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GIANT CLAM SANCTUARIES

IN THE KINGDOM OF TONGA

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EXECUTIVE SUMMARY

From June of 1987 to October of 1990 a public environmental improvement project to enhance the stocks of giant clams in Vava'u has proved highly successful. The report of this project is divided into three parts. The first part details public involvement in the establishment and maintenance of community giant clam sanctuaries. This is important because it tells people in other island areas how to go about community based environmental improvement.

The second part deals with how we scientifically proved the giant clam sanctuary actually improved stocks of wild giant clams on nearby reefs. This is important because it is the first proof that marine sanctuaries for invertebrates with larval development actually improve local wild stocks.

The third part examines the biology of the giant clams of Vava'u.

SUMMARY OF PART 1

A SUCCESSFUL ENVIRONMENTAL IMPROVEMENT PROJECT

THE ESSENCE OF ENVIRONMENTAL IMPROVEMENT

A successful environmental improvement program changes the way people behave so there is a measurable improvement in the flora, fauna, or condition of a resource. Changing people's behavior is a process of altering cultural bad habits. In Tonga, the public addiction was to take whatever individuals happened to want from the sea with no thought to the survival of the coral reef creatures.

Stopping addictions is a difficult task. Even when individuals know that they are endangering their personal health and family well-being they are unable to give up alcohol and tobacco addictions. Getting people to stop environmental abuse is even more difficult because individuals are asked to give up their personal desires for some long-term community need that may never effect them personally. In this project, individuals of the village were being asked to leave the giant clams in the sanctuary alone. This is not an easy urge to resist if a person is hungry and the children are hungry and there are many large, tasty, nutritious giant clams right in front of the village.

The tools used to combat drug abuse are the same ones needed to combat environmental abuse. The first step is to increase the feeling of self worth. I do not refer to money or fame, but to the feeling that one is a cherished creation of God, a creation that can make life better, and not worse, for one's self and others. The second, and closely related, tool is Loyalty. Loyalty and respect to the miracle of God's creation (including the individual, the community, the land and sea and all the living creatures created and blessed by God). If case workers have a profound understanding of these two key spiritual strengths, personal and cultural rehabilitation is possible.

If agents of change don't include these elements, and rely on buying environmental respect with aid money, the people will continue to abuse themselves and the intricate plan of life around them. One has only to look at the record of trying to solve drug abuse by pouring laws and money on the problem.

THE VAVA'U GIANT CLAM TEST

A community based marine sanctuary for giant clams was set up in the Vava'u island group of the Kingdom of Tonga. The public environmental improvement project gave the community participants knowledge of the need for, and problems associated with, marine sanctuaries. During a community sponsored contest, fishermen gathered scattered adults of giant clams from a large area. The clams were placed together in circles inside the boundaries of sanctuaries to act as a brood stock to enrich surrounding reefs.

Project volunteers used all available means of promoting public assistance and understanding. While all lines of public communication are needed in such a project, a locally produced short educational video was the most productive method of teaching new concepts to the island people.

Before and after surveys of the wild stocks of giant clams demonstrated the sanctuary enhanced local recruitment on adjacent reefs. Village people observed an increase in the settlement of clams on nearby reefs and this helped develop community support.

The Falevai Community Giant Clam Sanctuary has been maintained six years by the Vava'u community with minimal support by the Governor's Office in Vava'u, the Ministry of Lands, Survey and Natural Resources and the Ministry of Fisheries.

The success of the Falevai sanctuary and presentation of an award for the `Best Vasuva Sanctuary' at the September 1989 Agriculture Show resulted in 10 other villages requesting assistance from the Vava'u Fisheries Department Extension Service to set up community giant clam sanctuaries at their villages. Three more sanctuaries were established in September 1990.

SUMMARY OF PART 2.

DO THE SANCTUARIES INCREASE RECRUITMENT ON ADJACENT CORAL REEFS?

There is little doubt sanctuaries work as they should for some plants and animals. Bird sanctuaries, for example, protect important nesting sites. If people leave the nesting birds alone, the population of birds will increase. But what about marine animals, like giant clams, whose young go through a free-swimming larval stage? The swimming stage might drift off with the ocean currents and settle on reefs far away - or perhaps sink at sea and die.

Prior to this study, there was little evidence to show marine sanctuaries would actually work to increase wild populations on nearby reefs.

Extensive base-line surveys began in June of 1987 and continued until the installation of the first community giant clam sanctuary at Falevai in January and February of 1988. Teams of divers surveyed the same stations again from July to October of 1988, 1989, and 1990. In all, survey teams covered more than 47 kilometers of shallow water reefs and spent more than 250 hours in the water actively mapping and searching for giant clams.

Scientific tests were set up to determine the impact of the broodstock of giant clams in the sanctuary on nearby recruitment.

There was no evidence of recruitment of the smooth giant clam *Tridacna derasa* prior to the installation of the sanctuary, Surveys from 1987 to 1988 showed overfishing had seriously endangered this species in the inner island group of Vava'u and lowered the adult stock to below levels required for successful recruitment. Only 18 adults were located in the entire inner island area of Vava'u.

The first juvenile *Tridacna derasa* appeared eight months after the sanctuary was installed. The numbers of juveniles increased in 1989 and again in 1990, on reefs adjacent to the sanctuary and extending up to 8 kilometers away. By the end of 1989, survey teams had found more juvenile *Tridacna derasa* in the inner island group of Vava'u than have been recorded from the all the surveys on giant clams on the Great Barrier Reef combined. In 1990 the number of juvenile *Tridacna derasa* almost doubled. The total found in 1989 and 1990 probably exceeds the number of wild juvenile *Tridacna derasa* from all the surveys made in the Pacific combined.

A brood stock of the rough giant clam, *Tridacna squamosa*, was also included in the sanctuary. Settlement rates of these increased in parallel with, and geographically linked to *Tridacna derasa* settlement.

The data support the concept of community-based marine sanctuaries as a method of conservation of giant clams in rural island areas.

SUMMARY OF PART 3.

GROWTH AND MORTALITY

The fastest growing giant clam in Tonga was the rough giant clam (*Tridacna squamosa,* locally known as Matahele). It produced the most meat during the first ten years, reaching one kilogram of meat (wet weight) and 326-mm (13 inches) in shell length in ten years. *Tridacna derasa* (the smooth giant clam, Tokanoa molemole) grew at the same rate (about 5-mm per month) but produced less meat than *Tridacna squamosa* of the same size (about 768gm wet meat weight in 10 years). *Tridacna maxima* (the common giant clam, kukukuku) was the slowest growing giant clam (about 2-mm per month). The clams were determinate growers, reaching their full size in 15 to 20 years. Most clams grew slower as they aged. After growth stopped, the shell thickened and decreased in size through bioerosion.

Tridacna squamosa (Matahele) has not grown well in hatchery and nursery conditions but it is naturally adapted to the deep inner lagoons of Vava'u and, because larvae would be expected to remain in the lagoon until settlement, these clams are the best giant clam for sanctuary enhancement of wild stocks. If broodstocks of *Tridacna squamosa* are set up in Neiafu Tahi, Vaipuua Lagoon and Hunga Lagoon they can be expected to be highly productive

There was considerable individual variation in growth rates but we found no significant correlations to explain it. Live coral formed a barrier for growth for *Tridacna maxima*. One color variety of *Tridacna maxima*, Black with tan or green spots, grew faster than other color varieties, perhaps because of a more efficient strain of zooxanthellae symbionts. This is an important find for hatchery-aquaculture programs because tests in the Philippines have shown *Tridacna maxima*, unlike the other species, survive well when placed on the reefs at very small sizes. Small juveniles of other species must be placed in plastic or wire cages and tended twice a week. Even then, the other species suffer heavy mortalities from nursery induced predators and parasites if left unattended. Transplanted juvenile Black with Tan or Green-spot *Tridacna maxima* (Kukukuku) grew nearly as fast as *Tridacna derasa* reaching 178-mm in shell length in about 4 years.

The three species inhabited distinct, but overlapping microhabitats on the reefs. *Tridacna maxima* preferred raised, dead heads of *Porites* coral. *Tridacna squamosa* commonly attached to dead portions of live branching corals and *Tridacna derasa* settled on dead branching coral rubble and detached, when more than 250-mm in shell length, to live in sand and rubble areas at the base of reefs.

Mortality averaged about 30% of the standing stock of *Tridacna maxima* and 68% of the wild stock of *Tridacna squamosa*. Octopus, fish, and the mollusks *Cymatium muricinum* and *Chicoreus ramosus* ate juvenile giant clams. Giant clams entered the subsistence fishery at about 100-mm shell length and fishing pressure was intense in the inner island area of Vava'u.

PART 1 VAVA'U COMMUNITY GIANT CLAM SANCTUARIES

A SUCCESSFUL ENVIRONMENTAL IMPROVEMENT PROJECT

ABSTRACT

A community based marine sanctuary for giant clams was set up in the Vava'u island group of the Kingdom of Tonga. The public environmental improvement project gave the community participants knowledge of the need for, and problems associated with, marine sanctuaries. During a community sponsored contest, fishermen gathered scattered adults of giant clams from a large area. The clams were placed together in circles inside the boundaries of sanctuaries to act as a brood stock to enrich surrounding reefs.

Project volunteers used all available means of promoting public assistance and understanding. While all lines of public communication are needed in such a project, a locally produced short educational video was the most productive method of teaching new concepts to the island people.

Before and after surveys of the wild stocks of giant clams demonstrated the sanctuary enhanced local recruitment on adjacent reefs. Village people observed an increase in the settlement of clams on nearby reefs and this helped develop community support. The community giant clam sanctuary has been maintained three years by the Vava'u community with minimal support by the Ministry of Lands, Survey and Natural Resources and the Fisheries Department.

BACKGROUND

In September of 1990, during the annual Vava'u Agricultural Show, His Majesty, King Taufa'ahau Tupou IV gave the people of Falevai Village a prize for "The Best Giant Clam Sanctuary". This was the successful finale of a four year public environmental improvement project to revitalize the stocks of giant clams. Community giant clam sanctuaries are now a part of Tongan culture. The story is one of the few instances in the Pacific where a local community changed its behavior to improve the marine environment.

At a time when scientists are becoming more and more alarmed by the continued degradation of natural resources and the environment, Tonga's Pacific neighbors would do well to pay attention to how the people of the Vava'u Island Group started the long term process of turning this dangerous decline around.

