Aquaculture Potential On Niue

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PREFACE

The Government of Niue requested the assistance of the Forum Fisheries Agency in conducting feasibility studies on the aquaculture of certain organisms on Niue. In particular, to conduct feasibility studies of culturing fresh-water prawns, crayfish and giant clams. The interest by the government on inland fresh-water aquaculture was mostly spurred by various reports by certain individuals and organisations which suggested certain species as holding potential for aquaculture development on Niue. The plan for giant clam culture however, is aimed primarily at augmenting natural stocks since the populations of local stocks have been reported to be decreasing due to fishing pressures and natural disasters such as cyclones. A secondary aim of the giant clam project is to look at the potential of exporting meat to the Polynesian market in New Zealand and the export of juvenile clams for the U.S. aquarium market.

The terms of reference for the study were as follows:

* Investigate the technical and economic feasibility of culturing fresh-water prawns, fresh-water crayfish and giant clams, giving consideration to possible environmental impacts;

* Produce a report which refers to the results of research and development into these areas in other South Pacific countries;

* Provide information on potential markets for the three organisms.

The field work for this report was conducted during the last week of February 1994, jointly executed by FFA and ICLARM (CAC, Solomon Islands) as part of the Memorandum Of Understanding (MOU) between the two organisations.

The report is generally divided into three main areas: (i) the culture experiences of the selected organisms in other countries in the South Pacific; (ii) assessing the possibility and economics of setting up a giant clam project using a land-based hatchery and nursery; and (iii) examination of the island characteristics to assess the potential of setting up an inland aquaculture project for the culture of freshwater prawns and crayfish using the basic requirements for such an undertaking.

Funding for this was provided by International Centre for Ocean Development (ICOD), through FFA's Research Coordination Unit and New Zealand Overseas Development Assistance (NZODA). The assistance provided by Mrs Sisilia Talagi, Director, as well as the staff of the Niue Department of Agriculture, Forests and Fisheries, is greatly appreciated. We are especially grateful for the assistance, guidance, provision of information and exchange of ideas provided by Mr Brendon Pasisi, Fisheries Adviser, Niue Fisheries Division.

The authors assume full responsibility for the contents of this report. Opinions, where expressed, are theirs alone and in no way reflect the policy of FFA, ICLARM, the Niue Department of Agriculture, Forests and Fisheries or the Government of Niue.

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NIUE AQUACULTURE DEVELOPMENT PLAN OBJECTIVES

The **overall objectives** of the proposed aquaculture development on Niue are:

I. to determine means of augmenting declining important natural stocks of certain marine food organisms and enhancing local reef resources by supplementing native fisheries populations;

II. to provide other possible mechanisms for generating export products; and

III. to provide economic opportunities to create interest for Niueans living overseas to return to Niue.

1. Establishment of a Giant Clam Hatchery.

Specific development objectives:

(i) primarily, to augment declining stocks of the native giant clam species, *Tridacna squamosa* and *T. maxima*;
(ii) secondarily and of low priority, to generate a possible export product (e.g. giant clam meat targeting a possible market in New Zealand and/or juvenile clams for the aquarium trade in the US.

2. Production of Fresh-water Prawns and Crayfish.

Specific development objectives:

(i) to provide an alternative for import substitution of imported food products
(ii) create an additional tourist attraction on Niue and establish a possible additional export commodity.

1. INTRODUCTION

The economy of Niue is based on agriculture which is small relative to the size of the island due to poor soil fertility and the fact that the soil layer is thinly distributed over limestone and basement rock. After the Second World War, the population of Niue increased to a peak of 5,194 in 1966. However, the population has declined steadily since then to 2,239 people counted in the 1991 Population Census. The decline is due mainly to out-migration (Statistics/Immigration Unit, 1993). Of the 1,222 Niueans aged 15 years and over counted in the 1991 census, 868 (71 per cent) were employed in the paid and unpaid workforce, 46 (3.8 per cent) were unemployed and 308 (25.2 per cent) were economically inactive during the week prior to the census. The employed population breakdown, by occupation, and the economically inactive population, by main activity, is given in Table 1.1 as reproduced from Statistics/Immigration Unit (1993). Table 1.2 gives the breakdown, by age group, of the employed, unemployed and economically inactive Niuean populations in 1991 as summarized from the same source above.

Table 1.1: Occupation of the employed population and main activities of the economically inactive population of the 1,222 Niueans 15 years of age and over, as recorded in the 1991 population census. (Source: Statistics/Immigration Unit, 1993).

EMPLOYED				ECONOMICALLY INACTIVE			
Occupation	**Males**	**Females**	**Total**	**Main activity**	**Males**	**Females**	**Total**
Professionals/Legislators	72	77	149	Unemployed	9	4	13
Technicians	36	8	44	Domestic Duties	2	101	103
Clerks/Service	47	128	175	Education	36	43	79
Agric/Fishery	79	19	98	Other	34	64	98
Craft	81	35	116	Not Applicable	8	7	15
Operators	26	4	30				
Elementary	78	19	97				
Not Stated	89	70	159				
Total	**508**	**360**	**868**	**Total**	**89**	**219**	**308**

Table 1.2: Employed, unemployed and economically inactive Niuean populations by age group recorded in the 1991 population census. These are for the total population aged 15 years and over. (Source: Statistics/Immigration Unit, 1993).

AGE GROUP	EMPLOYED			UNEMPLOYED			ECONOMICALLY INACTIVE		
	Males	Females	Total	Males	Females	Total	Males	Females	Total
15-24	139	66	205	7	16	23	43	54	97
25-34	122	79	201	3	8	11	4	30	34
35-44	79	75	154	0	3	3	3	15	18
45-54	79	80	159	2	3	5	4	25	29
55 +	89	60	149	3	1	4	35	95	130
Total	**508**	**360**	**868**	**15**	**31**	**46**	**89**	**219**	**308**

Almost 30 per cent of the total population of those aged 15 years and over on Niue were recorded as unemployed and economically inactive during the 1991 census.

In an effort to develop some productive industries, the Government of Niue wishes to examine the feasibility of developing various options in this area. One of the candidate fields identified is aquaculture. The initial interest in inland aquaculture seems to have originated from certain individuals who claimed to have identified existing markets overseas for products such as fresh-water prawns. These observations were mostly made during overseas trips. Further interest seems to have been generated from a report produced in 1993 by the South Pacific Trade Office on the potential of aquaculture in Niue. The report identified freshwater crayfish (marron) and freshwater prawns as potential culture species considering the warm climate and the existence of good clean underground water, flat land which is easy to develop, and infrastructure. Village "greens" were identified as potential areas to build on and empty houses and schools were suggested for use in ancillary services (Harris, 1993). The same author was of the opinion that an aquaculture facility with an attached barbecue restaurant, similar to tourist attractions found in New Zealand, would fit in with Niue's plans for expansion of the tourist industry. However, the same report cautioned that a detailed research is required to assess the viability of such a venture.

The Niue Department of Agriculture, Forestry and Fisheries has shown great interest in the conservation and development of giant clam resources in Niue during the recent past. A report prepared by Dalzell *et al* (1993) entitled "Fisheries resources survey of the Island of Niue" was a result of surveying work carried out in July 1990 under the auspices of the South Pacific Commission's Inshore Fisheries Research Project and the FAO Regional Aquaculture Development Project. Estimates of stock densities of *T. maxima* and *T. squamosa*, the two species present in Niue, were made from survey works. *T. squamosa* was present at a calculated density of 14 clams per hectare and *T. maxima* at 89 clams per hectare, corresponding to calculated standing stocks of 3,815 and 24,252 clams respectively. The authors considered that although the standing stocks of *T. maxima* were low, the fishing pressure was not sufficient to consider this species as being threatened. The consumption rate, however, was considered high enough to establish conservative measures that will allow the natural populations of *T. squamosa* to re-establish as its stocks were considered to be in a depleted status. Interestingly, at the time of their report the number of active fishermen was considered to be 20 people with many of them being non-Niueans. Although there was no time for extensive interviews, and no questionnaire was prepared for the purpose of this study, some of the fishermen interviewed considered that there were only 6 active fishermen on the island in 1994. They were also of the opinion that the subsistence fishermen were only harvesting clams close to shore (within 40m), and in waters shallower than 10 m. This observation therefore concurs with the Dalzell *et al*. (1993) report that the stocks are being lightly exploited. However, earlier giant clam exploitation rates and probably in addition to the effects of recent cyclones, have resulted in the present depleted status of the local *T. squamosa* stocks.

The recommendations and suggestions of the Dalzell *et al*. (1993) report with regards to giant clams were:

- To limit any mariculture efforts to obtaining some cultured juvenile clams, and conducting small scale experiments in subtidal protected areas.

- To collect and arrange some *T. squamosa* in relatively sheltered areas at a depth of 20-25m, with three to six rings of 20 to 25 clams arranged in a circle of 5m diameter. The rings were to be monitored every two months by the Fisheries Division staff.

- To repeat the clam survey after 3 to 5 years if no further cyclones had occurred to compare stock densities under normal conditions with those just after a cyclone.

In November 1992, the Niuean Department of Agriculture Forestry and Fisheries expressed its desire to the Forum Fisheries Agency (FFA) to initiate a project designed to reseed Niuean reefs with giant clams of the native species, *T. maxima* and *T. squamosa.* Specifically, the request was to conduct a cost comparison assessment of producing juvenile clams locally, by means of a hatchery, as opposed to importing juvenile clams from an existing hatchery. FFA produced a report in February 1993 entitled "Niue giant clam reseeding. Cost comparison local production (hatchery) and importation (juveniles or larvae)." In his summary, Bell (1993a) stated, "the establishment of reserves, in areas where native giant clam stocks still exist, and the collection and creation of clam clumps within the reserves, remains the only safe and cheap means in any effort to enhance native populations. Although it would naturally take time, the risk of introducing new diseases and genetic material that would be detrimental to local resources, is nil". Furthermore, the same author noted that the introduction of fisheries regulations for the management of the native giant clam stocks seems to be essential at this stage. Of primary importance is the ability to enforce these regulations consistently and effectively.

In August 1993, the Government of Niue made a request to FFA for a feasibility study for the establishment of a giant clam hatchery. The objectives of the hatchery were to provide a means of replenishing the natural stocks, whilst also providing an export income for the island. Both the Minister and Director for Agriculture, Forestry and Fisheries stated verbally that any proposed activity should be cost effective and self-supporting.

2. AQUACULTURE INITIATIVES OF THE SELECTED ORGANISMS IN OTHER SOUTH PACIFIC COUNTRIES

2.1 Giant Clams

Giant clam research and development throughout the South Pacific.

Research into the reproduction and larval culture of giant clams began in the early 1980's. This was mainly as a response to the over exploitation of giant clams, especially the larger species such as, *T. gigas* and *T. derasa*. These were being decimated in some areas by Taiwanese vessels and sometimes by local populations. There was therefore a need to repopulate stocks that had been over-exploited, and to provide a farmed source of the products that were obviously in demand.

The Micronesia Mariculture Demonstration Centre (MMDC) in Palau began working on giant clam culture in 1983. It is now the largest producer of giant clams and is running at an economically sustainable level. The University of Papua New Guinea (Motopure Island Research Centre) was also involved in the first attempts at larviculture but on a smaller scale than that being used at the MMDC. Australia became involved in giant clam culture in the mid-1980's, first with a project at the University of New South Wales and then through a larger project funded by the Australian Centre for International Agriculture Research (ACIAR). The ACIAR project was based at James Cook University, Townsville, and had a research facility on Orpheus Island. There were outposts of this project initially in Fiji, Philippines and Papua New Guinea but by the late 1980's it also included Tonga, Cook Islands, Kiribati and Tuvalu while shedding the Papua New Guinea module. In 1987 the International Center for Living Aquatic Resources Management (ICLARM) began constructing a Coastal Aquaculture Centre near Honiara in the Solomon Islands and by 1990 had begun the establishment of an ongrowing facility in the Western Province, Solomon Islands.

There are two privately run clam farms currently in operation; one in Australia and one in the Marshall Islands. These farms rely mainly on clam farming for their income but in the Australian operation, a large part of the income is derived from tourism. It is believed that a private operation is soon to begin in Palau which will be taking over giant clam farming from the MMDC facility.

The success or failure of the various facilities established throughout the Pacific has been highly variable. In cases where no clam production has taken place, other aspects such as stock assessments, aquaculture awareness and marine education have been of benefit. A brief summary of the programmes implemented in some of the countries and the major problems or successes is given below. This information is intended as a general guideline of present status and is not necessarily up to date for each country. Operations in the Philippines, Australia and Palau will not be discussed further.

2.1.1 Cook Islands

The Cook Islands' first involvement with giant clam culture was in 1986 when a shipment of 1,000 *T. derasa* was imported from Palau. Of these, only 160 survived to sexual maturity. The Cook Islands hatchery on Aitutaki was established with assistance from ACIAR in 1990. The hatchery utilises a land-based operation constructed of fibreglass tanks, a wooden header tank and cement drains. The hatchery has suffered from some major design faults, notably power supply, header tank design and the placement of the tanks. The large cohorts of *T. maxima* that were produced in the past were lost when the only pump failed. No back-up pumping facilities were available. Despite these problems the hatchery has achieved a small production of *T. maxima* which is now in the ocean nursery. It is also in possession of *T. gigas* imported from James Cook University (JCU) as potential broodstock. The site is exposed to cyclones. The hatchery has suffered from a lack of political motivation, mainly due to the emphasis of the Fisheries Division on pearl oysters and has not received sufficient operating funds in the recent past. Some of the fibreglass hatchery tanks were broken when a water spout picked them up, and threw them some distance away (Whitford, *pers.comm*., 1994). It is possible that the hatchery will be revitalised in the near future with a third phase of AIDAB funding.

The ocean nursery is situated inside a lagoon in shallow water and is sheltered from the main force of cyclones, but has the disadvantage of being away from the land based operation. It is not totally secure. There have been no sales of clams from Cook Islands to date.

2.1.2 Federated States of Micronesia (FSM)

The main purpose of giant clam facilities in the FSM is to assist in restocking the reefs with giant clams. The FSM hatchery based on Kosrae has persistently been plagued with problems of poor water quality. Broodstock of *T. gigas* and *H. hippopus* were imported from Marshall Islands and MMDC, Palau. Three thousand imported clams were distributed from this facility to Chuuk, Yap, Kosrae and Pohnpei in 1992 for marketing or restocking. Pohnpei has a small hatchery but has problems with theft of broodstock (Lindsay, 1993). Small grow-out farms (3-5) have been established that aim to supply local Japanese restaurants on a small scale. Yap has also imported 80,000 clams from Palau for reseeding its reefs.

The Kosrae ocean nursery has had similar problems to Pohnpei, in that there is theft of stock. This, and a high rate of predation from *Cymatium* gastropods, has resulted in the ocean nursery being moved to a village in the southwestern tip of Kosrae (CTSA, 1993). The consequences of this move are unclear as yet.

The hatchery has conducted marketing trials of various species of giant clam for the local restaurant trade using clams imported from Palau. Spawning trials have been conducted but larvae culture has not been successful.

2.1.3 Fiji

Fiji Fisheries Division was involved in the ACIAR giant clam project in 1984. Stock surveys were conducted initially and these resulted in a 10 year ban on the export of giant clam meat. In 1986 it was decided to reintroduce *T. gigas* into Fiji and set up a quarantine facility on Makogai island to receive clams from James Cook University (JCU). The hatchery facility was constructed on Makogai in 1988 as an extension of the quarantine unit. It produced over 100,000 seed clams per year by 1991, with another 150, 000 being stocked in an ocean nursery directly in front of the hatchery. The system consists of 6 x 1,000 litre and 2 x 2,000 litre fibreglass tanks in the hatchery, and 7 large splasher pools with 6 shallow concrete raceways in the land based nursery. The hatchery is limited due to the size of the pump and the configuring of the reticulation system. The hatchery was unquestionably the most efficient of the hatcheries established by the ACIAR project and had, by 1993, established a business relationship with an aquarium company that could have paved the way for making Makogai a self-funding operation. The hatchery site has had some problems with low winter water temperatures resulting in slightly slower growth rates than is found in other more equatorial hatcheries. The hatchery proved efficient and its operation is currently being funded by government. There is a possibility of additional funding for the project from AIDAB.

Approximately 1,000 clams from the ocean nursery in Makogai were distributed to villages and resorts around Fiji for trial ocean nursery growout. Unfortunately a cyclone, in 1993, decimated the ocean nursery stocks with over 200,000 clams between the ages of 18 months and 3 years old being lost (Batibasaga, 1993). Stocks are currently being replenished and currently stand at approximately 215,000, the majority of which are under 1 year old. In an effort to prevent future catastrophic losses from cyclone damage, clams are being maintained on floating ocean nursery rafts. The clams are transplanted into these rafts at 6 months of age and remain there for a year, after which they are put onto the seabed at depths of greater than 6 metres. This method does limit the amount of stock that can be put in the ocean nursery and it would only be possible to return a few floating cages to land prior to and during a cyclone. The depth reduces the growth rate slightly. The effectiveness of this system to prevent cyclone damage is unknown as yet.

2.1.4 Solomon Islands

The International Center for Living Aquatic Resource Management (ICLARM) was established in the Solomon Islands in 1987. Its initial research thrust was aimed at developing low technology techniques for the mariculture of giant clams. To date the centre has spawned over 60 cohorts of giant clams, some from each of the 6 species present in Solomon Island waters. Clam larvae have been sent from the Solomon Islands to the Philippines and Western Samoa in an effort to repopulate decimated local stocks of clams. The hatchery is capable of producing 330,000 six month old clams per year. The clams are then distributed to various ocean nurseries around the country.

Much of the ICLARM work has been aimed at developing low-cost techniques for village-based farming. To date there have been 40 village trials, some of which have lapsed due to lack of care by the participants concerned and others have been terminated by ICLARM due to the practical difficulties involved in maintaining trials in remote locations. At the present time there are 20 active trials and a long list of applicants for future trials. Some of the village farms that have been established are now on the verge of becoming commercial entities in their own right. Most of the village growout takes place in cement based cages raised up above the seafloor. However, the CAC has also developed a novel form of ocean nursery rearing: cultivating clams in cages suspended from rafts and longlines in areas otherwise unsuitable for giant clams has also been developed. This method has been taken up by the Fiji project. There are now substantial stocks of clams that are ready for sale to the aquarium trade and several thousands are awaiting use in the test marketing of clams to the live seafood market. Marketing to the aquarium trade has been taking place on a small scale since early 1993 but there have been problems with transport mortality. New packing equipment and regimes have recently been instigated and it is believed that transport mortality will no longer be problematical.

