1989 PROJECT REPORT

THE TONGAN
GIANT CLAM (VASUVA) REVITALIZATION PROJECT

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ABSTRACT AND TABLE OF CONTENTS

1.0 GIANT CLAM CIRCLES BEGAN AS A PUBLIC AWARENESS PROJECT:

During Environment Week of June 1986, the Kingdom of Tonga planted a brood stock of giant clams (*Tridacna derasa* or *Tokanoa molemole*) on a reef in Nuku'alofa Harbour in an attempt to revitalize the stocks of these animals on the northwestern reefs of the island of Tongatapu (Chesher 1986).

The project, organized by 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, was the first attempt to increase natural populations of giant clams (Vasuva) using relocation of natural stocks and their subsequent protection in microparks.

1.1 IT WAS A MODERN APPLICATION OF A TRADITIONAL IDEA:

The relocation of natural stocks of giant clams into shallow protected embayments is not, itself, a new idea. Johannes (1982) reported the people of Manus Island in Papua New Guinea collected giant clams and placed them in protected areas on the reef. These clams were left alone until long periods of bad weather prohibited normal fishing activities. Chesher (1980) observed stocks of relocated and protected giant clams in the Shortlands Islands of the Solomon Islands and near Tagula in Papua New Guinea. Senator A.U. Fuimaono of American Samoa remembers, during the 1940's the villagers on Manono and Apolima Islands in Western Samoa kept stocks of giant clams off their villages on the shallow reef, collecting them while small and allowing them to grow in "gardens". Reports of protected giant clams placed near villages have also come from Savaii in Western Samoa.

Although a by-product of these cultural practices may have been a local increase in the natural population of giant clams, their purpose was intended as emergency food stocks and not, as in the modern example, a dedicated effort to revitalize the dwindling stocks of *Tridacna derasa*.

The modernized version of this ancient custom may prove important not only for maintaining and improving clam stocks, but as a means of increasing a feeling of environmental custodianship in the public mind.

1.2 GIANT CLAMS ARE BECOMING EXTINCT:

The project is taking place at a crucial time. There were once four species of giant clams in Tonga. One of these species, *Hippopus hippopus,* has already become extinct in Tonga. In July of 1987, dead shells of *Hippopus hippopus* were discovered near a dredging site in Neiafu Tahi. Judging by the numbers of *Hippopus hippopus* was once an important element in the Tongan diet. Today it is extinct (see 3.2.1 below)

The larger species of giant clams have become extinct or seriously endangered in many Pacific Island areas through overfishing (Hestler and Jones 1974, Bryan and McConnel

1976, Pearson 1977, Hirschberger 1980). Although apparently abundant within the recent past, *Tridacna gigas* has not been seen alive in New Caledonia or Fiji for the past two decades (Magnier, Adams, personal communication). McKoy (1980) found stocks of *Tridacna derasa* dangerously low in Tonga and stressed the need for protective measures to avoid overfishing all the giant clam stocks. McKoy also recorded the apparent extinction of *Hippopus hippopus* in Tonga. The International Union for the Conservation of Nature and Natural Resources (IUCN) has placed both *Tridacna gigas* and *Tridacna derasa* on the endangered species list.

1.3 AQUACULTURE OF GIANT CLAMS MIGHT PREVENT EXTINCTION:

As a result of the concern over dwindling stocks of these important food animals, an extensive international research project has been underway for some time to increase knowledge of the biology of the giant clams and methods by which they may be cultured (Munro and Helslinga 1983). Both *Tridacna gigas* and *Tridacna derasa* have been successfully mass cultured in running sea water systems in Palau (Helslinga et. al.1984) and juvenile specimens have been shipped to Guam, Yap, Hawaii, Pohnpei, California, Fiji, the Philippines and Marshall Islands (Helslinga et al. 1983, 1984, Lopez and Helslinga 1985). There have, however, been questions raised about environmental problems which might follow transfers of giant clams from one ocean area to another (Munro et. al 1985).

The culture of giant clams has been successful in Palau and Australia as a research project. A trial commercial scale hatchery has been started in the Solomon Islands and the researchers involved urge other interested countries to await the results of this facility before attempting further hatchery efforts (Pernetta 1986).

1.4 BIOLOGICAL AND ECONOMIC COMPLICATIONS STILL EXIST WITH AQUACULTURE OF GIANT CLAMS.

Hatcheries and subsequent transplants of seedling stock to reefs or other countries have many technical, biological and economic hazards. Perron, Helslinga, and Fagolimul (1985) report, for example, that an outplanting of seed clams from Palau onto a reef in Yap resulted in an infestation of a gastropod *Cymatium muricinum*. These small gastropods are predators of juvenile giant clams (they do not kill adults) and divers had to clear them from the seed clam trays by hand to prevent serious loss of the stocks. Buckley and Itano (1988) also report serious mortalities of seed clams by *Cymatium muricinum* in American Samoa (3.3 below).

Other, still unknown diseases and predators may seriously hamper clam culture activities in the future. Since the giant clams mature to female size only after 5 to 8 years, and since the new shipment guidelines (Munro et. al 1985) call for the shipment of seedlings, not adults, any new hatchery where adults are not locally available would need to operate for quite a long time before actually producing any product.

The aquaculture of giant clams may lead to a reprieve for the giant clams in local areas but this has not yet been demonstrated. So far, the high-tech aquaculture projects have been directed and managed by non-islanders, and supported by scientific research grants. When the funds run out the aquaculture projects may stop and the clams will be no better off than before. The director of the Palau Maritime Mariculture Demonstration Center has said that *Tridacna gigas* is now much less common in Palau than it was in the past, even though aquaculture of this species has been successfully done in Palau for nearly 15 years (Helslinga, personal communication).

1.5 BROOD STOCK AQUACULTURE (VASUVA CIRCLES) HELPS IN TWO WAYS:

High-tech solutions do nothing for the more extensive problem of destruction of marine resources throughout the Pacific. The loss of the giant clams is intimately tied to a widespread lack of appreciation or understanding of the coral reef environments and a rapid increase in the availability of tools to destroy the coral reef habitats. This is why the Tongan giant clam circles are so important. They can be done without foreign aid, cost very little, and are aimed directly at the major issues; the biology of the clams and the psychology of the people.

While the problems of Aquaculture of giant clams are being worked out, the natural stocks need to be protected and, if possible, augmented. The basic reason for the clams becoming rare or extinct needs to be examined and various features of the biology of the tridacnid clams must be researched. Above all, the public needs to be made aware of how to use marine resources wisely. The vasuva circle project provides a basis for these needs.

1.6 GIANT CLAM CIRCLES WILL PROTECT AND AUGMENT NATURAL STOCKS.

The discovery of juvenile *Tridacna derasa* and *Tridacna squamosa* in 1989 (see 3.2.2 below) demonstrated that the giant clam circles actively improve the local wild stocks. The reasons that brood stocks of Giant Clams increase the natural population of giant clams are:

1. Giant clams are males when they are first sexually mature and later become functional hermaphrodites (Wada 1954). Spawning is induced in nature by the presence of chemicals associated with the gametes. Normally the spawning cycle involves the release of sperm and subsequent release of eggs. "This results in a chain spawning reaction over a reef but renders the species liable to the non-fertilization of eggs in depleted populations."(Munro and Helslinga 1982).

2. The larger the clam, the more eggs are produced. The increase of eggs is a logarithmic relationship F = 0.00743L to the 4.03 power (for *Tridacna maxima* Jameson 1976). Which means the larger adults are the main egg producers and are important to the level of population fecundity.

3. The larval lifespan is short, about one week depending on conditions (Gwyther and Munro 1981, Beckvar 1981) and the juveniles apparently settle

out near the adults. In areas where giant clams are kept in embayments for emergency food supplies there is an abundance of clams of all sizes in the same bays and in nearby fringing reef environments (Yamaguchi 1977, Chesher 1980, unpublished data).

1.7 PUTTING BROOD STOCK CLAMS IN CIRCLES HAS SEVERAL ADVANTAGES:

Placement of the clams into circles has several advantages:

1. The orderly placement of the clams assures they will not be mistaken for a natural population but were clearly placed there by someone. Mistaking a clam circle for a natural population is not likely if the circle is put near a village and is done as part of an environmental awareness project. But its symmetry should help identify it as separate from natural stocks to anyone who is not familiar with the project.

2. The spacing of the clams is important to maximize spawning potential. Braley (1984) has presented evidence that maximum spawning activity can be inhibited by clams which are too far away or too close together. The circle makes the spacing regular and places the clams in a position to assure nearby clams will detect any spawning activity regardless of the direction of the water currents at the spawning time.

3. Regular spacing also prevents placing the clams too close together and thus risking the attraction of predators and the rapid spread of diseases through the stock.

4. A broken circle will be at once obvious and the dead or missing clam can be replaced to repair it.

5. Each member of the circle can be identified by its position and this will assist in keeping track of individual specimens for growth studies as well as spawning and mortality studies.

1.8 THIS RESEARCH PROGRAM WAS ORGANIZED TO TEST BROOD STOCK AQUACULTURE OF GIANT CLAMS IN TONGA.

To find out if giant clam circles can be organized on a community level and to see if they actually work, the Marine Research Foundation and the Center for Field Research, supervised by the Ministry of Lands, Survey and Natural Resources, began studies on the giant clams of Tonga. The project began in June of 1987 and will continue until October of 1990.

The research program was designed to:

1. Conduct hydrographic and bathymetric studies of the embayments of Vava'u to determine the most favorable locations for vasuva circles.

2. Investigate the distribution, growth, and mortality of existing natural stocks of all species of giant clams in the Vava'u island group.

3. Investigate the predators and diseases of the giant clams in Tonga and identify potential hazards for large settlements of clams or for grow-out sites from any future culture activity.

4. Study spawning activities in the clam circles to determine optimum spacing of the brood stock and subsequent egg and larval dispersal in the embayments.

5. Gather base-line information on subsistence and commercial harvesting of the clam species.

6. Prepare educational materials to demonstrate the need for the giant clam circles and raise public awareness of the function of brood stock aquaculture.

7. Increase public awareness of the need for vasuva circles and encourage the community to install one or more in the most favorable locations in Vava'u.

2.0 RESEARCH METHODS WERE DESIGNED TO FACILITATE LOCAL FOLLOW-UP:

Earlier work on giant clams by McKoy has proved difficult to use for population dynamics studies. Following commonly used techniques, McKoy counted and measured clams during a timed period of swimming. This produced a crude estimate of population size as one's ability to find smaller clams depends on many factors including the experience of the diver, the amount of sunshine on a particular day, wave and current activity, the coral cover, and how long a diver has already been in the water.

To adequately study giant clam populations, a technique was needed whereby large numbers of clams could be individually mapped in such a way that future researchers could return to the exact site and determine if the specimen had grown or died or if new settlement had occurred.

A practical method of making a reasonably economical map of the distribution of giant clams was thus a major aim of this project. To achieve this, we adopted the two shore station azimuth intersection technique (Northrup 1987, Page 880).

The two shore station azimuth intersection technique is an accurate system for fixing the location of something out on the water. If the exact location of each land station is known, the distance between them (the Base Line), and the angles between the base line and the object being sighted, the resulting triangle of the base line and the sight lines pinpoints the position of the boat or diver in the water. The method was used throughout the study for plotting depth contours, tracking the movements and discoveries of diving teams, plotting the movements of current markers, and locating and relocating stations on the map.

