full benefits of this initiative, research is urgently needed to develop an effective release strategy for hatchery produced white teatfish.
Expected outcomes:	(1) Improved knowledge of best marine habitat for survival and growth of white teatfish juveniles; (2) Test of whether old fish ponds are suitable for grow-out of white teatfish juveniles; and (3) Improved capacity of Kiribati aquaculture officers in release strategies and monitoring of released white teatfish.
Funding:	$15,200

Growth and survival of hatchery produced white teatfish (*Holothuria fuscogilva*) juveniles in the wild

Antoine Teitelbaum[1] and Karibanang Aram[2]

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[2] Ministry of Fisheries and Marine Resources Development, Tarawa, Kiribati

1. Background:

The Kiribati Beche-de-mer Project was initiated in the mid 1990's as a result of concern over the overfishing of the commercial sea cucumber species, white teatfish (*Holothuria fuscogilva*). Hatchery production of white teatfish was initiated through the Japanese Overseas Fisheries Cooperative Foundation (OFCF) and the Government of Kiribati. From 1997 to 1998 several hatchery runs produced approximately 8000 juveniles but the joint project concluded in 1999. Since then, the Government of Kiribati, through the Fisheries Division, has been maintaining production at the beche-de-mer hatchery and have released approximately 20,000 white teat juveniles into the lagoon. However, the releases and monitoring has not yet provided good estimates of post-release survival of white teat juveniles. The juveniles are highly cryptic and rarely seen. Most of the released juveniles appear 'lost' and are never found during the monitoring period. Moreover, individuals found in surveys cannot be equivocally distinguished from wild stock. The economic and practical feasibility of restocking, in terms of number of surviving adults versus the cost of hatchery-production, is questionable unless effective release and monitoring strategies are developed.

A previous mini-project on cultured white teatfish juvenile release was conducted in 2005. Knowledge gained from ACIAR-WorldFish studies in New Caledonia that developed optimum release methods for juvenile sandfish (*Holothuria scabra*) was utilised to develop suitable protocols for white teatfish. Unfortunately, no juveniles were available for release to test the proposed techniques. Until now there were no juvenile white teatfish to continue the study but in late 2009, a successful spawning produced 200 juveniles (approx. 4 cm length) with which to run a small-scale release trial (Fig. 1).

Figure 1. Juvenile hatchery-produced white teatfish (*H. fuscogilva*)

Although the original proposal aimed to grow sandfish out in un-used fish ponds, there were insufficient juveniles available when the study commenced. This objective was dropped and the mini-project had the following two objectives:

1) Investigate survival and growth of hatchery produced white teatfish juveniles in different inshore marine habitats; and
2) Build capacity of Kiribati aquaculture officers in release strategies and monitoring of released hatchery-produced white teatfish juveniles.

2. Project Methodology

Because there were only small numbers of juveniles for the trial, and because keeping track of those released in the past has been unsuccessful, the juveniles were caged so that they could not escape from the release area. Cages were constructed of locally available wire mesh and shadecloth (Fig. 2).

Figure 2. A cage constructed in sandy-silty habitat in North Tarawa.

Knowledge gained from the previous study indicated that dark coloured surfaces such as hard reef substrata with epilithic algae, and certain sea grass, may camouflage the juvenile phase of white teatfish and provide protection from predation. Several characteristic habitats within the lagoons of Kiribati were tested in the trial: (1) seagrass beds (Abaiang); (2) hard substratum (Abaiang); and (3) sandy-silty substrata near mangroves (North Tarawa). Two cages (1.5x1.5 m area, 1 m high) were deployed in each habitat.

Before transport to the release sites, juvenile white teatfish length was measured to the nearest mm. The juveniles were transported from the hatchery to the release sites in plastic bags with oxygen and carefully released into their new habitats. Fisheries officers placed

30-35 juvenile sea cucumbers in each cage. They were released at North Tarawa and at Abaiang on January 15 and 17, respectively.

3. Results

3.1 Post release observations

Sizes of juveniles placed in the three habitats are shown in Table 1. The largest juvenile released was 51 mm and the smallest was 8 mm.

Table 1. Number, mean length (mm, ±se) and length range of juveniles released in each habitat type.

Habitat	Number		Mean length (mm) ±se		Length range (mm)	
	Cage 1	Cage 2	Cage 1	Cage 2	Cage 1	Cage 2
Sand/silt	35	35	29 ± 1	27 ± 1	16 - 50	14 - 48
Rubble	35	35	27 ± 1	28 ± 1	12 - 44	14 - 45
Seagrass	31	30	24 ± 2	21 ± 2	11 - 51	8 - 51

No mortality of juveniles occurred during or following transport. The sea cucumbers were observed in the sea pens on the days following their release. They were observed excreting sand only a few hours after being placed in cages in each habitat. This may be evidence of feeding since they are thought to have voided their guts prior to release.

The following observations were made in each habitat in the days immediately following release:

Sandy silty substratum – The released animals were observed a few days after release to have travelled around the cage, staying mainly in the corners or along the walls in areas where some shelter was offered. Smaller individuals climbed the pen wall and escaped, some also escaped under the pen wall where other fauna (worms, etc) had created holes. None were observed to bury in the sediment (Fig. 3). This habitat had lots of shellfish and other benthic fauna that may have adversely affected the juvenile white teatfish. One cage was constructed near mangroves in an area with low water flow and the other in a high-flow area.

Figure 3. Juvenile released into the sandy/silt substratum cage.

Hard rubble substratum – On the day following release, the sea cucumbers placed in the hard substrata environment had covered themselves with pieces of coarse sand and small rubble (Fig. 4). They were observed to group together, this being the only habitat where this behaviour was observed.

Figure 4. Juveniles recently released into the rubble substratum cage (left) and 24 hours later, covered with coarse sand and rubble (right).

Seagrass habitat – The day after release (Fig. 5), no small individuals were observed (either dead, escaped or hidden in the seagrass), but larger animals were found due to the presence of sandy excreta nearby. Counting was difficult due to the turbid water that is characteristic of this biotope if disturbed.

Figure 5. A juvenile being released into a seagrass habitat cage

3.2 Juvenile monitoring

Storm conditions and rough seas destroyed the Abaiang cages (seagrass and rubble substrata habitats) on January 25th, a week after deployment and the trial was concluded.

In the sandy-silty habitat at North Tarawa, bad weather did not affect cages. The two cages were checked on Jan 26 and again on Feb 23 (10 and 37 days post release). On Day 10, one cage still had 15 juveniles inside (mean length of 34±3.4 mm, min. 11 mm, max. 50 mm) and the other cage had six juveniles (mean length of 37±4.6 mm, min. 22 mm, max. 51 mm). Although the mean juvenile length had increased in both cages, the maximum and minimum lengths indicate that the survivors were in the same length range that was released, and we cannot assume they grew in that period. Highest mortality occurred in the cage in the low-flow area. Juveniles were observed climbing the cage walls on Day 10 and it

was assumed some had escaped. A mesh lid was attached to the cage to prevent further loss. A dead juvenile, cut into two pieces, was also observed and believed to have been attacked by a crab or other predator.

When officers checked the cages on Day 37, no juveniles were observed and the trial was concluded.

4. Impacts

4.1 Scientific

This mini-project had potential to provide important insights into release strategies for a high-value sea cucumber species that is not cultured elsewhere in the Pacific. This species is very cryptic as a juvenile and little is known about it. If monitoring had been successful, valuable scientific information would have been generated.

4.2 Capacity impact

The capacity building objective was achieved. Kiribati MFRMD officers gained skills in transport methods for juvenile sea cucumbers, release strategies, pen construction, experimental design and monitoring of released juvenile sea cucumbers.

4.3 Community impact

The project, if successful may have benefited communities by identifying ways to improve the success of release programs for white teatfish, a high-value holothurian. White teatfish are a source of income for many fishers in Kiribati. It would also have enhanced a priority research commitment of the Government of Kiribati, significantly building on a decade of research into this species.