The Solomon Islands benefits from having high year-round seawater temperatures which means that spawning may be possible throughout the year. Solomon Islands is not directly in the path of cyclones and has many sites that are well protected. These features reduce the risk of total loss from severe storms.

The success of the giant clam project in Solomon Islands can be attributed to the hatchery being sited on an ideal area, employment of highly professional staff, availability of sufficient funds through aid and the support from the main base, ICLARM, Manila.

2.1.5 Tonga

Clam circles

The Ministry of Lands, Survey and Natural Resources, with the cooperation of the Fisheries Division of the Ministry of Agriculture, Forestry and Fisheries and the Marine Research Foundation, established the first giant clam circle in Tonga during the Environment Week in June 1986. It was set up on a reef in Nuku'alofa harbour, using local broodstock of *T. derasa*. This was an attempt to revitalize the stocks of these animals on the northwestern reefs of Tongatapu Island (Chesher, 1989). Four such circles were set up in Vava'u Harbour (ACIAR, 1992). The first community giant clam sanctuary was established in early 1988 at Falevai, Vava'u. Three additional sanctuaries were established in September 1990 with funding from FAO (Chesher, 1993).

Chesher (cited above) reported that recruitment of *T. derasa* and *T. squamosa*, has occurred as a result of the installation of sanctuaries in Vava'u. The Falevai sanctuary was reportedly very successful. However, the same author also wrote that when the villagers abdicated their responsibility to look after the clams, the clams began to vanish. This is presumably referring to the involvement of the Ministry of Fisheries, which took over responsibility for checking on the clams, starting in 1990. Failure of other clam circles were attributed to poaching of broodstock (ACIAR, 1992).

Hatchery

The Ministry of Fisheries was a partner in the second phase of the ACIAR funded project on, "The Culture of the Giant Clam (Tridacnidae) for Food and Restocking Tropical Reefs", from 1989 to 1992 (ACIAR, 1992). The principal objective of the Tonga section was to establish a hatchery-nursery for the production of clams, to enhance local populations, as well as possibly establishing commercial clam farming in the country. The Tonga module was executed by the Ministry of Agriculture, Fisheries and Forestry in collaboration with the James Cook University of North Queensland, and funded by the Australian Centre for International Agriculture Research. Fa'anunu (1993) listed the ACIAR project as providing:

- rehabilitation of the hatchery with all equipment necessary for giant clam spawning;
- operation costs;
- wages for project leader;
- training; two staff in Australia, and 2 in Fiji for 1 month;
- technical advisers; twice/year for 1-2 months duration;
- travel for Project Leaders annual meeting.

The results during the ACIAR phase are reported in ACIAR (1992). The main achievements include:

- the establishment of a hatchery designed for simple operation and maintenance;
- successful application of hatchery production procedures;
- initiation of ocean nurseries for farming trials;
- training for local officers in all aspects of giant clam mariculture techniques;
- re-introduction of locally extinct giant clam species;
- establishment of the presence of the newly described giant clam species, *T. tevoroa*.

A five year Japan International Cooperation Agency (JICA) project, Aquaculture Research and Development Project, was initiated in October 1991. JICA assistance included provision of funds and expertise in various fields. Five long-term JICA experts in fish-culture, seed production, shellfish culture, stock survey and a coordinator, work for the project. The project started with the renovation of the existing land-based mariculture facilities at the Fisheries Division that were damaged by Hurricane Isaac in 1982. The main purpose of the project is to strengthen aquaculture and resource assessment capabilities at the existing mariculture centre in Tonga, and to implement technical cooperation through technical guidance and advise to the Tongan counter-part personnel. Under this programme, stock enhancement of giant clams forms a major component.

Spawnings at the hatchery, and production of juveniles is summarized below for the Giant Clam Project at the Ministry of Fisheries during both the ACIAR project and the current JICA programme:

Spawning and Hatchery Production:

Date	Species	Production	Ocean distribution
Dec, 1989	*T. derasa*	25,000: 8-month old	placed in ocean nurseries 1990
1990/1991	*T. derasa*	30,000: 1-year old	??
1991/1992	*T.derasa*	100,000: May, '92	
	T. squamosa	400,000: May, '92	16,400 to o/nursery in June 1993
	T. derasa	1,700: 5-6-month	500 to Fiji after 3 months
		(1,200: remained in hatchery)	300 to o/nursery in June 1993
Nov., 1992	*T. derasa*	20,000: 3-months old	fast growing 3,500 to o/nursery in Aug-Oct, 1993
Nov., 1992	*T.tevoroa*	2,000: 3-months old	416 to o/nursery in Aug., 1993

Giant clam species introductions

The following clams were introduced into Tonga between 1990 and 1991 as new species introductions, the purpose of which was unclear.

Species	Date	Number Imported	Age at Importation	Number Transferred to Ocean nursery
T. gigas	Aug., 1990	260	10 months	5, Dec., 1990
T. gigas	April/May, 1991	11,000	5 months	2,800 Vava'u in October, 1991
				1,000 Ha'apai in October, 1991
				4,000 Nuku'alofa in October, 1991
H. hippopus	April/May, 1991	20,000	3 months	14,000 Nuku'alofa, November, 1991

Ocean nurseries

Tonga has vast shallow lagoon areas with sandy bottom which are ideal for ocean nurseries. Six trial farm ocean nurseries were established by the Ministry of Fisheries in 1990. These include four in Vava'u and one each on Ha'apai and Tongatapu. Most of the nurseries at Vava'u were set up inside established clam circles (ACIAR, 1992). The farm on Tongatapu is in front of the hatchery at Sopu. ACIAR (1992) listed the number of giant clams in nurseries at the end of 1991 as follows:

Location	Species	Number
Tongatapu	*T. gigas*	3,000
	H. hippopus	14,000
	T. derasa	13,000
Ha'apai	*T. derasa*	3,000
	T. gigas	1,000
Vava'u	*T. derasa*	8,000
	T. gigas	2,000

It was not possible to obtain updated data and information concerning the status of these ocean nurseries.

Two new nurseries were established in 1993 under the current JICA/Ministry of Fisheries giant clam programme. The first one was that on Atata Island, involving the whole community, which was initiated in March 1993. The number of giant clams transplanted in 1993 include 2,000 twenty-month old *T. derasa* and *T. squamosa*, and 20 two-year old *T. gigas*. By October, 1993, only 5 *T. gigas* were left. The second nursery was established in Kolonga in October, 1993. This is also a community undertaking and 2,000 two-year old *T. derasa* have been transplanted there.

Establishment of three more nurseries around Tongatapu is a possibility under the current JICA work programme. Under this 3-year programme, 2,000 *T. derasa* will be given free for each nursery established. In addition, cages and cement blocks will also be given free, providing that maintenance is done and security provided by the community. The project will concentrate on *T. derasa* and *T. tevoroa*. The choice for these two species is because of their superior growth and survival rates (Sone, JICA, 1993, *pers. comm.*).

<u>Funding</u>
The giant clam project in Tonga has been mostly financed by external funding, initially through the ACIAR project and presently JICA.

2.1.6 Western Samoa

<u>Hatchery</u>
In early 1987, the Fisheries Division conducted searches for *T. squamosa* and *T. maxima* to serve as breeders for spawning purposes. The results indicated very low populations around Upolu Island. In late 1987, the Division's Senior Marine Biologist, through South Pacific Aquaculture Development Programme (SPADP) financial assistance, took a three-week training course in giant clam rearing at the Micronesian Mariculture Demonstration Centre (MMDC), Palau. This led to the establishment of a small-scale giant clam hatchery at the Fisheries Division in early 1988. This was funded by SPADP utilizing land-based concrete ponds that were built under Japanese aid (Bell, draft).

Initial propagation trials using only 4 locally collected specimens of *T. squamosa* were successful in mid-1988. Eight thousand juvenile clams were harvested in December of the same year.

Due to the lack of mature broodstock collected locally, twenty *T. squamosa* breeders were imported from Tokelau in early 1990. These were held in the hatchery concrete ponds. A spawning was obtained in 1990 but rearing of larvae was not successful.

No spawning trials has been conducted on *T. maxima*.

The hatchery has been inactive since then except to act as a quarantine station for imported clams.

<u>Introduction of giant clam species</u>
In May 1988, 500 *T. derasa* yearlings were imported from MMDC. About half were kept in the Fisheries ponds and the other half transplanted to Moataa lagoon. Those placed at Moataa lagoon exhibited slower growth and higher mortality than those kept in land-based ponds at the Fisheries. By the end of 1988, only 12 clams remained at Moataa and were taken back to the Fisheries.

Apart from the initial importation of *T. derasa* yearlings in 1988, further shipments were made including other giant clam species. The Namu'a Aquaculture Farms Ltd. imported 700 *T. gigas* juveniles from a private hatchery in Cairns, Australia in September 1990, of which half were dead on arrival. `After two months of quarantine (at the Division's hatchery), the survivors were placed in the ocean nursery at Namu'a (Zann, undated).

One hundred and fifty thousand *H. hippopus* post-larvae were imported from ICLARM's Coastal Aquaculture Centre in the Solomon Islands in November 1990. `Although several thousands reached visible size, all died by February 1991 because of pump failure, high temperatures and heavy rainfall' (Zann, undated).

A consignment, consisting of 10,000 *T. gigas* and 25,000 *H. hippopus* juveniles was donated by the Orpheus Island hatchery. Due to a mislay in New Zealand for several days, only 500 *T. gigas* were alive while only 500 *H. hippopus* were dead on arrival. An additional 10,000 *T. gigas*, to replace those lost in the previous shipment, were donated in July 1991, all of which survived the journey.

A shipment of juvenile clams from the Fiji Fisheries hatchery, consisting of 4,950 *T. derasa* and 270 *T. squamosa*, arrived Apia in July 1992 for the `Giant Clam Rehabilitation Programme'. A second shipment from Fiji, consisting of 1,700 *T. derasa* and 50 *T. squamosa* juveniles arrived in February, 1993. A total of 15,000 clams from Fiji was targeted for this programme. These were for the private farm, Namua Aquaculture Farms Ltd.

Lagoon nurseries

The local private company, Namu'a Aquacultural Farms Ltd, was initiated in 1989 and Fisheries Division donated about 3,000 *T. squamosa* juveniles for their farm at Aleipata, in mid-1989. At the same time, three village clam culture projects were started by the Fisheries Division at Aleipata and Salani. The remaining *T. squamosa* and *T. derasa* juveniles that were held in the Fisheries Division ponds were transferred to the Namu'a farm in late-1990 and 200 of the former and 20 of the latter were placed at the marine reserve at Palolo Deep (Zann, undated). Virtually all of the *T. squamosa* placed in the marine reserve were eaten by predators in the first week.

The severe cyclone, Ofa, that hit the country in February 1990, resulted in an almost complete loss of clams planted in lagoon nurseries.

Additional giant clams were transplanted at the Namu'a nursery in 1991. However, the second cyclone, Val, that hit the country in December, 1991 completely wiped out the stocks. Prior to the cyclone, 23,700 *H. hippopus* seeds, 6,800 *T. gigas* and 4 *T. squamosa* broodstock were in the nursery (Bell, draft).

Juvenile clams, 1,260 *H. hippopus* and 200 *T. gigas*, kept at the Fisheries Division hatchery were transferred to Namu'a after the cyclone Val. In addition, 4,100 juveniles clams from the July 1992 shipment from Fiji, were also transferred to the nursery. As of August 1993, a total of 2,505 *T. derasa*, 160 *T. gigas* and 800 *H. hippopus* were at the nursery while 1,704 *T. derasa* and *T. gigas* were being kept at the hatchery. Meredith (1993, Clamlines No.12, November 1993) reported that the Namu'a Aquaculture Farms Ltd had about 4,000 clams at its lagoon nursery towards the end of 1993.

Extensive shallow sites with sandy bottom exist within the lagoons in Western Samoa which are ideal for lagoon nurseries.

2.1.7 American Samoa

Hatchery

The giant clam project in American Samoa was initiated in 1986 by the Department of Marine and Wildlife Resources in an effort to develop and enhance local reef resources by supplementing the native giant clam populations. One thousand 16 months old *T. derasa* were introduced from MMDC, Palau in the same year. This was followed by two separate shipments, totaling 2,200 juveniles of the same giant clam species in 1987.

A giant clam hatchery was set up in mid-1990 and was operational by the end of the same year. The original objective of setting up a hatchery in American Samoa was for the production of limited clam seeds as "start-offs" for interested farmers and to serve as a demonstration for those interested in running their own hatchery. However, extra costs, the unwarranted option of having a private or more than one hatchery, and the lack of qualified hatchery operators, prompted the Department to concentrate on one hatchery to produce enough juveniles for giant clam farms throughout the Territory.

The larval culture method originally employed was the extensive method. However, due to consistent unsuccessful batch rearings and low production from batches that were successfully reared to juvenile clams, a semi-intensive system was developed. The major improvements applied in the semi-intensive method was the indoor culture of larvae in 1-micron filtered sea-water for the first 8 days, and the provision of 50 per cent shade over the outdoor settling tanks when larvae were transferred there. The improved system took more than a year to complete and to produce much improved results in terms of 5-month old juvenile production. This was due mainly to delays in equipment delivery from overseas and the fine tuning necessary in larval rearing procedures.

Successful clam spawnings and rearing results at the American Samoa hatchery were recorded in Bell (1993b) as reproduced in Table 2.1.1.

Table 2.1.1: Giant clam successful spawning at the American Samoa hatchery.

Spawning #	Date	Species	Larval culture method	Batch fate
1	30 Jan, 91	*T. derasa*	Extensive	no survival by Day 70
2	02 Apr, 91	*T. derasa*	1/2 Extensive/1/2 Intensive	harvested 4,039 5-month old juveniles
3	10 Jun, 91	*T. derasa*	Intensive	complete larvae loss by Day 8
4	30 Aug, 91	*T. derasa*	Intensive	≅ 100 survived to juveniles after Cyclone Val
5	16 Nov, 91	*T. derasa*	Intensive	≅ 60 survived to juveniles after Cyclone Val
6	??	*T. derasa*	Intensive	complete larvae loss by Day 6
7	29 May, 92	*T. derasa*	Intensive, new system	harvested 300 five-month old juveniles
8	17 Jun, 92	*T. derasa*	Intensive, new system	harvested > 25,000 five months old juveniles
9.	09 Jul, 92	*H. hippopus*	spawned on own	batch discarded on Day 3
10	15 Sep, 92	*H. hippopus*	Intensive, new system	complete larvae loss by Day 2

The departure of the programme manager in 1992 resulted in the hatchery becoming inactive in terms of spawning and juvenile production. The operation was limited to maintaining juvenile clams produced from spawnings in early 1992. This led to withholding of funds by funding agencies which eventually resulted in a complete non-operational status by about mid-1993.

<u>Giant clam importation</u>

Prior to the establishment of the giant clam hatchery, juvenile clams of *T. derasa* were introduced from Palau for ocean culture trials. Due to the absence of mature broodstock of the target species, *T. derasa*, when the hatchery in American Samoa became operational in 1990, six years old breeders were also imported from MMDC. Under comparative studies of different species, juveniles and broodstock of *H. hippopus* were also introduced. The involvement of American Samoa in one of the regional giant clam projects resulted in the introduction of *T. gigas*. Table 2.1.2 records all the importation of giant clams under the project, as recorded in Bell (1993b). All of the imported clams underwent a quarantine period in land-based tanks prior to transplanting in the lagoon nurseries.

Table 2.1.2: Giant clam introductions for the American Samoa giant clam project.

Date	Species	Number	Generation	Clam Age	Source
26 Nov., 1986	*T. derasa*	1,000	F1	16 months	MMDC, Palau
12 Nov., 1987	*T. derasa*	1,400	F1	18-21.5 months	MMDC, Palau
17 Nov., 1987	*T. derasa*	800	F1	2.5 months	MMDC, Palau
12 Sep., 1990	*T. derasa*	22	F2	6 years	MMDC, Palau
18 Jan., 1991	*T. derasa*	18	F2	6 years	MMDC, Palau
22 Feb., 1991	*T. derasa*	1,800	F2	15 months	MMDC, Palau
20 Jun., 1991	*T. gigas*	2,000	F1	14 months	MMDC, Palau

23 Jun., 1991	*T. derasa*	2,000	F2	12 months	MMDC, Palau
29 Oct., 1991	*T. derasa*	1,000	F2	12 months	MMDC, Palau
29 Oct., 1991	*H. hippopus*	1,000	F2	26 months	MMDC, Palau
29 Oct., 1991	*H. hippopus*	25	F2	3.5 years	MMDC, Palau

Lagoon nurseries

Three lagoon nursery sites were established under the project. All of the sites were located within lagoon areas in different villages all having different depths. The shallowest site (at Ofu) was only three feet at low tide and was only a short distance from the barrier reef. The area was sometimes affected by strong wave action and currents. The "farm" site was in an area where rocks and coral heads were removed for the nursery and the bottom was sand and rubble. The second site (at Alofau) was about 8 feet deep but was not too close to the barrier reef with the bottom substrate being sand/rubble. This area sometimes received fresh-water influxes. The best site was located at Nu'uuli at which clams were planted at depths of 11-15 feet. The areas used were quite far in from the barrier reef and thus well protected from wave action and strong currents. This was actually a "hole" in the lagoon with sand bottom and good coral growth nearby. Table 2.1.3 records transplanting details from each site.

Table 2.1.3: Details of giant clam ocean lagoon transplantation in American Samoa.

Nursery site	Start date	Depth (ft)	Species	# clams planted	Age (months)	Clam Tally, July 1992
Nu'uuli	1 July, 1991	4	*T. derasa*	408	20	401
		10	*T. derasa*	408	20	357
	13 Sept., 1001	14	*T. derasa*	112	22	105
		16	*T. derasa*	112	22	103
	28 Feb., 1992	4	*T. derasa*	292	16	216
			H. hippopus	292	20	291
	28 June, 1991	11	*T. derasa*	1,971	12	1,796
			T. gigas	1,929	14	1,539
	June, 1992	15	*T. derasa*	1,980	15	1,949
Alofau	25 Nov., 1991	8	*T. derasa*	100	24	48
	28 Feb., 1992		*T. derasa*	120	13	12
			H. hippopus	120	17	11
Ofu	14 June 1991	3	*T. derasa*	371	19	156
	12 Nov., 1991	3	*T. derasa*	320	13	215
			H. hippopus	320	17	259

Mortality was low in the Nu'uuli nursery mainly because manually collection of the predator snail, *Cymatium muricinum,* and maintenance were conducted three times a week there. In addition, the area was well protected from wave action and strong currents. Even during Cyclone Val, clam losses at this site was minimal. Clam losses recorded in the other sites were quite high. The main causes were *Cymatium*, waves action and Cyclone Val. Current status of the established nurseries is not known.