THE TURN AROUND

As long ago as 1979, New Zealand marine biologist J. L. McKoy warned the government of Tonga one species of giant clam, *Hippopus hippopus* was probably extinct and another, *Tridacna derasa*, was on the brink of extinction. They were vanishing because giant clams must have a population of old adults, close together, in shallow water so they can successfully spawn and replenish the reefs with young. Overfishing had eliminated stocks of adults in Tonga. The remaining specimens, scattered far apart in deep water, were not producing enough young.

During Environment Awareness Week of June 1986, the Kingdom of Tonga responded to this warning. Fishermen collected 100 large adult *Tridacna derasa* (known in Tonga as *Tokanoa molemole*) and arranged them in circles on a reef in Nuku'alofa Harbour. This brood stock sanctuary would, it was hoped, improve spawning success and rebuild the numbers of this endangered species on Tongatapu's coral reefs. The Tongan Ministry of Lands, Survey and Natural Resources organized the giant clam sanctuary project with the cooperation of the Department of Fisheries.

Giant clam sanctuaries may help solve the problem of how Pacific Island Nations can regulate the giant clam fishery. It is almost impossible to enforce size limits or other fishery regulations in the small, remote islands of the Pacific. By protecting brood stocks in community based sanctuaries and letting people catch and eat the young which settle down outside the sanctuary, the problem of maintaining the stock is much easier and very inexpensive. Nobody has to feed or care for the big clams; just place them in a sanctuary and convince everyone to leave them alone. The only maintenance needed is the replacement, once a year, of any big clams which may have died. Since the giant clams may live for more than one hundred years, new ones don't have to be added very often. Providing, of course, nobody steals them from the Sanctuaries.

THE DANGER

Critics of the program pointed out someone might raid the brood stock area and kill the giant clams, thus making the situation worse, not better. But, in the absence of any laws or regulations against fishing the clams, and the absence of any conservation force necessary to supervise such laws, fishermen would eventually take the large clams from the reefs anyway. Surveys showed there were no juvenile *Tridacna derasa* on the reefs within easy reach of fishermen, and this proved the scattered adults were not successfully spawning anyway. Why not put them together and at least try to make a sanctuary work?

The viewpoint of the critics was, in itself, revealing. In 1986 neither Government officials nor the general public believed a marine sanctuary for giant clams would survive without a 24-hour guard. Everyone was sure the sanctuary would be raided. This was a self-perpetuating, negative belief system. If everyone agreed the clams would be stolen, many individuals thought they might as well take some before the clams were all gone.

The negative community self-image prevented any self-help action towards the improvement of local marine environments. Resources were expected to continue to decline, and future generations of Tongans would inherit even greater poverty and hunger. The goal of the giant clam sanctuary project was to change this attitude: to develop a way for rural island communities to improve the marine environment.

THE PROJECT GOES PUBLIC

The key to success of the project was public awareness. The hypothesis was: If people fully understood the reason for giant clam sanctuaries, they would voluntarily - as a community - protect and maintain the brood stock of clams. In essence, the people of the community had to decide the giant clam sanctuaries were necessary. They had to decide taking giant clams from the sanctuary was an immoral act, to be punished by peer-group displeasure (Hudson 1984b).

Communities, like individual people, have habits and habits are difficult to change. In Tonga, society habitually uses the marine resources as common property. According to common law, no person can prevent any other person from taking whatever they like from the sea - especially when it comes to feeding the family. The result of this morality is, `If I don't take that small clam, the next person will'(Halapua, 1982). There are few legal restrictions on what can or can not be taken. With the exception of a handful of species listed in the Birds and Fish Preservation Act, there are no seasons, no size limits, and no enforcement. The new Fisheries Act of 1989 may improve this situation but there will surely be problems with enforcement unless the Government takes an active interest in public awareness and participation (as of October 1993 the regulations for the Act were still not in effect).

In prior generations, Tongan people took what they needed from the reefs to provide food for their families. When they had enough to eat, they stopped fishing. Serious commercial fisheries are a recent development in Tonga. Fishermen obtained expensive boats and outboard motors with development bank loans. This created a new kind of fisherman - one who would fish for money and not stop fishing until the desire for cash was satisfied. As everyone knows, the desire for cash is never satisfied.

Commercialism, modern diving equipment, outboard motors and seaworthy fishing boats have only become common in Tonga in the past 20 years, so the lack of a community conservation ethic is a problem of this generation and the future. Without face-mask and flippers, without a modern boat, large adult giant clams in 5 to 30 meters depth and open water conditions were reasonably safe. But today, they are rapidly vanishing. Technology almost always outstrips morality with devastating results. Already, in Tonga, the shallow water marine resources are overfished and the coral reefs badly damaged (IDEC 1990).

PUBLIC AWARENESS

Changing public behavior is the most difficult but the most necessary task of environmental improvement. Whenever a community must act to preserve a resource, individuals must sacrifice their own personal interest. In the case of the giant clams, individuals must overcome their personal desire to kill the clams in the sanctuary; even if they are very hungry or want to sell the meat for money they need badly.

If the community feels it is more important for an individual to have easy access to food than to protect the clams for future generations, the clams won't survive long. If, however, the people feel the clams in the sanctuary are vital to the maintenance of their social obligations, nobody will harm them.

If the community fails to achieve a conservation ethic, the resources will continue to decline and eventually result in increased poverty, hunger, and dependency.

METHODS

OUTLINE FOR A SUCCESSFUL ENVIRONMENTAL IMPROVEMENT PROGRAM

DEFINITION: A successful environmental improvement program changes the way people behave so there is a measurable improvement in the flora, fauna, or condition of a resource.

THE TEST: Success must be determined by a measurable change in behavior of the public and in the resource. Establish how to measure this first.

THE TONGAN GIANT CLAM REVITALIZATION PROJECT:

1 THE PROBLEM

- 1.1 The Giant Clam *Tridacna derasa* is almost extinct in Tonga.
  - 1.1.1 Big clams are the ones which make eggs.
  - 1.1.2 People are eating all the big clams.
- 1.2 The Tongan public is not aware of this.

2 THE TEST

2.1 People will be aware of the problem and willing to help.

2.2 People will leave the giant clams in the sanctuary alone.

2.3 More giant clams will be found on the reefs.

3 THE STRATEGY

3.1 Get people to understand:

3.1.1 There is a shortage of big clams

3.1.2 Soon there may be no more big clams

3.1.3 Only the people can help the clams

3.2 Assure legal protection

3.3 Get the people to restore ability of clams to survive

3.3.1 Collect scattered adult *Tridacna derasa*

3.3.2 Place them together in shallow water

3.3.3 Leave them alone to produce young

3.3.4 Maintain the population of adults

3.3.5 Eat only smaller clams outside the reserves

4 ACTION PLAN

4.1 Communicate the problem and strategy to the people

4.1.1 Written media

4.1.2 Radio

4.1.3 Meetings

4.1.3.1 Fonos

4.1.3.2 Fisheries/Fishermen

4.1.3.3 Personal talks with Town Officers

4.1.3.4 Churches

4.1.3.5 Coconut Grapevine

4.1.3.6 One on One volunteer surveys

4.1.4 Video

4.2 Organize Activities

4.2.1 Fishermen's Contest to Collect clams

4.2.1.1 Advertising for contest outlines problem

4.2.1.2 Cash awards from community establishes community ownership of clams.

4.2.1.3 Use Community Clams for brood stock Governor selects village

4.2.1.4 Geographic Position of Village

4.2.1.5 Security

4.2.1.6 Willingness of Village people to help

4.2.2 Village selects local site for clams

4.2.2.1 Within easy sight of village center

4.2.2.2 Not so close or shallow drunks or kids can get at them.

4.2.2.3 Where boats do not anchor

4.2.2.4 With clean water, no fresh water run-off or rivers or siltation.

4.2.2.5 Sheltered from waves

4.2.2.6 Good tidal flushing

4.2.2.7 Upcurrent or centrally located in island group so larvae do not wash out to sea.

4.2.2.8 2 to 15 Meters deep

4.2.2.9 Oceanic salinity, temperatures 26-31^{o}C.

4.2.2.10 Coarse, thin sand or rubble with scattered live corals.

4.2.3 District and Town Officer helps

4.2.3.1 Talk to village people

4.2.3.2 Select location for sanctuary

4.2.3.3 Obtain village sanctuary license

4.2.3.4 Keep an eye on brood stock

4.2.3.5 Give periodic talks to people

4.2.4 Give the clams a chance

4.2.4.1 Install the circles of adults

4.2.4.2 Leave them alone

5 CHECKING TO SEE IF IT WORKS

5.1 Do the people understand?

5.1.1 Pubic surveys

5.1.2 Evaluate and supply more information

5.2 Are the Community Clams OK?

5.2.1 Map each clam, its size and condition

5.2.2 Remap clams every few months

5.2.3 If any are missing, report this to community

5.3 Is the Brood Stock making young?

5.3.1 Establish survey stations around inner islands

5.3.2 Map all clams at each station

5.3.3 Remap stations at yearly intervals

5.3.4 Determine recruitment of brood stock species and measure change produced by sanctuary.

5.3.5 Report results to community

6 REVISE ACTION PLAN AS NEEDED

6.1 To keep the giant clams in the brood stock unmolested

6.2 To increase recruitment and survival of young

6.3 To encourage more community brood stocks

6.4 To make giant clam brood stocks a cultural tradition.

7 FOLLOW-THROUGH

7.1 Establish yearly prizes for best giant clam sanctuary

7.2 Survey circles on regular basis

7.3 Include educational materials in schools

7.4 Make video about success to replay each environmental awareness week.

RESULTS

THE VAVA'U GIANT CLAM PROJECT

The Ministry of Lands, Survey and Natural Resources realized the need to develop the public's awareness about the usefulness of marine sanctuaries. Tonga is not a wealthy country and the Ministry of Lands, Survey and Natural Resources does not have funds or personnel to patrol or protect marine reserves in Tongatapu, let alone the other three major island groups. If marine sanctuaries are to work in Tonga, the people must make them work.

The government guarded the sanctuary in Nuku'alofa Harbour. A boat with two men moored over the sanctuary every night for two years. The Ministry of Lands, Survey, and Natural Resources realized they would not be able to defend the giant clams against thieves indefinitely. In addition, since no base line studies had been made, nobody could prove if the brood stocks really enhanced the natural stocks.

In June of 1987, therefore, the Ministry of Lands, Survey and Natural Resources initiated the public awareness project outlined above in the Vava'u Island Group (Figure 1).