5. Conclusions and recommendations

Although the project did not achieve its primary objective, there were lessons learned. The MFRMD staff gained valuable skills in setting up this trial and will be able to replicate the study when juveniles become available again. MFRMD is organising further spawning of white teatfish in order to resume release trials in the future. A major constraint, however, is the difficulty of obtaining white teat fish broodstock due to over-exploitation of this high-value species throughout the Kiribati atolls.

Despite the juveniles only being observed for a few days, some potentially useful (albeit speculative) information can be gleaned from the results. The initial response of the animals in the silt and seagrass habitat indicated that they do not readily bury in soft substrata. In the sandy habitat, very little shelter was available and they aggregated in the corners of the cage. This suggests they may prefer a microhabitat with some shelter. Juveniles released in the rubble habitat did not move to the edges of the cage but used pieces of rubble as camouflage.

The following recommendations could be made for future research into release habitat:

- Stronger cages which are built so as to prevent escape should be used in sea trials.
- Studies must be carried out when bad weather is less likely.

- Monitoring must be carried out at more regular intervals (weekly at least and daily for the initial period after release) in order to observe juvenile behaviour and collect data.
- The same habitats could be used in a repeat of the trial, but taking into account what has been learned from this trial. For example, a microhabitat with crevices for the animals to hide under appears to be desirable since burying does not seem to be an option. The difficulty of penning off such an area might be overcome by providing artificial habitat such as bricks with holes in them and large pieces of dead coral (cleared of predators such as crabs). Seagrass habitat should be tested again as Reichenbach (1999) found smaller white teatfish (<450 g) almost exclusively in seagrass habitat and larger individuals on the lagoon floor in the Maldives.
- Studies of preferred release habitat could also be done in tanks in order to determine juvenile white teatfish response to a variety of shelters.
- The size of the released juveniles was quite small, the average was less than 3 cm and many were less than 1 cm long. Smaller individuals were observed to climb more readily than the larger ones. For future studies, it would be preferable for the animals to reach a larger size at the hatchery or in some other controlled environment before release.

6 References

Reichenbach, N. (1999). Ecology and Fishery Biology of *Holothuria fuscogilva* in the Maldives, Indian Ocean (Echinodermata: Holothuroidea). Bull. Mar. Sci. 64:103-113.

7. Acknowledgements

We wish to thank Aranteiti Tekiau and Tarabwati who assisted greatly with the field work. Also Cathy Hair who assisted with preparation of the report

Australia

(Appendixes 2.24 to 2.26)

Appendix 2.24

MS0906

Development of sandfish sea ranching ACIAR project, Goulburn Island, Australia

ACIAR Pacific Aquaculture Grant: **Project Summary**		**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**
Project Title:	**Development of sandfish sea ranching ACIAR project, Goulburn Island (MS0906)**	
Goal:	To provide assistance to develop a larger ACIAR Project for an Indigenous sandfish (*Holothuria scabra*) sea ranching project	
Objective(s):	The project will achieve this goal through the following objectives: 1. Participate in meetings and carry out liaison with prospective Northern Territory collaborators (Tasmanian Seafoods, Northern Territory Fisheries, Warruwi community); and 2. Develop a variation document to restart the ACIAR-WorldFish activity in NT.	
Project location:	Goulburn Island (Australia)	
Project partner(s):	Tasmanian Seafoods P/L, Northern Territory Fisheries, Warruwi community, The WorldFish Center	
Dates / duration:	One year, 2009	
Project description:	This mini-project will provide focused, short-term support to facilitate the recommencement of an earlier ACIAR project.	
Justification:	ACIAR are keen to provide input into Indigenous aquaculture projects and had put substantial effort into an earlier attempt at this project. Part of Ms Cathy Hair's role in FIS 2006/138 was as coordinator of the project for the NT node of the ACIAR-WorldFish sea ranching project.	
Expected outcomes:	1. Development of a new project 2. Liaison with all parties to ensure success of new project 3. Go between for different parties in NT and Philippines (WFC)	
Funding:	**$2,500**	

Development of sandfish sea ranching ACIAR project, Goulburn Island

Cathy Hair
James Cook University, Townsville, Australia

1. Background:

Sandfish (known as trepang in NT) was first exported from northern Australia in the mid 1700's by the Macassans and is presently the main sea cucumber species fished in NT. Aboriginal communities do not exploit the resource for commercial or subsistence purposes, and all six NT commercial sea cucumber fishing licenses are held by Tasmanian Seafoods Pty Ltd (TSPL), a diverse Australian seafood production and processing company with interests in sea cucumber fishing and processing. The potential for sea ranching of sandfish (*Holothuria scabra*) to generate income for coastal communities led to the WorldFish Center ACIAR project FIS/2003/059 Sea ranching and restocking of sandfish (*Holothuria scabra*) in Asia-Pacific. The project has been running in the Philippines since July 2007 and a mid project review was held recently in May 2009. It was recommended that ACIAR continue the project for the next 2.5 years. The original project concept included an Australian component, conceived as a joint venture between the ACIAR-WorldFish Center project and the Warruwi Community Inc (WCI), and TSPL.

Under the previous agreed arrangements, Ms. Cathy Hair was designated as co-ordinator of the NT node of the project. Funding for the Australian node was sought from the Aboriginal Benefit Account (ABA), which provides grants or loans for the benefit of NT Aboriginals. However, funding from ABA did not eventuate, and this component of the project was dropped.

Through this mini-project intervention, however, efforts to develop an Australian sea ranching node were rejuvenated, a new partner (Northern Territory Fisheries) was brought into the project and an ACIAR Variation contract drawn up and signed off to reinsert this component back into the over-arching ACIAR-WorldFish sea ranching project.

2. Project Methodolgy

2.1 Travel and meetings

Ms Hair carried out three trips to Northern Territory to achieve the objectives of the mini-project:

1. Travel to Darwin from 8-10 June, 2009 for a initial meeting with potential stakeholders and to scope out potential for a renewal of the project proposal.
2. Travel to Darwin from 3-5 August, 2009 for a more formal meeting with stakeholders (i.e. Tasmanian Seafoods, Northern Territory Fisheries Department aquaculture staff), and Mr Barney Smith, ACIAR Fisheries Program Leader. The purpose of this meeting was to discuss the various roles of the groups involved and confirm commitments from stakeholders. Meeting minutes are provided in Appendix 1.
3. Travel to Darwin and Goulburn Island 19-23 October, 2009 to meet with Warruwi community members and collect *H. scabra* broodstock in anticipation of spawning activity in the 2009/2010 summer season. There is sufficient time for a single spawning season and sea ranching release, so time is of the essence to get the funding approved for this research project.

2.2 Broodstock Collection

Travel to Goulburn Island is expensive, the third trip used a charter aircraft to travel to Goulburn Island, so maximum value was gained from this trip. In addition to site inspection and discussion with Tradtional Land Owners (TLOs), about 90 broodstock were collected. Permission was sought from Warruwi TLOs before taking any broodstock from the island. Ms Hair, NTF aquaculture staff and a Warruwi sea ranger, walked around the seagrass release area at low tide and picked up the largest individuals they could find. Due to weight and other practical restrictions, the sandfish could not be transported in water but were wrapped in wet cloth, packed in foam eskies (Fig. 1) and flown back to Darwin within 4 hours of collection.

Figure 1. Broodstock collection in Mardlark Bay, South Goulburn Island. Collection of large sandfish individuals from shallow seagrass meadows (left) and packing of sandfish in wet cloth in eskies.

3. Outcomes

The liaison activities carried out by Ms Hair succeeded in the project development and she prepared an ACIAR project variation document that was approved for funding (Appendix 2). Although at a reduced budget and effort than the original 2006 proposal, it still allows a “proof of concept” study to be undertaken to establish the feasibility of sea ranching of sandfish in an Indigenous community in Australia. Funding is expected to be available in early 2010.

The sandfish broodstock that were collected during this phase of the project will be spawned and juveniles reared to be released in a suitable area (yet to be chosen). The broodstock are to be held at the TSPL farm for future spawning and juvenile production if necessary.