American Samoa has limited lagoon areas ideal for ocean nurseries due to the limited barrier reefs in existence.

Funding

The American Samoa giant clam project was almost completely funded by external funding agencies including employment of the programme manager.

Summary

The summary accounts of the status of various projects around the region helps to emphasise various aspects of giant clam culture. These are:-

1. Only four hatcheries are selling clams at the present time.
2. Most hatcheries have depended on external aid funds.
3. If strong leadership/ expertise is unavailable hatcheries tend to flounder.
4. Cyclone damage has been the major cause of catastrophic loss throughout the region, including countries which have ideal sites for both hatcheries and lagoon nurseries.
5. Ocean nurseries require a lot of maintenance and manual removal of predator snails to minimize mortalities.
6. Production in most of the smaller hatcheries is unpredictable.
7. In many of the areas where hatcheries are based, introductions of clams have also been made. These have not always followed strict quarantine protocols and disease/parasite introductions are very likely to have occurred.
8. High land based production of clams does not guarantee a high number of marketable animals.
9. The success of giant clam circles is difficult to quantify and is also subject to catastrophic loss due either to poaching or cyclone damage.
10. Giant clam farming is now moving from the development phase to the commercial phase and its commercial viability looks assured.

2.2 Fresh-water Prawns (*Macrobrachium rosenbergii*)

The culture of the giant Malaysian fresh-water prawn, *M. rosenbergii*, has been initiated in several South Pacific Islands where environmental factors, such as, soil characteristics and availability, and water resources, are more ideal for inland fresh-water aquaculture. Most of these islands are volcanic; have deep top-soil with appropriate texture and characteristics, such as high water holding capacity, for the construction of earthen ponds; have perennial streams or springs for water supply fed into earthen ponds by gravity; ideal culture-water temperatures throughout the year and the existence of other developments, such as feedmill, which are relevant to aquaculture development.

To date, none of these undertakings have reached commercial production level of this species due to various factors.

2.2.1 Western Samoa

One thousand juveniles of *M. rosenbergii* were imported from AQUACOP (now IFREMER), Tahiti, in 1979, and stocked in brackish water ponds used for the culture of the Mexican molly, *Poecilus mexicana*, for live bait for the pole-and-line skipjack fishery. Under low stocking densities, the prawns had good growth and survival rates. The prawns that survived served as broodstock for the first propagation experiments conducted at the Fisheries Division hatchery in Apia.

For grow-out, three earthen ponds (one 1,740 and two 2,900 m^2 surface area totaling to less than 10,000 m^2) were constructed at Solaua. This site was estimated to be capable of supporting 50 acres of earthern ponds considering land availability (large flat area), soil suitability (topsoil depth of more than 1 m and good water holding capacity) and stream water availability (perennial stream flows through the land).

Because of the difficulty, inconsistency, risk of introducing pathogens and high costs involved in depending on overseas supplies of prawn post-larvae, a fresh-water prawn hatchery, to supply post-larvae for the grow-out ponds, was established at the Fisheries Division in Apia. The facility was capable of producing 180,000 post-larvae per year. Larvae culture method employed was originally a hybrid of the Hawaiian “green water” and the CNEXO intensive “clear water” systems. The system that was eventually established was a variation of the clear water one. Survival rates from larvae to post-larvae was around 40 per cent with a rearing period of 35 to 40 days. The production costs were estimated to break-even at WS$25.00 per thousand post-larvae produced.

The prawn culture period in the grow-out ponds, from post-larvae stocking to marketable size, was usually 8 to 11 months with partial harvest conducted in the 6th and 7th month. The production from one pond was 363 kg in eight months with some individual prawns weighing 57-91 g each after 10 months of pond culture. The calculated production would thus be about 0.1252 kg/m^2/year (or 1,252 kg/ha/year) to 0.2086 kg/m^2/year (or 2,086 kg/ha/year), which is considered low for a commercial operation.

Local and overseas markets were identified. The APEX company in Cook Islands offered to take a weekly supply of 500 lb of prawns, head on, at US$5-6 per pound.

The government hatchery provided the local prawn farm, which was private, with post-larvae free of charge for a few years as an incentive. However, the local entrepreneur abandoned the project when government decided, in 1983, to apply the break-even costs of production from the hatchery. The entrepreneur claimed that prawn production from the ponds was not sufficient to cover his expenses. The Fisheries Division continued to maintain *M. rosenbergii* broodstock until the whole project ceased in 1987 due to lack of interest shown by those who had potential sites.

The results indicate that fresh-water prawn farming was technically feasible, but economically risky, in Western Samoa. The low prawn production, leading to low returns as compared to input, was attributed to several factors listed as follows:

- poor pond management (due to lack of "know-how" experience)
- poor intake water engineering
- water seepage from the ponds
- lack of proper feed (absence of a suitable inexpensive binder)
- high initial investment.

2.2.2 Fiji

The fresh-water hatchery was opened up in 1983 at the Naduruloulou Research Station. The hatchery was capable of producing 500,000 post-larvae (Pls) per year but had the potential of producing 3-4 times this number. The *M. rosenbergii* project was part of the Fiji/Japan Aquaculture programme. A Japanese Prawn Expert and his team of local staff successfully produced Pls from a makeshift hatchery towards the end of 1982 and in 1983 a permanent hatchery was established and hatching techniques improved upon in each succeeding year (Ledua, 1992).

Larval rearing trials continued, and in 1984, 5,300 pls were produced. Trials on artificial feed formulation were conducted.

The hatchery produced more than 300,000 pls during 1985. Mass production of this species was found to be technically feasible under Fiji conditions.

Due to the high mortality rates experienced when stocking pls directly into earthen ponds, a series of intermediate culture trials were conducted in 1985 and 1986 at the Naduruloulou Research Station (Takano, 1987). Production from ponds after 6-8 months of direct stocking ranged from 200-1,100 kg/ha/year (Vereivalu, 1987. *pers. comm.*). The aim of providing an intermediate phase was to provide a culture medium to condition pls fresh from the hatchery prior to introduction to the earthen ponds. The concept was that survival during this phase can be minimized by maintaining good water quality and produce healthy, hardy prawns for the grow-out phase in the earthen ponds. The trials utilized knock-down tanks. The results were not satisfactory due to slower growth rates obtained in the tanks than it did in ponds. The mortality rates were also not improved.

By 1986 hatchery production reached the 1 million pls per year mark and yields of up to 1.2 mt per ha per year were achieved in the grow-out trials at the Naduruloulou Research Station. Work on feeds formulation and grow-out trials were continuing (Fisheries, 1986). Grow-out trials continued in 1987 and a start was made on prawn/fish polyculture. Initial results were very promising (Fisheries, 1987). Hatchery production in 1988 was 90,000 pls. These were used for the poly-culture trials with tilapia and grass carp (Fisheries, 1988).

Lal (1987) reported an average production from the hatchery of 64 pls per liter and estimated production costs at $7.00 per thousand pls. The larvae culture method used was the clear-water technique and the facilities was capable of producing 2 million pls annual.

Attempts to rear larvae of the native fresh-water prawn, *M. lar*, failed. The larvae could not survive in freshwater or low salinity (below 25 per cent) except that some managed to survive to the fifth zoea stage in salinity of 25 per cent.

Experiments on feed formulation continued during 1991 with some promising results. No pls were produced.

Despite vast improvement in rearing techniques, no one took up the venture as a commercial undertaking (Ledua, 1991). Reasons for project unattractiveness include, low market price, high feed cost, and technical constraints. The project came to a halt in 1992. Problems were encountered with *Macrobrachium* culture in ponds at the station, which led to stunted growth and high mortalities in juvenile prawns fed with local chicken grower pellets. It was suspected that feed was one of the sources of the problem and thus the study for a better feed (better binder and higher protein content) was initiated in 1992. Two JICA experts were recruited in August 1992 for this purpose. However, since there were no more *Macrobrachium* left by that time, the experts started work on formulating feed for tilapia and carp until more *Macrobrachium* are imported (Vereivalu, 1992, *pers. comm.*). In addition, the yields obtained from grow-out culture were low for commercial production.

However, plans for this project include a new start at the end of 1992 to re-assess the potential using locally formulated feeds etc. from the JICA feed formulation project underway at that time (Ledua, 1992). There were no more *Macrobrachium* broodstock by mid-1992 so stocks would have to be imported again. No updated information could be obtained.

Ideal conditions for inland aquaculture exist in Fiji. Soil is deep and has the correct characteristics for construction of earthern ponds; it has perennial rivers and optimum temperatures.

2.2.3 Solomon Islands

The South Pacific Aquaculture company started its fresh-water aquaculture operation at Aruligo in the late 1980’s using nine 1-acre earthen ponds culturing *M. rosenbergii*. However, the operation using this prawn species was found to be uneconomical due to several factors and problems. The main ones include:

- shortage of fresh-water during some periods at the site;
- long culture period of about 1 year before harvest;
- a lot of wastage from the harvested prawns as the head makes up more than 50 per cent of the body weight; leading to,
- low returns.

Subsequently, the operation switched to culturing the marine shrimp, *Penaeus monodon*. This necessitated construction of new earthern ponds closer to the sea, the source of culture water. The venture has since been successful and additional grow-out ponds are currently being constructed.

2.2.4 Cook Islands

The culture of the giant Malaysian fresh-water prawn, *M. rosenbergii*, was initiated in Cook Islands in early 1992 after a technical officer from the Ministry of Marine Resources had completed an attachment on prawn rearing with EVAAM in Tahiti (Richards, 1993). Two 250 m^2 ponds, constructed on private land at Matavera on Rarotonga near a good on-land water supply, were stocked with 5,000 post-larvae each. The prawns were fed with pelletised feed. Initial mortality in the first four weeks was 15 per cent followed by approximately another 20 per cent

(Richards, cited above). The prawns were harvested from the ponds on 25 May 1993 (about 1 year after stocking) with a yield of 5,000 prawns weighing a total of 80 kg (Richards, cited above). This is equivalent to a yield of 0.16 kg/m^2 or 1,600 kg /ha/year. This yield is low as far as commercial operation is concerned.

The following observations were made by Richards (1993) concerning results of the first fresh-water prawn culture trial in Cook Islands:

- prawn farming is technically feasible (possible) in Cook Islands;
- high costs of imported feed (NZ$8.00 per kilogram) preclude an economically viable operation at this stage;
- further work would be required to establish the economic feasibility of farming this species of prawns in Cook Islands;
- factionalised land-tenure disputes may be problematic.

Summary

1) Apart from French Polynesia and New Caledonia which receive a lot of assistance from France, the culture of the fresh-water prawn, *M. rosenbergii*, has been tried in only a few (4) island countries in the South Pacific;
2) All of these islands are volcanic, have deep and good soil characteristics for earthern ponds construction, most have good surface water supply and optimum temperature range;
3) Consistent, reliable and sufficient water supply is vital to the success of the prawn farming operation. Unreliable water supply was one of the major factors that caused the operation in Solomon Islands to switch to culturing saltwater shrimps;
4) Commercial size ponds require very high initial investment;
5) Due to high costs of juvenile prawns importation, freight mortalities, unreliability of overseas sources, possibility of introducing new pathogens and diseases and the relatively ease in producing juvenile prawns, hatcheries were also set up in two of the four South Pacific countries that initiated prawn farming;
6) Hatchery production levels attained were considered good for commercial purposes, but obtaining consistent production was a problem;
7) Formulation of proper local feeds for the grow-out phase in ponds was a problem leading to stunted prawn growth and thus low production;
8) Imported commercial feeds for prawns were very expensive;
9) Productions from grow-out ponds were mostly low for commercial purposes and thus the operations were uneconomical;
10) Yields were also inconsistent due to various reasons which were not specifically identified;
11) The market value of fresh-water prawns is relatively low as compared to cultured salt-water shrimps;
12) The relative large head portion in fresh-water prawns is a disadvantage in terms of value for markets;
13) Local markets are limited but markets appear to exist in neighbouring countries;
14) Prawn culture projects in Fiji and Western Samoa have been abandoned. Further development of the project in Cook Islands is uncertain.

2.3 Fresh-water Crayfish: the Australian redclaw, *Cherax quadricarinatus*; the yabby, *C. destructor*; and the marron, *C. tenuimanus*.

2.3.1 Western Samoa

The only culture trial of fresh-water crayfish conducted in the South Pacific islands was that done in Western Samoa. This involved the species; *C. quadricarinatus* and *C. destructor* introduced from Australia in early 1993. The introduction was also the only one which has taken place, so far, involving these species to any South Pacific country. The project was a joint venture between a local family and an Australian partner.

The ponds utilised were those used for the fresh-water prawn culture in the late 1970's and early 1980's at Solaua.

Two separate shipments of crayfish juveniles, totaling approximately 6,000 individuals, were made during the March-April, 1993 period. The juveniles were transferred directly to Solaua on arrival and distributed into three earthen ponds already filled with fresh-water.

After about a month of the operation, the farm manager (Australian partner) left. No records could be located on any aspect of the grow-out operation prior to the departure of the manager. This prompted a request from the local entrepreneur to the Fisheries Division for advice on feeding, pond maintenance and operation as well as marketing. He was only concerned with recovering at least some of his financial investment in the project.

Uncooked rice, and occasionally taro, was used as feed. These were administered twice a week at a rate of 10 kg per week for each of the three ponds. After experiments with locally available material, a feed comprising of spent barley from the brewery, taro scraping, uncooked rice and tripe was formulated and administered.

After about 6 months of pond culture, a sample of the crayfish was taken in September, 1993. The sample indicated that the average weight of the animals for each pond ranged from 20 to 80 g. After two weeks of application of the new formulated feed and feeding schedule in October, 1993, the average crayfish weight for the three ponds was 74.1 g (Pond 1 - 85 g, Pond 2 - 64.5 g, Pond 3 - 72.7 g). This corresponded to an average increment of 9.55 g per week. Berried female crayfishes as well as crayfish juveniles were observed in November, 1993 (Mulipola, 1994). This indicate that natural reproduction had been established. The large crayfishes observed were 90 g and more which is bigger than the usual marketable weight of 80 g for these species.

In November, 1993, one of the ponds completely drained out due to a big hole near the sluice gate caused by burrowing crayfishes. A lot of these holes were also discovered along the pond sides and bottom causing collapsing of side walls and water leakage from the bottom (Mulipola, quoted above). Crayfishes were able to crawl out of the ponds and across to the nearby stream even after erecting a corrugated iron fence around the perimeter of each pond.

Overseas markets for the locally cultured crayfish has been tried in Fiji and Cook Islands. A sample of thirty 80 g crayfishes was sent to Cook Islands while approximately 700 animals were sent to Fiji to assess their market value there. There has been no information received from these markets yet. Harvestable size crayfishes were also sold to local restaurants and shops.

Summary

1) The culture of fresh-water crayfish has only been tried in one South Pacific island country;
2) The ponds used were those originally utilised for the culture of freshwater prawns;
3) The basic requirements for fresh-water prawn culture also apply to fresh-water crayfish. However, fresh-water crayfish culture demands additional requirements, e.g. (i) provision of hiding places to avoid burrowing causing ponds to collapse and (ii) a fence is required around each pond to prevent crayfish from escaping as they have the capability of crawling across land;
4) Growth, survival and production rates have not been properly assessed in island situations;
5) Formulation of local feeds have not been properly formulated and tested;

6) Markets are not assessed yet.

3. AQUACULTURE FEASIBILITY STUDIES ON NIUE

The species of interest for aquaculture were identified by the Niue Government prior to the field-work. Accordingly, certain environmental parameter requirements for the culture of those species were selected as key (determining) factors in assessing the feasibility of setting up an aquaculture venture on Niue. For inland fresh-water aquaculture, the main factors taken into account include; land availability, soil availability, soil type, texture and characteristics; fresh-water availability and costings involved; access to markets, for supply of juveniles, feed and export of products; and other minor factors. Further consideration of the minor factors were discontinued, and thus not discussed in this report, because of the results obtained concerning the main determining factors. For giant clams, the main factors considered were; availability of suitable sites for construction of a hatchery and land-based nursery; possible systems for supplying sea-water; availability of suitable sites for ocean nurseries and grow-out; access to markets; the particular requirements of the aquarium market and the cost of marketing relative to other producers. Suggestions for alternative management regimes for the local giant clam stocks are also given.

3.1 Giant clams

3.1.1 Hatchery - site selection factors

The evaluation of the potential for the farming of giant clams on Niue was conducted by assessing the suitability of sites for both land based hatchery culture and ocean nursery culture. There is a basic checklist of selection criteria for the siting of a hatchery and ocean nurseries which have been summarised by Heslinga (1990), Braley (1992) and Calumpong (1992). Every giant clam farm established to date has used both phases of the culture process due to the high cost of holding clams in tanks throughout the whole culture period. The requirements of each phase are discussed separately where necessary. Factors such as meteorological effects, infrastructure, personnel and water quality are common to both aspects and are discussed below.

a. Meteorological effects

Niue lacks an outer reef and is isolated in a vast area of the Pacific. Because of this factor, wave action is directly related to meteorological conditions occurring both near and far from the island. The prevailing winds are from the North East to South East. A wind rose showing mean wind frequency, speed and direction is given in Figure 2, as reproduced from Kreft (1986).

Surface winds in the South East trade wind regime are usually moderate to fresh but locally may be 35-50 km/h for a few days at a time (Kreft, 1980). This trade wind regime results in a rugged Eastern coast that is often subjected to high wave conditions.

Niue lies in the cyclone belt, with the vast majority of cyclones coming from the Northwest. The west coast of the island is therefore most subjected to wave damage during cyclones. There have been 18 cyclones recorded between 1905 and 1990, an average of one in every 4.7 years. Major cyclones have struck the islands in 1959, 1960, 1968, 1979, and 1990. Cyclone Ofa, in 1990, caused extensive damage to the island with waves overtopping cliffs 18m high, causing damage to buildings situated adjacent to the cliffs and up to 100 m inland.