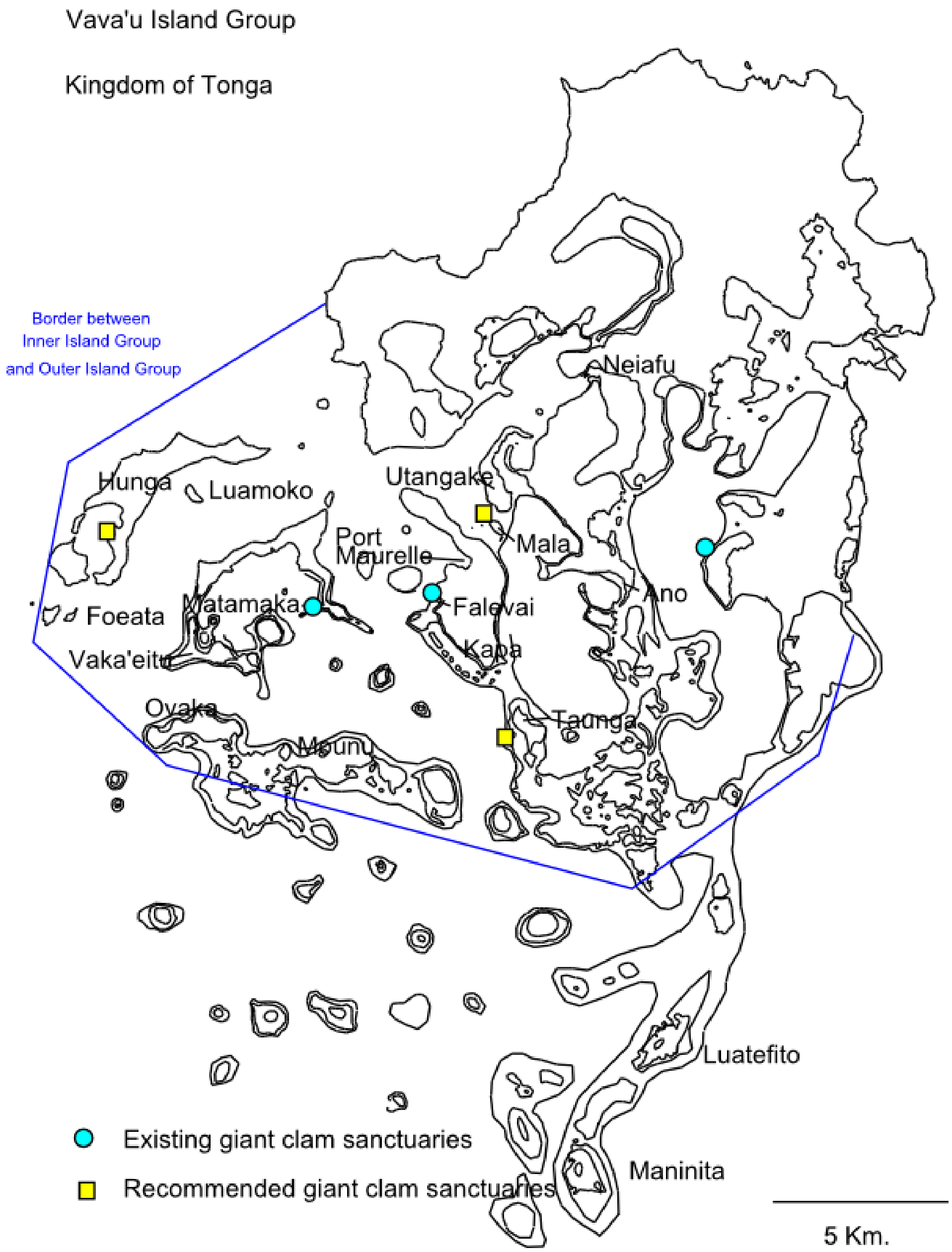

Figure 1. Vava'u Island Group, showing the locations of Giant Clam Sanctuaries and place names used in this report.

Base-line surveys were begun to determine the condition of the existing stock of giant clams and to study the environmental conditions suitable for future giant clam sanctuaries. Educational materials were prepared and private and public meetings held to discuss the giant clam sanctuary ideas. Surveys were conducted to find out what the people of Vava'u knew about giant clams, and to introduce the idea of giant clam sanctuaries.

A CONTEST

In December of 1987 the people of the Vava'u Island Group decided to build a community giant clam sanctuary. The Governor of Vava'u, Dr. S. Ma'afu Tupou, (now acting Minister of Lands, Survey and Natural Resources) urged the local business community set up a small fund for cash prizes for the fishermen who could catch the most *Tridacna derasa* (Tokanoa molemole) and *Tridacna squamosa* (Matahele) to put into a community sanctuary.

Fishermen searched for two months and only found 12 *Tridacna derasa*, underscoring the severe depletion of the local stocks in the inner island group of Vava'u. Finally, during a calm spell, the fishermen were able to reach more remote reefs and gather more, enough to build a respectable brood stock. Two community brood stocks were made, one with the 72 *Tridacna derasa* and another with 75 *Tridacna squamosa*. They were placed in shallow water (3-15 Meters) directly in front of Falevai village, on Kapa Island in a centrally located part of the Vava'u Island Group.

The clams were arranged in circles so they could be easily counted and so the eggs and sperm would be well mixed during spawning no matter which direction the water currents were flowing at the time. Each circle had ten clams: nine around the circumference spaced at least two meters apart and one in the center. The circles, each about 10 meters in diameter, were laid out in depths from 4 to 15 meters in a site selected by the village people. Each circle had only one species in it and the *Tridacna derasa* circles were grouped in one part of the sanctuary and the *Tridacna squamosa* circles in another.

The district officer, Vanisi Fakatulolo, took charge of overseeing the protection of the giant clam brood stock. On behalf of the community, he obtained a permit under an old fisheries "fish fence" law to protect the stock in the clam reserve (this law was repealed in 1989 and the sanctuary has had no legal status since then).

Radio, newspaper and magazine articles informed the public of the need for, and the benefits of, the brood stock sanctuary (Anon. 1987, Chesher, 1986, 1987a,b,c, 1889a,b). Fonos were held to tell the people in the 31 villages of the Vava'u Island Group to leave the giant clams alone.

In theory, nothing prevented people from using the sanctuary area for fishing or recreation. In practice, however, nobody did because if some clams were discovered missing, whoever had been seen swimming in the area would be blamed.

Mr. Fakatulolo notes, "Before this community project, some individuals tried to make their own private clam circles but in a small community someone will always have a score to settle and eventually the clams will be stolen and eaten. It is important to have the people know the new clam circles belong to everyone. Anyone can eat the young ones made by the circles but nobody can eat the ones in the sanctuary. If everyone understands, there is no problem with enforcement."

SOCIAL OBLIGATIONS

In Tonga, social obligations (Faka'apa'apa) are the most important aspect of a person's life. Allowing *Tridacna derasa* (Tokanoa molemole) to become extinct would be an unforgivable failure on the part of this generation of Tongans to fulfill the social obligations to future generations of Tongans. The major reason people have left the giant clams in the Falevai Community Giant Clam Sanctuary alone is because it is a social obligation to do so; a responsibility to maintain a good supply of these sea creatures for the families of all the people of Tonga.

"If a man allows his farm to go to ruin or spoils the soil, he is not meeting his social obligations to his family." explained Mr. Fakatulolo. "If anyone takes clams from the community sanctuary, he is spoiling the production of the sea and is not meeting his social obligations to himself, his family or his community."

"It's like planting a fruit tree," another Vava'u man said, "You have to wait for several years before it begins to produce fruit but then it goes on making plenty of fruit for everyone for many years." Since giant clams may live almost a century, the people of Vava'u could enjoy the fruits of the giant clam circles for generations to come. If the stocks are maintained by replacement of any which die, giant clams will always be a part of the Tongan diet.

In 1988, we made an educational video explaining, in English and in Tongan, the concept of the community giant clam sanctuary. In the video His Majesty King Taufa'ahau Tupou IV endorsed the project, saying, "The giant clam sanctuaries are a benefit to everyone and should not be raided by irresponsible people."

PROOF

I, along with volunteer divers from Earthwatch International, conducted extensive surveys of the existing stock of wild clams prior to and for three years following the installation of the giant clam sanctuary. The total area mapped by the survey teams from June of 1987 to October of 1990 was over 47 kilometers. More than 250 hours were spent in the water, actively searching and measuring the wild population of clams. The scientific data on settlement of clams showed the sanctuary resulted in a return to normal, healthy recruitment as a result of the giant clam sanctuaries (see part 2 of this report).

The people of Falevai Village knew the project was successful even before the survey team scientifically confirmed it. "The people found many baby vasuva on the reefs near the village and on Nuku and A'a Islands," said Vanisi Fakatulolo. "The children brought them home and ate them. Now everyone knows why they should leave the big ones alone in the sanctuary. They can see the results. We have never seen so many baby clams on these reefs before."

THE REAL SUCCESS

The real test of the project was not how many juvenile clams could be found on the reefs, but if the community changed its behavior and attitude towards their marine resources.

The people of Falevai and neighboring villages passed the test. They left the giant clams in the sanctuary essentially unharmed for six years. Interviews showed the village people protected the clams because they understood the reason for the sanctuaries and had a strong sense of community loyalty.

Surveys taken when the project was first begun showed the people did not, at that time, believe it was possible to leave giant clams in shallow water off a village without constant guard. Today, this attitude has changed and a new community confidence has emerged for working together to improve the marine resources.

What happens, in such a system, if the public trust is violated? In 1989 five clams were stolen from the sanctuary. The loss was quickly discovered and the culprit found. In a small island community little passes unnoticed. I asked Vanisi Fakatulolo how the community dealt with the problem.

He said, "A group of men got together and went to see the man who took the clams. We told him to come with us and took him down to the reef at low tide. I showed him some baby Tokanoa molemole and some baby Matahele on the reef. We told him these are the result of the giant clam circles in the sanctuary and they were for everyone's benefit. We told him each big clam in the sanctuary will make thousands of baby clams. When he steals a big clam from the sanctuary, he is stealing thousands of baby clams from everyone in the village. Now he understands and will never touch them again.'

There is no greater determent to poaching from a sanctuary than the displeasure of one's friends and neighbors.