4. Impacts

4.1 Scientific impacts

There were no scientific impacts from this mini-project. However, future studies to be carried out in the large ACIAR-WorldFish project have potential for scientific impacts. Unlike other areas in Asia where overfishing has occurred, there are still stocks of sandfish found in the areas where releases will take place. This provides an opportunity to investigate the effects of enhancing existing fisheries with hatchery produced juveniles.

4.2 Capacity impacts

The larger ACIAR-WorldFish project has potential to increase capacity in an Indigenous community and in the State Fisheries agency of Northern Territory, Australia. Sea rangers of the Warruwi community will help to design and install pens for sandfish monitoring. They will assist project scientists in releasing juvenile sandfish, then collecting data on growth, survival and movement during the sea ranching trial. Additional hatchery training will be provided to the following Australian counterparts: Cathy Hair (JCU DABL); a hatchery technician from the private sector partner, Tasmanian Seafoods; and a hatchery technician from the NT government Darwin Aquaculture Centre.

4.3 Community impacts

The remoteness of many Aboriginal communities means that development and employment opportunities are few. Sea ranching of sandfish suits their traditional extensive approach to resource use, and they live adjacent to suitable habitats. MS0906 'Development of sandfish sea ranching ACIAR project, Goulburn Island' succeeded in obtaining funding for a "proof of concept" study to be undertaken to establish the feasibility of sea ranching of sandfish in an Indigenous community in Australia (as part of the larger WorldFish Center Asia-Pacific sandfish project FIS 2003/059). If shown to be economically and socially feasible, sea ranching of sandfish can be expected to provide communities with a modest but sustainable income stream and, more importantly, employment for a number of community members.

There is growing pressure for increased involvement of Aboriginal communities in the fishing industry and management of inshore marine resources. The larger ACIAR project resulting from MS0906 'Development of sandfish sea ranching ACIAR project, Goulburn Island' could lead to increased participation of Aboriginal community in management of their trepang resource. Consequent social benefits might arise from community empowerment, local job creation and training opportunities.

5. Conclusions and Recommendations

The research work will commence in early 2010 and be completed by October 2011 (i.e. conclusion of both FIS 2003/059 and FIS 2006/038. Results will be reported to ACIAR via reporting mechanisms of FIS/2003/059. Summary of the results will also be presented in FIS/2006/038 as 25% of Ms Hair's time on this project is allocated to co-ordinating the NT sea ranching node.

6. Acknowledgements

We wish to acknowledge the assistance provided by Graham Williams, Ann Fleming and Evan Needham of Darwin Aquaculture Centre (Northern Territory Fisheries Department), Will Bowman and Grant Leeworthy (Tasmanian Seafoods P/L), Barney Smith (ACIAR) and Warruwi community members.

Appendix 2.25

MS1004

Transfer of Pacific experience to Indigenous Australian sustainable aquaculture: sponge culture, from FSM to Torres Strait, Queensland

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU James Cook University WorldFish Center USP The University of the South Pacific	**SECRETARIAT OF THE PACIFIC COMMUNITY** **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**

Project Title:	**Transfer of Pacific experience to Indigenous Australian sustainable aquaculture: Sponge culture, from Pohnpei to Torres Strait (MS1004)**
Goal:	Assist a fledgling Australian Indigenous aquaculture operation by exposing them to a similar Pacific operation.
Objective(s):	Specific objectives are to: 1) Facilitate a one-week hands-on training trip to a Pohnpei sponge farm for staff of the Kailag sponge farm (Yorke Island); 2) Build capacity of Kailag sponge farm personnel.
Project location:	Pohnpei, Federated States of Micronesia
Project partner(s):	Kailag Enterprises, Pohnpei sponge farm association
Dates / duration:	8 days, Aug-Sept 2010.
Project description	Much of the research undertaken through ACIAR Project FIS 2006/038 is also of relevance to Australia. The physical and social context to the development of indigenous Australian aquaculture has much in common with the Pacific Islands, particularly with respect to initiatives involving small communities located in remote, tropical areas. Sponge culture has been established in Pohnpei, Federated States of Micronesia. Experience and knowledge from established sponge farms would be invaluable to a recently commenced Indigenous operation in Torres Strait. This mini-project study tour will provide an opportunity for company staff to experience first hand how the sponge culture industry operates in FSM and establish a relationship between similar enterprises in Australia and Pacific Islands.
Justification	A major goal of ACIAR Project FIS 2006/038 is to provide technical support for Indigenous Australian aquaculture ventures. This is very difficult as it takes a long time to get ventures started in Australia due to stringent approval processes. This intervention will increase the chances of success of an Indigenous venture by providing training in farm techniques, processing and marketing.
Expected outcomes	(1) Increased capacity of Indigenous aquaculture operators. (2) Improved chance of success for an Indigenous aquaculture activity.
Funding:	$9,500

Transfer of Pacific experience to Indigenous Australian sustainable aquaculture: Sponge culture, from Pohnpei to Torres Strait

Chris Robertson and Samson Lowatta
Kailag Enterprises Limited

1. Background:

A goal of ACIAR Project FIS 2006/038 is to provide technical support for Indigenous Australian aquaculture ventures. Much of the research undertaken through ACIAR Project FIS 2006/038 is also of relevance to Australia. The physical and social context to the development of indigenous Australian aquaculture has much in common with the Pacific Islands, particularly with respect to initiatives involving small communities located in remote, tropical areas. Sponge farming is well established in Pohnpei, Federated States of Micronesia (FSM). In Australia, the first commercial sponge farm has been initiated at Masig (or Yorke) Island in the Torres Strait, north Queensland. It is a ten hectare farm operated by Kailag Enterprises Ltd (KEL), an Indigenous not-for-profit company based at Yorke Island (also known as Masig Island). Both the Kailag and FSM farms produce *Coscinoderma mathewsi* for the bath and beauty products market.

The mini-project provided an opportunity for two Kailag Enterprises personnel to travel to Kolonia in Pohnpei (FSM), and spend one week undergoing training in aspects of sponge farming and export quality sponge production. In particular, the on-farm training focussed on the Kailag personnel experiencing FSM sponge farming methods, processing methods and marketing.

The objectives of the mini-project were to:
1) Facilitate a one-week hands-on training trip to a Pohnpei sponge farm for staff of the Kailag sponge farm;
2) Build capacity of Kailag sponge farm personnel.

2. Project Methodolgy

2.1 Summary of Events and Visits

The following meetings and field trips were carried out by the KEL personnel (Chris Robertson and Samson Lowatta) during the one-week trip from 29th August to 6th September 2010.

1. Meeting with Simon Ellis, Director, The Marine and Environmental Research Institute of Pohpei (MERIP)
2. Visit to MERIP sponge farm near Mwand Island
3. Diving trip near Parem Island with MERIP staff to collect wild sponge for stocking on farms
4. Dinner meeting with Dr Hiro Ito and visit to his pearl hatchery near Nett Point
5. Visit to Waldren's farm to cut up and stock sponges
6. Visit to MERIP

3. Outcomes

3.1. Visit to the MERIP sponge farm

The Marine and Environmental Research Institute of Pohpei (MERIP) is a Non Government organisation (NGO) that assists individuals and communities in fisheries, environmental management and aquaculture management. They assist sponge farmers in the region with farm establishment, stocking and marketing of products, and they operate a few farms of their own as demonstration farms. We visited the sponge farm near Mwand Island by boat with Waldren Lohn;

he works for MERIP in coordinating the 20 sponge farmers, as well as operating his own farm. We spent more than an hour snorkelling around the farm to inspect the sponges.

It is arranged as an array of string lines hung across two or more ropes attached to a reef and strained across a small reef cove (Fig. 1). Individual sponges are attached on a loop of nylon string about 10 inches long, and spaced about 18" apart. The string lines hang down to 4-5m deep and some submerged floats are used to keep it central to that depth in the middle.