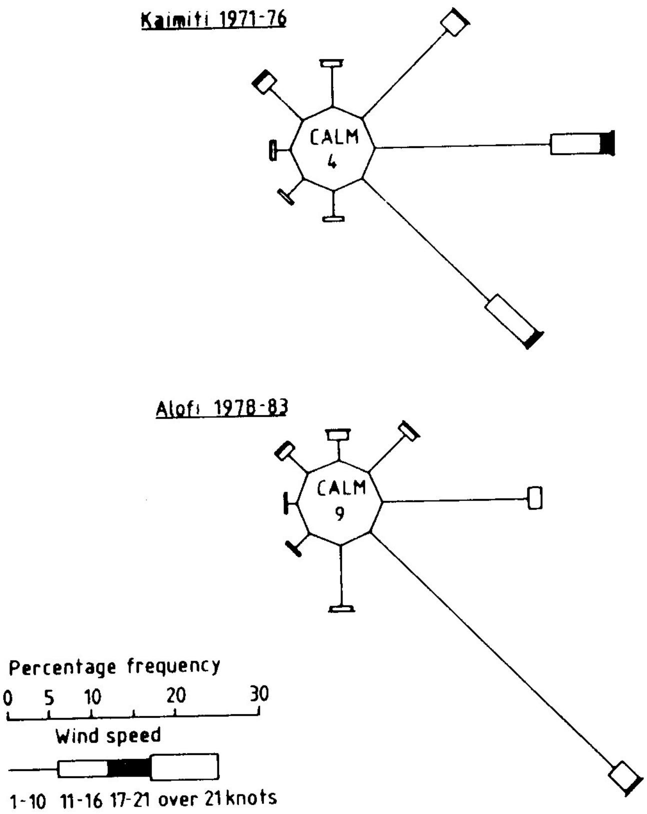


Figure 2: Mean annual wind frequencies (percentage) of surface wind directions frequencies from 3-hourly observations for Kaimiti and Alofi (Source: Kreft, 1986).

b. Site evaluation.

The basic topographical characteristics of Niue are described in section 3.2.2.b. but of special importance to the positioning of a hatchery is that the island is a raised coral atoll with the top of the cliffs being at least 8m above sea level in most areas. The height of the cliffs and the available land area puts an immediate premium on the cost of pumping seawater into the hatchery facilities. A hatchery is best placed as close to sea level as possible. Most giant clam hatcheries throughout the region have a pumping head of less than five metres inclusive of friction loss.

Niue has no lagoon and the coastline of the island descends precipitously to over 1,000m within 5 km of the shore. There is no true hermatypic coral reef . Instead the island is in part surrounded by a rock platform varying from a few metres to just over a 100 metres in width. Large parts of this are subtidal, the remainder intertidal (Dalzell *et al.*, 1993). The consequences of this lack of seaward protection on the establishment of a hatchery are that the degree of protection to capital equipment such as pumps and pipelines is minimal and made more hazardous due to the nature of the sharp limestone cliff rock. The installation of a pumping system would therefore be both risky and expensive. The choice of suitable sites is therefore limited. Map studies coupled with notes on the recommended areas as given by Bell (1993a) resulted in four sites being inspected more thoroughly as potential hatchery areas. These sites are compared in Table 3.1.1.

Table 3.1.1: Comparison of four potential hatchery areas on Niue.

Site	Avatele	Fakailena (In Alofi)	Limu sea track near Namakulu	Amanau
Land owner:	Village	Family	Village	Government
Elevation:	7 metres	8-10 metres	5-10 metres	18 metres
Pumping site:	Protected bay, good flushing	Rough limestone cliff into deep water	Normally protected area at base of seatrack	Cove beneath cliff or via borehole into cave
Area available:	Sloping site 20x40 m	Rough pinnacles 30x40m	Small flat area of 10x30m	Leveled areas of 20x40 & 20x60m
Exposure:	Site flooded to 20m in cyclone Ofa	Rough cliffs and subject to overtopping by waves	Exposed area in cyclone conditions	Height gives good protection from waves but was overtopped by Ofa, pipeline problematical
Electric supply:	Single phase power at site	Three phase power 100m away	Single phase close to site	Three phase supply at site
Access:	Sea track adjacent to site	No direct access road 100 m	Sea track adjacent to site	Direct access
Ranking:	2	4	3	1

Additional notes:

Avatele: the site has a good area for pumping from and an easily worked land area. The area is too small however to site a commercially sized hatchery. It would be suitable for a quarantine area or small hatchery. Being at such a low elevation is at risk of being destroyed in a cyclone.

Fakailena: exposure of site, leveling costs and lack of protected pumping area are negative features of the area - not recommended.

Limu: the small area, leveling requirements of adjacent areas and potential inundation during cyclones are negative aspects of the site.

Amanau: very high pumping head (18m). Possibility of putting borehole into a saltwater cave beneath site would reduce exposure of pumps to storm damage but is technically difficult and expensive. Height of site would make it the least at risk to cyclone damage. Suitable land area and adjacent facilities.

Recommendation:

Given the limited choice of sites, the site at Amanau provides the largest area adjacent to existing facilities and although still under threat of inundation in a cyclone, it has the most protected shore facilities. To reduce the risk of cyclone damage, tanks could be created by dynamiting rock to create sunken rather than free standing tanks. The cost of dynamiting would also be a cheaper option given the high cost of cement on Niue. A quoted cost of US$11.14 per cubic metre of blasted rock was given by the Public Works Division. This does not, however, overcome the cost or difficulty of pumping to the site. The cost of pumping to 22m is high and could not be done using a centrifugal pump without it being placed at the base of the cliff where it would be exposed to storm swells. A submersible pump would therefore need to be used. This could either be pumping from the cove below with the pipeline enclosed in a casing and attached to the cliff face or the possibility of drilling a borehole into a saltwater cave under the site was investigated. A dive in the cave revealed very clean walls indicating extensive scouring and wave action. Talks with the local civil engineer indicated that the precise drilling of a bore into a saltwater cave would be technically difficult. The cost of a bore would be high as there is no longer a drilling rig on Niue, special importation would therefore be necessary. With a rig based on Niue an estimated amount for a bore of this depth would be NZ$3,000.

c. Infrastructure

Due to its size and relative prosperity, the infrastructure serving Niue is excellent. There is a comprehensive road network both encircling and crossing the island. As mentioned previously, there are a number of newly constructed sea tracks that allow access to the shore in areas that were previously hard to reach or inaccessible.

Electricity is available around the island although three phase power is only available in and around Alofi township itself. Three phase power would be advantageous to a hatchery in that it provides a cheaper option especially in terms of maintenance if using electric pumps for the hatchery facility. Electricity costs are high, being 32 cents per kwh, which is a subsidised rate. The actual cost is 43 cents per kwh. The subsidised cost is almost double that of places such as Palau and the Solomon Islands giving an immediate commercial disadvantage. As power is not a high percentage of the operating costs for a hatchery this in itself is not of too much concern. Of more importance is that the supply is reliable. This and the fact that diesel costs are high, would indicate the use of electric pumps. The availability of electricity would also enable submersible pumps to be used which would be a major advantage in an area where low elevation pumphouses are at risk.

Internal and external communications are excellent with a telephone system that serves the whole island and provides international telephone, telex and facsimile communications.

Shipping and air transport are available on a regular but limited basis. There is a monthly ship service from New Zealand that serves the island bringing most of the food and hardware products and can carry refrigerated or freezer containers in addition to normal containerised cargo. Currently there is no frozen product being shipped out from Niue. The cost of a freezer container to Auckland is approximately NZ$3000. Air services are also good with flights Niue-Apia, Niue-Rarotonga and Niue-Auckland once a week. The weekly flights to Auckland are an Air Nauru service and there appears to be some doubt as to the continuity of this service.

The DAFF has a limited amount of technical equipment that would be of use to a hatchery facility on the island. Such equipment includes bench saws, arc welders and compressors. There is no fibreglass used on the island but cement mix and blocks are locally available although at a high cost. One cubic metre of ready mixed cement costs NZ$158.63 and the price per cement breeze block is NZ$3.00 per piece at the government rate. The technical expertise to construct and maintain buildings, mechanical and electrical equipment is locally available.

d. Water quality

The quality of seawater adjacent to Niue is excellent for giant clam rearing, although the low temperatures in winter are likely to suppress growth rates and result in distinct spawning seasons. The silt load is very low with visibility of 30m or more. There is freshwater influx at some points on the coastline where it seeps out from the freshwater lens, but generally the water is pure oceanic at 35 ppt (parts per thousand). The dissolved oxygen levels are high and if anything, it would be supersaturated at many potential intake zones due to the surf breaking over the reef flats. A normal seawater pH is expected and pollutant loading would be negligible due to the very low population density. The only area that may be of reduced water quality is at the wharf in Alofi as ship discharge is possible here. The parameter of water quality that is not ideal is the water temperature fluctuation. Mean air temperature ranges from an average in Alofi of 26.6°C in February to 22.9°C in July and August. The mean monthly temperatures for Alofi between 1930 and 1980 are given in Figure 3 (as reproduced from Kreft, 1980).

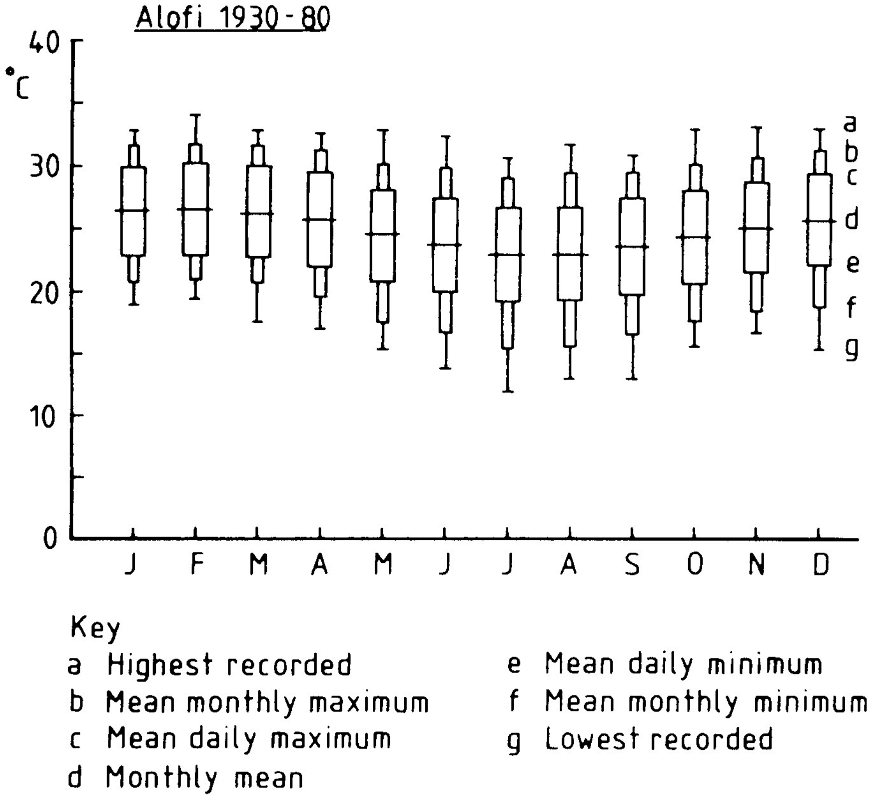


Figure 3: Mean monthly temperatures for Alofi between 1930 and 1980 (Source: Kreft, 1986).

Kreft (1980) summarises details on the seawater temperature as follows "the mean monthly sea surface temperature of the sea in the vicinity of Niue ranges from approximately 24°C in the cooler months to 28°C in the warmer months (estimated by Taylor and Thompson, 1980). The annual cycle of sea surface temperature is consistent with the mean air temperatures as shown above, the sea surface temperatures being generally 1-2°C warmer in all months". Such annual variation would affect giant clam farming in two ways. It would firstly result in a short spawning season. The temperature profile shown in Figure 2 would suggest that clams would spawn between December and March when the temperature is highest. One consequence of this is that the risk of loss of clams due to disease / pump failure etc. and then being unable to replace them by a subsequent spawning is greater. It will also be of no benefit of having clams in the tanks for less than a year as they could not be replaced by a second spawning. The second consequence of lower temperature will be a slower growth rate of clams as compared to clams being grown in countries near the equator. The growth rate of clams in Tonga, at a latitude of 22° South, is dramatically less than those cultivated elsewhere. The giant clam project at James Cook University's Orpheus Island research station, which is on a similar latitude to Niue, had problems of winter mortality and reduced growth rate in winter. Niue's temperatures would not be as low as those found on Orpheus Island as it has much greater maritime influence but is likely to merit the use of a similar greenhouse setup in winter to that used on Orpheus island. Naturally this will be more expensive than an open system.

e. Personnel

The personnel available in the Fisheries Division are of a high calibre but are limited in numbers. There are two permanent staff officers, one with a B.Sc. and one with a Certificate in Tropical

Fisheries. The graduate has also had experience with giant clam farming gained at James Cook University. The Division has two casual staff. Both of the officers are qualified divers and there is a dive instructor working on Niue who could train recruits. Given the scope of the present fisheries programme there would have to be further recruitment to staff a hatchery. A minimum of one full time manager and two full time casuals would be required for a small hatchery operation. Training at an existing giant clam hatchery, such as ICLARM in Solomon Islands or MMDC in Palau, is highly recommended if a hatchery was to be built.

f. Potential environmental impacts

Giant clam farming is a relatively innocuous activity when compared to other industrial or intensive farming processes. The impacts on the environment of setting up a giant clam operation are as follows:

Land. Coastal land shall be utilised. In the majority of countries where giant clam hatcheries have been set up, this is the most sought after and therefore expensive land. However, Niue has extensive areas of unutilised coastal land and the area identified as the most suitable for a hatchery belongs to the government.

Water requirement. A land based nursery has a small requirement for freshwater, which is mainly used for the washing of tanks. The consumption rate would be similar to a large household. The seawater requirement is large but would be for raw unmodified seawater and so, in itself, would have no impact.

Effluent. The main effluent would be seawater. The farming of giant clams results in only minor modifications to the seawater, because clams are predominantly phototrophic and are therefore not given any organic material to stimulate growth. Fertiliser in the form of ammonium sulphate or nitrate is added on a daily basis at a rate of 20 ppm and some farms add phosphorous once a week at a rate of ???. These quantities are reduced in the tank by the clams and are so small on exit from the system that no impact, such as enhanced algal growth is noted at the outlet points of established farms. In other cases though, fertilizers are not used at all. Other effluent takes the form of pseudofaeces from the clams, basically consisting of dead or dormant zooxanthellae (symbiotic dinoflagellates), faeces from the grazers that are used for cleaning algae from the tanks and algae itself. Cleaning of tanks usually involves the use of bleach. It is standard practice to run effluent with bleach to ground.

Visual impact. Giant clam farms are usually regarded as having a positive environmental impact, not necessarily for the constructions themselves but for the attractive animals that they contain.

3.1.2 Ocean nursery - site selection

a. Site availability

The criteria required for the selection of an ocean nursery site are described by Heslinga (1990); Braley (1992) and Calumpong (1992). The basic requirements are for shallow, easily accessible, protected water of a high quality.

The topography of Niue, combined with its exposure to severe weather conditions means there is no site that would normally be identified as an ideal ocean nursery. The weather coast of the island would not allow regular access to an ocean nursery site due to the wave conditions. The leeward coast is affected by cyclonic conditions as described above. To escape damage from wave conditions as encountered during a cyclone, an ocean nursery would have to be placed at depths greater than 10 m. Survey of a potential ocean nursery site in Avatele revealed that Cyclone Ofa had caused a high level of damage to a depth of 20 m. The seabed was composed of base rock on top of which was a significant regrowth of a variety of branching and massive corals. It was obvious therefore that cyclone Ofa had destroyed the majority of coral outcrops.

To operate a normal ocean nursery, which consists of cages placed on trestles in such an environment is unlikely to be a viable proposition. To manage an ocean nursery at a depth of greater than 10 m would both be costly, due to the capital and operating costs of the dive equipment necessary and be restrictive in the time available for ocean nursery monitoring.

There are two other alternative options in this type of environment.

One option would be to place clams directly into holes in the rock initially covering them with a net using a method similar to that used in Okinawa for the restocking of reefs with *T. crocea.* This option would be viable for a restocking programme but would be a difficult method to employ if a large number of clams were to be settled in this manner as would be the case for a commercial operation. This method is also unlikely to be of any benefit to *T. squamosa* as unlike *T. maxima* this has no burrowing capability.

The second option is to use floating ocean nurseries (FON's) but the level of exposure in Niue is likely to be substantially higher than other sites where FON's have been used. It is therefore unclear as to how transferable this method would be. In cyclonic conditions clams would either be transferred to a land base or lowered into deep water.

b. Environmental impact

Reef: Traditional ocean nurseries using benthic cages cover a relatively small area. For instance that used by the MMDC covers an area of approximately 100x30 m. In order to reduce impact such nurseries are placed on gravel substrates rather than over areas of coral. The only impact from this is therefore the shading effect on the gravel that will reduce algal growth, which is however, more than compensated for by the algal growth on the clams and cages. If the technique of planting clams directly into the reef was attempted then it is likely that due to the husbandry activity being carried out in the area, coral growth would be affected within that area. The use of FON's in shallow waters would cause shading and increase siltation. However, since the areas in Niue would be deep, these effects would be minimal.

Water quality. Giant clams when gathered in a large group, act as a sink of inorganic nutrients but are probably a source of organic matter. They can therefore stunt the growth of organisms that rely on inorganics, such as corals, in the immediate vicinity if such material were not in sufficient quantities to accommodate the additional needs. But due to the output of pseudofaeces, and more importantly, the provision of a large surface area by both clams and cages, ocean nurseries generally act as artificial reefs attracting a variety of both molluscs and fish herbivores and consequently carnivores.

Visual impact. The only time that an ocean nursery will have a visual impact from the land is when FON's are used. These can either take the form of longlines or a series of rafts. The extent of the nursery is obviously related to production, but usually one 7'x4' raft would support 2,400 six-month old clams. Benthic culture of giant clams would provide a scenic environment for divers.

3.1.3 Market Access

There are three main markets for giant clam products and an incidental tourist market that may be utilised. Each of these shall be discussed below in the Niuean context.

a. Aquarium market

It has been estimated by Gervis (1993) that the size of the aquarium market is between 300,000 - 450,000 aquarists in the U.S.A alone. Each one of these is likely to take one or two clams. It is probable that the European market is of a similar size. The market will not be an annual market. It will decline significantly once customers have received their first clams.