The Ministry of Fisheries encouraged the presentation of an award for `The Best Clam Sanctuary' during the annual agriculture show. The award was presented by His Royal Majesty, King Taufa'ahau Tupou IV. As soon as the award was announced, in July of 1990, ten other Vava'u villages asked the Fisheries Department to help them set up their own giant clam sanctuaries.

The United Nations South Pacific Aquaculture Development Programme (FAO/UNDP) supplied funds to pay local fishermen to find more large giant clams for the new sanctuaries. By September, fishermen were able to collect enough clams from the remote reef areas to build three more sanctuaries, each with 50 *Tridacna derasa* and 50 *Tridacna squamosa*.

The Fisheries Department took on the responsibility of inspecting the sanctuaries at regular intervals. This turned out to be a mistake because the village people did not continue to conduct inspections and the Fisheries personnel did not alert the community to declining numbers. When informed 12 clams were missing from the Falevai sanctuary between 1990 and 1993, the villagers were very upset. They resumed close observation of the Sanctuary and in August of 1993 observed fisheries personnel take a *Tridacna derasa* from the community sanctuary.

Following the set-up of the additional three sanctuaries in 1990 16 *Tridacna derasa* and 34 *Tridacna squamosa* were stolen from the Ovaka sanctuary. It was located out of sight of the nearby village. The remaining clams were moved to Ofu in December of 1990. There were 8 more *Tridacna derasa* missing and two dead from natural causes at Ofu by October of 1993.

The Officer in Charge of Fisheries in Vava'u told me many clams were missing from the sanctuary set up at Taunga. They removed the remaining clams without warning or consultation with the village people and took them to Ofu. I was, however, unable to find any additional clams when I surveyed the area in October of 1993.

As of October 1993 the sanctuary at Matamaka was completely intact with only two clams of each species dead from natural causes.

Despite these small losses, the village people remain convinced the sanctuaries are a good idea and intend to continue them. Taunga has said they will replace the clams themselves.

DISCUSSION

GOVERNMENT VERSUS THE PUBLIC, A COMMON PROBLEM

The concept of gathering scattered adult giant clams and placing them in protected areas to enhance spawning success and improve local recruitment has been strongly recommended by many fishery scientists including, Adams et al (1988), Lewis et al (1988), Sims and Howard (1988), Alcala (1988), Beckvar (1981), Gwyther and Munro (1981), and Munro (1986). The major problem was theft of the clams from the protected areas.

Theft problems have been reported almost everywhere giant clam hatchery work or brood stock attempts have been attempted. Government organized brood stock or hatchery production clams have been stolen in Western Samoa (Gawel, personal communication), The Cook Islands (Sims and Howard 1988), American Samoa (Buckley and Itano 1988), Yap (Price and Fagolimul 1988), and the Philippines (Estacion 1988).

Marine parks and sanctuaries have been unsuccessful in many Pacific nations because they are extremely difficult to patrol. The people who have traditionally fished these areas are not normally consulted before the establishment of the park. If the government attempts to prevent traditional use of the resource without common consent, it can only lead to trouble.

In Tonga, permanently restricted areas of the sea's resources, where no fishing may go on, is against ancient cultural practices (IDEC 1990 and Halapua 1982). Chesher (1984) and Paine (1989) reported habitual violation of the marine reserves in Tongatapu. Johannes (1982) reported similar problems in Western Samoa. When an underwater trail and clam reserve was set up in the Pangaimotu Reef Reserve in Nuku'alofa in 1989, the Ministry of Lands, Survey and Natural Resources attempted to enforce a ban on fishing in the area. Six months later the underwater trail was destroyed and the brood stock of giant clams killed. This may have been a protest by people who habitually fished the area and did not understand why they should be excluded.

The Ministry of Lands, Survey and Natural Resources abandoned surveillance of the original clam sanctuary in Nuku'alofa harbor in 1989. By 1993 only 22 clams were left.

In 1990, Fisheries personnel took at least 200 giant clams from Vava'u to provide a brood stock for their hatchery project in Tongatapu. By 1993 they needed to get additional stocks from Ha'api.

In Vava'u, early attempts to create giant clam sanctuaries by individuals were failures. One individual set up private giant clam sanctuaries in the hope it would bring him aid money - not because he understood the concepts involved or cared about providing future generations of Tongans with giant clams. If he could get a boat, diving equipment, or cash, he was all for the idea. Governments can sometimes act the same way and the availability of large sums of money to assist island governments to set up parks and reserves does not, by itself, do much to foster a genuine understanding of the issues. While the reserves exist on paper, their boundaries may not be respected by the public and therefore, do not exist as a biological fact. Where individuals or government agencies attempt to set up giant clam reserves there has been and will continue to be problems with theft.

The success of the Vava'u community giant clam sanctuary project was based on a sincere effort to include public participation and to call upon the community spirit to change its destructive behavior to a new, constructive morality towards its natural resources.

Reaching out to the public was a difficult and time-consuming process. It also went against the general attitude of some government workers who saw themselves as different from `the public.' Gawel (1984) pointed out many government workers feel the general public is untrained and therefore has no valuable input to planning schemes. This observation was clearly demonstrated by the behavior of fisheries personnel in Tonga, even after considerable discussion and workshop training on public extension services. It did not help that overseas experts selling the wonders of giant clam hatcheries (and providing salaries to the fisheries workers) were - and remain - skeptical of the ability of villagers to maintain their resources and even more skeptical of the ability of giant clams to reproduce by themselves.

The village people should check on the clams in the sanctuary themselves on a monthly basis. Each year the sanctuaries should be inspected by a government agency and awards given for the best maintained sanctuary. If sanctuaries are not maintained, village meetings should be held with concerned government officials and the issue debated openly.

CULTURAL PRECEDENTS

In other nations where village reef rights were once practiced, restricted areas meant outsiders could not fish without permission, but the reef areas were not closed to residents. Some parts of a reef were restricted, from time to time, allowing it to recover. But such areas were normally re-opened for fishing after a short time (Johannes 1977, 1978, 1982, 1984a,b).

Community reserves for giant clams existed in other areas in the past. MacLean (1978) 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. Then they were used as emergency food supplies. I observed stocks of relocated and protected giant clams in the Shortlands Islands of the Solomon Islands and near Tagula in Papua New Guinea (Chesher 1980). The Tagula stock was subsequently destroyed by Fisheries personnel in an attempt to export the meat (which rotted and was thrown out).

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.

Govan et al (1988) report some local individuals in Marovo Lagoon in the Solomon Islands are now maintaining clam gardens for conservation purposes. Alcala (1988) reports fishing communities and individuals at four island sites in the Philippines are maintaining protected areas for broodstocks of giant clams and ocean nursery sites for juveniles raised in hatcheries.

Community marine sanctuaries and reserves do work in Pacific islands, providing they are based on common understanding and are supported and protected by the local people. This is a question of education (Hudson 1984a) and spiritual commitment.

EFFECTIVE EDUCATIONAL MATERIALS (VIDEO)

Island governments need educational materials aimed at rural island audiences explaining - in island terms and local languages - what marine sanctuaries and reserves mean to the future of the community and how the people can help (Hudson 1984a).

In the Vava'u project, video was the most effective means of communicating these complex ideas. Although the literacy rate is high in Tonga, rural island people do not often read and they don't absorb complex ideas via radio programs. Fonos and churches are ritualized and involve very little opportunity for the introduction of novel, complex ideas. Schools are staffed with underpaid and often transient teachers struggling to deal with the whole range of educational issues. Island people are reluctant to talk with each other about new issues they don't fully understand. But everybody likes to watch videos, and today, video players are common in almost all schools and many homes. Even in the remote island villages in Vava'u the people have access to at least one machine.

Vava'u people saw the 30-minute video, "The Giant Clam Circles of Vava'u," again and again. There was a Special English and a Tongan version. Copies were given to Neiafu schools and to two of the villages where clam sanctuaries were established. It was broadcast on local TV many times. Copies were in all the video rental shops - often loaned for free. `Aisea Tuipulotu, Officer in Charge of the Fisheries Department in Vava'u, said, "The video was very helpful for us. It is very difficult to get people to understand something new and takes a lot of talking. Even then, they don't always believe you. But the video shows them, in pictures, what it is all about and they understand."

A second, more dramatic video on the sanctuaries was made in 1990 and widely distributed throughout the community. It's Tongan name was ``Do not kill the mother of all Tokanoa.'' It's Tongan cast were all fishermen and villagers. There was a Tongan language version and a Special English version. Surveys in 1993 indicate that more than half of the Vava'u community saw and understood the video. It was still being actively viewed in 1993.

COMMUNITY SANCTUARIES COULD HELP MANY ISLAND AREAS

The loss of the giant clams throughout the Pacific is tied to a widespread lack of appreciation or understanding of the coral reef environment combined with a rapid increase in the availability of tools to destroy the coral reef habitats. This is why the Tongan giant clam sanctuaries are so important. They are easy to understand, cost very little, and are aimed directly at the major issues: the biology of the clams and the psychology of the people.

The giant clam sanctuaries of Tonga represent a new approach to conservation of marine resources in island environments. Other kinds of sea creatures might respond well to small community-based brood stock sanctuaries, thus allowing the people of the islands to rebuild and perhaps exceed the natural productivity of the sea.

The process of enhancement of the dwindling marine resources of the Pacific requires the strengthening of community feelings of self worth and loyalty and respect to God's intricate plan of creation.

PART 2 DO COMMUNITY GIANT CLAM SANCTUARIES INCREASE RECRUITMENT ON ADJACENT CORAL REEFS?

ABSTRACT

A Community Giant Clam Sanctuary was set up in Vava'u, in the Kingdom of Tonga to increase public understanding of marine sanctuaries and to attempt to improve settlement of juvenile clams on surrounding reefs.

There was no evidence of recruitment of the smooth giant clam *Tridacna derasa* prior to the installation of the sanctuary, Surveys from 1987 to 1988 showed overfishing had seriously endangered this species in the inner island group of Vava'u and lowered the adult stock to below levels required for successful recruitment. The first juvenile *Tridacna derasa* was found eight months after the sanctuary was installed. The numbers of juveniles increased in 1989 and again in 1990, appearing on reefs adjacent to the sanctuary and extending up to 8 kilometers away.

A brood stock of the rough giant clam, *Tridacna squamosa*, was also included in the sanctuary. Settlement rates of these increased in parallel with, and geographically linked to *Tridacna derasa* settlement.

The data support the concept of community-based marine sanctuaries as a method of conservation of giant clams in rural island areas.