Figure 1. Sponges stocked on string loops attached to ropelines

The site is a small reef cove approximately 30 m across in a reef system along the edge of Mwand Island. These cove formations are very common part of the reefs around Pohnpei, where the reef edge is convoluted and drops away to deep between the outcrops. There appeared to be no current and very little wind at the site; Waldren said that this was typical and why they had chosen it. The farm design was based on the techniques developed by Dick Crofts, an American scientist who had lived in Pohnpei for many years until he passed away about 2005.

The farm has around 3000 sponges stocked, in an area of 30m x 20m. The string array is one layer with no other layers below it even though there is plenty of room for more sponges. They have proven that some sites are better than others – the well protected but clean reef sites get better growth rates than other sites closer to the main island where runoff and siltation can slow growth or even kill sponges. It is very apparent that this variety of *C. matthewsii* grows well in calm conditions, it does not need a regular current and water exchange for optimum growth. Even though the actual growth rates of Pohnpei sponges may be lower than the same species at Yorke Island, the consistent growth and ease of farming sponges in Pohnpei is dramatically different to the Kailag farming system.

When they want to work on the sponge lines (stocking, cleaning, harvesting etc) they can simply pull up the string lines with a big float and rope that brings the stringlines virtually to the surface, allowing easy access to the sponges by snorkelling (Fig. 2). All of the work on the sponge farm is conducted by snorkelling, by using the string array design and by virtue of the very calm conditions, making the work effort easy and safe. Some sponges have died or dropped off the line because of the line shaking, some have died from the initial cutting. Some algae fouling occurs on the string line but rarely on the actual sponges (Fig. 3). Waldren said that he has to clean them by hand sometimes (every few months) to minimise the fouling on sponge growth. However it does not appear to be a problem, some fish were observed grazing on the growth occurring on sponges and strings. A hard *Acropra* coral is also growing on the sponge ropes in small clumps (Fig. 4).

MERIP are also growing *Spongia matamata* (Fig. 5) which is a soft and small sponge, very easy to grow into a small rounded sponge that will suit the market for makeup applicators and remover. It is easy to clean – just squeeze it a few times and allow it to be dried. Simon's partner has been using one for 6 months to apply and remove her makeup and it is still working well even though it is a delicate sponge. It is a smaller sponge on the reef; they can only get 4-5 explants per cutting.

Figure 2. Sponge lines covered with algae

Figure 3. Big floats to lift up the sponge lines

Figure 4. Coral growing on ropelines

Figure 5. *Spongia matamata* on the reef

3.2. Diving Trip to collect wild sponges

We travelled to a reef area near Parim Island to dive with MERIP staff and collect wild sponge cuttings for stocking on a farm. The site was a flat reef area in 10-20 m depth with very little current, visibility was about 20 m. The sponges observed were mostly *C. matthewsii* as well as *S. matamata*, and some had been cut a few years previously. The *C. matthewsii* sponges were huge in comparison to the same species at Yorke Island, with some being 60 cm in diameter.

The divers cut off a portion approximately two thirds of the sponge (Fig. 6) and inserted a string through it to transport back to the boat (Fig. 7). The two divers collected approximately 30 sponges each on each dive which filled two large eskies in the boat. Other sponges were dumped on a reef flat and stored until they could be transported to a farm.

Figure 6. Waldren Lohn cutting a wild *C. matthewsii*

Figure 7. Transporting the cut sponges on strings

The large size sponges and relative ease of collection on the reef is a significant difference with our situation in Torres Strait (Fig. 8). The sponges collected around Yorke Island are around 25% of the size of the Pohnpei sponges, and they are often well dispersed and difficult to find on a collection dive. There is no permit system or approval for collection of wild sponges in Pohnpei, the sustainable management of collecting stock for farming is self-imposed by MERIP and presumably is effective given what appears to be a very abundant resource around the local reefs

Figure 8. Samson Lowatta with a large Pohnpei sponge

3.3. Masahiro Ito and the Pohnpei pearl oyster hatchery

Dr Hiro Ito is the Director of Aquaculture Development, College of Micronesia Land Grant Program, based in Pohnpei. His role assists communities around all of Micronesia in establishing and managing aquaculture enterprises. We met with him over dinner and visited the hatchery briefly. He wanted to ask us about the proposed pearling venture with Okinawa in Torres Straits, and actually had a lot to say about the Japanese company and the proposal. His hatchery is now producing sea cucumber, black pearl and rabbit fish for stocking in aquaculture.

Ryuku Pearl is a large and respected Japanese pearl company, with a long history in Japanese pearling industry. It was the first company to use hatchery spat in Japan. They now buy spat from another operator, as well as use their own hatchery. They have several pearl farms, a hatchery and several retail outlets. The Ryuku pearl brand is well known and respected as good quality.

In recent years there has been a problem for black pearl farming in Japan from mortalities caused by temperature drops in winter. Sudden and or sustained lower temperatures in the coastal waters have killed oysters and it is apparent the company wants to continue in its production of black pearls by trying a new area for black pearl, as well as diversify their silver lip pearl production.

All of the big pearl producers around the world now try for individuality in marketing, by adopting a 'brand' with a colour and lustre reputation. Western Australia has the big silver pearl, French Polynesia has dark black pearl, Tahiti has coffee colour, Micronesia now has the 'blue' pearl – Ryuku may be seeking a new brand with its move into Torres Straits.

He thinks it is a better strategy to start a pearl farming business with half pearl (mabe), and to get a hatchery going early in the venture so you can afford to have plenty of reared shell to practice seeding on, and to kill whole stock lines to harvest mabe. He thinks a bigger wider shell is heavier and assumed to grow big round pearl, whereas a thinner shell is not as good for round pearl. It would be wise to seek agreement with Ryuku for the Torres Strait islanders to receive technician training as well as farm training, to ensure they get a more lasting career opportunity.

3.4. Waldron's Sponge Farm

We visited Waldrens sponge farm which is close to his house on an island near Mwand Island and is set up in a reef cove similar to all the other farms. He grows sponges for approx. 2 years from cuttings to fatten and 'round' them. They do not appear to grow quickly as compared to the growth rates of 200% p.a. in Torres Strait. Cuttings from the wild sponges are approximately 500 cc when stocked on the farm (8x8x8 cm) and are usually harvested when they are nicely rounded at around 3-5 inches on 3 sides (9x9x8 cm, equates to approximately 650 cc) after 2 years. He has two large sponges left on the lines after 10 years of growth, and they are around 35 cm in diameter (14 inches diameter, 1300 cc in volume, basketball size), indicating that the annual growth rate is slow (may slow down as the sponges reach a larger size).

Waldren completed a lot of work many years ago with Dick Croft (his step father) on stock selection to test if sponge shape, growth rate etc can be selected from wild stock, with no definitive result. All the sponges seem to grow in an unpredictable way, and he has no way to select stock for better growth or shape. He gets some algae fouling on the string lines but it isn't a serious problem, it doesn't seem to grow on the sponges and he just cleans it off now and then. It has no effect on sponge growth. The older lines are changed every few years because they get overgrown with a small white ascidian.

He grows *Spongia matamata* as well on the same lines – it grows quickly and 'rounds up' in 9 months to a 5-8 cm diameter size that will suit the makeup applicator market. It is apparent that this species of sponge will enable the sponge farmers to diversify their product line. A white 'fungus'

(may be a soft ascidian, Fig. 9) that grows over sponges on the lines can eventually cause mortality, it occurs on only a few sponges and he removes it sometimes but has found that it doesn't stop the sponge dying. It is not a spreading disease and has minor impact on his production.

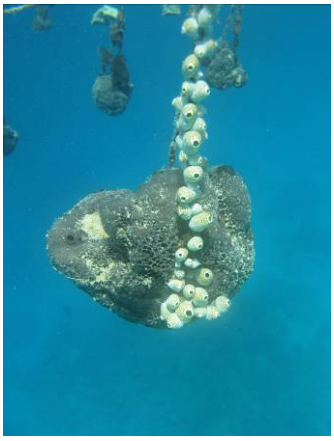

Figure 9. White ascidian growing on sponges

Figure 10. Samson Lowatta attaching sponges on stringlines

We helped Waldren stock some new sponges on his farm by assisting him in cutting the wild sponge, inserting strings through the sponge, and stocking them on the rope lines (Fig. 10). We completed all the work on snorkel in the shallows of the reef next to the farm site, and it took 3 people around 3 hours to stock 700 sponges. Stocking 1,000 sponges per day does not appear too difficult for a sponge farmer if he has a few helpers. The striking feature that we observed about his farm was how sheltered it was, with very little current or wind compared to Torres Strait, and that it was so close and accessible to his house.