MMDC and ICLARM aim to each put about 25,000 clams per year into the market with other farms such as Reefarm in Australia also supplying limited quantities. The aquarium market is likely therefore to support farms in the Pacific region for another five years or so. This assumes an increase in the number of farms producing clams and an increase in the production of existing farms. The market can therefore be regarded as a means to create a quick cash flow and pay off some of the initial capital outlay. The current prices, which are shown for *T. maxima* and *T. squamosa* (the two species available on Niue) in the table below, are high. The prices vary according to species, mantle color and size of the animal. It should be noted that the marketplace prefers variation in both species, sizes and colors. Niue will obviously be limited in this regard as it has just the two species and will not easily be able to raise the clams to over one year of age. This is due to the fact that the space required to keep older animals increases exponentially. As an example a 15m^2 tank could hold 22 500 six month old clams (2.5 cm), 7 500 one year old clams (4-6cm) and just 450 two year olds (8-12cm).

The current price list for aquarium clams (price in US$) are as follows:

Size (cm)	6	8	10	12	14	16	18	20
T. squamosa	2.05	3.05	4.45	6.05	7.90	10.00	12.50	15.00
T. maxima (gold)	2.05	3.05	4.45	6.05	7.90	10.00	12.50	15.00
T. maxima (blue)	2.50	3.50	5.00	6.50	8.50	8.00	13.00	16.00

The main market for aquarium clams at the present time is Los Angeles. With present packaging methods the maximum time for shipment is 36 hours. The present route to Los Angeles from Niue via Apia and Auckland falls within this time limit being a total of 28 hours, including 3 hours for packing and unpacking. The total cost for shipments of more than 100 kg is presently US$3.55/kg. This is a slightly higher rate than that being paid by the MMDC and ICLARM but should be reduced for shipments of greater than 250 kg and therefore would be competitive on freight terms.

b. Meat

If giant clam farming in the Asia-Pacific region is to be sustainable at production levels greater than 300-500 000 clams per annum then entry into the food market will be necessary in the medium term. There are various ways to sell clams. These include:

- live clams for sushi and sashimi;
- adductor muscle and mantle meat separately; or
- as smoked, dried or pickled meat.

Currently, meat sales are only being made to the live seafood market. The nature of the product and the culture methods involved mean that the volumes of giant clam produced will never be on the same scale as mussels or oysters. This therefore necessitates marketing giant clams as a rare luxury product to outlets such as high class, live seafood restaurants catering mainly to S.E. Asian clientele. Niue would be in a good geographic location to serve such markets as New Zealand, Australia and Fiji, although there are still import restrictions in place in Australia.

Markets for clam meat products in fresh, frozen, dried or pickled forms will be competing directly with other seafoods that are less expensive to produce and of a similar quality. These markets are not being actively pursued.

The live seafood market requires clams of between 10 and 25 cm or 2 and 5 years of age, while the meat market may require clams of 7 years old or more. Due to the lack of suitable ocean nursery areas in Niue growth to this age would be both problematical and expensive.

c. Shell market
Tisdell (1990) discussed the large market for giant clam shells. This market is often more lucrative than that for meat. This fact has been overlooked in many of the papers discussing the meat market, making giant clam farming appear more marginal than it may actually be (Tacconi and Tisdell, 1992a, b & c; Ram, 1992; Tisdell *et al*, 1993).

The market for shells, however, does not cover all species or sizes. The shells most in demand are *Hippopus hippopus* in the size range of 15-20 cm and *Tridacna gigas*, as large as possible. *T. squamosa* and *T. porcellanus* are also in high demand (Tisdell and Wittenberg, 1989). Unfortunately for Niue, *T. maxima* shells are not in high demand. The sale of live clams as seafood should promote the concept of eating the clam and taking the shell away after the meal. When sold in this manner, the shell will automatically have value.

d. Tourism
Tourism can provide a source of income to clam farmers that is not directly related to production. Many tourists are interested in merely viewing the farming process and seeing giant clams, this is not otherwise possible for people who live outside of the giant clams natural range. In addition to this, tourism can provide a direct outlet for sales of clam products such as crafted shells, T-shirts and meat products. A substantial proportion of the income at the MMDC and Reefarm is derived from tours and direct sales.

Niue as yet does not have a substantial tourist market. The number of non-Niuean tourists was 1,185 in 1982 and approximately 2,000 in 1993. Agents of the tourist authority indicated that a total of 3 000 tourists per annum by the year 2000 was the goal.

3.1.3 Economic analysis of land based production.

Economic analysis of a giant clam farm functioning with just a land-based nursery is given below. Analysis is only given for land based nursery production as it is believed that the risk involved in running an ocean nursery for commercial purposes in Niue is unquantifiable at present. The technology that would have to be used in Niue is either not used elsewhere or not under the same severity of conditions. It may be possible in the future, given adapted technology, to use a FON system in combination with a land based nursery. Such a combination could provide a means of making giant clam production on Niue profitable. A design and testing phase would need to be undertaken to establish a viable system for this area.

The use of a purely land-based nursery system places heavy constraints on production if clams more than one year old are required. This is because clams exhibit exponential growth rates; therefore the area into which they can be stocked also increases exponentially. In the example given, which is of a 400 square metre nursery tank area, either 70,000 x 6 cm clams or 9,600 x 10 cm clams and 7,520 x 6 cm clams may be produced. The decrease in numbers of all the clams produced is not compensated for by the price differential involved.

Analysis A presents the case of a nursery solely producing 6 cm clams for the aquarium trade. A revenue from tourism is also included. The result of this analysis shows that, theoretically, this would be a highly profitable enterprise. [The opposite could happen in reality.] The net result of the production is that a large quantity of small clams of only two species must be marketed in a short timeframe. Clams in the 6 cm size class are not in great demand by the aquarium trade. Therefore, it is likely to be difficult for aquarium dealers to absorb such a large quantity of small clams at one time. Either a reduction in price or an inability to sell the clams is probable. If the price was to drop from US$2.05 to US$1.00 per clam, the facility would no longer be profitable.

Analysis B shows costs and revenues resulting from a combined production of both 6 and 10 cm sized clams in conjunction with a revenue from tourism. The 10 cm size class is currently the most popular with aquarium dealers. The analysis reveals that to have totally land based operation, production of clams to this size would be very unprofitable.

Both of the cases presented assume perfect production each year with no catastrophic loss at any time, an unlikely scenario. The analyses account for a fully financed self-funding operation including salaries for Fisheries staff to be involved.

No account has been made in these models to quantify the benefits of being able to restock clams or of including the production of other species such as trochus or turban shells that are also valued by aquarium dealers. Such options are beyond the scope of this work.

On the basis of these models and the general features of and conditions on Niue island, it is concluded that a purely land-based, self-funding giant clam nursery would be economically risky and technically difficult.

Analysis A. Economic analysis for hatchery solely producing 15 month (6cm) clams for the aquarium market. All figures are in US$.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
CAPITAL COSTS										
Hatchery										
Lab +office bldg	4000									
Tanks	2000									
Water reticulation	500									
U.V.System	1000									
Air system	600									
Total cost	8100									
Land nursery										
Pumps	4600				4600					
Borehole	12000									
Tanks 40m2 @ 900/tank	9000									
Reticulation @ 150/tank	1500									
Drainage @ 100/tank	1000									
Tools	2000									
Packing shed+equipment		4000								
Air blowers @ 1 per 5 tanks	2000	0								
Total capital costs	32100	4000	0	0	4600	0	0	0	0	0
OPERATING COSTS										
Manager salary	11000	11000	11000	11000	11000	11000	11000	11000	11000	11000
Labour salary	5500	11000	11000	11000	11000	11000	11000	11000	11000	11000
Part time staff		2000		2000		2000		2000		2000
Maintenance	3210	3210	3210	3210	3210	3210	3210	3210	3210	3210
Electrical costs@ 3 Kwh/hr	6500	6500	6500	6500	6500	6500	6500	6500	6500	6500
Consumables	5000	5500	6050	6655	7321	8053	8858	9744	10718	11790
Total Operating costs	31210	39210	37760	40365	39031	41763	40568	43454	42428	45500
Total Costs	71410	43210	37760	40365	43631	41763	40568	43454	42428	45500
Cumulative costs	71410	114620	152380	192745	236376	278138	318706	362159	404587	450087
REVENUE										
Tourism		3000	4000	5000	6000	7000	8000	9000	10000	11000
Harvest of 6 cm clams		143500	0	143500	0	143500	0	143500	0	143500
Total revenue	0	146500	4000	148500	6000	150500	8000	152500	10000	154500
Cumulative revenue	0	146500	150500	299000	305000	455500	463500	616000	626000	780500
Annual balance	-71410	103290	-33760	108135	-37631	108737	-32568	109046	-32428	109000
Cumulative balance	-71410	31880	-1880	106255	68625	177362	144794	253841	221413	330413

Analysis B. Economic analysis for hatchery producing both 6 and 10 cm clams for market

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
CAPITAL COSTS US$										
Hatchery										
Lab +office bldg	4000									
Tanks	1600									
Water reticulation	500									
U.V.System	1000									
Air system	600									
Total cost	7700									
Land nursery										
Pumps	4600				4600					
Borehole	12000									
Tanks 40m2 @ 900/tank	9000									
Reticulation @ 150/tank	1500									
Drainage @ 100/tank	1000									
Tools	2000									
Packing shed+equipment		4000								
Air blowers @ 1 per 5 tanks	2000	0								
Total capital costs	32100	4000	0	0	4600	0	0	0	0	0
OPERATING COSTS										
Manager salary	11000	11000	11000	11000	11000	11000	11000	11000	11000	11000
Labour salary	5500	11000	11000	11000	11000	11000	11000	11000	11000	11000
Part time staff		2000		2000		2000		2000		2000
Maintenance	3210	3210	3210	3210	3210	3210	3210	3210	3210	3210
Electrical costs@ 3Kwh/hr	6500	6500	6500	6500	6500	6500	6500	6500	6500	6500
Consumables	5000	5500	6050	6655	7321	8053	8858	9744	10718	11790
Total Operating costs	31210	39210	37760	40365	39031	41763	40568	43454	42428	45500
Total Costs	71010	43210	37760	40365	43631	41763	40568	43454	42428	45500
Cumulative costs	71010	114220	151980	192345	235976	277738	318306	361759	404187	449687
REVENUE										
Tourism		3000	4000	5000	6000	7000	8000	9000	10000	11000
Harvest of 6 cm clams	0	15416	0	15416	0	15416	0	15416	0	15416
Harvest of 10 cm clams			42720		42720		42720		42720	
Total revenue	0	18416	46720	20416	48720	22416	50720	24416	52720	26416
Cumulative revenue	0	18416	65136	85552	134272	156688	207408	231824	284544	310960
Annual balance	-71010	-24794	8960	-19949	5090	-19347	10152	-19038	10292	-19084
Cumulative balance	-71010	-95804	-86844	-106793	-101704	-121050	-110898	-129935	-119643	-138727

Assumptions made in calculations for analysis A and B.

Hatchery

- Tanks - The price given is for 4 x 500 l fibreglass tanks to be used for the rearing of larvae to the pediveliger stage and 4 x 2000 l outdoor splasher pools for rearing of larvae from the pediveliger to the juvenile stage.

Land Nursery

- Pumps - the price given allows for the purchase of two pumps (one main, one backup) and those costed are KTZ 37H submersible pumps that will give a flow of $18m^3$/hr at a 26 metre head.

- A cost for the replacement of these pumps after five years is given.

- Bore hole - The cost has been estimated using a cost of $3,000 NZ dollars to make a 6 inch bore to 25 metres with the additional cost being attributed to the necessity to import a drilling rig plus operator from New Zealand due to the lack of a local rig.

- Tanks - The tank dimensions are 10 x 4 x 0.7 metres and will be constructed by blasting holes into the ground and lining them with cement. The reason for this method of construction is because the cost of blasting is cheaper than that of constructing a free standing facility given the price of cement in Niue. The facility shall also be less prone to cyclone damage when constructed in this manner.

Operating Costs

- Manager salary - This has been included due to the need to employ a fisheries officer full-time in this position which would result in the need to recruit a replacement officer.

- Labour salary - This is estimated on one full-time labor in the first year and two full-time thereafter.

- Part-time staff - There will be a need to employ part-time personnel to assist in packing and other marketing activities.

- Maintenance - Maintenance costs are estimated at 10% of total capital costs.

- Electricity - Costing has been assumed a full-time use of 3 kilowatts per hour at an unsubsidized rate of 0.43 NZ dollars per kilowatt hour.

- Consumables - This is for replacement of such items as office equipment and supplies, fertilizer, feeds, filters, fuel, and other hatchery consumables.

Revenue

- Tourism - It is assumed that no tourist shall visit the facility in the first year. In the second year of operation allowance has been made for 1000 tourists at $5 NZ dollar per head visiting the facility. Increased income from tourism thereafter is due to both an envisaged increase in the number of tourists and increase in the products available from the facility.

- Revenue from Clam Sales

  Clam growth rates of 4mm per month have been used.

  The number of clams harvested from tanks are based on the following estimates of potential stock densities per 40 square metre tank:
  6 months (2 cm) = 28,000 clams per tank
  15 months (6 cm) = 10,000 clams per tank
  25 months (10 cm) = 1,200 clams per tank

  Price of clams: 6 cm = US$2.05
  10 cm = US$4.45

  Analysis A: Economic analysis for hatchery solely producing 15 month (6 cm) clams for market. In order to optimize the use of a land based nursery for this production , it is necessary to initially stock three tanks with juvenile clams. These would be grown out to six months of age and should result in enough clams to be transferred into the other seven tanks. The three tanks would then be utilized for further spawnings while the clams would be stocked in the other seven tanks for a further nine months and then harvested. A 30 per cent mortality from between the ages of 6 to 15 months is assumed. [A much lower mortality has been attained in other hatcheries]. Final harvest is calculated for 10,000 clams per tank for seven tanks at a unit price of US$2.05 per clam. Due to the 15 month grow-out cycle it will only be possible to harvest every second year.

Analysis B: Economic analysis for a hatchery solely producing both 6 cm and 10 cm clams for the aquarium market. In this scenario it is necessary to stock two tanks with larvae and grow them to 15 months of age. These could then be transferred into eight additional tanks at a lower stocking density. Given a 30 per cent mortality rate from 15 to 25 months of age, this should be sufficient to achieve full stock densities of 1,200 clams per tank at harvest. An excess of 7,520 fifteen months old clams should be produced and marketed from the initial two tanks. These two tanks shall then be used for further rearings. The harvest of 10 cm clams shall consist of eight tanks at a density of 1,200 clams per tank at a unit price of US$4.45 per clam.

The costs of setting up a small hatchery capable of producing 5,000 clams per year for restocking purposes is given in Appendix 1. It is assumed that the manager spends only half of his time at this hatchery.

3.1.4 Improvement and management of natural stocks of giant clams

Having reviewed the various farming permutations possible in Niue and detailing their limitations, it is suggested that the proper management of existing stocks is the course of action to be followed. A similar recommendation was made by both Dalzell *et al*., (1993) and Bell, (1993a).

As mentioned previously, Dalzell *et al.*, (cited above) estimated a stock density of 89 clams/ha for *T. maxima* and 14 clams/ha for *T. squamosa* for the whole of Niue. The *T. maxima* population was reasonably evenly distributed whereas that for *T. squamosa* exhibited a clumped distribution. At that time it was stated that although the *T .maxima* population was low but was not under threat. A short survey at Avatele during this visit, one of the areas with the highest density of clams (416.6/ha in 1990), indicated high recruitment of 1 and 2 year old *T. maxima*. To a certain extent this confirms the good health of the stock.

T. squamosa stocks do appear to be threatened. The exact status is unclear, but it is possible that local populations may no longer be self-sustaining. As noted by Dalzell *et al* (1993) there is a need for some conservation measures for this species, although the form this should take was not mentioned. It was stated that "because the eastern side of the island is inaccessible for most of the year we feel that marine reserves are not warranted on the reefs of Niue". Such an approach could lead to the loss of *T. squamosa* from the western coast as this is the most heavily fished coast and could be recruitment limited. As the hydrographic data is limited, it is not apparent whether a spawning of clams on the eastern coast would result in recruitment on the west coast. It is probable that due to the prevailing south to north easterly winds any eggs and larvae produced from a clam spawning on the east coast would be carried along the eastern coast and then out into deeper water. Stock recruitment on the west coast would therefore not occur from spawnings on the east coast.

There are a variety of methods that could be used to assist in the conservation and which should ultimately increase local giant clam stocks. These include:

a) a total ban on fishing,
b) enforcing a minimum size at harvest of 25 cm shell length for *T. squamosa* and 15 cm for *T. maxima.*
c) designating restricted areas for the fishery,
d) congregating broodstock into reserve areas,
e) the introduction of stocks from elsewhere in the Indo-Pacific.

Due to the nature of the fishery any one or a combination of several of these options is possible.

Option e) is not recommended as any introduction of stock would have to consist of large individuals. If there is no hatchery available to receive and quarantine larvae and juvenile clams, the introduction of disease or parasites could occur. In addition, unfavourable genetic dilution of existing local stocks from imported clams could result. However, if local stocks become depleted to the extent that they were no longer self-sustaining or became extinct, the import of clams could be recommended. Import from the nearest genetic stock (Cook Islands, Tonga or Samoa) is advised. This could be the situation with local stocks of *T. squamosa*. However, a stock and recruitment assessment of this species is recommended prior to the importation of any clams.

Of the options given above a combination of b) and d) above is recommended for implementation.

To assist in the implementation of new regulations, it is suggested that a public awareness campaign be mounted. Such a campaign should describe the present status of the giant clam stocks, the reasons for the low numbers and the methods that may be used to protect the stocks. As there is an active newspaper and local television station on the island this should not be a difficult process.

The enforcement of a minimum size limit is a logical measure to implement and should not be too arduous as there is only one store selling live clams. Enforcing such a regulation for local consumption would be difficult but could succeed if it is done in conjunction with a publicity campaign and a measuring device of some form is distributed to active clam divers. The measuring device could take the form of a marked screwdriver, which is the tool most often used for extracting clams from the rocks. It could then be reasonably assured that fisherman would carry the measure with them at the time of diving.

The congregation of broodstock into distinct areas to enhance spawning success is not guaranteed to increase recruitment. One of the main reasons for the interest to start the giant clam culture project is that field research findings had established that natural recruitment was low and erratic, even in untouched stocks, and that culture would remove the bottleneck in natural regeneration. However, giant clam reproductive success is likely to be strongly influenced by the density of clams in a given area. If the clams are too far apart the pheromones emitted on egg release will be too dilute to trigger mass spawning in adjacent clams. Furthermore, greater distance between clams substantially reduces the likelihood of fertilization as the chance of eggs and sperm meeting is much reduced. The giant clam circle project in Tonga reported some recruitment success but it was not quantified. The same project also received negative publicity when it was found that some of the broodstock had been poached.