The base map was constructed by digitizing available charts and aerial photographs of Vava'u using a CAD/CAM program (Aegis Draw+) on an Amiga 1000 computer. This program allows a maximum of 250 layers which can be shown in any combination and has infinite zoom capabilities. Resource habitat areas were measured using a commercial image analysis program (PhotoLab) which can count pixels of each color appearing in an image. Each pixel represents a known area and thus the area surveyed can be easily determined.

2.1 HYDROGRAPHIC AND BATHYMETRIC STUDIES WERE DONE FIRST:

What are the optimal environmental conditions for the growth and reproduction of the various species of Tridacnid clams?

To answer this question we examined environmental conditions where the clams were abundant around the islands of Vava'u, taking into consideration that the "best" natural conditions may not have any clams because of human predation.

We also examined environmental conditions in areas where clam circles might be installed.

The primary physical parameters measured were:

1. Depth
2. Water currents
3. Water clarity
4. Substrates
5. Wave action
6. Water Temperature
7. Salinity

These parameters were measured and mapped into an electronic atlas for: Neiafu Tahi Harbor, Neiafu Harbor, Tapana Island Lagoon, Mala Island Pass, and the area from Port Maurelle to Nuku Island.

2.1.1 DEPTH TRANSECTS

Depth transects were done using a recording fathometer mounted on an inflatable boat. The boat was steered carefully along the 2-meters, 5-meters, 10-meters, 20-meters, 40-meters, and 80 meters depth contours and its position tracked at 30 second intervals by the shore teams.

The transit data was entered into an Amiga 1000 computer.

Two computer programs were written in Basic by John Seibert, Richard Chesher, Kristin Percoda, Bruce and Mary Feay, and Tom and Delta Greene. The first, called MAPDATA, formed a database for the field data.

When the data file from MAPDATA was run through a second program, "MAP", the computer calculated the position of the boat at each 30 second interval in the coordinate units of the electronic map and entered these coordinates in the map file. This automatically drew the depth contours on the map using a different color for each depth.

The electronic map was structured in 250 possible layers each of which can be displayed or not as desired. The depth contours were placed on their own layer so depth could be shown in relation to the distribution of giant clams or any other parameter.

2.1.2 WATER CURRENTS:

Water currents were mapped using drogues which floated at preset depths. The two shore teams took periodic bearings on the floats.

The transit readings were entered into the computer. The MAP program automatically calculated the speed of the currents and plotted the movement of the drogues onto a separate layer of the electronic map.

2.1.3 WATER TEMPERATURES:

Water temperatures were recorded on a maximum-minimum thermometer submerged at the site of the giant clam circles. They varied from a low of 20^{o} C. to a high of 31^{o} C.

2.2 NEW METHODS MAPPED NATURAL POPULATIONS OF CLAMS:

Divers surveying the reefs for giant clams were tracked by the two survey teams on shore. Each dive team had a brightly colored flag (either white, day-glow red, yellow, or orange). When a team found something it wanted to record one team member would look down and position the flag directly over the object to be mapped, and wave the flag.

The other diver of the team would watch the shore teams. When the shore teams saw a diver's flag go up they took the bearing of the flag, noted this angle, the time, and the flag color in the notebook and then waved a flag of the same color to indicate the measurement had been made. When the diver saw the same color flag being waved by both teams the diver's flag was lowered and the time and reason for waving the flag was recorded on a plastic slate.

At the end of a survey session, the notes from the dive teams and the angles from the right team were entered into the left team notebook. Later this was entered into the MAPDATA program and when run through the MAP program the computer would draw, each on its own layer of the map, the exact location of every specimen of giant clam found (by species), the exact path followed by each dive team (in different colors matching the color of the team's flag), and it would calculate the number of meters covered by each team.

Prior to the dive each team would draw on their dive slates, from aerial photographs or direct observation, the coral heads or configuration of the reef they were to survey. They signaled the shore teams from each landmark (coral head, patch reef, etc.) on their slate. If clams were located, the divers would signal and then draw, as carefully as possible, the coral(s) and the position of each clam specimen (plus its size and color) on the coral. The resulting drawing was recorded in the field notebook along with the shore bearings to that spot at the end of the day.

When especially small specimens were found, aluminum tags made from cut up aluminum drink cans and inscribed with a sharp awl, were nailed into the coral near the specimen. The tag and its number was included in the diver's drawing of the location.

Because the drawing program used to make the electronic maps can zoom to any size, the drawings of the coral heads were entered onto the maps in nearly correct proportions. Individual clams were marked on these drawings in correct colors and their sizes indicated.

Using this method it was possible to return to the exact coral head and determine if a particular clam was still there, if it had changed color, and if it had grown.

2.3 UNDERWATER TELEVISION MONITORED PREDATORS:

A closed-circuit television was set up in Neiafu Harbor to monitor predation activities of Potu Patu, a murex gastropod *Chicoreus ramosus*. Specimens of *Chicoreus ramosus* were kept in a chicken-wire cage and starved for at least one week to assure they would be active when tested. They were then placed into a fenced in area of sand which filled the field of the television camera. Specimens of giant clams and other bivalves were introduced into the test area and movements plotted on a shore-based monitor.

Specimens of blacklip oysters, jewel box oysters, pen shells, and small oysters were placed into the cage to determine the range of bivalves which *Chicoreus ramosus* would eat.

2.4 PUBLIC SURVEYS DETERMINED THE USE OF THE EXISTING STOCK:

Volunteers interviewed residents of Vava'u to determine how the public now uses the giant clam stocks, what the public knows about the biology of the clams, and how effective the public awareness program was.

Two separate surveys were conducted. The first was oriented to the use of the stocks and resource areas around the Vava'u island group. It was conducted in conjunction with a fisherman registration survey by the Fisheries Department.

The second vasuva survey was oriented towards use of the giant clams as food animals and knowledge of their biology.

2.5 EDUCATIONAL MATERIALS WERE PRODUCED:

The giant clam project was oriented towards establishing a community interest in protecting a stock of giant clams as a brood stock to reseed the coral reefs of Vava'u. Since the brood stock had to be in shallow water and since giant clams have a reasonable cash value and are desired food animals, the brood stock would be (and is) in considerable danger from poachers.

Tongan custom and legislation allows everyone to participate in the sea's resources and no one has the right to prevent anyone from taking any sea creature from any location. The only exceptions to this are sea turtles which are protected for part of the year and fish or other sea creatures which are caught in fish traps and therefore already someone else's property. There are five marine reserves established off the coast of Tongatapu but none in Vava'u. Observations showed fishermen fished the marine reserves in Tongatapu unless they were continuously guarded.

The Government Vasuva circle in Nuku'alofa Harbour had a small boat with two men anchored over it every night to protect it from poachers. Maintaining a continual guard over the brood stock is a time-consuming and expensive proposition. For the concept to work over an extended time, a means was needed to educate the public on the idea that the brood stocks were a common resource and that they should not be raided by irresponsible people.

Some legal protection was needed. A Vava'u policeman, Siobe Hungalu, showed it was possible to apply the 1924 Fish Fence Law to obtain a license to protect the clams on a local area of shallow reef. The license costs $2 per year and prevents anyone but the licenced person from taking the organisms which he or she has caught.

To obtain the license the person involved must go to the Fisheries Department. The officer in charge issues a letter of recommendation to the applicant stating the area to be licensed and the reason for the license. The applicant takes this letter to the police office where, for $2, a license is issued for one year.

The applicant may then announce over the radio or in any other way make public the fact that the clams in this area are not to be taken.

To strengthen this, several popular articles were prepared for the local newspaper about the need for giant clam brood stocks. The articles were translated into Tongan. Radio announcements were made about the giant clam project, one of which was produced by the police and explained that people could be legally prosecuted for taking clams from licensed brood stock areas.

2.6 A METHOD FOR COMMUNITY ACTION WAS DEVISED:

Early attempts of single individuals to install clam circles failed when the circles were destroyed by poachers. It was evident the project would not be likely to succeed if conducted by a single individual. If it was a community project, and the brood stock was owned by the whole island group, it had a much greater chance of success. Therefore a contest was arranged for divers to go and collect the giant clams for the brood stock circles.

Funds were donated by the Ministry of Lands, Survey and Natural Resources and many individuals and businesses of Vava'u to reward the divers and provide cash prizes for the divers with the most clams.

The contest was given radio and newspaper advertising and created enough public interest to assure that many people became familiar with the goal of the project.

The surveys mentioned above also aided in gaining public awareness of the project and its goals.

3.0 RESULTS HAVE BEEN ENCOURAGING:

After nearly two years the community giant clam circles at Falevai have not been disturbed by poachers. Only two specimens have died from natural predation. The people of Vava'u understand the reason for the giant clam circles and are supportive of the project.

In 1989 the villagers began finding juvenile *Tridacna derasa* and *Tridacna squamosa* ranging from the circles south as far as Taunga. This area had been extensively surveyed in 1987 and 1988 and not a single juvenile *Tridacna derasa* was found. The juvenile specimens of both species found in 1989 were all between 80 and 100-mm in shell length, supporting the idea they came from a single spawning of the giant clam circles when they were installed in January and February of 1988. Surveys in other areas of Vava'u continued to show no juvenile *Tridacna derasa*.

3.1 VAVA'U HAS SEVERAL GOOD LOCATIONS FOR BROOD STOCK AQUACULTURE:

Figure 1 shows the island group of Vava'u with local place names and geographic features mentioned in this report. The initial locations to be surveyed for potential clam circle sites were based on places where there was an area of reasonably shallow water and where water currents would keep the larvae in close proximity to the adults until settlement. The sites had to have clean water and be reasonably easy to observe from a village or whoever would be protecting the stock.