3.5. The Marine and Environmental Research Institute of Pohpei

We visited the MERIP Research Station on the southern end of the island and inspected the giant clams, juvenile fish and corals they are rearing for the aquarium trade. They also sort and process sponges harvested from the various farms, and distribute them to buyers from the station.

1. Sponges are selected and graded for shape, texture, and size. Some sponges can be too soft in texture and are rejected because they have no 'body' as a sponge.
2. Many of the sponges have natural holes in them as part of their anatomy for internal water flow. Sponges with small holes are not rejected, while those with large gap holes are either cut in two or rejected.
3. Similar to harvesting of deformed shaped sponges at KEL, they find it difficult to identify live sponges that are rounded but still have large gap holes internally – the tissues cover it up.

Processing

They do not use any chemicals in processing – they clean harvested sponges by leaving them in a tidal cage for two weeks and then simply wash them 2-3 times in a domestic washing machine. Harvested sponges are taken to a tidal cage near the mangroves, and are checked regularly after two weeks. They are collected if they spring back out after being squeezed, indicating that all of the internal dead tissue has been cleaned out of the sponge skeleton. Waldren prefers to check them

regularly and remove the cleaned sponges when they are ready because they can lose their fibre strength if left longer in the sun. The cleaned sponges are washed in a machine, first with powder and then rinsed a few times. They prefer not to use chlorine or other chemicals because they want to keep the colour and natural product style (Fig. 11).

Figure 11. Waldren and Samson with harvested sponges

Production

The estimate of sponges sold from all of Pohnpei production (20 farms) p.a. is 5-6,000. The current standing stock in all the 20 farms is around 22,000 so Simon expects to see the sales to rise if Waldren can keep the other farmers motivated, or they can get more farmers involved, or if the price lifts. They sell 3-4" sponges for US$4-5 to a NZ company who distributes them with other natural beauty products. They also sell to a local Japanese guy who retails them in his local supermarket and ships them to a retailer in Japan. Waldren sells his seconds locally for around US$1-3. They have found it is harder to sell bigger sponges. MERIP have recently sent sponges to a buyer in San Diego and will consider online selling using the PayPal payment system.

The MERIP sponge farm is a way of increasing the production numbers because it appears difficult to get more farmers interested. As it is, MERIP staff provide a lot of help to the other farmers – collect the stock and deliver it to their farm, may cut and string with them as well, and then buy them back.

4. Impacts

4.1 Scientific impacts

There were no scientific impacts from this mini-project as it was a study tour for the sponge farm personnel.

4.2 Capacity impacts

The two KEL personnel benefited from the trip through gaining new ideas about farming methods, a better understanding of processing techniques and good information on marketing. In particular, Samson Lowatta, a Masig Islander and farm manager, benefited from the technical and social interaction with Pohnpein sponge farmers. He spent time and worked with a Pohnpei sponge farmer in stocking sponges, and learnt a new technique in attaching sponges to farm lines, as well

as a different view on the biology and husbandry of the wool sponge *C.matthewsii*. A strong outcome for Samson was his observation that the Pohnpei sponge farming techniques are simple and easy compared to Torres Strait, primarily because of the very favourable weather and site conditions (low wind and currents). He recognised that Torres Strait farming conditions are more challenging, but can improved with some ideas from Pohnpei to make them more efficient. As a result of the trip and experience gained, he plans to establish a trial at Yorke Island using the Pohnpei farming system (string lines from a reef edge, with access by snorkel). Samson will pass his new knowledge on to others at the Kailag farm.

4.3 Community impacts

If the study tour results in improved sponge farming methods, processing or marketing for KEL, then community benefits will ensue since KEL is an Indigenous not-for-profit company. A more profitable company will lead to more money for the community and potentially greater employment on Yorke Island.

The study tour also provided some social exchange between islanders and sponge farmers alike (Fig. 12). Chris Robertson and Samson Lowatta gave a presentation to MERIP staff about the Kailag sponge farm, as well as an underwater video of SCUBA diving conditions. Another movie of Masig islander traditional dancing provided a look at customary lifestyles on Masig and provided plenty of laughs and conversation about the similarities and differences of Melanesians and Micronesians.

Figure 12. Samson with the friendly MERIP staff

5. Conclusions

The following points sum up the knowledge gained on sponge farming in Pohnpei by the trainees and the outcomes from the mini-project.

1. The Pohnpei sponge farmers are well advanced in their farming methods with substantial NGO support, but are comparatively low in production despite excellent farming conditions.

2. The sponges farmed in Pohnpei are *Coscinoderma matthewsii* (same as Yorke Island) and *Spongia matamata*, a small delicate sponge that has real potential in the market as a ‘makeup applicator’.

3. The wild *C. matthewsii* sponges collected for farm stocking are huge in comparison to the Yorke Island sponges, and it is relatively easy for the farmers to stock a 1,000 sponges in one day

4. The sponge farms are established in sheltered reef areas where currents and winds are very low in comparison to Yorke Island. The farms are usually directly in front of the farmer's house and easily reached by boat. The farming technology used is very simple and it is easy to stock and inspect the sponges by snorkelling.

5. Sponge prices received by farmers and the NGO producer (MERIP) are US$3-6 ($3.80 to $7.60) per sponge packaged in a eco-friendly style mesh bag and label, significantly lower than what KEL expects to sell similar size sponges

6. Despite the ease of farming systems, strong NGO support and virtually ideal growing conditions, the annual production of sponges from Pohnpei is low, and may not increase significantly unless the prices obtained are increased dramatically.

7. Kailag has benefited from the trip in new ideas about farming methods, a better understanding of processing techniques and good information on marketing. Samson Lowatta wants to establish a trial at Yorke Island using the Pohnpei farming system (string lines from a reef edge, with access by snorkel)
8. The technical visits and social interaction with sponge farmers was invaluable for Samson and for any future consideration of information exchange between Australia and Pohnpei.

7. Acknowledgements

Kailag would like to thank Cathy Hair, James Cook University (and the ACIAR program) for the excellent assistance in funding and arranging the travel and training outcomes from this project.
Simon Ellis and all his staff at MERIP provided a very warm hospitality and assistance during our stay in Pohnpei, and enabled us to learn a lot about new techniques in farming, processing and marketing of sponges in Micronesia. The information gathered from this trip will provide significant benefits to Kailag in our sponge farming venture.

Appendix 2.26

MS1008

Transfer of Pacific experience to Indigenous Australian sustainable aquaculture: live rock culture, from Tonga to Western Australia

ACIAR Pacific Aquaculture Grant: **Project Summary**	Australian Government Australian Centre for International Agricultural Research JCU James Cook University WorldFish Center USP The University of the South Pacific	SECRETARIAT OF THE PACIFIC COMMUNITY **BP D5 98848, Noumea Cedex** **New Caledonia** **Tel: +687 26.20.00; Fax: +687 26.38.18;** **E-mail: spc@spc.int**
Project Title:	**Transfer of Pacific experience to Indigenous Australian sustainable aquaculture: live rock culture from Tonga to tropical Australia (MS1008)**	
Goal:	Facilitate development of live rock culture enterprises in Indigenous Australian communities through a targeted training course.	
Objective(s):	Specific objectives are to: 1) Conduct a training course in live rock culture techniques at One Arm Point Hatchery, Broome; 2) Build capacity of Indigenous aquaculture operators, students and TAFE teaching staff.	
Project location:	Broome, Western Australia	
Project partner(s):	Bubbamarda Abrolhos Live Rock company, Kimberly TAFE, Bardi Aboriginal Community, WA Fisheries	
Dates / duration:	Nine days.	
Project description	Much of the research undertaken through ACIAR Project FIS 2006/038 is also of relevance to Australia. The physical and social context to the development of indigenous Australian aquaculture has much in common with the Pacific Islands, particularly with respect to initiatives involving small communities located in remote, tropical areas. Live rock propagation and culture have been established in two PICs, Fiji and Tonga. A current mini-project in Tonga (MS0902) is funding research and technology transfer to develop the live rock industry there in response to closure of the wild harvest activities. Experience and knowledge gained in these countries would be invaluable to an Indigenous operation in Western Australia which is about to commence. This mini-project will utilise trained staff from the Tonga project to train Indigenous businessmen and students in live rock culture techniques.	
Justification	A major goal of ACIAR Project FIS2006/038 is to provide technical support for Indigenous Australian aquaculture ventures. This intervention will increase the chances of success of an Indigenous venture.	
Expected outcomes	(1) Increased capacity of Indigenous aquaculture operators. (2) Improved chance of success for an Indigenous aquaculture activity.	
Funding sought:	$15,000	