It is suggested however, that seven clearly marked areas be established and that these areas be under the care and jurisdiction of the local council. Each area need only be 20x20 m and contain 50 animals. The areas should be between 10 and 15 metres deep and either be of a coarse gravel substrate or on rock that has had depressions formed in it using a hammer and cold chisel or other such tools. The depth and substrate specifications are to help prevent catastrophic loss during cyclones and from poachers. The seven areas cover the whole of the west coast and be situated in bays and on points. The areas from north to south are adjacent to Talava, Namakulu, Makapu point, Tomb point, Halagigie point, Avatele and Tepa point (refer to Figure 4).

The public awareness campaign, site surveys, collection and establishment of broodstock for these areas could be conducted by the incumbent Fisheries officers. To designate the chosen areas, the Department of Agriculture, Forests and Fisheries would have to put a submission to cabinet who would in turn need to seek agreement from the village councils concerned. If an agreement is reached, the necessary legislation could be in place by September 1994. It will also be necessary to make a revision to the Fish Protection (Amendment) Act 1985 in order to implement a change in the size at harvest. The time required to make such a change is unknown.

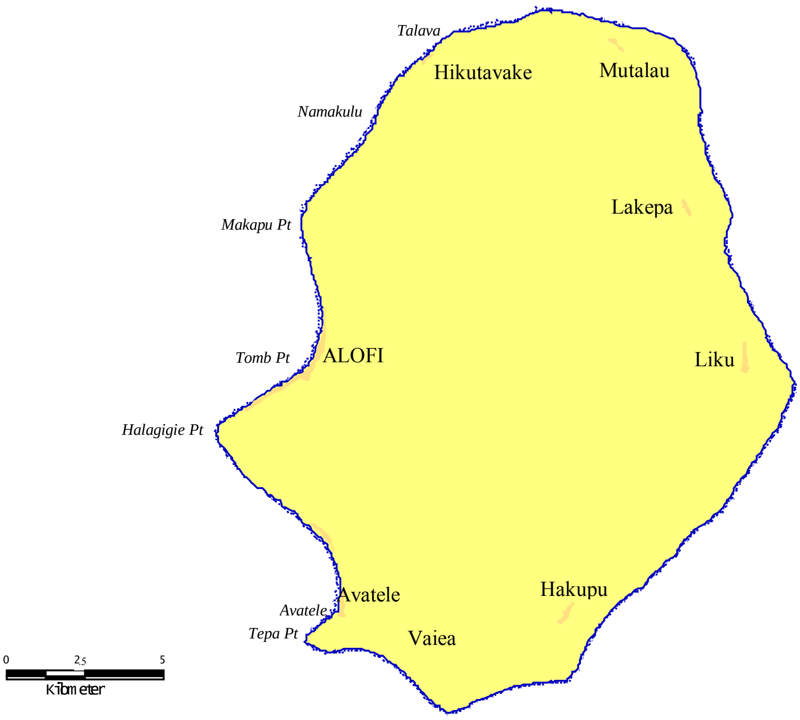


Figure 4: Map of Niue Island showing suggested areas for seven clam circles on the west coast. Some villages are also shown.

<u>3.2 Fresh-water Aquaculture - Prawns and Crayfish</u>

Evaluation of the potential of fresh-water aquaculture on Niue was conducted by assessing the basic parameters required for such an undertaking for the selected species, as discussed under each of the following sub-headings.

3.2.1 Basic requirements for inland freshwater aquaculture

The feasibility of developing an inland aquaculture project requires that several very important requirements are satisfied. The best situation is where all of these factors are ideal, requiring little input to make them so. These factors are discussed in New and Singholka (1985) for freshwater prawn farming and are summarised below. Even though the discussions were specifically for freshwater prawns, the principals apply to inland freshwater aquaculture of any species. Most of the information contained in the following subheadings have been extracted directly from New and Singholka (cited above).

<u>a. Access</u>
New and Singholka (1985) reported that the prime requisite for the success of any farm is that there is a market for its produce. They wrote, " the scale, nature and locality of the market is the first topic that should be considered in the selection of a site and the results of this evaluation will determine the manner in which the farm is designed and operated". The farm must not only close to its market but the road access must be good.

Economic assessment of the farm must include the costs of obtaining post-larvae for stocking. “Transport costs can add enormously to basic stocking costs and prices of the post-larvae themselves tend to rise as the distance between the farm and the nearest hatchery increase”. Thus the farm should be close to the source of fry supply.

Another factor that is considered is the availability and cost of getting feeds to the farm. Availability of commercial feeds produced locally is an advantage. This means the presence of a commercial feed mill. Importation of commercial feeds is expensive.

b. Land availability and topography

An essential component in pond construction is the availability of suitable land to accommodate enough ponds to make the operation economically viable. For example, it has been calculated for Hawaii that at least 8 acres of ponds are needed before any profit can be realised. The amount of water availability is an important element that also influences this factor.

New and Singholka (cited above) wrote that for ponds, “the ideal site slopes gently (not more than 2 per cent) and ponds constructed on it can be gravity filled and drained”. However, the authors also added that, in practice, many successful farms exist where the only feasible method, not only of filling but also of draining the ponds is by pump. The costs of filling and draining ponds can be substantive, especially where pumps are used, and can form major costs which must be considered in assessing a site before embarking on an aquaculture project.

c. Soil

The average depth of ponds used for inland aquaculture is 0.9 m. Thus the site must have consistent soil depths of more than 1 m deep through out the area to be used to enable excavation. However, where soil depth is shallower, there must be enough soil available from somewhere else for moval into the site to enable above ground bunds construction.

The soil used for pond construction must be fertile. This is because a considerable amount of food intake by prawns is from natural sources. Soil nutrients are absent in concrete ponds leading to a marked reduction in the amount of natural food available. Successful freshwater prawn culture requires water with pH 7.0-8.5. Thus the soil pH must be near neutral. Potentially acid sulphate soils are not preferred as they have pH values of 4.5 or less, together with high concentrations of soluble iron, manganese and aluminium (New and Singholka, 1985).

“Ponds should be constructed on soils with good water retention characteristics or where suitable materials can be economically brought onto the site to improve water retention”. Thus “soils consisting of silt or clay or a mixture of these with a small proportion of sand normally have good water retention characteristics”. However, the clay content should not exceed 60 per cent. Clay types in soils that are excellent for earthern ponds are kaolin, montmorillonite and hillite clays. “Pervious soils, which are very sandy or a mixture of gravel and sand, are unsuitable unless the water table is high and surrounding areas are always water logged”.

d. Water source

The supply of good quality water and on a reliable basis is a critical factor in assessing the suitability of a site for inland aquaculture. New and Singholka (1985) listed the provisional criteria for water supplies for freshwater prawn farming as follows:

pH	7.0 - 8.5
Total hardness	<150 (preferably <100) ppm
Temperature	18° - 34°C (optimum 29° - 31°C)
Dissolved oxygen	(DO) >75% saturation

Temperatures below 14°C or above 35° are lethal to freshwater prawns.

Additionally, water must be free from pollution, especially agricultural chemicals, and as predator free as possible. Due to its chemical and microbiological quality as well as the lack of predators, underground water is the preferred water source for farming.

Water is used mainly to fill ponds, replace water loss through seepage and evaporation, flow through for continuous culture and emergency or flushing use. Water requirements for pond rearing of freshwater prawns for different sized farms are given in Table 3.2.1 as reproduced from New and Singholka (1985).

Table 3.2.1: Calculated water requirements for pond rearing of freshwater prawns for different sized farms. (Source:New and Singholka, 1985).

	QUANTITY OF WATER REQUIRED			
Farm water surface area[1] (ha)	Pond filling[2] (m^3/min)	Maintenance flow[3] (m^3/min)		Consumption[4] (m^3/min)
	Maximum	Minimum	Maximum	Average
0.2	2.50	0.03	0.11	0.12
0.5	2.50	0.07	0.28	0.31
1.0	2.50	0.14	0.56	0.68
2.0	2.50	0.28	1.12	1.26
3.0	3.75	0.42	1.68	1.89
5.0	6.25	0.70	2.80	3.14
10.0	12.50	1.40	5.60	6.28
20.0	25.00	2.80	11.20	12.57
40.0	50.00	5.60	22.40	25.14

[1] average water depth used is 0.9 m
[2] filling ponds initially and subsequently and for rapid flushing in emergency. Assumption: (i) the unit pond size is 0.2 ha and that a pond can be filled within 12 hours, and (ii) it will never be necessary to fill more than one pond (or 10% of the farm surface area, whichever is the greater) at one time. Local experience will tell if this allowance is either insufficient or too generous.
[3] continuous water demand, based on 140 l/ha/min minimum and 560 l/ha/min maximum. Actual requirement depends on whether "continuous" culture is practiced or not. The minimum figure should cope with average seepage and evaporation losses.
[4] this consists of the maximum maintenance rate, assuming "continuous" culture for the whole farm, plus the quantity necessary to fill all ponds four times per year, averaged out to a volume per minute average consumption basis.

"While the minimum farm size for economic viability may depend on other factors, the quantity and continuity of water supply available sets an absolute technical limit on the pond area and on the potential productivity of the farm" (New and Singholka, 1985).

3.2.2 Situation on Niue

a. Access

Markets: potential overseas markets for both freshwater prawns and crayfish are; New Zealand, Cook Islands and possibly American Samoa. Flight connections from Niue to all these destinations are direct and therefore ideal. Depending on how lucrative the overseas markets are as compared to local outlets, generally, the further away the market is the less profitable the operation become. The local market will be very limited in terms of demand. An interview with the chef of Niue Hotel indicated that the hotel will have no problem in absorbing 5-10 kg per week. This is equivalent to only 260-520 kg a year for this hotel alone. The motels and restaurants could probably absorb a little more than this amount altogether. However, it must be noted that the number of tourists visiting Niue is not consistent throughout the year but peak during the May-October period. The main importer of seafood on Niue is K. Mart. Unfortunately, the manager was overseas during the study and no accurate data on seafood imports could be obtained. However, the following estimates were given (it has been assumed that each box contains 10 kg of seafood):

Seafood Item	Estimated import frequency	Estimated Amount per import	Estimated Annual Import	Means of sales locally
Shrimps	once every 3 months	2x10 kg boxes	80 kg	hotels & restaurants
Oysters	depends on orders from hotels etc but about twice a year	2 x10 kg boxes	40 kg	hotels & restaurants
Scallop	twice a year	1 or 2 boxes	30 kg	hotels & restaurants
Flounder	??	??		mostly retailed
Mussel (1/2 shell)	every month	10x10 kg boxes	1,200 kg	mostly retailed

The main seafood import by K. Mart to Niue are mussels, which has been estimated to be about 5 mt annually from the limited information available. Mussels constitute more than 80 per cent of the total imports of seafood. Imports of fish and seafood as recorded for the period July 1991 to June 1992 by the Statistics /Immigration Unit (1992, draft) are as follows:

Food Item	Quantity (kg)	CIF (NZ$)	Source
Fish; other kinds, excluding fillets, livers, and roes, frozen	30	449	New Zealand
Fish; dried, salted or in brine, smoked fish, fish meal fit for human consumption	142	2,863	New Zealand
Crustaceans	60	585	New Zealand
Mussels	695	6,888	New Zealand
Molluscs (oysters & scallops?)	70	1,198	New Zealand

The crustacean food item probably consists of shrimps and prawns and is only 60 kg for the 12-month period. This is about the same as that estimated for K. Mart. This quantity indicates a very limited local market for the product. The CIF value for crustaceans is NZ$9.75 per kg.

Juvenile supply: *M. rosenbergii* hatcheries currently in operation exist in French Polynesia (and possibly New Zealand). Again flight connections from these sources are excellent. However, relying on overseas sources of juveniles is not always reliable, shipment can be risky and costs can be economically prohibitive.

Artificial commercial feed supply: In the absence of other related developments which can be utilised for the production of local supplementary feed, commercial aquaculture in Niue would require importation of commercial artificial feeds. This is normally a major determining consideration in commercial aquaculture operation. For Niue, New Zealand would be the closest source.

b. Land Availability

The total land area of Niue is 259 km^2 (25,900 ha) and a large portion of the island is covered with scrub with several thousand acres of dense indigenous forest with no surface water. “The island is characterised by a rugged and rocky coastline, featuring steep cliffs, caves, deep chasms and blowholes” (Anon, 1990). It is a raised coral reef with the highest point at 65 m (Leslie, 1980) consisting solely of limestone in the form of emerged reefs forming terraces at 180-215, 65-80, 40-45 ft and possibly another at 115-130 ft. (Schofield, 1959). Only three terraces have been accepted with the lower terrace, the Alofi Terrace, being some 28 m above sea level while the rim of the upper terrace is some 69 m above sea-level (Anon, 1991). Overall, Niue can be regarded as flat. However, in its micro-topography it is uneven and broken (Leslie, 1980). Outcrops of hard reef-rock occupy 48 per cent of the surface of Niue island (Wright and Westerndorp, 1965).

Land use and availability for potential development: Large scale agriculture development on Niue has been limited by several factors of which the following three are the major ones:

- relatively small size of the island;
- soil fertility is poor; and
- soil is thinly distributed over coralline limestone and basement rock

Results of the 1989 Census of Agriculture on Niue indicated that of the total 259 km^2 of land area, 30 to 40 per cent is unsuitable for agriculture. Most agriculture practices use shifting cultivation and long periods of fallow are common (Anon, 1990). A total of 3,903 land parcels were counted in 1989 with the following breakdown in terms of use:

In use	1,156 (30%)
Under coconuts	770 (20%)
Fallow	1,977 (50%)

(Note: the average area of parcel "in use" is equal to 5.9 acres. Fallow parcels were either all bush, fallow or had only abandoned crops on them).

Under the "In use" category, it was found that only 23 per cent was under crops, 3 per cent was ready for planting and that 74 per cent was actually in fallow.

Land tenure system: Results of the 1989 Agriculture Census on Niue indicated that almost all of the "titled" lands are family owned. Of the total of 1,156 parcels of land "in use", 95 per cent (1,081 parcels) were family owned. Table 3.2.2 shows the number and area (acres) of parcels by location and land tenure as given in Anon (1990).

Table 3.2.2: Number and area (acres, in brackets) of parcels "in use" by location and land tenure in 1989. (Source: Anon. 1990).

District	Family owned	Leased	Other	Total
Makefu	56 (419.3)	-	4 (19.0)	60 (438.3)
Tuapa	110 (504.8)	4 (19.0)	5 (46.3)	119 (570.1)
Namukulu	15 (94.8)	-	-	15 (94.8)
Hikutavake	58 (189.5)	1 (2.0)	3 (13.5)	62 (205.0)
Toi	45 (199.0)	-	3 (13.0)	48 (212.0)
Mutalau	107 (728.5)	-	5 (21.5)	112 (750.0)
Lakepa	67 (395.0)	-	8 (15.5)	75 (410.5)
Liku	61 (241.4)	1 (4.0)	1 (1.0)	63 (246.4)
Hakupu	121 (915.3)	-	5 (9.4)	126 (924.6)
Vaiea	11 (99.5)	1 (282.0)	2 (10.0)	14 (391.5)
Avatele	87 (421.3)	-	-	87 (421.3)
Tamatautoga	108 (484.6)	-	4 (4.5)	112 (489.1)
Alofi	120 (649.1)	1 (2.0)	15 (38.0)	136 (689.1)
Lefuka	24 (262.3)	-	-	24 (262.3)
Paluki	91 (546.9)	-	12 (167.8)	103 (714.6)
TOTAL	1,081 (6,151.1)	8 (309.0)	67 (359.4)	1,156 (6,819.5)

The parcels of land classified under the "other" category include those being looked after for family/friends overseas.

The total area in use (6,819.5 acres = 2,759.4 ha), as recorded in Table 3.2.1, represents only 10 per cent of the total 25,900 ha of land on Niue. Thus, about 23,140 ha (90 per cent) of land on Niue is not in use.

Land lease and lease rates: Only 10 percent of all the land in Niue has been surveyed and "titled" (Director, Lands and Titling Department, 1994, *pers. comm.*). Leasing of land for use is straight forward when dealing with those that have been titled. Current normal lease rate is about $NZ 400-500 per year for a 0.5 to 2 acres for houses on renewable basis. Valuation of different areas has not been conducted. However, the process of development on untitled lands can be complex and may take a long time. When an untitled land is identified as a potential area for any development, the Lands, Titling and Surveyors Department is notified of the developer's intention. The Department then advertises for families who might have rights over the land to apply for titlement. All application for titlement is handled in the Lands Court. In straight forward cases, it normally takes 3-4 months from lodging of applications to finalisation of the titlement. However disputes between families on land can take a long time to settle. Once the titlement is settled, the lease agreement, arrangement and conditions, require the support of the majority of the family or individuals who have rights to it by ancestral heritage. The Lands Court confirms the lease when this requirement is satisfied. All titled lands is held by ancestral rights.

The Crown can acquire land it requires. However this power has not been exercised.

Harris (1993) reckoned that ponds could be built on one of the flat “greens” near one of the abandoned villages and that surrounding empty houses and schools could be used for ancillary services. The Department of Agriculture, Forestry and Fisheries identified only the Vaiea “green” as the only possible site. Vaiea village is still occupied by about 20 people although a lot of houses have been abandoned. The actual “green” area is only about an acre but the surrounding flat area is quite substantive.

c. Water Resource

Due to the very porous nature of the soils on Niue, there are no surface streams present nor are there any areas of impeded drainage. Thus dry spells, which have been defined by Kreft (1986) as periods of 15 days or more during which no rainfalls or less than 1 mm rain/day, are common. The current water supply comes from a ground-water system. Prior to the establishment of the ground-water supply from bores, rainwater collected from roof tops and stored in concrete reservoirs, cave pools and the dug well at Fonuakula, were the sources of water supply (Jacobson and Hill, 1980). Schofield (1959) noted that small supply was obtained from small ponds on the floors of caves and that “during the dry months, water was severely rationed and many green coconuts were used for their juice”. In 1980, Jacobson and Hill (cited above) reported existing water supply then as consisting of rainwater tanks, one dug well and 45 operating bores spread around the rim of the island. The bores delivered 600-800 l/hour for the Alofi town, the villages, and agriculture development projects. The same author noted that irrigation was possible provided high-yielding bores could be developed.