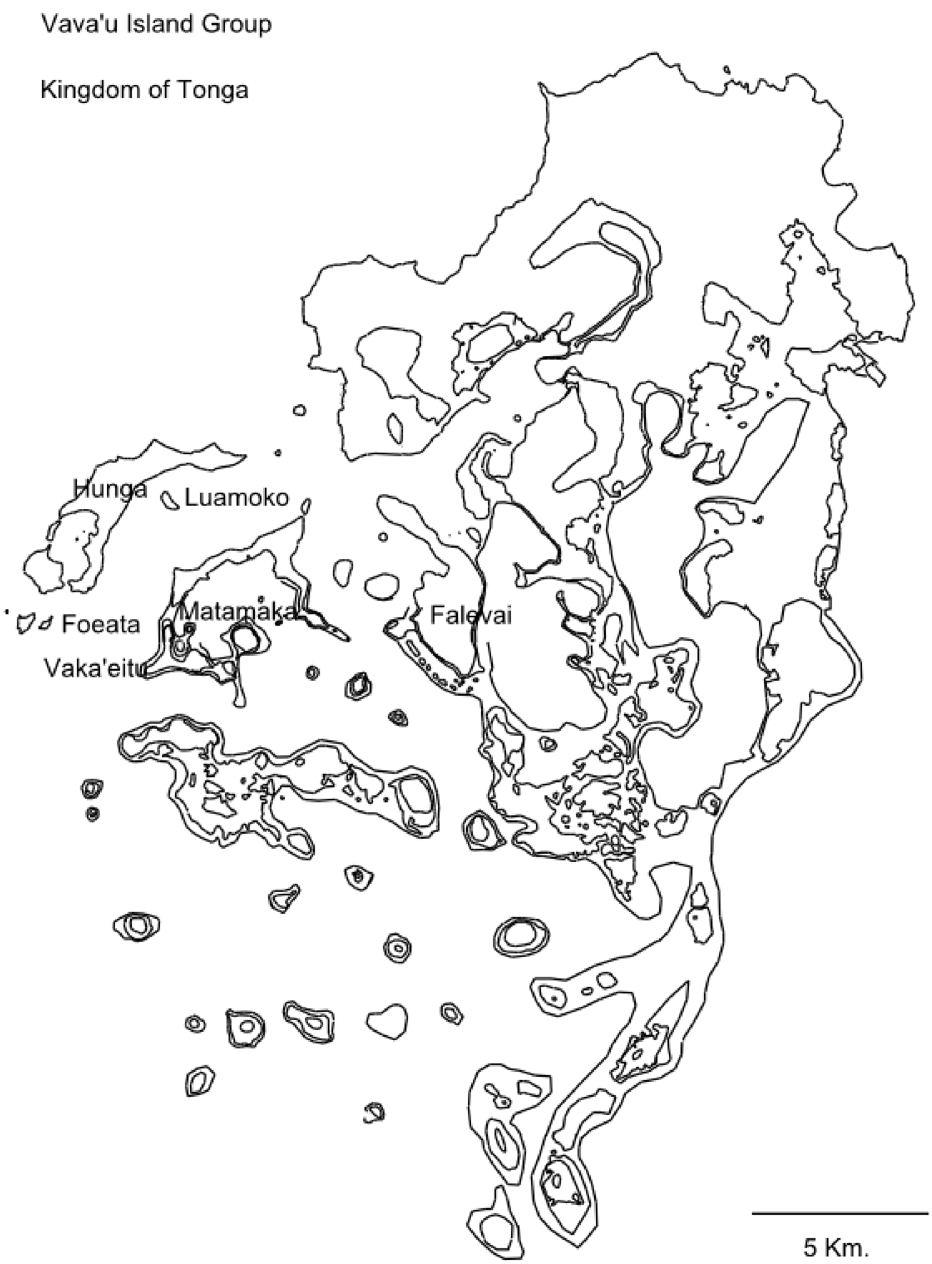

Figure 1. Vava'u Island Group

3.1.1 THE HABITAT FOR GIANT CLAMS IS EXTENSIVE:

The shallow water marine zone from the intertidal zone to a depth of 10 meters is about 76 square miles. The zone between 10 meters and 40 meters (the maximum limit for Tridacnid clams) is about 87 square kilometers. Not all of this area is suitable habitat for Tridacnids, however.

Figure 2 shows the potential habitat for Tridacnid clams. The best habitat zone, between the intertidal and 10 meters depth and with sandy or coral substrate, is about 49 square miles. The deeper zone between 10 and 40 meters, which may contain some Tridacnids, is only about 65 square kilometers when muddy or sandy areas are subtracted. Shallow water sandy or muddy areas which may have a few scattered Tridacnids comprise another 28 square kilometers.

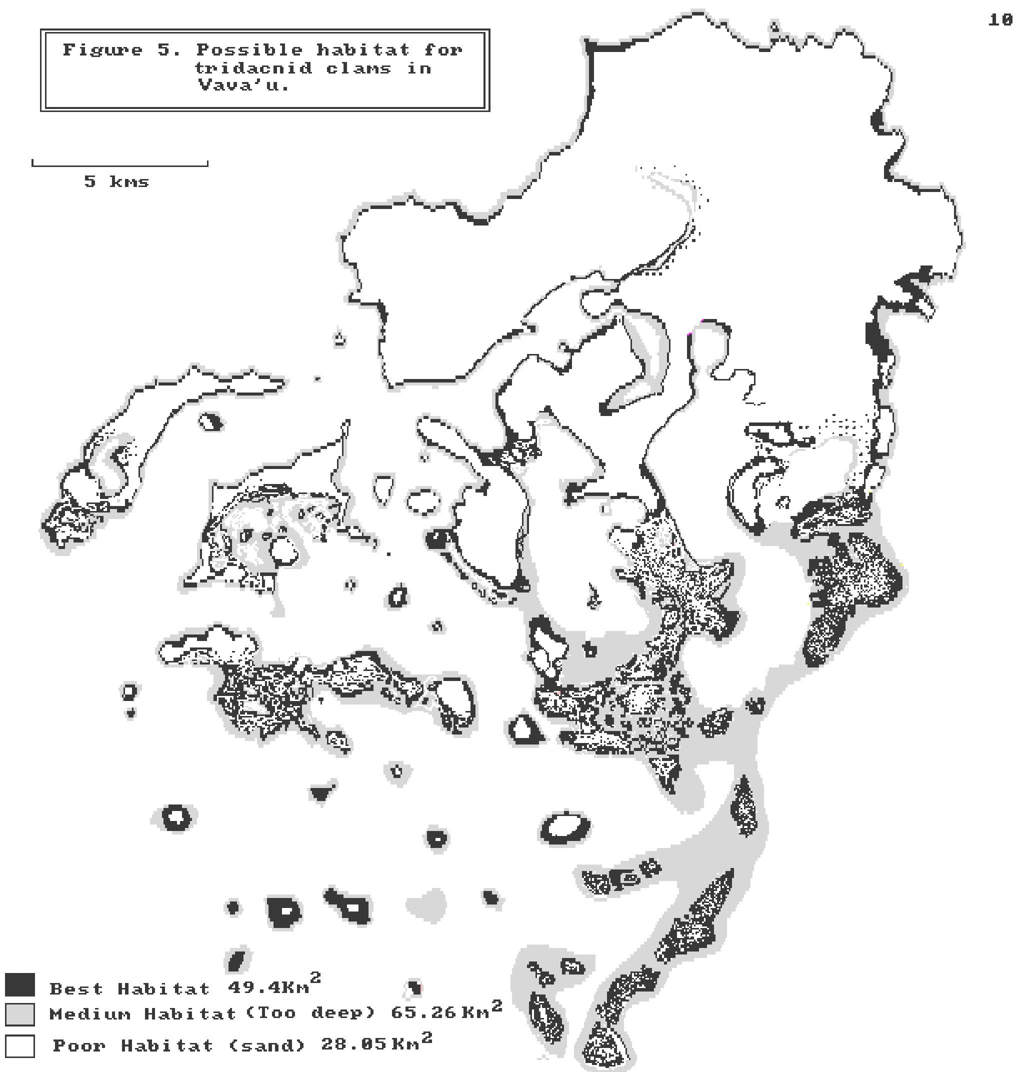

Figure 5. Possible habitat for tridacnid clams in Vava'u.

It is important that much of the prime habitat is steep-sloped coral reef areas because these are easily fished and fishermen can search and take a large percentage of the stock from these narrow, ribbon-like habitat zones.

3.1.2 FALEVAI WAS CHOSEN FOR THE FIRST COMMUNITY CIRCLE:

The village of Falevai, on the island of Kapa, was selected for the first community circle because it had a shoal area with very clear water just off the village wharf. There was a new police station being built within sight of the clam circles (the only police station in the outer islands). The District Officer, Mr. Vanisi Fakatulolo, was interested in the project and resided within sight of the clam circle area. Surveys showed the area adjacent to the village had one of the best populations of tridacnid clams in the Vava'u island group.

According to the older fishermen of the village both *Tridacna derasa* and *Tridacna squamosa* had once been reasonably common off the village and in adjacent areas.

The area held the most abundant stocks of juvenile *Tridacna squamosa* found during the surveys and was therefore considered a favorable environment for these animals.

The central location of Falevai in the Vava'u Island Group also argued well for the brood stock location. Larvae produced by the circles would be expected to restock reefs over a considerable area in the central island group.

3.1.3 OFU, MALA, HUNGA, AND TAUNGA ARE GOOD LOCATIONS:

The flats just to the north of Ofu satisfy the criteria for a good brood stock area. There are extensive shallow water areas surrounding the area, it is right in front of the village, the water is clear and there is a reasonable tidal current flowing over the site. Specimens kept there by Siobe Hungalu grew well and survived without incident. A major advantage to the Ofu location is that larvae from the project would be expected to reseed a very large area including the flats to the east and to the southwest of Ofu and perhaps even portions of the central island group. Ofu is upcurrent from most of the island group.

The pass adjacent to the small island of Mala, between Kapa and Utangaki Islands, is another excellent location for brood stock aquaculture. The water is clear and shallow, currents flow rapidly through the pass, the natural population of *Tridacna maxima* and *Tridacna squamosa* does well there. Two villages overlook the pass and could thus provide excellent protection.

One drawback to the Mala location is that it is a proposed site for a causeway to connect the two islands. Such a causeway would be expected to significantly cut water flow through the pass and reduce the site's biological usefulness. It should be pointed out that the pass probably is instrumental in the vitality of the entire harbor area and the causeway could cause irreparable damage to the biota there.

Hunga Lagoon has a small natural stock of *Tridacna squamosa* and, as the lagoon is almost totally enclosed, the potential for a brood stock to increase the natural population to very high levels is very good. There is a round depression between the two small islands on the eastern side of the lagoon which would be an excellent site for a brood stock. Surveys showed the lagoon presently has very little in the way of useful food stocks and that the adjacent lagoon south Hunga is likewise overfished.

Hunga village overlooks the proposed brood stock site and affords excellent security and easy access to the stocks. Stocks of *Tridacna squamosa* should be the first to be established here since this clam is best suited to the quiet embayment locations.

Because Hunga Lagoon is so nearly enclosed and yet has excellent water quality, it may be one of the best places to experiment with brood stock aquaculture. Results should be dramatic and easily observed as most of the larvae would be expected to remain in the lagoon during development. Other forms of sedentary food animals, such as oysters, valuable sea shells, and beche de mer should also be experimented with in Hunga Lagoon. The larvae from the experiment would, however, not be expected to spread to other areas of the Vava'u group as the overall current moves from east to west.

The island of Taunga offers a good location for brood stock circles of *Tridacna derasa*. There is a good shallow reef area for the stocks just in front of the village and larvae from the area would be expected to reseed the extensive network of central south reefs including the reefs at Taunga.

3.1.4 THE INNER EMBAYMENTS WERE EXCELLENT FOR *TRIDACNA SQUAMOSA* BUT NOT FOR *TRIDACNA DERASA*:

Tridacna squamosa were found naturally in the inner embayments such as Neiafu Harbor, Vaipua Lagoon, Hunga Lagoon, and Neiafu Tahi. They grew faster and produced more meat than *Tridacna derasa* in this environment.

Tridacna derasa kept in Neiafu Harbor and Neiafu Tahi Harbor did not exhibit good growth. Several developed a "white spot" disease (see section 3.3 below) and some of these specimens died. Part of the problem may have been that the experimental stocks were placed too deep (10 to 15-meters), but growth studies of transplanted clams in similar depths showed those in the harbor grew much more slowly.