BACKGROUND

During Environment Week of June 1986, the Kingdom of Tonga planted a brood stock of smooth 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 1987).

The concept was suggested as a conservation strategy by Beckvar (1981) "Conservation practices should be initiated by consolidating some of the now scattered clams into breeding units, encouraging higher juvenile recruitment by increasing the probability of successful fertilization. Breeding populations could be introduced to areas where clams are now extinct and regulations imposed to restrict harvesting."

Gwyther and Munro (1981) said, "Adult clams should ideally be arranged in loose clumps to increase the chances of successful fertilization when they reach maturity and commence natural breeding."

Later, Munro (1986) elaborated, "Stocks of *T. gigas* and *T. derasa* are in danger of extinction in many parts of their range. In these areas it appears that the only conservation measure which is likely to be effective will be the aggregation of remaining individuals into strictly protected reserves where there is a chance of successful reproduction and dispersal of larvae over the surrounding areas. An extension of this concept is to use these aggregations as brood stock for a system of hatcheries for restocking of reefs."

Similar recommendations were made by Adams et al (1988), Lewis et al (1988), Sims and Howard (1988), and Alcala (1988).

TONGA TESTS THE STRATEGY

The Tongan environmental improvement giant clam project was organized by the Ministry of Lands, Survey, and Natural Resources, the agency responsible for parks and reserves in the Kingdom. The Ministry of Fisheries and the Marine Research Foundation assisted in the Environmental Week activity. It was the first attempt to increase natural populations of giant clams (locally called Vasuva) using relocation of natural stocks of adult clams into sanctuaries.

The idea behind a wildlife sanctuary is, of course, to prevent people from killing rare or endangered species or, in the case of the coral reef marine reserves, to preserve and protect the coral reef ecosystem and all its inhabitants.

There is little doubt sanctuaries work as they should for some plants and animals. Bird sanctuaries, for example, protect important nesting sites. If people leave the nesting birds alone, the population of birds will increase. A single, small Japanese island, named Torishima, was set aside as a sanctuary of the short-tailed Albatross. Today, the sanctuary is all that is keeping this bird from extinction (Ackerman 1990).

But what about marine animals, like giant clams, whose young go through a free-swimming larval stage? The swimming stage might drift off with the ocean currents and settle on reefs far away - or perhaps sink at sea and die. Maybe none would settle within the local island group. If this happened, the protected adults would die off by natural mortality, and the sanctuary would eventually fail.

Prior to this study, there was little evidence to show marine sanctuaries actually work to increase local productivity. Russ and Alcala (1988) reported data confirming the increase of local coral reef fish populations near a voluntary coral reef marine reserve in the Philippine Islands. They also documented a decrease to former levels when the villagers voted to open the reserve to fishing again. Fish also have a swimming larval stage, so this report hinted at the possible success of marine reserves for species like giant clams. But, since larvae of many marine organisms are attracted to adult populations, one might argue the evidence from the Philippine experiment demonstrated the reserve acted to encourage settlement of larval reef fishes from other areas. There was no evidence to show whether or not the reserve itself significantly enhanced local stocks by increased fertility.

A REASONABLE HYPOTHESIS

The natural distribution of giant clams in Tonga suggested giant clam sanctuaries would improve local recruitment. There were no *Tridacna derasa* east of Tonga and ocean currents move from east to west through the island group. The natural populations of *Tridacna derasa* on the easternmost reefs of Tonga clearly maintain themselves in these often isolated places yet there can be no recruitment from up-current because the species does not occur up-current from these reefs. How does the population maintain itself there if not from local recruitment?

Nobody knows what happens to the millions of larvae spawned from a single large *Tridacna derasa*. Some possibly do drift off with the ocean currents. But the micro-environments of coral reefs and the water eddies set up by coral formations are complex. Evidently, some larvae do stay in the immediate vicinity of the adults, or the isolated easterly populations of Tongan clams could not maintain their populations.

In other areas of the Pacific where giant clams were kept in embayments for emergency food supplies surveys showed an abundance of clams of all sizes in the same bays and on nearby fringing reef environments (Chesher 1980, and unpublished data). This could represent evidence of local retention of larvae or it could mean larvae from elsewhere settle in areas where adults are already located.

The only way to know for sure was to set up a giant clam sanctuary in an area where there was base-line information on distribution and recruitment of the wild stock of giant clams and see, over a period of years, if there was or was not an increase in settlement of juvenile clams.

GIANT CLAMS ARE ENDANGERED

The project began at a crucial time. The larger species of giant clams have become extinct or seriously endangered in many Pacific Island areas through overfishing (Hester and Jones 1974, Bryan and McConnel 1976, Pearson 1977, Hirschberger 1980). McKoy (1980) found few *Tridacna derasa* in Tonga and stressed the need for protective measures to avoid overfishing the giant clam stocks. The International Union for the Conservation of Nature and Natural Resources

(IUCN 1983) has placed both *Tridacna gigas* and *Tridacna derasa* on the endangered species list. One species of giant clam, *Hippopus hippopus,* has already become extinct in Tonga.

WHY GIANT CLAMS WERE BECOMING LOCALLY EXTINCT

Giant clams do not withstand fishing pressure very well. Within the past 30 years, face-masks, flippers and outboard motors have helped a growing population of fishermen collect giant clams more rapidly and efficiently than ever before. In most island areas there has been, at one time or another, commercial attempts to harvest giant clams for export. Some of these have used SCUBA or Hookah underwater breathing equipment to take the giant clams from the reefs. These so-called pulse fisheries can reduce the spawning adults to such a low level the local population cannot recover.

Giant clams rely on symbiotic zooxanthellae for food and the shallower the clam, the more nutrients it receives from its symbionts (Munro and Heslinga 1982). The more nutrients it receives, the more eggs it can make. Spawning is triggered by the presence of metabolites from other adult clams. These requirements indicate giant clams need a population of large adults reasonably close together in shallow water for survival.

Giant clams do not become egg producers until they are 5 or 6 years old and the larger clams, 15 years and older, are the major egg producers. There are few places in the shallow waters of Pacific Islands where someone does not look at the bottom within a 6 year time span. As a result, there are few places where there are populations of large adults reasonably close together in shallow water and the larger species are vanishing.

HOW GIANT CLAMS REPRODUCE

When giant clams reach sexual maturity at two or three years of age, they are males (Wada 1954). At five or six years of age, they begin to make eggs as well as sperm and each giant clams becomes both male and female. Many of the smaller giant clams only release their male spawn even when they have eggs inside them and it is not until they are older that they begin to release the eggs as well (Heslinger et al 1984).

When they spawn, giant clams let go of the male spawn every few minutes for perhaps an hour or two. Then they pause for about thirty minutes and begin to release eggs. Both eggs and sperm emerge from the excurrent siphons of the giant clams, rising into and dispersing in the sea water.

Because they release sperm and then wait before releasing eggs, giant clams probably do not fertilize themselves. When self-fertilization has been done experimentally, growth and survival of the young is poor compared to cross-fertilized clams (Alcazar 1988). The spawn floats in the sea water until it passes over another giant clam. The second one senses the spawn and releases its own sperm and or eggs. These combine with the spawn of the first giant clam and begin to develop into larvae. If the spawn of one giant clam does not pass over another giant clam the spawn will die in 6 to eight hours (Heslinga et al 1984).

Within 48 hours after the eggs have been fertilized, they become disk-shaped, swimming veliger larvae with a fringe of hair-like paddles along one edge. The larvae are about 0.1-mm in diameter. After three to 5 days (the period has not been determined for larvae in the wild), the clam larva develops a small foot, swims down to the sea floor, and begins to hunt for a place to settle down. At this stage it is about 0.2-mm in shell length. In large tank aquaculture experiments, *Tridacna derasa* larvae settle out five to seven days after fertilization (Heslinga and Watson 1985).

If the larvae can't find a place to settle down, the shell gets so heavy they can no longer swim. If they sink in water deeper than 90 or 100 feet they will die. Some larvae in laboratory conditions can survive up to 20 days (Beckvar). As mid-Pacific ocean currents commonly run past Tonga from east to west at 10 to 11 miles per day (Anon. 1969), Tongan giant clam larvae would have to survive 18 to 20 days to reach the Lau Group of Fiji.

Many fish and other coral reef animals eat larval clams while they are swimming and when they settle on the reef. Reid and King (1988) believe the period immediately after settlement may be one of the most critical periods in clam survival. Only a few of the fertilized eggs, perhaps only one in 100 million, will find a place to land on the reef and survive the first year of life.

WHY GIANT CLAM SANCTUARIES HELP

Without a population of large adult giant clams reasonably close together in shallow water, the species can't effectively reproduce. In the inner island group of Vava'u survey teams found no stocks of adult *Tridacna derasa* in shallow water or close together in deeper water. There were no juveniles of this species. The installation of a brood stock of large adult *Tridacna derasa* on a centrally located reef would, therefore, be expected to help the species re-establish itself in the area.

The reasons brood stocks of Giant Clams might be expected to increase the natural population of giant clams are:

1. Spawning is induced in nature by the presence of chemicals associated with the gametes. "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 Heslinga 1982).

2. The larger the clam, the more eggs are produced. The increase of eggs is a logarithmic relationship $F = 0.00743L^{4.03}$ (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. Larvae may settle near adults, apparently attracted by metabolites from the adult population (McKoy 1980, Adams et al 1988, Chesher 1991b).

PUTTING BROOD STOCK CLAMS IN CIRCLES

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.

2. The spacing of the clams may be important to maximize spawning potential. 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 attracting predators and promoting the rapid spread of diseases through the stock.

4. A broken circle will be 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.

RESEARCH PLAN

This research project was designed to find out if giant clam sanctuaries could be organized on a community level and to see if they repopulated nearby reefs with juvenile clams. The Marine Research Foundation assisted by the Center for Field Research, and supervised by the Ministry of Lands, Survey and Natural Resources, and in cooperation with the Ministry of Fisheries, began the Vava'u project in June of 1987 and continued until October of 1990.

SIX TESTS

Recruitment in tridacnid clams can be expected to vary dramatically from year to year according to availability of nutrients, presence of larval predators, water currents, temperature, and spawning success. It was possible, therefore, that quite by chance, a year of excellent recruitment might happen during the period immediately following the installation of the clam circles. Juveniles from wild clams not in the sanctuary might therefore, confuse the results.