Rainfall: Kreft (1986) notes that rainfall in Niue is generally of a convective nature, tending to occur frequently during the afternoon or evening when temperatures are highest. The average annual rainfall is about 2,009 mm, with January, February and March as the wettest months. During the wet season (November-April) approximately twice as much rainfall is received as the dry months (May-October). In some years, however, there may be little difference in rainfall between the two seasons and the rainfall pattern can generally be described as erratic with very dry or wet months possible at any time. Very dry periods (no rain) commonly last for 15-17 days and there may be more than one such period a year. Wright and Westerndorp (1965) wrote that the average annual rainfall of 80 in (2009 mm) on Niue is roughly equivalent to that in the drier western districts of Savai’i Island in Western Samoa.

Table 3.2.3 records the total monthly rainfall (in mm) and air temperatures (in °C) at Alofi between 1988 and 1993. The temperature figures are averages of the maximum recorded at 7 am local time.

Table 3.2.3: Total monthly rainfall and air temperatures recorded at Alofi for the period 1988-1993 (Source: Telecom, Niue).

Year	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	Rainfall	70.3	205.8	118.0	494.6	203.6	71.0	99.6	113.0	221.7	385.6	296.8	780.0
	Temp	30.6	32.3	31.3	29.2	28.6	27.5	26.5	26.7	27.9	28.7	28.5	29.3
1989	Rainfall	972.8	441.8	126.8	322.1	112.1	100.3	43.2	8.2	23.6	192.6	253.3	131.0
	Temp	29.6	29.2	30.8	29.5	28.7	27.5	26.7	26.9	28.3	29.0	28.4	28.0
1990	Rainfall	126.3	353.4	156.8	312.5	182.6	106.5	215.7	5.8	127.3	87.3	70.4	136.7
	Temp	30.2	30.0	30.3	28.5	28.8	27.7	26.7	27.5	27.5	28.1	28.6	29.7
1991	Rainfall	242.4	511.4	315.4	37.9	132.4	58.1	61.5	41.5	72.0	71.0	133.9	53.4
	Temp	27.0	30.4	30.7	30.0	27.7	27.1	26.9	27.1	27.2	27.2	29.2	29.1
1992	Rainfall	60.7	105.1	174.2	155.8	343.5	28.3	197.4	194.2	101.9	322.1	56.6	306.6
	Temp	30.1	30.2	29.1	28.2	27.9	27.3	26.6	26.4	27.8	27.8	27.9	29.1
1993	Rainfall	186.9	21.7	190.5	461.9	66.9	33.7	67.8	209.3	184.9	120.7	8.0	178.2
	Temp	29.9	30.1	28.7	28.5	27.4	26.1	25.0	26.4	26.2	25.9	29.5	30.5

Jacobson and Hill (1980) estimated that two-thirds of the rainfall on Niue is taken up evapotranspiration, and that only one-third infiltrates the ground and maintains the freshwater layer, overlying salt-water within the limestone.

Ground water: The main source of fresh-water for Niue is from ground-water which is a fresh-water lens floating on salt-water. It is the sole source used (and available) by government for the local domestic tap-water supply. "The fresh-water layer is 50-80 m thick in the centre of the island (6 km from the coast) and increases to 100-150 m thick 1-2 km inland from the coast, then disappears within 500 m of the coast where salt-water mixes with the freshwater along fissures in the limestone" (Jacobson and Hill, 1980). The same authors estimated the annual recharge to groundwater to be 624 mm. The conclusions and recommendations made by these authors after carrying out investigations on the groundwater resources of Niue were as follows:

* groundwater on Niue is contained in a freshwater layer overlying salt-water. The thickness of the freshwater layer is 50-80 m beneath the central basin of the island, and over 100 m beneath the peripheral rim. Salt-water intrusion is evident for 500 m inland from the coast, where mixing has been facilitated by fissures in the limestone.

* the elevation of the water-table is 1.8 m above sea level in the centre of Niue, and fresh-water generally flows radially outwards to the sea.

* water-balance calculations for a model freshwater layer 50 m thick drawn up to 25 m indicate that the safe yield of the Niue aquifer is about 11,000 l/day/ha (11 m^3/day/ha).

* aquifer tests carried out on specially constructed bores in the interior of Niue indicate that safe long-term pumping rates could be up to about 8 l/s. To avoid upconing of salt-water, drawdown should be controlled to be no more than one-half the elevation of the water-table above the mean sea level datum.

* the use of turbine pumps yielding 1.5-2.5 l/s was recommended, and bores of this capacity could be spaced at one per 15 ha.

"As a first approximation, groundwater development in the interior of Niue could be by a borefield with one bore producing about 8 l/s (=480 l/min=0.48 m^3/min) to every 63 ha".

The groundwater is pumped up from the water table which is 54-58 m below ground in some areas. However, the water table is shallower along the coastal area.

The current tank capacity for the local fresh-water supply on Niue is not sufficient to accommodate any additional uses for commercial purposes. It can only supply domestic (household) needs.

[The volume of water to be pumped up for any purpose is limited to 23 litres per sec. (1.38 m^3 per min.) per pump. In addition, a minimum distance has also been set between pumps. Pumps currently used for the domestic water supply include SP 8A-15, single phase, motor power of 2.2 Kw. This pump has a capacity of pumping up 8.2 m^3 of water per hour (or 0.137 m^3 per min.). Complete cost for one of these pumps, including accessories and installation is about $NZ 15,000-20,000].

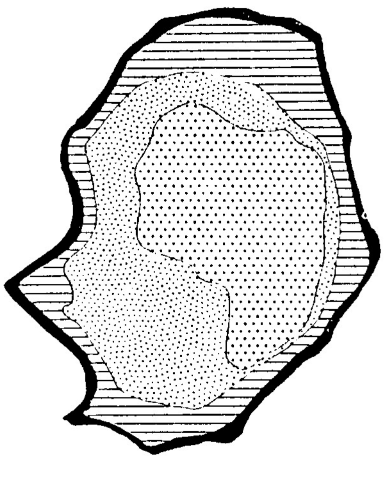
Water requirements for rearing fresh-water prawns in ponds, for different pond sizes, are given in Table 3.2.1. [Using the maximum allowable pumping capacity of 1.38 m^3 per minute per pump on Niue and comparing it with the quantity of water requirements for different pond sizes in Table

3.2.1, the allowable water quantity can accommodate continuous water supply for about 2-3 ha of ponds.**]** Using the safe long-term pumping rate of 8 l/s (=0.48 m^3/min) to every 63 ha, only about 3 ha of ponds can be maintained (for every 63 ha). However, the $NZ15,000-20,000 SP 8A-15 pump will only be able to continuously supply maintenance water sufficient for a 0.5 ha pond. Thus, to feed a 3 ha pond, a pump with the capacity more than 3 times that of SP 8A-15, would be required. The costs would probably increase at the same rate.

d. Soil

Niue island is an elevated coral reef with all exposed rocks being coral-reef limestones and various erosion derivatives such as sands and conglomerates (Wright and Westerndorp, 1965). The highest point is now 65 m above sea level (Miller, 1980). **[**"The island shows four main landform categories: (i) the rim of the plateau representing an ancient reef one-half to three-quarters of mile in width; which encircles (ii) a central depressed area representing an ancient lagoon with a maximum depth of 100 ft and occupying an area of approximately 41,700 acres; (iii) outside the rim is the seaward slope formed by the emergence of the ancient reef; and etched in this slope is (iv) an incomplete encircling shelf, varying in width from one-eighth to one-quarter of a mile" (Wright and Westerndorp, 1985).**]** The original volcanic island on which the earliest coral reef formed is now believed to be buried by coral limestones and is hundreds of feet below sea level. Volcanic ash, blown in from a now extinct submarine volcano or from active volcanoes in the Tonga Group, together with limestone and ***makatea*** are the parent materials from which Niuean soils have formed, with the volcanic ash being the main soil forming parent material (Leslie, 1980). The volcanic ash concentrated in deeper pockets between limestone outcrops where limestone surface is uneven. Soil covers only 52 per cent of the surface of Niue and is generally thin (Jacobson and Hill, 1980). Different from volcanic islands, soil on Niue is not renewable in that it is not weathered from local rocks.

Soil patterns: Wright and Westerndorp (1965) grouped soils found on Niue into four broad series as shown in Figure 5.



Hikutavake series   Fonu[illegible]la series

Hakupu series   Palai series

Figure 5: Generalised soil pattern on Niue Island (reproduced from Wright and Westerndorp, 1965).

The soil pattern was confirmed as correct and true by Leslie (1980). Detail information for each soil type was also given by Wright and Westerndorp (1965) and has been reproduced below.

Hikutavake series: this soil series on Niue is confined to the rocky periphery of the island, extending over a range of altitude from sea level to a little over 200 ft.

(i) Hikutavake rocky silt loam: although this soil occupies undulating to gently rolling topography, about 90 per cent of the surface is occupied by outcropping coral limestone. Surface soils are usually very shallow with occasional deeper pockets. A common profile is listed in Appendix 2. Of the total 1,045 acres covered by this soil, 105 acres is soil and 940 acres is rock.

(ii) Hikutavake hill soils: occupies the moderately steep slopes between sea level and upper plateau with about 95 per cent of surface occupied by coral rock outcropping. This soil is restricted to narrow but deep pockets, to fissures and to subterranean cavities. The profile is the same as (i) above but with a higher proportion of rock fragments. Of the 4,900 acres covered by this soil, 245 acres is soil and 4,655 acres is rock.

(iii) Hikutavake-Hakupu complex: occurs mainly on the flatter parts of the Alofi terrace and is the main soil on which villages are sited. In villages, this soil has a surface layer, 6-20 in. deep. A common profile is listed in Appendix 2. Of the 840 acres of this soil, 740 acres is soil and 100 is rock with limestone outcropping occupying about 12 per cent of the surface.

Hakupu series: this is confined to the rim of the upper plateau at altitudes ranging from 160 to 210 ft and the soils seldom extend more than 1.5 miles inland from the rim of the plateau.

(i) Hakupu silt loam: occurs on flat to undulating topography and is almost always planted in coconuts. A common profile is listed in Appendix 2. Of the 4,220 acres covered by this soil, 3,699 acres is soil and 620 acres is rock with limestone outcropping occupying about 15 per cent at surface.

(ii) Hakupu silt loam, variant with many limestone outcrops: occurs on undulating to gently rolling topography where soil mantle is considerably broken by coral outcrops and up to 40 per cent of surface is rocky with much in pockets between rocks. A common profile is listed in Appendix 2. Of the 7,630 acres covered by this soil, 3,700 acres is soil and 3,930 acres is rock with limestone outcropping occupying about 52 per cent at surface.

(iii) Hakupu stony silt loam, variant with very many limestone outcrops: occurs on gently rolling relief near the rim of plateau at altitude 180-215 ft. Outcropping coral may occupy up to 80 per cent of the area. A profile is shown in Appendix 2. Of the 4,560 acres occupied by this soil, 510 acres is soil and 4,050 acres is rock with outcropping limestone occupying 89 per cent at surface.

Fonuakula series: these soils are extensively developed in the western and south-western sectors of the plateau at altitudes ranging from 140 to 190 ft above sea level. Much is covered with fern and open, low, second-growth forest.

(i). Fonuakula silty clay loam: the surface of this soil is virtually free of coral outcrops. Many profiles are shallower than 15 in. with some deeper (36-42 in.) which are confined to pockets in the ***makatea*** and that many are narrow and funnel shaped. A typical profile is shown in Appendix 1. This soil and the shallow phase in (ii) below occupy 8,480 acres of which 8,000 acres is soil and 480 rock. Outcropping limestone occupy about 6 per cent at surface.

(ii). Fonuakula silty clay loam, shallow phase: usually occurs in complex association with (i). The soils are fairly uniform ranging from 9-10 in. in depth. A common profile is shown in Appendix 2.

(iii). Fonuakula silty clay loam, variant with many limestone outcrops: surface ground is rocky with about 50 per cent occupied by coral outcrops. Relative good soil for taro with pockets of deep soil. A common profile is shown in Appendix 2. Of the 7,310 acres covered by this soil, 3,710 acres is soil and 3,600 rock.

(iv). Fonuakula silty clay loam, variant with very many limestone outcrops: about 70 per cent of surface is occupied by outcropping coral limestone. Widely used for banana growing. Soil is restricted to shallow pockets and deep fissures (8-15 in.) but average soil depth is nearer to 6 in. with a common profile as listed in Appendix 2. Of the 4,720 acres covered by this soil, 1,180 acres is soil and 3,540 acres is rock.

(v). Fonuakula silty clay loam, variant with fine ironstone gravel: commonly adjacent to (i) above but has eroded bare surface and loose surface layer of fine hard-baked aggregates and gravelly ironstone concretions and is called locally as "desert soils" and are only of limited value to agriculture in their natural state. Of the 1,270 acres covered by this soil, 1,200 acres is soil and 70 acres is rock with outcropping limestone occupying 6 per cent at surface.

Palai series: these soils are developed mainly in the centre of the plateau at an altitude range of 100-140 ft above sea level. Many of these soils still support tall forests.

(i). Palai clay loam: surface is fairly free from rocks and coral outcrops occupy not more than 20 per cent. The soil grows good coconuts and yams and bananas and kumaras. A typical profile is shown in Appendix 2. Of the 2,090 acres covered by this soil, 1,670 acres is soil and 420 is rock.

(ii). Palai clay loam, variant with many limestone outcrops: about 40 per cent of soil surface is occupied by outcropping rock. The soil is slightly acid with topsoil high in organic matter. Good soil for taro or yams with a typical profile as shown in Appendix 2. Of the 9,710 acres covered by this soil, 5,830 acres is soil and 3,880 is rock.

(iii) Palai clay loam, variant with very many limestone outcrops: about 65 per cent of surface consists of outcropping rock and the soil occurs in patches between outcrops and the pockets are seldom more than 18 in. but mostly only 6-8 in. deep. It is the main banana-growing soil but also good for taro. A typical profile is given in Appendix 2. Of the 7,860 acres covered by this soil, 2,750 acres is soil and 5,110 is rock.

(iv). Palai clay loam, variant with fine ironstone gravel: surface is usually about 10 per cent rocky and common near sites of ancient inland villages. Topsoil is high in organic matter but low in the subsoil. A typical profile is given in Appendix 2. Of the 270 acres covered by this soil, 250 acres is soil and 20 acres is rock.

The classification (mineral constituents) of soils of Niue is given in Table 3.2.4 as reproduced from Wright and Westerndorp (1965).

The clay types in soils that are needed for earthen pond construction are; kaolin, montmorillonite or hillite clays. These are not found in sufficient quantities or are completely absent from Niue soils as indicated in Table 3.2.4.

The physical properties of soils in Niue were described by Miller and Blakemore (1980) as "all very high in clay, but as the clay is very strongly tied together into larger aggregates it does not behave physically as a high-clay soil and has, for example, low bulk density (high pore space) and very high permeability to air and water". Leslie (1980) notes that "with the exception of the depleted soils ("desert" lands) topsoils have these common features: dark (organic-rich) colours; strongly developed, fine, nut structure; and friable consistence. Subsoils vary considerably in depth but in common, have; strongly developed fine crumb structure; 'fluffy', very friable consistence; no stones or any impediment to root development or water movement". Thus the soils do not clod or aggregate and are free draining and well aerated with low water-holding capacities. Wright and Westerndorp (1965) noted that there are no soils with permanent water table within the range of roots and thus all soils are well drained. Furthermore, the author noted that the limestone is so porous that there are no surface streams and no areas of impeded drainage. Jacobson and Hill (1980) noted that very rapid infiltration can be observed everywhere on Niue and that even after prolonged heavy rainfall, the ground is dry in a few minutes. (Tests on drill core indicate horizontal permeability of about 0.6 m/day and a vertical permeability of about 0.2 m/day).

A discing scheme was introduced in early 1960's in an effort to increase the area under cultivation of both food and export crops and to develop part of the "desert" area on the Government Farm at Vaiea for pastures for cattle grazing (Widdowson, 1980). Even though the scheme increased the area of crops cultivated and made the land easy to plant, the same author noted that repeated discing resulted in poor crop yields even with the use of NPK fertilisers. Furthermore, discing the shallow soils, has created the detrimental effect of mixing soil with ***makatea*** which was harmful to crop growth.

Miller and Blakemore (1980) wrote that the soils of Niue are very similar in their chemical properties and the pH levels are not far from neutral.

Table 3.2.4 : Soil classification (mineral constituents) of soils of Niue. (Source: Wright and Westerndorp, 1965).
[Key: ss=dominant; s=much; m=considerable; d=definite; w=weak; tr=trace; -=not detected].

Soil type	Locality	Gibbsite	Goethite	Crandallite	Haematite	Boehmite	Calcite	Dolomite	Kaolin	Magnetite
Hakupu silt loam	Liku	-	m	ss	-	m	-	-	-	d
		tr	m	ss	-	-	-	-	-	d
Hakupu very rocky silt loam with very many limestone outcrops	Hakupu	-	m	ss	-	m	-	-	-	d
		-	m	ss	-	m	-	-	-	d
	Kofika forest	s	s	m	?	m	-	-	?	d
		s	s	m	d	?	-	-	-	d
		s	s	?	m	-	?	-	-	d
Fonuakula silty clam loam	Namoui road	s	s	m	m	?	-	-	-	d
		s	s	m	m	?	-	-	-	d
		s	s	m	w	?	-	-	-	d
		s	s	m	d	d	-	-	d	d
Fonuakula stony silty clay loam, shallow phase	Alofi-Avatele road	m	m	-	m	-	d	d	-	d
Fonuakula rocky silty clay loam	Fuata	s	s	m	-	-	-	-	-	d
Fonuakula very rocky silty clay loam with many limestone outcrops	Tumufa	ss	m	m	-	?	-	-	-	d
		ss	m	m	-	-	-	-	-	d
Fonuakula gravelly silty clay loam with fine ironstone gravel	Fatiau airstrip	ss	s	d	w	-	-	-	-	d
		ss	s	d	w	-	-	-	-	d
		-	-	-	-	-	ss	s	-	-
Palai clay loam	Palai	ss	m	m	w	-	-	-	-	d
		ss	m	m	w	-	-	-	-	d
Palai rocky clay with many limestone outcrops	Fetuna	ss	m	m	-	?	-	-	-	d
		ss	m	m	-	?	-	-	-	d
	Tukuofe	s	s	m	-	-	-	-	-	d
		s	s	m	d	d	-	-	-	d
		s	s	s	w	m	-	-	w	d
Palai very rocky clay loam	Palai	s	s	m	w	-	-	-	-	d
		s	s	m	w	-	-	-	-	d
Palai gravelly clay loam with fine ironstone gravel	Fetuna	s	s	?	?	-	-	-	-	d
		s	s	?	?	-	-	-	-	-
		s	ss	?	d	-	-	-	-	d

The depth of volcanic ash over ***makatea*** in Niuean soils varies considerably over short distances. Most of areas are covered with only a thin layer of topsoil except a few pockets found towards the interior. The **Vaiea "Green"** has a top soil that is only about 4 in. deep. Even though it is clayey in texture, it does not hold water well when tested. The topsoil is slightly mixed with gravel with the immediate underlying layer as very hard limestone rubble. The area is believed to have been cleared off when leveling it for the village "green" and it seems that the soil could have been subjected to discing. The Vaiea area fall under the Hakupu soil series.