3.1.5 TRANSPLANTATION OF ALL THREE SPECIES WAS EASY:

No special treatment is required for transplanting adult giant clams. Care should be taken not to break the shell during collection and the animals should be kept out of the water for the least amount of time possible. The fishermen who transplanted the larger clams simply piled the clams in their boat and left them there while they fished and later motored back to their village.

Juvenile tridacnids require special treatment when being transplanted. Coral reef fish and invertebrates are highly territorial. Strange objects, such as a small clam, suddenly placed on a coral reef will immediately attract the attention of the local reef dwellers. We observed a wide variety of small reef fishes approaching and often attacking juvenile clams when they were simply placed on the reef. Wrasses, in particular, are prone to attack the young clams.

Therefore it was necessary to place the juvenile clams with some care. Since they attach to the substrate, they must be placed on dead coral rock, not live coral, and put in a location which offers some natural protection and camouflage. A clam placed on an open, bare coral rock is more likely to be attacked than one placed in a crevice.

To foil the curious fish, we cut aluminum cans into 25 by 40-mm rectangles. The size of the juvenile clam was embossed into the tag with a sharp nail and then the tag was nailed to the bottom, in the open, about 20 or 30 centimeters from the newly transplanted juvenile clam. The reef fish and invertebrates were attracted to the shiny aluminum tag and this diverted their attention from the clam. Using this technique we had a 100% survival of transplanted juveniles of all three species.

Juveniles were placed in buckets of water when being transplanted and were not left out of the water for more than a few minutes. Juvenile specimens reattached to the substrate within 48 hours when placed on suitable dead coral areas.

Adults of *Tridacna derasa* transport easily. They close their valves and retain a fluid environment inside. Of a total of 96 *Tridacna derasa* transplanted, ranging in size from 86-mm to 542-mm, only one died from the transplantation. Some of the specimens were left out of the water for more than 6 hours, but it is best to limit this time to less than 3 hours when possible.

Tridacna squamosa, when removed from the water, "gapes" and the water is lost from the interior. Of 72 transplanted *Tridacna squamosa*, 15 died. They probably should not be left out of the water for longer than two to three hours. Specimens had no trouble reattaching to the substrate within 48 hours.

Only seven small, *Tridacna maxima* were transplanted. Five of these were left out of the water for about 6 hours and then placed on coral substrate. All specimens lived and, contrary to the findings of McKoy (1980) all specimens quickly reattached and reburrowed into the coral substrate. The specimens grew well and were still alive after two years.

3.2 THE NATURAL POPULATIONS OF T. DERASA AND T. SQUAMOSA ARE ENDANGERED:

From June of 1987 until October of 1989, the researchers searched favorable reef areas for specimens of *Tridacna derasa, Tridacna squamosa, Tridacna maxima* and *Hippopus hippopus*. The research team measured a total of 2718 *Tridacna maxima*, 253 *Tridacna squamosa*, and 18 *Tridacna derasa.* (Not counting 45 juvenile *Tridacna derasa* produced by the brood stock circles). No *Hippopus hippopus* were located. Thus the relative abundance of the three remaining species were:

Tridacna maxima	90.9%
Tridacna squamosa	8.5%
Tridacna derasa	0.6%

Fishermen, encouraged to bring in *Tridacna derasa* for the community clam circles, found an additional 85 *Tridacna derasa* and 89 *Tridacna squamosa,* mostly in areas south of the main island group during a long calm period in February of 1988 when they were able to fish reefs normally subjected to heavy surf.

Figure 3 shows the sites spot-surveyed and mapped. Spot surveys were timed dives to get an estimate of the Tridacnid population over a broad area. Mapping surveys were done with shore teams and mapped locations of clams, recording their precise location, species, size, color, and habitat.

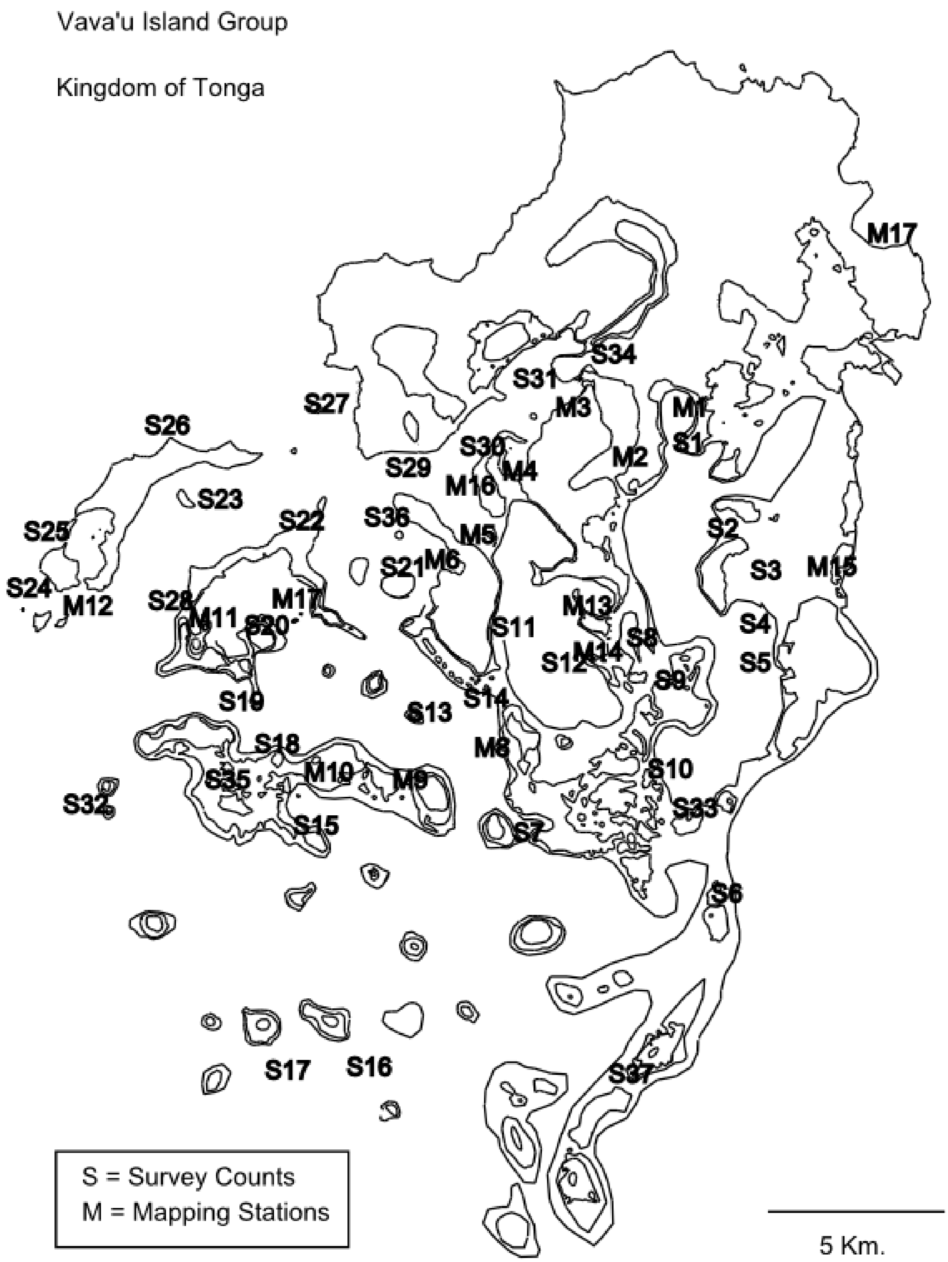

Figure 3 Areas surveyed and Mapped in Vava'u

3.2.1 *HIPPOPUS HIPPOPUS* IS EXTINCT IN TONGA:

McKoy (1980) suggested *Hippopus hippopus* might be extinct in Tonga. He found some recently dead specimens around Tongatapu, but no live specimens and no shells in Vava'u or Ha'apai. Our survey located numerous *Hippopus hippopus* shells which were excavated during the construction of a boat harbor in Neiafu Tahi, Vava'u. We were also able to locate dead shells in shallow water reef areas around Mounu Island.

The shells buried in the mud at Neiafu Tahi were clearly dumped there by fishermen at some time in the past as *Hippopus hippopus* normally lives in shallow water open reef flats. As some were buried under a meter or more of mud and by the large number present, it would appear that *Hippopus hippopus* was fairly common in Vava'u and was a favored food item for many years.

Shells were shown to older members of the community, including the honorable, Dr. S. Ma'afu Tupou, (then Governor of Vava'u). These men remembered *Hippopus hippopus* being captured from the outer reef areas on the eastern side of the Vava'u Island Group about 60 years ago. One fisherman, about 75 years old, remembered they had more meat than the other vasuva and tasted better. Nobody, however, remembered a name for *Hippopus hippopus* other than the generic name of vasuva.

A reward of $50 was offered to anyone who could bring in a live *Hippopus hippopus*. A specimen was put on display in the fishing cooperative and shown to numerous fishermen. The reward was announced on the radio and in the newspaper. The reward has been a standing offer for over a year and not one specimen has been found.

Demonstrating an actual extinction helped convince people that there really was a threat to the giant clam population. When the first dead shells of *Hippopus hippopus* were shown to fishermen several claimed to know where there were many of them still on the reef. Others insisted that they must still be out there, somewhere, if only in deeper water.

Hippopus hippopus, however, probably became extinct because it is unable to live in deeper water. It normally lives on the reef top and does not attach to rocks, thus making it extremely vulnerable to fishing.

3.2.2 *TRIDACNA DERASA* IS ON THE VERGE OF EXTINCTION:

Of major interest to the project was the condition of the stocks of *Tridacna derasa*. This is the largest of the Tongan giant clams, and was thought to be the best suited for aquaculture projects. Preliminary evidence from McKoy (1980) and Chesher (1986) indicated the population of *Tridacna derasa* was very low and the two and a half years of subsequent survey activity proved this to be correct.

Tridacna derasa, because of its large size, clean, smooth shell and tendency to live on rubble areas or away from living coral, is easy to collect. It does not, after reaching about 250-mm in shell length, attach to the bottom. Divers with face masks spot it from the surface in depths up to 20 meters, lower a weight attached to a rope into the open shell and, when the valves close, haul the clam up to the boat. Smaller specimens in shallower water are simply picked up by hand.

Since it requires about 6 years for *Tridacna derasa* to reach first female maturity and since they are easy to see after they reach two years of age, a *Tridacna derasa* would have to go undetected for 4 years to reach breeding age. Although, on any given day, only a few fishermen are actively snorkeling, all inner island reefs are probably searched by local fishermen at least once in any 4 year period. Because of this, and because of earlier commercial fishing activities, the research teams and local divers were only able to locate 18 *Tridacna derasa* within the inner island area between June of 1987 and October of 1989 (excluding the juveniles produced by the circles).

Local fishermen were asked to indicate on a chart where they thought there were good populations of *Tridacna derasa*. These sites are shown in Figure 4. Sites which were substantiated are labeled "D" while sites which were designated by fishermen but not surveyed by the research team are labeled "D?".