Six tests were built into the project to establish if the high density of adult *Tridacna derasa* and *Tridacna squamosa* in the community sanctuary had a measurable impact on recruitment on nearby reefs.

1. To minimize the potential of other spawning *Tridacna derasa* increasing recruitment in the survey area, all specimens of *Tridacna derasa* located in the inner island area were moved into the sanctuary. This included clams found by local fishermen, sport divers and by the survey teams. Searches in deeper water for adult *Tridacna derasa* continued throughout the project. Only one adult *Tridacna derasa* outside the sanctuary was reported in the inner island group after the sanctuary was established.

2. Adults of *Tridacna squamosa* were more common in the inner island group than *Tridacna derasa*. Many adults were left in place so recruitment from these would follow pre-existing patterns. If there was an unusually good year for tridacnid recruits, the *Tridacna squamosa* juveniles would appear on the reefs over a broad area, unrelated to the settlement of *Tridacna derasa* juveniles or to the geographic setting of the sanctuary.

3. The populations of *Tridacna maxima* were undisturbed and no adults were moved into the sanctuary area. A good year for tridacnid larval development and settlement would be expected to show a comparable increase for all species.

4. Settlement of the clam juveniles from the sanctuary would be expected to be geographically related to the sanctuary. This was complicated by the variable water currents of the inner island group and the time to settlement of the larvae.

5. A size-frequency analysis of the wild stock would give an indication of existing recruitment patterns over several years prior to the onset of the project. The base-line wild stock survey began six months prior to the establishment of the sanctuary.

6. Surveys continued for four years. If recruitment improved on successive years the possibility of a random, one-shot recruitment causing the increase would be remote.

METHODS

SURVEY METHODS

To be able to show changes to recruitment to the wild stocks from the giant clam sanctuary there had to be a careful analysis of the wild stocks of clams in the central island group of Vava'u.

Figure 1 shows the island group of Vava'u, Figure 2 shows survey stations.

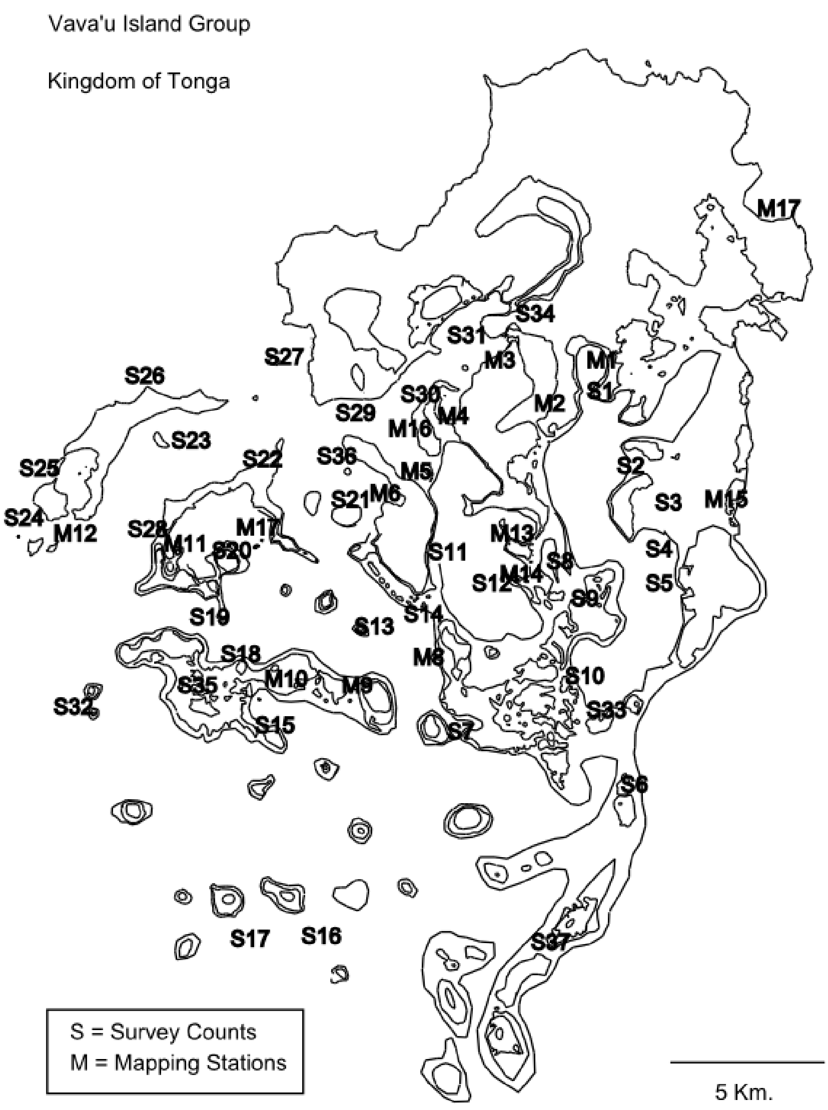

Figure 2. Survey and mapping locations in the Vava'u Island Group July 1987 to October 1990

Two survey systems were used. For rapid surveys of new areas, two teams of divers counted and measured clams during a timed interval. This was the same method used by McKoy (1980) and most of his stations were reexamined. This produced a surprisingly good and repeatable estimate of population size considering the ability to find smaller clams depended on 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 had already been in the water.

To adequately study giant clam populations, a technique was needed whereby large numbers of clams could be individually mapped so the researchers could return to the exact site in subsequent years and determine if the specimen had grown or died or if new settlement had occurred. We used the two shore station azimuth intersection technique (Northrup 1987, Page 880) to track the movements and discoveries of diving teams, plot the drift of current markers, and locate and relocate stations. Mapping surveys gave exact locations of individual clams, species, size, color, and habitat (see Part 3).

The survey teams surveyed the wild stocks of giant clams at the stations shown in Figure 2. Stations marked "S" were done using McKoy's method, those marked "M' were mapped using the two shore station azimuth intersection technique.

Each dive team had one full time project member and one or two assistants. All stations, therefore, were surveyed by the same team leaders throughout the entire survey. Figure 3 gives an example of a mapped coral patch in Port Maurelle. 21 coral patches were mapped in Port Maurelle. Each station listed in the tables in the appendix to this section of the report represent data collected from numerous mapped coral patches plus survey searches.

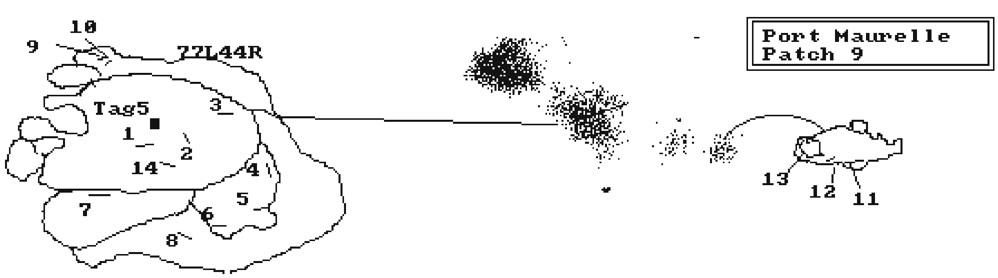

Figure 3 Map of Giant Clams on patch reef 9 in Port Maurelle, Kapa Island, 1987 to 1990

RECRUITMENT WAS MEASURED BY DIRECT MAPPING.

Recruitment to the population was measured directly, by mapping all individual clams on specific coral heads over the survey period. Specimens mapped in the survey sites measuring less than 30-mm for *Tridacna maxima* and less than 60-mm for *Tridacna derasa* and *Tridacna squamosa*, were considered first year recruits. These lengths represent about 12 to 18 months of growth (Chesher 1991b).

Our data indicated specimens of *Tridacna maxima* below 20-mm shell length and *Tridacna squamosa* and *Tridacna derasa* below about 50-mm shell length were too small to be reliably observed and some were missed during the mapping survey (The smallest *Tridacna squamosa* found was 13-mm, the smallest *Tridacna derasa* 31-mm, and the smallest *Tridacna maxima* 6-mm). Therefore, *Tridacna derasa* or *Tridacna squamosa* spawned in January or February, were not always found in June to October of the same year when they were 30 to 50-mm in shell length. By the following June, however, they were 90 to 100-mm in shell length and easily seen. Therefore, in the analysis of the data, recruits were considered as *Tridacna maxima* below 60-mm shell length and *Tridacna derasa* or *Tridacna squamosa* below 120-mm shell length.

Size frequency analysis of surveyed clam populations also provided data on recruitment before and after the installation of the community giant clam sanctuary.

TRANSPLANTING GIANT CLAMS

No special treatment was required for transplanting adult giant clams. Care was taken not to break the shell during collection and the animals were 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. Some of the clams were out of the water for up to 5 hours.

Juvenile tridacnids did 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, attract the attention of the local reef dwellers. We observed a wide variety of small reef fishes approaching and attacking juvenile clams when they were simply placed on the reef. Wrasses, in particular, attacked the young clams.

It was necessary to place the juvenile clams with some care. Since they attached to the substrate, they were placed on dead coral rock, not live coral, and put in a location which offered some natural protection and camouflage. A clam placed on an open, bare coral rock was more likely to be attacked than one placed in a crevice, or under the edge of a coral.

To foil 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 high 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* transported easily. They closed their valves and retained a fluid environment inside. Of a total of 233 *Tridacna derasa* transplanted into the four Vava'u sanctuaries, ranging in size from 86-mm to 542-mm, only two died from the transplantation. Some of the larger specimens were left out of the water for more than 6 hours, but it is probably 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 240 transplanted adult *Tridacna squamosa*, 18 died. They probably should not be left out of the water for longer than two to three hours. *Tridacna squamosa* were normally found attached to coral and were placed on hard coral substrate in the sanctuaries. Specimens reattached to the substrate within 48 hours. Some large specimens were placed in sand and rubble in the sanctuaries and these survived with no apparent ill effects.

Only seven juvenile *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) the specimens reattached within 24 hours and reburrowed into the coral substrate. The specimens grew well and were still alive after three years (Chesher 1991b).

RESULTS

LOCATION OF GIANT CLAM SANCTUARIES

The initial locations surveyed for potential clam circle sites were based on places where there was an area of reasonably shallow, clean ocean water and where water currents might keep the larvae in close proximity to the adults or within the central island group until settlement. The sites had to be easy to observe from a village. The bottom substrate had to be mixed coral and thin, firm sand. Areas where *Tridacna derasa* and *Tridacna squamosa* were present, or had been found in the past, were given priority.