Transfer of Pacific experience to Indigenous Australian sustainable aquaculture: live rock culture from Tonga to tropical Australia

Cathy Hair[1], Scott Mactier[2] and Bart Penny[3]

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[3] Kimberley TAFE, Broome Aquaculture Centre, Broome, Australia.

1. Background

Live rock is the term given to rock (either man-made or natural) used in home aquarium systems which has spent some time in the sea or tank and is covered in a range of marine plants, animals and bacteria. Wild live rock (old coral rock) is removed directly from a reef, shipped to the market place or pet shop and sold. Artificial rock is made on land using materials like cement, sand, pumice, shells, etc. It is placed in the sea or seawater tank for a period to build up growth and then shipped and sold in a pet shop (i.e. no removal of any matter from the reef).

Live rock has many uses in an aquarium. It performs a bio-filtration function (i.e. cleaning the water) and provides structure for attaching corals to and for fish to hide in. It is also aesthetically pleasing in a tank. Live rock is valuable because of what grows on it (Figs 1a, b). The most useful species are crustose (encrusting) coralline algae (CCA), microalgae, other algae and bacteria, all of which consume nutrients released by fish and corals, and release oxygen. Value-adding organisms include corals, sponges, clams, crustaceans and sea squirts which may also grow on the live rock and can potentially increase the overall value of a piece of rock.

a  b 

Figure 1. (a) A piece of crustose coralline algae (CCA), and (b) a live rock coated in CCA.

A live rock industry is regarded as a culturally appropriate, sustainable business opportunity for Indigenous Australians, even though this industry is relatively unknown in Australia. Live rock culture has been established in two PICs, Fiji and Tonga. A recent ACIAR mini-project in Tonga (MS0902) funded research and technology transfer to develop the live rock industry there in response to closure of the wild harvest activities.

There is currently a great deal of interest in Western Australia (WA) and Northern Territory (NT) in live rock culture technology. The workshop targeted three interested groups:

1. ‘Bubbamarda Abrolhos Live Rock’ venture, proposed by Shane Bonney and Eugene Whitby. They aim to develop ocean-based grow-out techniques for live rock in the Abrohlos Islands area in mid west WA, creating a sustainable industry that is suitable for Indigenous communities based on local sites and using local materials. Their application to WA Fisheries Department should be granted in the near future.
2. Kimberly College of Technical and Further Education (KimTAFE) and One Arm Point hatchery (OAPH) are developing a training course centred on the production and sale of

live rock as a sustainable enterprise for Indigenous communities, specifically the local Ardyaloon Bardi Aboriginal Community. They have also lodged an application to WA Fisheries for shore-based live rock culture.

3. Dominic Maymuru (Laynhapuy Homelands Association Inc.) had a scholarship from the Fisheries Research and Development Centre (FRDC) to assist him in gaining skills in aquaculture activities suitable to remote Indigenous communities in NT. Training in other commodities will be carried out at the Darwin Aquaculture Centre (DAC).

Much of the research carried out in the Pacific Islands region under ACIAR Project FIS 2006/038 (Developing aquaculture based livelihoods in the Pacific Islands region and tropical Australia or DABL) is also of relevance to Australia. The physical and social context to the development of Indigenous Australian aquaculture has much in common with the Pacific Islands, particularly with respect to initiatives involving small communities located in remote, tropical areas. Experience and knowledge gained in the Pacific would be valuable to the developing live rock industry in Australia. The primary aim of this mini-project was to transfer technology from Tonga to the Indigenous groups or individuals listed, as well as Kimberley TAFE staff, WA Fisheries extension and licensing officers, and others. This was achieved by conducting a three-day workshop in live rock culture techniques at OAPH, near Cape Leveque, about 250 km northeast of Broome (Fig. 2).

Figure 2. One Arm Point hatchery.

2. Project methodology

The workshop was designed and run by Mr Scott Mactier, the technical advisor. On the ground arrangements and additional expertise were provided by Mr Bart Penny of Kimberley TAFE College. Fifteen people attended the workshop (App. 1). Several participants had been nominated from ACIAR contacts (i.e. the Bubbamarda proponents and DAC attendees). To assess interest at One Arm Point, a flyer was posted and community members encouraged to sign-up for the course (App. 2). The workshop ran from 5-8 April, 2011.

2.1 Workshop program

The workshop involved minimal classroom sessions and maximum hands-on and practical sessions. The following activities were carried out during the three days of the workshop:

Day One (Tuesday, 5 April) – An introductory theory session was held in the morning at One Arm Point community centre. In the afternoon workshop participants had a tour of the hatchery by the manager De'arne Kershler and assistant manager Greg Marett. They were also shown artificial rock produced at OAPH, which had been in tanks for between one to six months prior to the workshop (Fig. 3). Finally, participants constructed the rock building table (Fig. 4).

Figure 3. Example of an artificial live rock after six months in an OAPH tank.

Figure 4. Constructing the rock-making table.

Day Two (Wednesday, 6 April) – Rock materials were discussed and rock-making methods trialled.

Imported materials were pumice (a light rock of volcanic origin collected from a Pacific island beach), and two sizes of 'scoria' (a heavier volcanic rock purchased from a Cairns landscaping supplier). Local materials used for the rock bases included cement, sand and water, combined with various amounts of shell grit, sand, rock salt, attapulgite (purchased from the supermarket as 'kitty litter') and water. A small amount of red oxide powder was added to some mixes to create a more natural base colour. If CCA does not cover the entire artificial rock, the bare section will appear reddish instead of cement grey. Examples of materials are shown in Appendix 3.

Scott demonstrated mixing a pumice artificial rock using ratios of materials based on his Tongan experience. There was sufficient pumice for a single rock only and this material was not readily available in the area. Following the first demonstration, the group mixed their own rock base 'recipes' with the available materials, either in a bucket for small volumes or a wheelbarrow for larger volumes (Fig. 5). Ingredient type and amount for each different mixes were recorded. A full list of rock recipes are appended (App. 4). Scott demonstrated how to make the mix the correct consistency and not too 'wet', which would otherwise reduce porosity and degrade the final appearance of the rock.

Figure 5. Hand mixing the rock base in a bucket (single rock) or wheelbarrow (batch mix).

Two main methods were used to make rocks from the trial mixes. These included:

(1) Tongan round rock method – a half rock was made by dropping mixture onto the table (Fig. 6a). The resultant rock was semi-spherical with a flat base. After the rock set (e.g. overnight), a small depression was made in the sand and the half rock upturned and laid in it so that it was held stable (Fig. 6b). If necessary, a wire brush was used to remove lose bits of sand or gravel from the flat base and create a clean surface for the next step. The same mixture was prepared again and dropped on top of the half rock to make a whole round rock (Fig. 6c). No effort was made to shape or arrange the mixture.

Figure 6. Tongan round-rock method of making an artificial rock composed of two semi-spherical halves concreted together. (a) First half rock, (b) hardened half-rock turned upside down in sand depression, (c) Second half-rock cemented on top. Note, one half-rock was made without red oxide.