Older fishermen indicated areas in and around the central islands as places where large numbers of *Tridacna derasa* had been collected. Two older fishermen gave locations on small central islands or isolated reefs as "secret" places where they had taken many *Tridacna derasa*. Some fishermen claimed to know of places where there were *Tridacna derasa* in the inner harbor areas, even in Vaipua Lagoon, but these were probably *Tridacna squamosa*. When asked, during the contest, to collect the *Tridacna derasa* from the inner harbour areas several fishermen went out looking but no clams were found.

Many of the sites described by the older local fishermen as being productive in the past were examined and although one or two specimens were sometimes found, the sites were fished out.

Younger divers indicated open water reef areas in depths of 1 to 20 meters as the best places to find *Tridacna derasa*. The consensus of younger fishermen indicated the largest existing stock was on the eastern sunken barrier reef and around some of the outer island reefs and shoals to the south of the main island group.

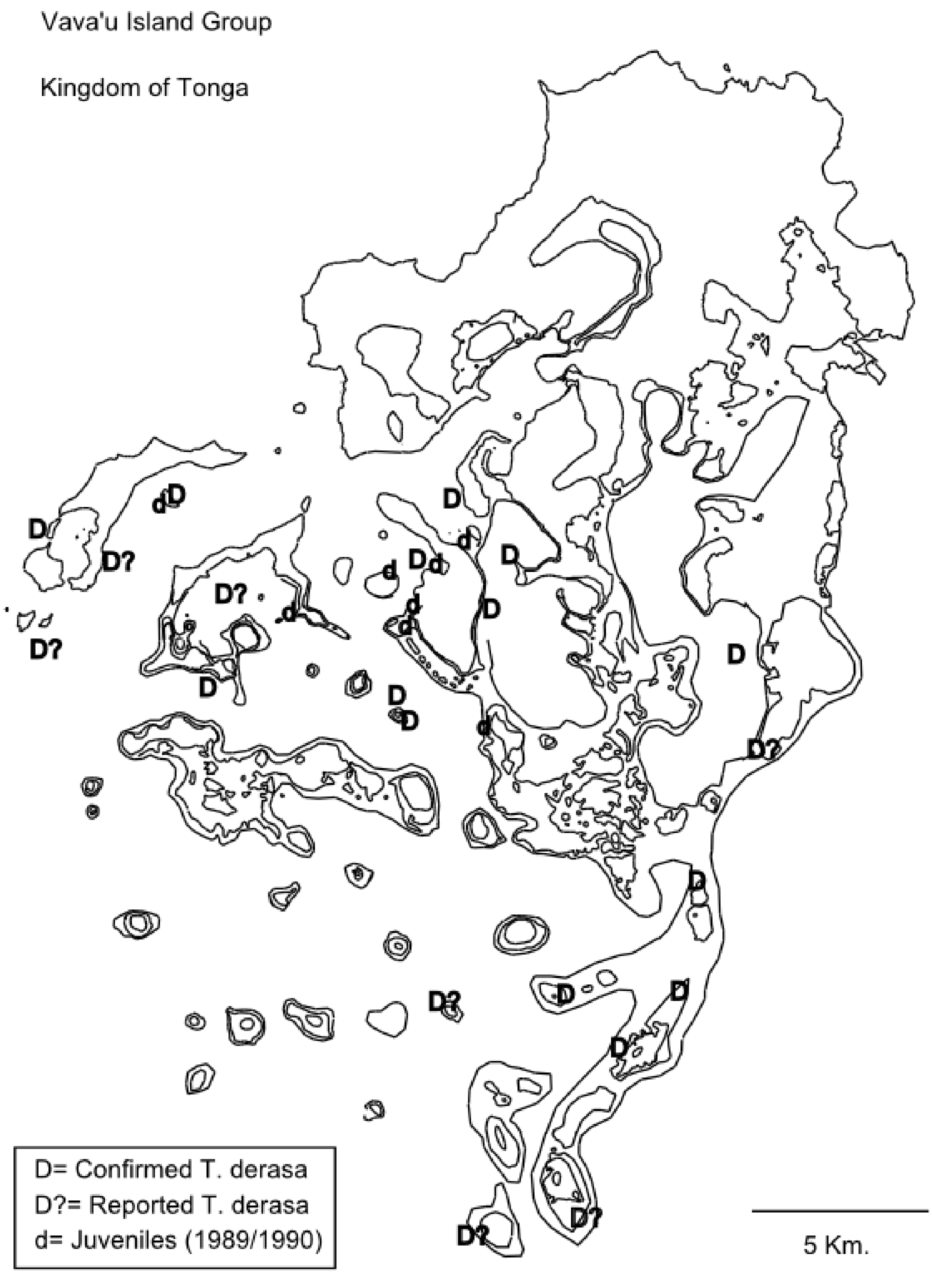

Figure 4. Locations of Tridacna derasa in Vava'u

Some fishermen thought the population of *Tridacna derasa* was badly overfished in Vava'u but said there were plenty of them in the Ha'apai island group. An experienced diver who fished the Ha'apai group in 1988, Tasi Afeaki, said he had collected large numbers of *Tridacna derasa* there but they were mostly in deeper water and the stocks were extremely limited and probably depleted following his activities. He felt the shallow water areas in Ha'apai were already depleted of *Tridacna derasa*.

From November of 1987 until January of 1988 a contest was held for all fishermen to collect *Tridacna derasa* for the proposed community clam circles. A fair market value was paid for all specimens as well as cash awards of $150, $100 and $75. The honorable Dr. S. Ma'afu Tupou, then Governor of Vava'u, actively promoted the contest by visiting the outer islands and encouraging fishermen to collect vasuva. The contest was advertised by fonos, town meetings, posters, word of mouth, during surveys, on the radio and in the newspaper.

One diver used SCUBA during his attempts to collect specimens, but, as the weather was blowing hard from the southeast for most of December, he limited his search to the inner island areas in depths of up to 30 meters. He found three *Tridacna derasa* and numerous *Tridacna squamosa*.

The end of the contest was delayed twice because bad weather prevented the divers from going to the islands and reefs south of the main island group. When a calm spell finally came, the divers did go out. Many specimens of *Tridacna squamosa* and *Tridacna maxima* were collected but the winner of the contest had only 4 *Tridacna derasa.* The second place fisherman had 3 *Tridacna derasa* and the third place winner had 2 *Tridacna derasa*. Although it had been made clear only *Tridacna derasa* would count towards the cash prizes, all the fishermen arrived with *Tridacna squamosa.* It was not clear if they did not know the difference or if they hoped we did not.

During a long calm spell following the contest, one group of fishermen continued to look for *Tridacna derasa*. They found a reasonable stock of them off one of the smaller islands to the south of the main island group. In about one week of fishing they brought in 14 *Tridacna derasa*. The following week they collected 35 *Tridacna derasa*.

The project personnel, using snorkeling and scuba, located a total of 18 *Tridacna derasa* in the central island group area. In Figure 4 the inner island sightings of *Tridacna derasa* show one "D" for each specimen found.

The depleted state of the *Tridacna derasa* population is supported by the contest fishermen's reports of taking the specimens from depths of 7 to 20 meters. This is the first generation of Tongan fishermen in Vava'u who have had outboard motorboats, face masks and flippers to get the *Tridacna derasa* from deeper water. The past 30 years have, therefore, been a time of harvesting an essentially virgin stock of giant clams.

Several fishermen believe there are huge numbers of *Tridacna derasa* in deeper water (30 to 50 meters) where they can not dive without SCUBA. This is not true, as the clam's need for sunlight for its symbiotic algae limit the depth range to less than 30 meters and they are extremely rare at depths greater than 20 meters.

The existing distribution of *Tridacna derasa* reflects fishing pressure more than biological preference of the species. Fishermen claimed they had, in the past, taken large specimens of *Tridacna derasa* from the intertidal zone along the eastern reefs of the Vava'u group and from the inner island reef environment.

In addition, the breeding success of the community clam circles in the protected waters of Falevai and the settlement of juvenile *Tridacna derasa* in depths just below the spring low tide line supports the idea they naturally survive and grow well in the inner island shallow areas and that fishing pressure is responsible for their present distribution.

3.2.3 *TRIDACNA SQUAMOSA* IS VULNERABLE AND HEAVILY FISHED:

Tridacna squamosa is much more abundant than *Tridacna derasa* in Vava'u. For every one specimen of *Tridacna derasa* located, 14 specimens of *Tridacna squamosa* were found. Their mantles are well camouflaged and they tend to live associated with live coral making them difficult to see from the surface. In addition, they attach to the coral with byssal threads and do not clamp their valves shut when touched. Therefore, divers can not collect them by lowering a weight on a rope into their valves. They must dive down and pull them loose from the coral. This means *Tridacna squamosa* has been reasonably safe from fishing in depths greater than 15 to 20 meters except during commercial harvesting using SCUBA or Hooka.

With the advent of the use of SCUBA and Hooka, and improvements in flippers and face masks, divers are able to harvest the larger specimens from deeper, protected waters. The shallow populations of *Tridacna squamosa* have already been heavily fished in the central island group and large, productive egg-layers were rare in depths less than 10 meters.

Specimens of *Tridacna squamosa* were found in Neiafu Tahi, Neiafu Harbor, Vaipua Lagoon, off Utangake, and in Hunga Lagoon demonstrating that this species survives well in the almost enclosed embayments of the Vava'u Island Group. This would give a distinct advantage to brood stock aquaculture of *Tridacna* squamosas because the embayments have long water resident times and the larvae could be expected to remain in the bays throughout their swimming phase.

253 specimens, mostly juveniles, were located in depths of 1 to 3 meters in the central island group area; especially near Mala Island and the area from Nuku to Port Maurelle. (This number includes specimens which were counted again on successive years).

Larger specimens of *Tridacna squamosa,* not included in the data on mapped clams, were found in a limited portion of the inner island area in depths of 10 to 30 meters. Fishermen, using SCUBA, regularly harvest *Tridacna squamosa* from the embayments of Vava'u.

The distribution of Tridacna squamosa is shown in Figure 5.

Figure 5. Distribution of Tridacna squamosa in Vava'u

3.2.3 *TRIDACNA MAXIMA* IS STILL COMMON IN VAVA'U:

Tridacna maxima is still reasonably common in Vava'u. This clam normally bores into dead coral and only the deeply toothed edge of the shell is exposed. As they grow beyond 70 to 80-mm in shell length, they protrude more and more from the rock, thus making them more vulnerable to fishing. *Tridacna maxima* is firmly attached to the bottom of its coral rock burrow with numerous, strong byssal threads and is thus difficult to remove, especially when smaller than 100-mm (the size of male sexual maturity).

The mantle colors of *Tridacna maxima* vary considerably from specimen to specimen, ranging from bright blue to grays and blacks, yellows and greens. The blue specimens are the easiest to see while some of the gray color patterns are excellent camouflage against their normal habitat of dead, gray coral rock. In an area of heavy human fishing pressure, one would expect the camouflaged colors to be more common than the visible ones. The incidence of colors did not indicate this to be the case. Figure 6 shows a graph of the relative frequency of color patterns from different stations.

Graphs of size distribution of *Tridacna maxima* (Figure 7) clearly show an abrupt drop in specimen size from 50 to 60-mm shell length, indicating that this is where fishing pressure begins.