The final site selection was made by the Governor of Vava'u and by the villagers of Falevai (Chesher 1991a). The Falevai Community Giant Clam sanctuary was located within sight of Falevai village in 3 to 15 meters of water. The area had a sloping bottom with scattered small corals and hard packed sand. There was a new police station being built within sight of the clam sanctuary (the only police station in the outer islands), and the District Officer, Mr. Vanisi Fakatulolo, was interested in the project and resided within sight of the sanctuary. The selected site was outside the area where boats normally anchored and considered to be an unproductive fishing area.

The site was suitable for both adults and juvenile tridacnid clams of all three species. In 1987, three adult *Tridacna derasa* were located in deep water (19 to 23 meters) between Nuku Island and Port Maurelle. Village fishermen reported this species was common in their area in the past (more than ten years in the past, less than twenty). *Tridacna squamosa* adults and juveniles were found in shallow and deep water. *Tridacna maxima* were common in the area.

The central location of Falevai in the Vava'u Island Group also argued well for the brood stock location. Larvae produced by the sanctuary would be expected to restock reefs in the central island group. Water current studies showed complex tidal and wind-driven water movements in the Falevai area would permit a proportion of the floating larvae to remain in the central island group during the first critical hours of the free-floating stage.

LATER AND FUTURE SITES

Following the success of the Falevai Community Giant Clam Sanctuary, ten other villages asked the Ministry of Fisheries to help them set up their own. By September 1990, three additional giant clam sanctuaries were installed at Taunga, Matamaka, and Ovaka. Of these, the Matamaka site was the best. It was located at the entrance to a large embayment formed by the islands of Nua Papu, Vaka'eitu, Langitau and Lape. A significant percentage of the larvae were expected to remain in the embayment until settlement. The depths and substrate in the lagoon was ideal for settlement and growth. The site was well protected from storms and directly in view of the village. It is also offshore to discourage casual night raids.

The Taunga site had excellent water quality. The site selected by the villagers was, however, too shallow and too exposed to hurricane force winds from the northwest. The sanctuary was later moved to another location because of missing clams. Recruits from this sanctuary would have settled over the entire inner island lagoon.

The Ovaka site, on the southwest corner of the inner island lagoon, was a poor location. The spawn might not remain in the area long enough to settle as it is in the leeward part of the lagoon. It was also the worst in terms of security because it could not be seen at all from the village and was in shallow water often fished at night. Sixteen *Tridacna derasa* and thirty four *Tridacna squamosa* were taken from the sanctuary during the Christmas festivities and the sanctuary was moved to Ofu.

The Ofu site was directly in front of the village. Ofu was in the Eastern sector of the Vava'u group and the spawn was expected to settle in the large bay to the west of Ofu and in the area of Tapana and Kapa. It was placed in 9 to 12 meters of water on the top edge of a steep, coral covered slope.

The shallow area between Mala and Utangake would be an excellent location for both *Tridacna derasa* and *Tridacna squamosa* sanctuaries. The substrate was hard, both species occurred in the area, it was directly in front of a village, well protected from storms, and had excellent water quality.

Growth and distribution studies showed *Tridacna squamosa* grew faster, produced more meat, and was better suited to the inner embayment habitats of Vava'u than *Tridacna derasa* (Chesher 1991b). The inner embayments, such as Vaipuua Lagoon, Neiafu Harbor, Neiafu Tahi, and the almost enclosed lagoon at Hunga would be excellent sites for *Tridacna squamosa* sanctuaries. A large percentage of larvae would be expected to remain in the embayments until settlement. The sites close to Neiafu would be the most difficult to maintain because of the large number of transient people in the area. The Hunga site would be the best in terms of protection and water quality.

DISTRIBUTION OF GIANT CLAMS IN VAVA'U

From June of 1987 until October of 1990, the researchers surveyed favorable shallow water reef areas for specimens of *Tridacna derasa, Tridacna squamosa, Tridacna maxima* and *Hippopus hippopus*.

The total numbers of each species found at the surveyed stations are shown in Table 1.

Table 1. Total numbers of giant clams found and time and distance searched 1987 to 1990.

YEAR	MAXIMA	SQUAMOSA	DERASA	METERS	HOURS
1987	1183	132	0	14486	64.35
1988	1032	99	2	15110	69.92
1989	1336	161	45	11290	64.75
1990	1044	266	82	6853	55.37
TOTAL	4595	658	129	47739	254.39
PERCENT	85.37%	12.22%	2.40%		

Figure 4 shows the distribution of giant clams at the major stations in Vava'u. The data are presented as numbers of clams found per hour searching.

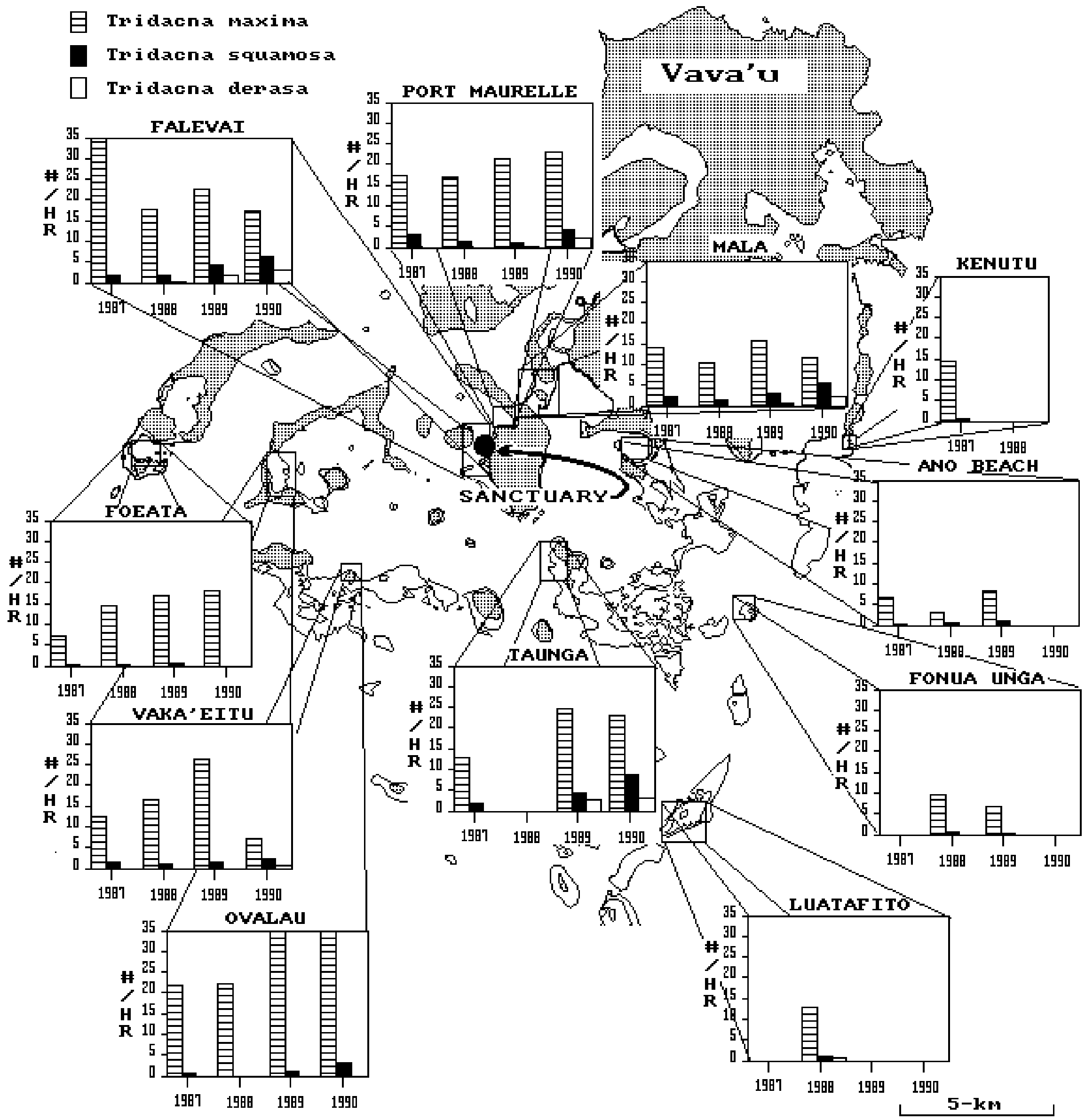

Figure 4. Distribution of giant clams in Vava'u

Fishermen, encouraged to bring in *Tridacna derasa* for the community clam sanctuaries, found an additional 233 *Tridacna derasa* and 240 *Tridacna squamosa*. These adults were mostly taken from isolated reef areas south of the main island group during a long calm period in February of 1988 and in September of 1990, when the the fishermen were able to fish reefs normally exposed to heavy surf. These specimens and the *Tridacna derasa* (18) and *Tridacna squamosa* (30) collected by local divers and the survey team from areas outside the survey station boundaries in 1987 were put into the community giant clam sanctuary and are not included in the table or Figure 4.

In September 1990, a local diver captured five specimens of a new species, *T. tevoroa.* One more was found in the local market. These were placed in the Falevai Giant Clam Sanctuary and were still in good condition as of October 1993.

Data on sizes and numbers of clams found per hour of search are presented in the appendix.

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. We found dead shells in shallow water reef areas around Mounu Island. *Hippopus hippopus* shells were excavated during the construction of a boat harbor in Neiafu Tahi, Vava'u. The buried shells were probably dumped there by fishermen many years ago. Some specimens were buried under a meter or more of mud. Judging by the large number of dead shells, it would appear *Hippopus hippopus* was fairly common in Vava'u and a favored food item for many years.

Older members of the community, including the honorable, Dr. S. Ma'afu Tupou, (then Governor of Vava'u) recognized the shells and remembered *Hippopus hippopus* being captured from the outer reef areas on the eastern side of the Vava'u Island Group about 60 years ago.

A reward of $50 was offered for 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. No specimens were found.

Demonstrating an actual extinction helped convince the local people there really was a threat to the giant clam population.

TRIDACNA DERASA *WAS ON THE VERGE OF LOCAL EXTINCTION*

The condition of the stocks of *Tridacna derasa* was, of course, a priority of the survey. This is the largest of the Tongan giant clams, growing to about one half meter in shell length. Preliminary evidence from McKoy (1980) and Chesher (1984) indicated the population of *Tridacna derasa* was dangerously low and four 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, was easy to see and collect. Specimens greater than 250-mm in shell length were not attached to the bottom. Local divers with face masks could spot *Tridacna derasa* from the surface in depths up to 20 meters. Deeper specimens were taken by lowering a weight attached to a rope into the open shell and, when the valves closed, hauling the clam up to the boat. Smaller specimens in shallower water were simply picked up by hand.