(2) Sand mould – a depression is made in either course or fine sand. The depression can be shaped by hand or using a suitably-shaped hard object such as another rock or piece of dead coral (Fig. 7a). The rock base mix is then poured into the sand mould (Fig. 7b). The mix can be patted down into a more solid shape (Fig. 7c) or 'sprinkled' loosely into the mould (Fig. 7d,e). Participants experimented with different rock shapes and designs.

Figure 7. Using sand moulds to make rock base. (a) Shape created in fine sand by pressing coral rock into it, (b) Shape created in course sand on the table using hand, (c) rock base mix in a course sand mould, (d) Jarman and Dominic making mould shapes and adding rock mix to a mould, (e) James making a mould.

Day Three (Thursday, 7 April) – Participants completed the second half of the Tongan round rocks that were started the previous day. The sand mould rocks had set. All rocks were assessed using the following criteria:

- structural integrity – rock held together without crumbling
- strength – rock did not break easily
- shape, colour and general appearance – rock looked similar to natural, wild rock
- weight – preferably lighter than wild rock, and
- porosity – large surface area and did not hold water

Where mixes were found to be deficient (refer to App. 4), participants devised improved recipes and looked for ways to address the problems. Standard cement was brought in to use because the first batch of rocks were made with a concrete - aggregate – sand mix, and did not harden properly. These new rock mixes were made and left to set overnight.

At the end of the day, Scott gave a brief overview of potential for value-adding techniques, e.g. culture and grafting soft corals and corallimorphs and placing them on rocks (Figs 8a, b).

Figure 8. (a) Scott demonstrating the kinds of soft coral that are suitable for culture and may be used to add value to live rock. (b) Sean holding a small natural rock covered with soft corals.

Day Four (Friday, 8 April) – This was not a full day but participants met briefly at OAPH to review the rocks made on Day Three before returning to Broome.

2.2 Tagging

An issue of concern for WA Fisheries was being able to distinguish artificial live rock from wild live rocks. At the workshop, the use of T-bar tags (designed for fish tagging) was trialled by inserting a tag in the rock while the cement was still wet (Fig. 9).

Figure 9. Shane and Eugene inserting a T-bar tag in an artificial rock.

2.3 Licence issues

The first two days of the workshop were attended by two WA Fisheries officers: the North Region Fisheries Managment Officer, Ms Pia Carter, and an Aquaculture Fisheries Management licensing officer from Perth, Ms Julie Wakefield.

3. Outcomes

3.1 Theory

The classroom session provided an introduction to live rock (wild and cultured), including what it is, why it is useful, how to make it, how to culture or farm it, processing and shipping, brief overview of markets and economics, and its relationship to the environment.

A PDF copy of Scott's presentation was distributed to participants after the workshop.

3.2 Artificial rock base practical session

The various artificial rock mixes trialled during the workshop and their assessments are presented in Appendix 4. All mixes used cement, sand and water. The best additional ingredient appeared to be shell grit or attapulgite. The most promising mixes were 'Attapulgite B', 'Straight Mix A', 'Beach Shell A', 'Attapulgite C', 'Beach Shell B' (see App. 4). Salt was a useful ingredient added to most of the mixes in order to increase porosity as it dissolves out of the rock when immersed in water. However, the amount needed to achieve good porosity without crumbling requires more investigation.

Aside from pumice, most of the promising rock recipes were quite heavy. The small amount of pumice at the workshop was useful as a demonstration but the pieces were too large. According to Scott, a better rock is produced from pumice pieces about 5-20 mm diameter. However, the attapulgite produced an acceptable appearance and was comparatively lighter.

Acceptable rocks were produced by both the Tongan round-rock and sand mould methods (Fig. 10). Rocks that were patted down into the sand moulds generally were heavier than those poured loosely, but were more structurally sound.

Rock structure was improved on from the second day when straight cement (not mixed with sand or aggregate) was used. Problems were encountered because of rain as the table was out in the open. Some rocks did not harden properly because of the early onset of rain after rock production. However, Bart reported that most rocks did harden up as time passed (i.e. when he checked them in the weeks following the workshop).

Figure 10. Examples of the better quality rocks that were made during the workshop.

3.3 Tagging

The fish tag technique worked well – the tag was very obvious and stuck well in rocks where the cement set properly (Fig.11). Information could be recorded using the tag number if desired. The tag could then be snipped off at the point of sale. The trial showed that the tags held firm when the rock set. It was agreed that it would not be possible to insert a similar tag into a natural rock. There was discussion about another tagging method – passing monofilament nylon fishing line through a rock during production – but this was not tested.

Figure 11. Tagged artificial rock.

3.4 Live rock licence proposal and advice

The WA Fisheries officers were able to learn more about the live rock industry and potential for aquaculture during the course, in particular from the theory session and first rock making session. Julie was also able to hold face to face discussions with Shane and Eugene (Bubbamarda Abrolhos Live Rock) who submitted a live rock aquaculture licence application to the Department in 2006. They are in the final stages of the application and the workshop

provided a valuable opportunity to discuss the process with a Department representative. Scott also provided expert input on their submission with respect to the technical aspects of live rock culture, specifically the nutrient cycling function of live rock and how to design farming systems in order to have negligible environmental impact. The proposal of Shane Bonney and Eugene Whitby—which had been in the WA approval system for more than 6 years—was approved in mid-September 2011. Information disseminated at this workshop plus the networking opportunity it afforded contributed to the resolution of this issue.

4. Impacts

4.1 Scientific impacts

There were no scientific impacts form this mini-project

4.2 Capacity impacts

This mini-project was a targeted technology transfer workshop. It enhanced capacity in several ways: (1) it provided potential live rock farmers with practical skills in making aquarium grade artificial live rock bases, theoretical knowledge about the biology of the product and important insights into marketing practices; and (2) fisheries and education extension officers were trained in the same skills so they can conduct similar courses in the future or provide support to workshop participants in the future.

4.2 Community impacts

As a result of the workshop, Bubbamarda Abrolhos Live Rock, obtained a license to farm live rock in Western Australia. Other Indigenous groups have the opportunity to pursue this activity in their communities if it is deemed to be economically feasible.

5. Conclusion

The workshop was the first of its kind in Australia and the first extension of Pacific experience in this field to Indigenous enterprises interested in this activity. Participants agreed that the theory session provided valuable knowledge on the science relating to live rock and information on how the industry operates. This information is important in developing any commercial operation based on this commodity. The Bubbamarda and OAPH participants have submitted live rock culture license applications to WA Fisheries. The theory and practical sessions, tagging trial and face-to-face discussions were of benefit to everyone, increasing WA Fisheries' awareness of the industry and the applicants' awareness of the licensing process.

The hands-on sessions were also regarded as useful by the participants. Scott's experience with industry requirements and artificial rock production provided the participants with skills that are difficult to obtain from other sources. The participants come from different areas and will have different materials available and will be culturing rock in different physical environments. However, the broad scope of the workshop covered all these aspects. The process of trial and error with rock mixes and the trouble-shooting exercises gave participants an understanding of the features that comprise a good artificial rock and the tools to develop rocks from the materials they have in their own areas. Pumice, the material used in Tonga to produce light rocks, is not readily available in most areas of WA (although Dominic says it is easy to source in his area of NT).

Two main areas for further investigation were identified during the workshop:

(1) There is a need to do more rigorous trials with materials that are weighed out carefully and final weight determined in order to establish which mixes produce light weight rock. During the workshop, there was an attempt to weigh the rocks but the results were not meaningful because there was no accurate record of how much mixture was used in each individual rock.