3.3 GIANT CLAMS GROW SLOWLY

All giant clams grew only a few millimeters per month and produced meat very slowly. According to our observations, *Tridacna derasa* and *Tridacna squamosa* grew at about 4 or 5 mm per month while *Tridacna maxima* grew about 2-mm per month for the first 10 years of life. Table 1 shows the sizes and meat weights of the different species.
To grow as wide as this page *Tridacna squamosa* would take a little less than 4 years, *Tridacna derasa* a little more than 4 years and *Tridacna maxima* about 15 years. To reach 250 grams wet meat weight (about half a pound) *Tridacna squamosa* would require just under 4 years growth, *Tridacna derasa* about 5 years and *Tridacna maxima* about 15 years of growth. Thus, compared to most other animals, such as fish or octopus or land animals like chickens and pigs, giant clams grow very slowly and are low net protein producers.

The biggest *Tridacna derasa* found was 542-mm (21 inches) in shell length. The largest *Tridacna squamosa* was 415-mm (16 inches) and the largest *Tridacna maxima* was 370-mm (14.5 inches).

TABLE 1

Growth of Tridacnid clams in Vava'u

	Tridacna squamosa				***Tridacna derasa***				***Tridacna maxima***			
Age	Length		Meat Weight		Length		Meat Weight		Length		Meat Weight	
Years	mm	inch	mg	pounds	mm	inch	mg	pounds	mm	inch	mg	pounds
2	123	5.4	51	0.1	116	4.2	22	0.1	56	2.2	6	0.01
4	222	8.8	271	0.6	204	8.0	138	0.3	100	4.0	30	0.07
6	276	10.9	569	1.3	271	10.0	344	0.8	134	5.3	66	0.14
8	310	12.2	840	1.8	320	12.6	596	1.3	160	6.3	106	0.24
10	335	13.0	1049	2.3	358	14.1	853	1.9	181	7.1	147	0.32
15	354	14.0	1332	2.9	416	16.4	1385	3.0	213	8.4	230	0.50

After giant clams become sexually mature as females and begin to produce more eggs, their growth slows down. The larger clams produce many more eggs than smaller ones and as more energy goes to the production of eggs, less is used for growth. *Tridacna derasa* over 400-mm in shell length (about 15 years old) only grew a few millimeters a year. Several *Tridacna derasa* over 350-mm shell length showed no growth at all in an 18-month period while others decreased in size because of shell decay. A 495-mm shell length specimen, for example, decreased to 486-mm shell length in one year.

Tridacna squamosa grows until it is about 15 to 20 years old and then appears to stop growing at whatever size is reached at that time. Specimens ranging from 320 to 390-mm shell length tended to show no growth at all or a decrease in size during a 20-month period of measurement.

Sufficient specimens of all species were tagged and remeasured to give a reasonable estimate of growth for the Vava'u specimens. Figure 8 shows the growth curves of all three species of vasuva found in Vava'u derived from tagged data using the Fabens (1965) von Bertalanffy growth analysis.
The length of the clam at time *t* is given by the equation:

$$L_t = L_{oo}(1 - e^{-K(t-t_o)})$$

where L_{oo} is the asymptotic length, K is the slope of the growth curve between tag and recovery times, and t_o is the hypothetical age the organism would be at zero length.

Table 2 compares the calculated growth curve data for the three species.

TABLE 2

Species	Loo	K	*to*	N
Tridacna derasa	467	0.144	-0.035	137
Tridacna squamosa	370	0.238	-0.026	157
Tridacna maxima	250	0.131	-0.026	400

The *Tridacna derasa* K value of 0.144 is slightly higher than the K values of *Tridacna derasa* from Australia (K=0.108) and is not significantly different from the K values from Fiji (K=0.134) (Munro and Adams, personal communication). In American Samoa, Buckley and Itano found cultured *Tridacna derasa* between the sizes of 70 to 170-mm grew at an average of 5-mm per month which also fits the observed Vava'u data.

The slope of the curve for *Tridacna squamosa* (K=0.238) indicates rapid growth for this species during the first 10 years of life. Figure 9 gives an expanded view of the first 10 years of growth for the three species showing that *Tridacna squamosa* grows faster during the early years than *Tridacna derasa*.

Figure 10, shows scatter plots of growth per month versus average shell length to give some idea of the variation in growth observed. In *Tridacna derasa* and *Tridacna squamosa* the scatter diagrams reveal a slowing of growth with increasing size.

The growth rate of *Tridacna maxima* was highly variable. Although the average growth rate was around 2-mm per month, individual clams were found which grew as much as 6-mm per month and some showed no growth at all.

Tridacna maxima growth was influenced by the nature of the substrate in which the clam is burrowed. Specimens surrounded by living coral grew poorly or not at all while specimens which were in branching coral areas or not embedded in the coral tended to grow more rapidly. Fastest growth of *Tridacna maxima* was obtained by transplanted specimens which were not deeply embedded in the coral substrate. These grew at almost the same rate as *Tridacna derasa* when young (Figure 11).

3.4 MEAT PRODUCTION WAS HIGHEST IN *TRIDACNA SQUAMOSA* IN THE FIRST 10 YEARS OF GROWTH.

McKoy (1980) calculated the relationship between the wet weight of meat and the length of the shell for all three Tongan Tridacnid clams. Using his formulas, growth in wet meat weight was calculated from the calculated length/age curves to produce the Wet meat weight curves shown in Figures 8 and 9.

Tridacna squamosa could prove to be the best giant clam for the proposed Tongan commercial aquaculture project because of its rapid growth and its preadaptation to enclosed, protected embayments. Figure 9 gives an expanded view of the growth rates of Tridacnids for the first ten years of life. *Tridacna squamosa* was clearly the fastest meat producer in the first decade of life.

Commercial aquaculture of giant clams must harvest the animals at a size where the meat production is rapid yet not so small as to compete economically with smaller, faster growing and less expensive clams. But harvesting would have to take place within a decade if the project is to be successful and within this time frame *Tridacna squamosa* is the most productive Tongan giant clam.

3.5 PREDATORS AND DISEASES COULD BE A PROBLEM FOR COMMERCIAL AQUACULTURE:

McKoy (1980) observed a large murex gastropod, *Chicoreus ramosus*, attacking Tridacnids. We also observed this in the field and under experimental conditions. An underwater TV was used to monitor feeding activities of *Chicoreus ramosus*. The gastropod attacked a wide variety of clams and oysters. In fact, caged specimens ate every kind of clam and oyster tested, including *Tridacna maxima*, *Tridacna squamosa*, and the other species listed in Table 3.

TABLE 3.
Specimens eaten by *Chicoreus ramosus* under captive conditions

Kukukuku	small giant clam	*Tridacna maxima*
Matahele	scalloped giant clam	*Tridacna_squamosa*
Kaloa'a	arc shell	*Anadara scapha*
Tofe	blacklip oyster	*Pinctada margaritifera*
Fotu'ohua	jewelbox oyster	*Chama isostoma*
Fai'ahu	thorny oyster	*Spondylus squamosus*
Tokalali	saw-tooth oyster	*Lopha cristagalli*
Tofeloa	hammer oyster	*Isognomon isognomon*
Kuku	box mussel	*Septifer bilocularis*
Ufi	black pen shell	*Atrina vexillum*

While *Chicoreus ramosus* does prey on Tridacnids, it will eat many other bivalves as well. Since *Chicoreus* or Potu patu is a favored food item for the Tongan people and since its shell is valuable for decorations or for sale to tourists ($2.00 each), it is not likely to be a serious threat to aquaculture efforts in Tonga.

Another shell, however, will almost certainly be a problem to any mass commercial aquaculture effort of giant clams in Tonga; *Cymatium muricinum*. *Cymatium* is a small (less than 25-mm), unattractive shell which has been a major pest to giant clam aquaculture efforts in many Pacific countries, including American Samoa. Buckley and Itano report up to 32% mortality of *Tridacna derasa* juveniles imported into American Samoa because of *Cymatium muricinum* predation. Specimens of *Cymatium* were found all year round and in all locations where nursery areas of *Tridacna derasa* were set up around Tutuila.

Cymatium has a very long larval life span (perhaps more than 6 months) and the larvae seek out concentrations of Tridacnid clams and swim in the incurrent siphons to settle in the clam's interior. There they begin eating the clam and continue to do so until the clam in consumed. Infestations of this predatory pest is apparently related to the close packing of seed clams in plastic cages and the close packing of the plastic cages on the reef.

If the young *Tridacna derasa* are simply set out on the reef they are quickly consumed by fish, octopus, crabs and other predators. Therefore, present aquaculture methods include placing the clams in plastic cages and then placing these on the reef. The dense concentrations of young clams creates a unique habitat for the attraction, successful settlement and growth of *Cymatium.* Divers must go out onto the reef and open all of the cages twice a week to remove the predatory snails. This is a very labor intensive activity and has made the commercial development of giant clam aquaculture uneconomical, especially since the cultured specimens must be tended for three years.

It is very important that an active *Cymatium* control program be maintained in any experimental aquaculture of giant clams in Tonga because if they are left alone to grow and breed in the experimental stock the effect would be to create a brood stock of these predators and their successful spawning could endanger the natural stocks of Tridacnid clams in Tonga.

Although *Cymatium muricinum* has been found in Tonga it is not abundant and only one specimen of *Tridacna maxima* was found which had been recently eaten by a *Cymatium*. While the predator may be expected to be a problem to any mass aquaculture attempts of giant clams, it may not be a serious problem for brood-stock aquaculture.

During transplanting of clams into the community clam circles, small specimens which were simply placed anywhere on the reef were gone within two days. A 107-mm specimen of *Tridacna derasa*, for example, placed on a flat, dead coral head in 20 feet of water immediately attracted the attention of a small Tangafa (Napoleon wrasse *Cheilinus undulatus*), known to be a predator of clams and other benthic invertebrates. Within one hour the wrasse killed the clam.

Specimens of clams which were placed in more protected (less visible) locations on the reef were more likely to survive. We devised a technique of placing a highly visible aluminum tag on the coral a few feet away from each small, transplanted clam. This attracted the attention of any passing fish and served as a diversion to protect the nearby clam. We had no further mortalities of transplanted clams, regardless of size, using this technique.

While the "diversion" technique would be uneconomical for commercial aquaculture, it served to support the hypothesis that young clams growing up from larval size are less prone to predation than those which are grown elsewhere and transplanted onto a reef. Newly introduced aquaculture clams attract the attention of reef fish in the area and are thus likely to be eaten unless they are packed into plastic cages.

Brood stock aquaculture results in normal distribution and settlement of larvae and it is unlikely that very high densities will result and create a habitat conducive to *Cymatium* infestation.

Several specimens of *Tridacna derasa* kept in Neiafu Tahi and in Neiafu Harbor developed a "white spot" disease. White areas, resulting from the loss of zooxanthelle from the mantle, developed around injuries or, in some cases, in a random pattern on the mantle. Two of the *Tridacna derasa* showed increasing numbers of these white spots and died in less than four months. Two specimens of *Tridacna squamosa* developed the white spots. One of these died and the other two were harvested to prevent further contamination of the circle.

Specimens of *Tridacna derasa* with white spot were removed from Neiafu Harbor and placed in the community clam circle at Falevai. These seemed to recover and are still under observation.