It is obvious from the above information that the top-soil on Niue is very thin (only a few centimetres) all throughout the island, where soil is found, making it impossible for the construction of earthen ponds deep enough for aquaculture purposes. In addition, the existing soil types have a very porous nature making them unsuitable for pond construction. Information obtained from the Civil Department indicate that only a few deep soil pockets exist and that the resource is very limited and will not be able to accommodate removal from where they are relative deep for the construction of ponds. Thus removal of topsoil to build pond bunds is not a possible option, especially when soil on Niue is not a renewable resource.

Soil Removal process: The only topsoil removal currently taking place is that scraped from the top of the ***makatea*** (sand) pits by government. The soil is sold to the public for gardens. The pits are owned by government but both the soil and ***makatea*** belong to the land owners who get NZ$10.00 and NZ$6.00 per load (5 m^3 of soil) respectively. The government re-sells these at NZ$72.85 and NZ$51.50 per load to the public. Between July 1993 and February 1994, only 11 loads of topsoil have been (possible to be) collected from the ***makatea*** pits.

The only circumstance in which pervious soils, which are very sandy or a mixture of gravel and sand, are suitable for pond construction is where the water table is high and surrounding areas are always water logged. On Niue, the water table is very deep and all soils have very low water-holding capacity.

e. Concrete ponds

Even though it has been reported that the prospects for the success of semi-intensive culture of fresh-water prawns in tanks using artificial habitats to increase surface area, aeration, etc., were good, commercial operations have centred on using earthern ponds due to production and economic reasons. New and Singholka (1985) noted that "the distinctive feature about tank culture is the absence of soil nutrients and a marked reduction in the amount of the natural food available". The same authors further noted that "although supplemental food is given to freshwater prawns reared in earthern ponds, a considerable amount of their food intake is from natural sources. It is therefore important to site the farm where the soil is fertile". The successful culture of freshwater prawns in concrete (reservoir) tanks, where available, has been considered a possibility at low densities. However, the construction of concrete ponds specifically for commercial freshwater prawns and crayfish culture is considered uneconomical. This is worsen when considering the situation in Niue due to extra costs involved in pumping up water from the low water table.

f. Possible environmental impacts

Land: Construction of ponds take up land and results in modification to the natural ecology of the area from clearing, excavation and the actual construction of the ponds. Constructed ponds become almost a permanent feature in an area.

Soil: A major concern if earthern ponds were to be constructed will be the removal of the very limited (and thin) topsoil layer from a lot of areas. This would deprive those areas of soils forever as soils on Niue is not a renewable resource.

Water: Water used for culture, if drained into the soil, may affect the water table causing contamination. If drained into the sea, the increase freshwater input would have detrimental effects on marine life, especially the limited corals. The huge water demand for continuous commercial aquaculture would put extra pressure on the water lens and if not monitored and controlled properly, any increase beyond the recommended pumping rates can result in upconing of salt-water.

g. Manpower

The existing Fisheries Division personnel is given under 3.1.1 (e). One of the staff officers has had some experience in site selection for fresh-water crayfish while attending university in Australia.

The present Fisheries work programme include: construction, maintenance and improvement of villages sea access tracks; construction, deployment, maintenance and replacement of fish aggregating devises (FADs); and review of Fisheries Legislation. The collection, compilation and analyses of fisheries landing data will be revived.

4. SUMMARY

4.1 Giant clams

Summary and recommendations

Observations

1. The infrastructure serving Niue and the seawater quality are quite adequate for giant clam rearing. The low seawater temperatures in winter are likely to suppress growth rates and result in distinct spawning seasons.

2. The personell available in the fisheres division are of a high calibre but are limited in numbers.

3. A land based and ocean nursery would have low environmental impact.

4. There is a burgeoning aquarium market that requires a variety of sizes and species but provides good returns.

5. The Niue tourist market is growing and revenue from this could offset some operational costs.

However

1. The force of the waves created by the trade winds, the height of the cliffs and the lack of any outer barrier reef preclude the establishment of a hatchery using a conventional pump and pipeline system along the entire Eastern Coast of the island from Vaihakea to Limufuafua point.

2. Cyclones usually come from the northwest which makes the siting of hatcheries on the west coast problematical. The construction of a hatchery in areas of low elevation involves a high element of risk.

3. The site at Amanau provides the most suitable site for a hatchery. However this is still under threat of inundation in a cyclone and would have a high cost of pumping due to its elevation..

4. The topography of Niue combined with its exposure to severe weather conditions means there is no site that would normally be identified as an ocean nursery.

5. To escape damage from wave conditions as encountered during a cyclone an ocean nursery would have to be placed at a depth greater than 10m. Alternative options for ocean nurseries such as placing clams in man made holes or putting them in floating ocean nurseries (FON's) have either not been tested before or have not been subjected to conditions that are likely to be encountered on Niue.

6. Economic analysis revealed that production of 6cm clams for the aquarium trade could in theory be profitable. It is probable, however that the market would not accept sporadic shipments of two species in such a limited size class. Further analysis demonstrated that the production of 10cm clams from a land based nursery is not economically viable.

Suggested action

1. It is not recommended that a commercially sized land-based or ocean nursery for giant clams be constructed in Niue.

2. A public awareness campaign describing the present status of giant clam stocks in Niue, the reasons for their low numbers and the methods that may be used to protect the stocks should be mounted.

3. The implementation of a minimum size at harvest of 25cm of *T.squamosa* and 18cm for *T.maxima* is recommended. The distribution of a clam harvesting and measuring tool could accompany such a regulation.

4. Seven areas on the west coast be established as protected areas for the congregation of *T.squamosa* broodstock.

5. Agreement from local councils and gazetting for the establishment of protected areas be legislated for before September 1994.

6. The preparation, marking, stocking and monitoring of each area to be carried out by the incumbent fisheries officers.

4.2 Land-based fresh-water aquaculture

1. The micro-topography of Niue island shows it as uneven and broken with outcrops of hard reef-rock occupying 48 per cent of the surface. However, land topography is generally flat making it ideal for construction of ponds.

2. The latest survey of land use in Niue indicate that more than half of the land was in fallow with 30 to 40 per cent of the total land area of 259 km^2 as unsuitable for agriculture. However, land use as detailed in the 1989 Agriculture Census indicate that 90 percent of the land was actually not in use with the majority of land parcels, in use, as family owned. There is therefore a lot of land available for additional and appropriate development.

3. Only 10 per cent of the total land on Niue has been "titled". Any developments on "untitled" land would require the titling process which could take a long time if different families put claims on a piece. For "titled" land, the support of the majority of the family, those with ancestral rights, is required before confirmation, by the Lands Courts, of any agreement for development (e.g. leasing out).

4. Soil on Niue is not a renewable resource in that it is not weathered from rock material present. The top-soil is thin, only a few centimetres, throughout the island. A few but small pockets of deep soil exist in some places, especially towards the interior. Thus soils are not deep enough for the construction of earthern ponds in any particular area.

5. Soil availability is very limited on Niue and there is not sufficient soil for moval from other areas to a particular site to build up earthern ponds on a commercial scale. In addition, environmental consequences of removing large quantities of soil would be disastrous for Niue. The only soil moval currently done on Niue is that scraped from the top of ***makatea*** pits and sold for gardening.

6. The soils on Niue are all very high in clay. However, the clay is very strongly tied together into larger aggregates that it does not behave physically as a high-clay soil and thus have high permeability to water, free draining and low water-holding capacities. The clay types required

to make earth ponding possible are kaolin, montmorillonite or hillite. None of these are available in sufficient quantities or are completely absent. Suitable materials which can be economically used on a site to improve water retention is minimum.

7. Soils have pH levels not far from neutral.

8. Repeated discing in the early 1960's resulted in mixing soil with ***makatea*** making the soil in these areas less favourable for pond construction.

9. Due to the very porous nature of the soils, there are no surface streams on Niue.

10. Annual rainfall is about 2,009 mm with January, February and March recorded as the wettest months. Approximately twice as much rain is received in the wet season (November-April) as does the dry season (May-October). In some years though, there may be little difference in rainfall between the two seasons. Rainfall pattern has been described as erratic with very dry or wet months possible at any time. The average annual rainfall on Niue was estimated to be roughly equivalent to that in the drier western districts of Savai'i Island in Western Samoa.

11. The only source of water for aquaculture purposes is ground-water, which is a fresh-water lens floating on salt-water. The water lens is 54-58 m deep at some places. Pond construction in areas with pervious soils is possible where water tables are high and surrounding areas always water logged. However, the water table on Niue is very low and no water logged areas exist as the soils have very low holding capacity.

12. The current fresh-water supply (tank capacity) on the island is only sufficient for household needs. It is not sufficient to accommodate commercial purposes.

13. **[**A pumping capacity limit is set for each pump installed on the island. This is currently set at 23 litres per second (1.38 m^3 per minute). This volume can only support water for maintenance requirement of a 2-3 aquaculture ha operation using "continuous" water system.**]** Using the safe long-term pumping rate of 8 l/s (=0.48 m^3/min) to every 63 ha, only about 3 ha of ponds can be maintained (for every 63 ha). Pumping up water at rates higher than the safe rate can cause upconing of the saltwater.

14. The pumping capacity of the SP 8A-15, single phase, 2.2 Kw pump currently in use on Niue for the supply of fresh-water is 8.2 m^3 per hour (0.137 m^3 per minute). This is only sufficient to continuously supply maintenance water adequate for a 0.5 ha pond. The estimated cost of the pump, including installation, is between NZ$15,000 and NZ$20,000, excluding running and maintenance costs. Higher capacity pumps would mean higher equipment costs, operational and maintenance costs.

15. Since the culture water is normally drained back into the soil, thus to the water table, contamination from aquaculture activities is a possibility.

16. Access to overseas markets for product exports and sources of seeds and feeds are considered good.

17. The use of concrete ponds is considered to be insufficiently productive and uneconomical. This situation is worsened by the fact that water is pumped up from a source that is very deep and that one bore in 63 acres can only provide continuous supply of water for a maximum of 3 ha. The current pump in use costs about NZ15,000-20,000 but it only has the capacity to sufficiently provide water for a 0.5 ha pond.

On the basis of the above information, inland aquaculture on Niue, using available local natural resources, is technically unfeasible. Other alternatives for pond construction, e.g. concrete, would be economically prohibitive.

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Appendix 1: Estimated costings for a small hatchery of the size sufficient to produce 5,000 juvenile clams per year for restocking purposes only.

	Year 1	Year 2	Year 3	Year 4	Year 5
CAPITAL COST (US$)					
Hatchery					
Lab + office building	4,000				
Tanks	2,000				
Water reticulation	500				
U.V. system	1,000				
Air system	600				
Land nursery					
Pumps	3,080				
Borehole	12,000				
Tanks 15 m^2 @ 450/tank	1,350				
Reticulation @ 150/tank	450				
Drainage @ 100/tank	300				
Tools	500				
Air blowers @ 1 per 5 tanks	500				
Total capital costs	**26,280**				
OPERATING COSTS					
Manager salaries	5,500	5,500	5,500	5,500	5,500
Labour salaries	5,500	5,500	5,500	5,500	5,500
Maintenance	3,458	3,458	3,458	3,458	3,458
Electricity costs	6,500	6,500	6,500	6,500	6,500
Consumables	1,000	1,000	1,000	1,000	1,000
Total operating costs	**21,958**	**21,958**	**21,958**	**21,958**	**21,958**
TOTAL COSTS	**48,238**	**21,958**	**21,958**	**21,958**	**21,958**
CUMULATIVE COSTS	**48,238**	**70,196**	**92,154**	**114,112**	**136,070**

Appendix 2: Profiles of representative soil types on Niue.

Hikutavake rocky silt loam

7 in. very dark grey to reddish black silt loam; very friable; strongly developed fine nutty structure breaking readily to crumbs and fine granules; non-sticky and non-plastic when moist;
17 in. strong brown silt loam; very friable to powdery; very coarse blocky structure breaking to single grains; non-sticky and slightly plastic when moist;
on hard limestone.

Hikutavake-Hakupu complex

4 in. very dark reddish-brown gravelly loam; friable; medium nutty and blocky structure breaking to medium granular structures; slightly sticky when moist;
4 in. dark reddish brown to brown very stony clay loam; friable to firm; medium blocky structure breaking to very strongly developed very fine blocky structure; slightly sticky and moderately plastic when moist;
on very compact mass of hard coral fragments.

Hakupu silt loam

1 in. black silt loam; friable; strongly developed very fine nutty structure; slightly sticky when moist;
3 in. dark reddish brown to dark brown loam; compact but friable; blocky structures, aggregates firm, but break under pressure to coarse granular structures; moderately sticky and plastic when moist;
4 in. strong brown loam; very friable; break to medium blocky structure and further to fine granular aggregates; slightly sticky and moderately plastic when moist;
1 in. strong brown to yellowish red silty clay loam; very friable to loose; fine granular structure; non-sticky and slightly plastic when moist;
on hard coral limestone, with a very thin layer of calcite forming on the interface between soil and rock.

Hakupu silt loam, variant with many limestone outcrops

2 in. dark grey silt loam, stony in part; friable to firm; medium blocky and nutty structure breaking to coarse granular structures; slightly sticky when moist;
7 in. brown silty clay loam; friable; medium blocky structure breaking to fine blocky structures; slightly sticky and plastic when moist;
13 in. strong brown silty clay loam; very friable; massive breaking readily to strong developed fine granular structures; non-sticky and slightly plastic when moist;
on hard limestone.

Hakupu stony silt loam, variant with many limestone outcrops

2 in. very stony dark brown silt loam; fine blocky and nutty structure breaking to moderate fine granular structures; slightly sticky and plastic when moist;
4 in. brown stony loam; friable; medium blocky structure breaking to fine blocky structure with firm aggregates; slightly sticky and plastic when moist;
10 in. strong brown silty clay loam; friable; coarse blocky breaking to fine granular and crumb structures; non-sticky when moist;
on hard limestone.

Fonuakula silty clay loam

2 in. dark reddish brown to dusky red silty clay loam; friable but smallest aggregates firm; fine nutty and blocky structure breaking to very fine blocky, granular and crumb structures; slightly sticky when moist;
5 in. reddish brown silty clay loam; moderately compact and firm to friable; coarse nutty and blocking structure breaking to fine blocky and granular structures; slightly sticky when moist;
10 in. red silty clay loam; very friable, almost loose in most places; massive breaking easily to very fine granular structures; slightly sticky when moist;
on soft limestone.

Fonuakula silty clay loam, shallow phase

6 in. dusky red to dark grey silty clay loam; firm to friable; fine nutty and blocky structure which is difficult to break down; slightly sticky when moist;
4 in. dark brown stony silty clay loam; friable to firm; medium blocky structure breaking to fine blocky and granular structures; slightly sticky when moist;
on soft weathering ***makatea*** with hard coral lime-stone

Fonuakula silty clay loam, variant with many limestone outcrops

2 in. dusky red silty clay loam; friable to firm; fine nutty and angular blocky structures; slightly sticky when moist;

3 in. dark reddish brown silty clay loam with occasional soft ironstone and many hard, baked aggregates; medium nutty and blocky structure breaking to fine blocky and granular structures; slightly sticky when moist;

4 in. reddish brown silty clay loam; friable; massive breaking to blocky structure and further to fine blocky and granular structures; slightly sticky when moist;

18 in. red silty clay loam; friable; massive powdering down to fine granular and single grain structures; slightly sticky when moist;

on soft weathering ***makatea***, in places somewhat sandy.

Fonuakula silty clay loam, variant with very many limestone outcrops

0.25 in. dry litter;

1.5 in. black silty clay loam; friable; fine nutty structure breaking to granular and crumb structures; slightly sticky when moist;

4 in. reddish brown to brown silty clay loam; friable; slightly sticky when moist;

1 in. reddish brown stony silty clay loam; friable; non-sticky when moist.

Palai clay loam

1.5 in. reddish brown clay loam; friable to free; nutty structure breaking to fine blocky and granular structures; slightly sticky when moist;

3 in. reddish brown clay loam; friable; angular blocky and nutty structure breaking to fine blocky and granular structures; slightly to moderately stick when moist;

8 in. red grading to dark red clay loam; friable; massive in place breaking to fine granular structure; slightly to moderately sticky when moist;

on weathering shell beds.

Palai clay loam, variant with many limestone outcrops

4 in. dark reddish brown to dusky red clay loam; friable; medium and fine nutty structure breaking to fine blocky and nutty structure; slightly sticky when moist;

5 in. dusky red clay loam; friable; medium blocky structure breaking to granular structure; moderately sticky when moist;

14 in. red to dark red clay loam; friable; massive breaking to fine granular structure; moderately sticky when moist;

on weathering shell beds and hard limestone.

Palai clay loam, variant with very many limestone outcrops

.25 in. forest litter;

0.5 in. reddish black to very dusky red clay loam; friable; fine, nutty structure breaking to crumbs; non-sticky when moist;

1.5 in. transition with worm mottling;

3 in. dark reddish brown clay loam; friable; medium nutty and blocky structure breaking to fine blocky and granular structure; slightly sticky when moist;

5 in. red to dark red clay loam; friable; massive in place breaking readily to fine granular structures; slightly sticky when moist;

on weathering limestone containing mush shell in places.

Palai clay loam, variant with fine ironstone gravel

1 in. dark reddish grey to dusky red gravelly clay loam with numerous fine hard ironstone concretions; moderately compact but friable to firm when broken; fine nutty and blocky structure breaking to fine granular structures; slightly sticky when moist;

6 in. reddish brown gravelly clay loam with numerous small hard ironstone concretions; moderately compact, firm to friable when broken; slightly sticky when moist;

8 in. dark red clay loam; friable; massive breaking to fine granular structure; slightly to moderately sticky when moist.