(2) There are questions about economic aspects of the industry. Efforts are made to produce a lighter rock to make handling easier and freight cheaper. However, live rock is sold by weight (e.g. in Cairns, the wholesale price is between AU$4-6 per kg). Savings made in freight need to compensate for the reduced value of lighter rocks. Alternatively, a different pricing structure may be needed, e.g. selling cultured live rock by the piece with a set price for small, medium and large rocks. Any group that attempts this activity in Australia will encounter costs associated with base materials, transport, freight, labour, etc. Information on market value, domestic demand, potential overseas markets and so on, is incomplete. In order to predict profitability and develop sound business plans, more work needs to be carried out in this area. An economic decision-making tool, such a those developed by Bill Johnston (QLD DEEDI) would be very useful for the live rock commodity (see http://agbiz.business.qld.gov.au/fisheries/aquaculture.htm for aquaculture examples of these models).

The workshop was successful and generated much interest. Participants should be able to improve their operations through skills and tips picked up during the course. There is also a network established with experts available now to contact if problems arise with their commercial operations in the future. The workshop was of particular benefit to the Indigenous groups who have applied for licences from WA Fisheries. We are hopeful that the information provided at the workshop has been of benefit to the licensing process for live rock proposals.

Acknowledgements

We wish to acknowledge Kimberley TAFE for assistance with logistics, equipment and transport. We are grateful to the One Arm Point hatchery management and staff for hosting the workshop at their facility. Also, thanks to the Bardi Community (Ardyloon Inc.) for use of their conference room and allowing the workshop to be held on their country. Finally, a big thank-you to the mixers and moulders and shakers who helped to make the workshop a success through their enthusiastic participation.

Appendix 1. Live rock culture workshop participant list.

Name	Organisation	Location
James Xavier	One Arm Point hatchery	One Arm Point, WA
Jarman Xavier	One Arm Point hatchery	One Arm Point, WA
Norliya Bin Hitam	One Arm Point hatchery	One Arm Point, WA
Sean Purantatameri	One Arm Point hatchery	One Arm Point, WA
Clint Stumpagee	One Arm Point hatchery	One Arm Point, WA
Shane Bonney	Bubbamarda	Geraldton, WA
Eugene Whitby	Bubbamarda	Geraldton, WA
Dominic Maymuru	Laynhapuy Homelands Association Inc. (FRDC Scholarship/DAC)	Laynhapuy, NT
De'arne Kershler	One Arm Point hatchery	One Arm Point, WA
Greg Marett	One Arm Point hatchery	One Arm Point, WA
Scott Mactier	James Cook University	Nuku'alofa, Tonga
Bart Penny	Kimberley TAFE	Broome, WA
Jens Knauer	Darwin Aquaculture Centre	Darwin, NT
Julie Wakefield	WA Department of Fisheries	Perth, WA
Cathy Hair	James Cook University	Cairns, QLD
Pia Carter	WA Department of Fisheries	Broome, WA
Chris Throsby	One Arm Point hatchery	One Arm Point, WA

Appendix 2. One Arm Point community flyer on the live rock training course.

LIVE ROCK

LIVE ROCK TRAINING COURSE
5TH – 8TH APRIL

WHAT IS IT?

It is like Rocks from the Sea, but we make it with Cement and Sand. Then put it into Tanks or in the Sea.

WHY?

Live Rock is worth Money because people will buy it and put it in their Aquariums.

- **When?**
  Four-Day Course
  5th – 8th April
- **Where?**
  One Arm Point Hatchery
- **What?**
  Hands on course, all materials, transport provided.
- Lunch and tea– breaks included.
- Places are Limited, so sign up now.

To Register, Please write name on Information sheet at Community Council before 28th of March.

Kimberley TAFE

Australian Government
Department of Education, Employment and Workplace Relations

JCU
James Cook University

ACIAR

Appendix 3. Examples of rock base materials (ingredients).

Pumice

Scoria (small)

Scoria (large)

Red Oxide (for colour)

Rock salt

Rock salt (bulk)

Attapulgite (‘kitty litter’)

Attapulgite (bulk)

Shell grit

Appendix 4.

Wednesday 6/04/2011

Mixture No/Name	Volume (Litres)	Ingredients	Tag No's	Comments
1 - Tonga	3.00	Pumice	400	Scott's Tongan Mixture. Light semi-porous
	1.00	Coarse Sand		
	1.00	Concrete		
	0.50	Water		
2 - Scoria	3.00	Big Scoria	399	Heavier than pumice, good appearance
	1.00	Coarse Sand		
	1.00	Concrete		
	0.50	Water		
3 - Scoria	3.00	Small Scoria	398	Bit more packed and not as good appearance as big scoria.
	1.00	Coarse Sand		
	1.00	Concrete		
	0.50	Water		
4 - Attapulgite A	3.00	Attapulgite	397	Fell apart, too crumbly. Not enough cement, good red colour
	2.00	Pool Salt	-	from Iron Oxide.
	1.00	Concrete	388	
	Sprinkle	Red Oxide		

5- Attapulgite B	3.00	Attapulgite	386	Good rocks, heavy and maybe not porous enough.
	2.00	Pool Salt	-	
	2.00	Concrete	381	
	Sprinkle	Red Oxide		
6 - Sand Mix A	2.00	Coarse Sand	380	Bit crumbly, bit too much salt - heavy.
	2.00	Pool Salt	-	
	2.00	Concrete	376	
	Sprinkle	Red Oxide		

Wednesday 6/04/2011

Mixture No/Name	Volume (Litres)	Ingredients	Tag No's	Comments
7 - Straight Mix A	1.00	Pool Salt	375	Heavy but porous. Bit crumbly on the outside but has potential to
	1.00	Concrete	-	be a good rock.
	Sprinkle	Red Oxide	369	
8 - Super Salt	2.00	Pool Salt.	368	Too much salt. Rocks broke up and. May have set better without
	1.00	Concrete	-	rain.
	Sprinkle	Red Oxide	359	
9 - Contraband A	1.00	Coral Rubble	358	Looked good, very heavy. Not that porous.
	1.00	Concrete	-	
	Sprinkle	Red Oxide	355	
10 - Super Shell A	3.00	Beach Shell Grit	354	Too crumbly, not enough cement.
	1.00	Pool Salt.	352	Rock fell apart.
	1.00	Concrete		
	Sprinkle	Red Oxide		

11 -Beach Shell A	1.00	Shell	353	Bit crumbly but porous. A little heavy, but not a bad rock. If set
	1.00	Concrete	351	without rain it could be a good mix.
	1.00	Salt		
	Sprinkle	Red Oxide		

Thursday 7/04/2011				
Mixture No/Name	**Volume (Litres)**	**Ingredients**	**Tag No's**	**Comments**
12 - Contraband B	3.00	Coral Rubble	394	Not porous - heavy. Very strong.
	0.50	Fine Sand	363	
	0.50	Attapulgite		
	1.00	Cement		
13 - Attapulgite C	3.00	Attapulgite	365	Bit crumbly, but porous. Without rain while setting it could be a
	0.50	Pool Salt	390	good rock. Maybe a bit more cement.
	0.50	Cement	383	
			393	
14 - Super Shell B	4.00	Beach Shell	396	Too heavy, too much sand and not enough cement.
	3.00	Fine Sand	362	Not porous.
	2.00	Pool Salt		
	1.00	Cement.		
15 - Beach Shell B	3.00	Beach Shell	359	Bit heavy, very porous. With a bit more cement could be a good
	0.50	Pool Salt	392	mixture.
	0.50	Cement		

16 - Beach Shell C	3.00	Beach Shell	361	Bit heavy, very porous. Not as crumbly as beach shell B
	1.00	Pool Salt	389	Good rock.
	1.00	Cement	366	
			360	
17 - Sand Mix B	2.00	Coarse Sand	388	Too much salt. Too crumbly. Bit more cement and longer set time.
	2.00	Pool Salt	352	
	1.00	Cement	375	
Thursday 7/04/2011				
Mixture No/Name	**Volume (Litres)**	**Ingredients**	**Tag No's**	**Comments**
18 - Straight Mix B	1.00	Pool Salt	359	Not crumbly, strong rock. Not porous. Bit more salt needed.
	2.00	Concrete	370	
			385	
19 - Attapulgite D	3.00	Attapulgite	371	Good weight, bit too crumbly. Without rain and longer set time it
	0.50	Pool Salt		could be a good mix.
	1.00	Cement		