The cause of the white spots appears to be stress related. Injuries to the mantle during collection sometimes resulted in the expulsion of zooxanthellae from the injured area. Subsequent survival of an infected animal seemed to be related to the habitat. If conditions were optimum the animal recovered. If the animal was too deep or water conditions less than optimum the white spots increased in number and the animal died.

Aquaculture efforts in Tonga must therefore expect to encounter problems with density related diseases and predators. The distance between one clam and another during grow-out phase should be at least 2-meters until tests have been completed on what levels of density packing results in infestations of *Cymatium* and/or diseases. The history of severe disease problems in aquaculture efforts due to high densities of the cultured animals is extensive, and includes sponge farming oyster, mussel and pearl culture.

"Density" is relative, in the marine environment, to water currents over the specimens. In calm water, clams a meter apart may be in danger of cross-contamination of diseases or pests. In areas of high water currents, however, clams a centimeter apart and perpendicularly arranged to the water flow are unlikely to contaminate each other as the rapidly moving water flow effectively isolates them.

It is, therefore, recommended that clams in grow-out areas for aquaculture be spaced one per four square meters of bottom or be placed in tidal race-ways where currents of one to two knots are maintained through the tidal cycle.

3.6 SPAWNING STUDIES WERE INCOMPLETE:

Because of the few specimens of *Tridacna derasa* and *Tridacna squamosa* available, no gonad samples were taken to ascertain the spawning cycle of these animals in Vava'u. We did, however, note spawning activities of *Tridacna derasa* on January 15th when captive animals were unloaded at the fisheries wharf in Neiafu Harbor.

In December of 1987 *Tridacna squamosa* in a circle in Neiafu Tahi were stimulated with gonad extract and although these exhibited spasmodic contractions they did not release any gametes.

In October of 1988, four *Tridacna derasa* in the community clam circle at Falevai were stimulated with hydrogen peroxide. They began spawning within a few minutes but did not incite spawning in other clams in the circle.

3.7 FISHING PRESSURE IS SEVERE:

McKoy's 1980 analysis of mortality for *Tridacna maxima* used Australian growth data and the declining slope of the size frequency distributions in Vava'u to arrive at a mortality estimate of Z=0.35 (ie. 35% of the population would die in a year). He felt, "The value for Vava'u (100-179 mm size group) of Z=0.35 is higher than all other values and is probably unrealistic..." In fact, our survey showed the slope of the size frequency distribution (July 1987 to February 1988) from 60 to 160-mm was exactly the same as the one McKoy derived (-0.026).

3.7.1 MORTALITY IS HIGH:

Mortality of all species of Tridacnids was determined directly by the mapping technique which showed exactly how many clams died in a one year period from a known population. Table 4 shows the mortality and recruitment for the three species at different areas in Vava'u between 1988 and 1989.

TABLE 4

Mortality and Recruitment of Tridacnids in Vava'u 1988 to 1989
(mx=*Tridacna maxima*, sq=*Tridacna squamosa*, dr=*Tridacna derasa*)

Location	Mortality			Recruitment		
	mx	sq	dr	mx	sq	dr
Port Maurelle	27.0%	70.0%	none	12.4%	13.5%	none
Mala	29.5%	78.6%	none	7.9%	14.0%	none
Nuku/Falevai	31.0%	69.0%	100%	9.0%	46.0%	200%

From a total known population of 750 *Tridacna maxima*, 216, or 28.8% died in one year from all stations in Vava'u. The mortality rate did not differ significantly from the different areas, ranging from a low of 27% in Port Maurelle to a high of 31% in the pass at Nuku. Thus, an estimate of 30% mortality per year for the total population is compatible with the 35% statistical estimate derived from the analysis of size frequency. Radtke (undated MS) examined an unfished population of *Tridacna maxima* at Rose Atoll and determined a natural mortality rate of 15.4%. Thus, about half of the observed *Tridacna maxima* mortality is assumed to be the result of fishing pressure.

Mortality of *Tridacna squamosa* was much greater, averaging 71.4% per year from all stations and ranging from a low of 69% at Nuku to a high of 78.6% at Mala. No estimate of natural mortality is available from unfished stocks, but the sharp cut off in size frequency of *Tridacna squamosa* in the inner island group indicates the observed mortality is dominated by fishing pressure.

Mortality figures of *Tridacna derasa* were not available as only two specimens were found in the study area sites and both of these were collected to be placed in the community clam circles.

3.7.2. RECRUITMENT IS LOW BUT IMPROVING NEAR THE CLAM CIRCLES:

Recruitment to the population was also measured directly. Any specimens found in 1989 in the survey sites which measured less than 30-mm for *Tridacna maxima* and less than 100-mm for *Tridacna derasa* and *Tridacna squamosa* were considered recruits. These lengths represent about 18 months of growth (the time interval between the installation of the community circles and the 1989 surveys). Our data indicate specimens of *Tridacna maxima* below 20-mm shell length and *Tridacna squamosa* and *Tridacna derasa* below about 50-mm shell length are too small to be observed reliably and were thus missed during the 1988 survey (Note: the smallest *Tridacna squamosa* found was 13-mm, the smallest *Tridacna derasa* 44-mm, and the smallest *Tridacna maxima* = 8-mm).

It is important to note that recruitment in Tridacnid clams can be expected to vary dramatically from year to year according to currents, water conditions, and spawning success.

There was a dramatic increase in both *Tridacna squamosa* and *Tridacna derasa* recruits in the area to the southeast of the Falevai community clam circles as compared to other areas further away from the site. *Tridacna squamosa*, for example, showed an average recruitment of 14% in Port Maurelle, Mala and Foeata while, at Nuku and Falevai recruitment was 46% at the mapped stations.

The increase of recruitment to the *Tridacna squamosa* and *Tridacna derasa* populations as a result of the community circles was so obvious that the villagers of Falevai noticed the abundance of juveniles along the reefs bordering the village, around Nuku and at A'a. Unfortunately, many recruits were taken by children when they were first discovered.

The study areas represented in the mortality and recruitment data given above comprised only a small portion of the total area surveyed. The mortality and recruitment data are only from stations where the populations were small, discrete, and accurately drawn on a detailed scale in 1988. A much greater area was carefully surveyed and clams counted and measured without making detailed drawings of the position of each clam.

The reef in front of Falevai was extensively surveyed in 1988 and no specimens of *Tridacna derasa* were found. In fact, except for a single 44-mm specimen found in October 1988 at Falevai, no juvenile specimens of *Tridacna derasa* were found at any of the surveyed stations in 1987 or 1988. In 1989, 18 juvenile specimens of *Tridacna derasa* measuring from 92-mm to 110-mm were located along 50 meters of this reef. Similarly, 6 specimens of *Tridacna derasa* within the same size range, were found in the pass at Nuku, 8 around A'a, 2 at Luamoka and 11 along the reef at Taunga.

The uniform size of the 1989 juvenile specimens, the lack of any in the previous two years of searching and the scarcity of small specimens of *Tridacna derasa* throughout the survey areas, combined with the proximity of the recruits to the community clam circles and the lack of any *Tridacna derasa* juveniles at control stations provided very convincing proof that the new juveniles represented offspring from the brood stock.

This concept is further supported by the dramatic increase in *Tridacna squamosa* juveniles ranging in size from 72 to 113-mm in the same areas where the juvenile *Tridacna derasa* were found. In control areas the *Tridacna squamosa* recruitment rate was low.
No brood stock circle of *Tridacna maxima* was constructed and there was no comparable increase in *Tridacna maxima* recruitment at any station as would be expected if, for some reason, conditions were exceptionally favorable for tridacnid larvae.

Recruitment for *Tridacna maxima* averaged 10.5% per year with a low of 8% at Mala and a high of 12% at Port Maurelle. The abundance of juvenile *Tridacna maxima* indicates this species is not being sufficiently depleted to endanger its existence. It is also evident, however, that fishing pressure is sufficient to prevent specimens reaching full productivity (which may require more than 10 years growth). Few specimens over 200-mm in shell length were found in the inner island group. It would seem advantageous to form a circle of *Tridacna maxima* adults larger than 200-mm in an attempt to increase the population of these clams in the inner island area.

3.7.3 VASUVA IS A FAVORITE SUBSISTENCE FOOD:

Figures 12 and 13 show the results of a survey of 126 people chosen at random in Neiafu and representing a cross section of Vava'u people. They lived in 20 villages and ranged in age from 16 to 70 years old. As shown in Figure 14, almost everyone liked to eat vasuva. Only three people said they did not eat vasuva for religious reasons.

The frequency of eating vasuva varied from several times a week to a few times a year. People from coastal villages, especially in the more protected areas, ate vasuva more often than those from interior villages or villages on exposed shore lines.

3.7.4 FISHERMEN AND THE PUBLIC WERE UNAWARE OF THE PROBLEM:

Local fishermen insisted there was an endless supply of *Tridacna derasa* and there was no cause for thinking the population might be endangered. One of the men who made a clam circle, Siobe Hungalu, also felt there was a huge stock of *Tridacna derasa* and that it could not be depleted by normal fishing activities.

He felt he personally knew the approximate location of some "Four or five hundred" *Tridacna derasa*. In an effort to make his own vasuva circle, Siobe Hungalu collected two *Tridacna derasa* in 1987. In 1988 he collected 23 *Tridacna derasa*. While he may know the location of several hundred *Tridacna derasa*, he did not realize an experienced dive team, using SCUBA or hooka, could collect about 100 per day and thus exhaust the stock in a week.

3.8 NEWSPAPER ARTICLES, RADIO, VIDEO AND PUBLIC DISCUSSION HELPED INCREASE PUBLIC AWARENESS:

A major goal of the Vava'u giant clam project was to foster a spirit of environmental stewardship in the people of Vava'u. At the outset of the experiment the general attitude of the fishermen and the public was that any clam (or other species of marine life) was fair game regardless of size or numbers available. "If I don't take it the next person will," was the rationale for taking very small clams, baby lobsters, lobsters with eggs, octopus with eggs or anything else.

There was no public acceptance of the idea of a protected area where large adult animals would be left alone to breed. People thought such an area, as a marine reserve or marine park, needed a government decree backed up with continuous enforcement. Continuous enforcement, however, has proven to be impossible due to limited manpower and funds. The marine parks of Tongatapu were observed being fished by local fishermen on several occasions and the clam circle installed by the Ministry of Lands, Survey and Natural Resources in Nuku'alofa Harbor required night watchmen to prevent people from stealing the clams.

We were advised from the start by a broad cross section of Tongans and local Europeans that the project could not succeed. People would steal the clams and eat them.

It was therefore considered important that the project be done by the community of Vava'u and not the research team or the government. To assure a feeling of ownership and pride of achievement, the people of Vava'u had to solve the problem of how to get the clams and protect them.

3.9 GIANT CLAM CIRCLES WORK BEST AS A COMMUNITY PROJECT:

The first attempt to build a clam circle was by a man named Matoto. He hosted "Feasts" for tourists at Ano Beach and thought a clam garden would attract visitors to his feast. He had divers look for *Tridacna derasa* for his circle but they only found one *Tridacna derasa* and three *Tridacna squamosa*. These were tagged with aluminum tags and placed in 2 meters of water off Ano Beach in August of 1987. In November, when Matoto was in the hospital, the clams were killed and the meat taken.

The second clam circle was made by the research team for the Governor of Vava'u and placed in shallow water at the old coaling station in Neiafu Harbor. The site was off property owned by the Governor and directly in front of the town officer's home. Seven *Tridacna squamosa* and one *Tridacna derasa* were tagged and put in 2 to 4 meters of water in August of 1987. By December, four of the clams had been removed, shell and all, from the circle.

The third clam circle was started by Siobe Hungalu off his town 'api at Neiafu Tahi. Hungalu is a policeman. He obtained a "fish fence licence" protecting his clams on a designated area of the reef. He began with five *Tridacna squamosa* and one *Tridacna derasa* in September of 1987. In December of 1987 the survivors from the Neiafu harbor circle were moved to Hungalu's circle and others were added to bring the total number of clams to about 20 specimens. Several times fishermen tried to take Hungalu's clams at night. He caught them and the clams were returned. Once someone slashed five clams with a bush knife. Finally, in January of 1988, two men took all of the clams while Hungalu was on sick leave in Ofu. The men were caught and told they would either be prosecuted or they had to replace the stolen clams with twice as many as they had killed. They elected to replace the clams.

During the June to December period, two articles were written for the Tonga Chronicle (in English and in Tongan) and the clam circles were discussed on the radio during Environmental Awareness Week and in announcements by Hungalu and the project team. After the clams were taken from Hungalu's circle the police department talked about the clam circles on the radio.

By December of 1987, it was clear the idea could not succeed if done by an individual (Tongan or outsider). It had to be a community effort. In December of 1987, the Governor of Vava'u, the Honorable Dr. S. Ma'afu Tupou (now acting Minister of Lands, Survey, Natural Resources), initiated a contest for divers to go and find *Tridacna derasa* for a community clam circle. Members of the public, the business community of Vava'u, and the Ministry of Lands, Survey and Natural Resources donated funds for prizes for the fishermen who could catch the most *Tridacna derasa*. In January of 1988 the contest ended and specimens obtained by the fishermen thus became community property.

The village of Falevai on Kapa Island, was selected by the Governor as the best place to build a community clam circle. A new police station was under construction there and the district officer lived in Falevai. In addition, the area was centrally located in the island group and larvae produced by the circle would be expected to reseed the reefs within the central area of the Vava'u islands. There was a suitable bottom, 2 to 15 meters deep, the water was clear and the area once had numerous *Tridacna derasa* and *Tridacna squamosa*.

The Governor called a fono and explained the purpose of the clam circles to all the town and district officers. The District Officer for the outer islands, Vanisi Fakatulolo called a town meeting and told the people of Falevai the intent and purpose of the clam circle. The people agreed to act as guardians of the clam circles and promised to leave them alone. The villagers of Falevai selected the position for the community clam circles on a section of the reef which was infrequently used but within easy sight of the village.

The clams were installed at Falevai in two stages. First, in January and February of 1988, 40 *Tridacna squamosa* and 30 *Tridacna derasa* were placed in 10 to 15 meters of water. The remaining specimens taken during and following the contest were placed in 15 meters of water in Neiafu Harbor. In June of 1988 examination of the Falevai circles showed all the clams were still there. Another group of *Tridacna derasa* and *Tridacna squamosa* were then moved from Neiafu Harbor to Falevai. The specimens at Falevai were relocated from 10 to 15 meters into 3 to 8 meters depths and arranged in three concentric circles. In October of 1988 the remaining clams were removed from Neiafu Harbor and taken to the community clam circle at Falevai.

As a further effort to support the community giant clam circle in Vava'u a 30 minute videotape was produced on the giant clam circle. The tape was done with two versions, one in Special English and one in Tongan. The project was fortunate to be able to have an interview with His Majesty the King of Tonga who, on camera, supported the idea of the community clam circles. The video was placed in three of the video rental shops in Neiafu and copies were given to three schools in Vava'u and made available to the other schools through the Tourist Bureau (which conducts a regular school program). Copies of the tape were also given to His Majesty, to the Honorable Dr. S. Ma'afu Tupou, and the Ministry of Lands, Survey and Natural Resources.

4.0 THE PROJECT IS WORKING BUT NEEDS MORE FORMAL LEGAL SUPPORT:

Because the clam circles have been protected by the community spirit and not by constant guarding, the project already has shown the desired result. How much of the will to leave the clams alone or to protect them against poaching is due to an understanding of the purpose of the clam circles and how much is due to the community responding to an outside plea for cooperation is not clear. Ideally, the community agreement should come from a common understanding of what the brood stock does and how everyone will benefit from the brood stock.

Community projects are a Tongan way of life, but generally such projects last a few days, a week or perhaps a month. The Community Clam Circle has already lasted more than two years. Initially, the project called for simply leaving the clams alone but in time some of the specimens will die and need replacement and this will require more than a passive agreement.

Most research or aid projects bring funds or equipment to the community. This project brings only an abstraction - a responsibility to improve the environment for everyone. The clams which have been gathered by the community and placed at Falevai are the only existing stock of breeding *Tridacna derasa* in the inner island group of Vava'u. By placing them together in shallow water they have become completely vulnerable. It would be easy to kill them, either for a quick meal or for sale.

But if the community does kill them, they condemn the future of Vava'u to a life without Tokanoa molemole. If this attempt at community action to improve the marine environment fails it is unlikely anyone will try again in the future and it is unlikely *Tridacna derasa* will survive. Everyone will be poorer.

Each specimen of *Tridacna derasa* in the Clam Circle represents thousands and thousands of future clams; young it would produce if left alive to breed. Killing one of these clams brings a kind of natural poverty to the people of Vava'u by stealing all the young that clam could have made if left alive in the clam circle.

Presently, the legal protection for the giant clams comes by using the fish fence licencing provision of the 1924 Fisheries Act. The process of building and maintaining giant clam brood stocks, or brood stocks of other coral reef animals would be greatly improved if the Government of Tonga would provide legislation clearly designed to allow for the licencing of submerged lands for the purpose of brood stock aquaculture.

4.1 BROOD STOCK AQUACULTURE OFFERS AN EXCELLENT GIANT CLAM MANAGEMENT TECHNIQUE:

Commercial fishing for giant clams is generally a "pulse" fishery where fishermen harvest all the large specimens and, when the stock is reduced to the point where further fishing is not profitable, they fish for something else. Unfortunately, when combined with the steady pressure of both subsistence and cultural fishing, this will inevitably lead to extinction of the giant clams. Cultural fishing is the result of the need for vasuva to satisfy social or family obligations (ie. an important relative visits from the United States and wants to take some vasuva meat back when he or she returns. Since the relative has sent considerable amounts of money to the family over the years, the family is obligated to supply the desired vasuva meat even if it is expensive to get in terms of time and fuel).

As Tridacnids are seldom found below 30 meters, their potential habitat for survival is a band, ranging from 60 to 100 meters wide, which winds along the steeply sloping, coral encrusted embayments and islands. A dive team can easily harvest all of the breeding specimens (and most of the juveniles) from three or four kilometers of this zone in a single day.

The stocks of the outer reef areas are more difficult to fish as rough weather prevents diving activities for part of the year. Thus the stocks in the outer island areas, especially to the south east of the main island group, might be expected to survive fishing effort better.

If, however, commercial efforts are made to harvest the remaining stocks of *Tridacna derasa* and *Tridacna squamosa* using SCUBA and Hooka, they could be removed during protracted calm spells relatively quickly. Cultural and subsistence fishing would prevent the regrowth of the stocks.

Because of the movement of water currents, the adults in the outer island group are probably not effective in revitalizing the stocks of clams in the inner island group. Therefore, moving some of these into protected clam circles in the inner island area may be a simple and effective method of restocking the depleted fisheries.

McKoy (1980) did not consider the use of brood stocks as a potential solution to a fisheries management program. Instead, he proposed:

1. Prohibit the use of SCUBA and Hooka for the taking of giant clams.

2. Prohibit export of giant clam meat.

3. Licence fishermen.

4. Prohibit loans for boats and motors used for clam fishing.

5. Impose a size limit of 115-mm.

None of these suggestions are enforceable in Tonga and none influence the taking of clams in cultural or subsistence fishing. In addition, the proposed size limit of 115-mm would guarantee the extinction of *Tridacna derasa* and probably *Tridacna squamosa* as these are not sexually mature until much larger.

Protected brood stocks, however, limit the area of enforcement to a very small focus and, if done with the consent and cooperation of the public, are easily installed and maintained. The only thing the government needs to do is encourage communities to undertake such projects and strengthen the legislation which gives authority to those who want to protect them.

4.2 THE MAFF GIANT CLAM AQUACULTURE WILL NEED PUBLIC SUPPORT:

The Ministry of Agriculture, Fisheries and Forestry is beginning an aquaculture project with giant clams. If it is successful in rearing young clams the government will then need to place the clams out into the marine environment for about 5 to 6 years so they can reach market size. If the people of Tonga are not encouraged to feel responsible and cooperative in this effort Tonga will have exactly the same problem that giant clam aquaculture has had in American Samoa where people poached almost all of the government's aquacultured clams.

It would be an inexpensive and nice gesture if the government could acknowledge the accomplishment of the people of Falevai and of Vava'u for establishing and maintaining the community giant clam circles. The annual Agricultural Show in Vava'u would be a good opportunity to present an appropriate award to the villagers of Falevai.

4.3 1990 FIELD WORK WILL PROVIDE ADDITIONAL DATA ON REVITALIZATION BY BROOD STOCK AQUACULTURE:

From July to October of 1990 a final set of measurements will be made of growth, mortality, and recruitment to the clams in the brood stock circles and in the wild populations adjacent to the clam circles as per the original application to Cabinet.

Additional public awareness activities will be conducted, including making a second video of a more generalized nature to help reenforce the public commitment to the project.

5.0 RECOMMENDATIONS

Based on the successful installation and production from the community giant clam circles in Vava'u and Nuku'alofa and the proof provided by this study that they are productive and that the public actively supports them, it is recommended that the cabinet consider:

1. Authorizing the Parks and Reserve Board, through the Ministry of Lands, Survey and Natural Resources, to provide for a licence to protect brood stocks of marine animals in specified areas of the shallow waters of Tonga, giving the licence holder the right to prevent anyone from taking specimens from reserves which are built and maintained to increase the spawning success of any suitable marine organism. The licence should establish the reserve under the legal protection of the Parks and Reserves Act with already existing legal provisions requiring public notification by the applicant of the intent to place a brood stock of animals on a certain area of the reef and the posting of a sign and either marker buoys or a fence to delineate the reserve area. Penalties are already set forth under this act for violators of Parks and Reserves rules and regulations.

2. Approve the issuance of a certificate or award to be presented to the people of the village of Falevai during Environmental Awareness Week of 1990 for their good work in the protection and maintenance of the Community Vasuva Circles for the island group of Vava'u.

3. That the newly appointed Parks and Reserves Board act through its member, the Director of Agriculture, Fisheries and Forestry, to encourage the construction of community Giant Clam brood stocks at Hunga Island, Taunga, and Ofu. People from Hunga and Ofu have specifically requested guidance in this matter and both the Agricultural Committee and the Fisheries Officers in Vava'u could be of help in the licencing and construction of the clam circles.

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