Since *Tridacna derasa* takes about 6 years to reach first female maturity and since they are easy to see after two years of age, a *Tridacna derasa* would have to go undetected for 4 years to reach breeding age. All inner island reefs were 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, fishermen and sport divers were only able to locate 18 adult *Tridacna derasa* and no juveniles within the entire inner island area between June of 1987 and October of 1990 (excluding juveniles found in 1988, 1989 and 1990 we believe came from the sanctuary).

McKoy, during surveys in 1978 and 1979, found only one *Tridacna derasa* in the Vava'u island group. He felt the distribution of this species in Tonga, on deep water open ocean reefs, was probably due to overfishing in shallower locations (McKoy 1980). This was an important consideration in the siting of the sanctuary and we sought additional data to determine if McKoy was correct.

In 1987, 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 5. Sites substantiated by the survey team are labeled "D" while sites designated by fishermen but not verified by the research team are labeled "D?". In the inner island area, each D represents a single specimen.

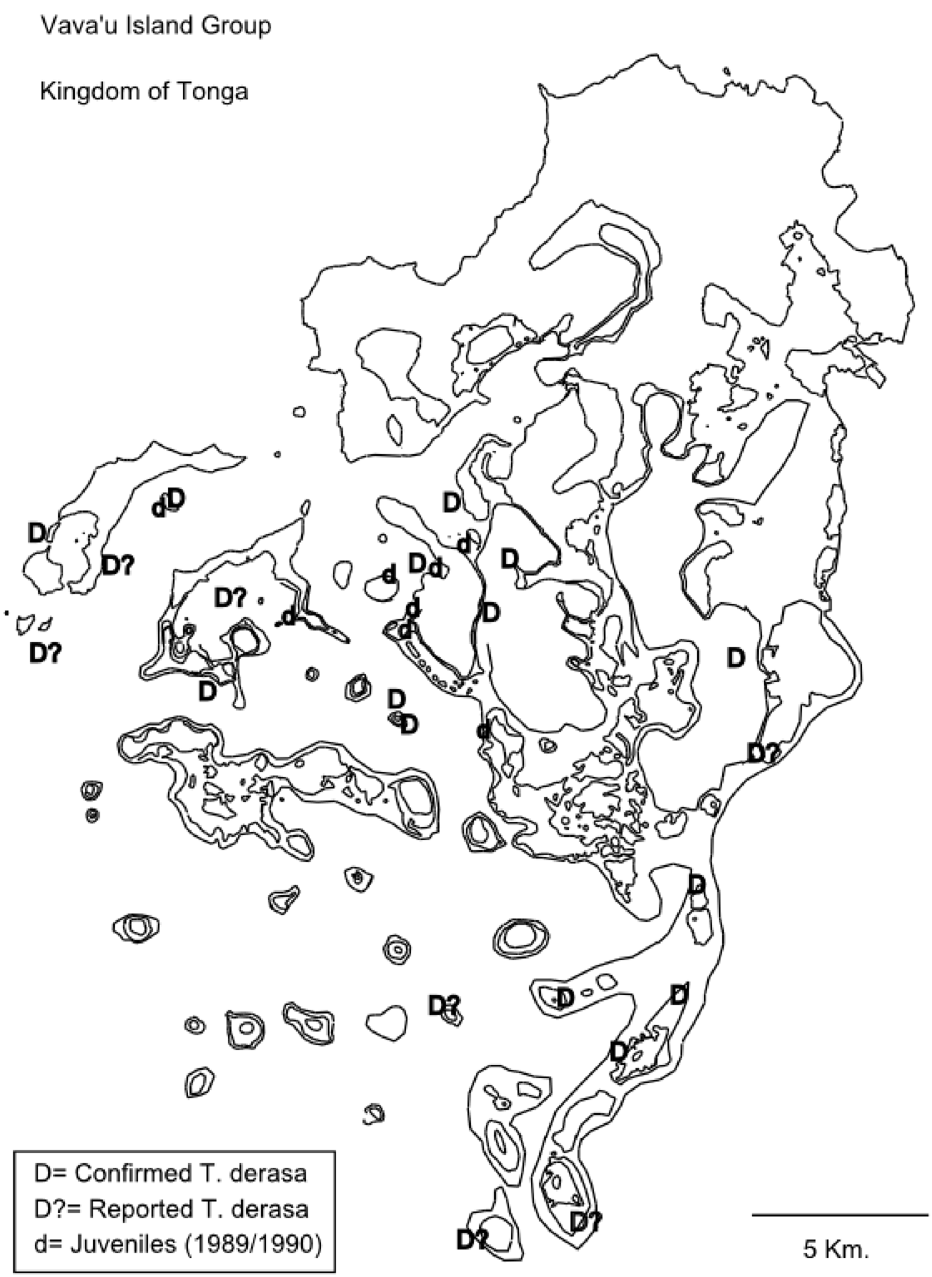

Figure 5. Sightings and reports of Tridacna derasa in Vava'u 1987 to 1990

Older fishermen pointed to inner island areas 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*.

The sites described by the older local fishermen as productive in the past were examined and although one or two specimens were sometimes found, the sites were fished out. Sites indicated by fishermen where later surveys showed no *Tridacna derasa* are not marked on Figure 5.

Younger divers indicated open water reef areas on windward, southern reefs in depths of 10 to 20 meters as the best places to find *Tridacna derasa*. The consensus of younger fishermen located the largest existing stock on the southern end of the eastern sunken barrier reef and around some of the outer island reefs and shoals to the south of the main island group.

Thus, the evidence agrees with McKoy's hypothesis that the present distribution of *Tridacna derasa* as an artifact of fishing pressure, not a natural habitat preference. The fishermen of the 1960's through to 1990 were 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 been a time of harvesting an essentially virgin stock of giant clams. The men who began this harvest in their youth claimed they took 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 sanctuary in the protected waters of Falevai and the settlement of juvenile *Tridacna derasa* in depths just below the spring low tide line supported the idea they naturally survive and grow well in the inner island shallow areas and that fishing pressure was responsible for their present distribution.

GETTING THE GIANT CLAMS FOR THE SANCTUARY

The honorable Dr. S. Ma'afu Tupou, (then Governor of Vava'u, now Minister of the Ministry of Lands, Survey and Natural Resources) announced a contest for fishermen to collect *Tridacna derasa* for the proposed community clam sanctuary. It began in December of 1987 and continued until January 1988. A fair market value was paid for all specimens as well as cash awards of $150, $100 and $75. The Hon. Governor actively promoted the contest by visiting the outer islands and encouraging fishermen to collect giant clams. The contest was advertised by fonos, town meetings, posters, word of mouth, during surveys, on the radio and in the newspaper (Chesher 1991a).

The end of the contest was delayed twice because bad weather prevented the divers from going to the more exposed islands and reefs. Most of the clams taken during the contest, therefore, came from the inner island area. 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*. *Tridacna squamosa* were also purchased to add to the sanctuary.

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 depleted state of the *Tridacna derasa* population, even in the southern reefs, was supported by the contest fishermen's reports of taking the specimens from depths of 7 to 20 meters. All of the shallow water *Tridacna derasa* were apparently fished out.

Several fishermen believed there were large numbers of *Tridacna derasa* in deeper water (30 to 50 meters) where they could not dive without SCUBA. This was not true, as the clam's need for sunlight for its symbiotic algae limit the depth range to less than 30 meters and they were extremely rare at depths greater than 20 meters. SCUBA surveys located all of the *Tridacna derasa* found by the survey team in the inner island group. These widely scattered adults were at depths ranging from 15 to 29 meters. No *Tridacna derasa* were found in depths over 29 meters. One local diver uses SCUBA for fishing. He searched a large area during the contest but only found three *Tridacna derasa*. The staff of Vava'u Water Sports, while conducting SCUBA tours throughout the island group, assisted in the project by reporting any finds of *Tridacna derasa* during their dives.

TRIDACNA SQUAMOSA *WAS VULNERABLE AND HEAVILY FISHED*

Tridacna squamosa was much more abundant than *Tridacna derasa* in Vava'u. A total of 658 specimens of *Tridacna squamosa*, mostly juveniles, were located in the survey areas in depths of 1 to 3 meters in the central island group area. They were especially abundant near Mala Island and the area from Nuku to Port Maurelle. (This number includes specimens counted again on successive years). Figure 6 shows stations where *Tridacna squamosa* were found. The shallow water populations of *Tridacna squamosa* were heavily fished in the central island group and large, productive adults were rare in depths less than 10 meters.

Figure 6. Distribution of Tridacna squamosa in Vava'u

Tridacna squamosa were better camouflaged than *Tridacna derasa* and their association with live coral made them difficult to see from the surface. In addition, adults were found solidly attached to the coral with byssal threads and did not clamp their valves shut when touched. Therefore, fishermen had to dive down and pull them loose from the coral. This means *Tridacna squamosa* has been reasonably safe from fishing in depths greater than 10 meters except during periodic commercial harvesting using SCUBA or Hooka.

Specimens of *Tridacna squamosa* were found in Neiafu Tahi, Neiafu Harbor, Vaipuua Lagoon, off Utangake, and in Hunga Lagoon demonstrating this species survived well in the almost enclosed embayments of the Vava'u Island Group. Sanctuaries of *Tridacna squamosa* in these embayments should be highly productive as the bays have long water residence times and the larvae could be expected to remain in the bays throughout their floating phase.

TRIDACNA MAXIMA *WAS STILL COMMON IN VAVA'U*

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

Large specimens of *Tridacna maxima* (>240-mm shell length) were rare in the inner island group, reflecting the intensity of fishing pressure on larger clams (Figure 4 and Table 14). Large *Tridacna maxima* were common in deeper water and on the windward sunken barrier reef. *Tridacna maxima* was uncommon in the inner embayments although specimens transplanted there grew well (Chesher 1991b).

DID THE SANCTUARY INCREASE RECRUITMENT?

The village people of Falevai had no doubt the sanctuary resulted in increased recruitment of *Tridacna derasa* and *Tridacna squamosa*. Prior to the 1989 field work, the district officer, Vanisi Fakatulolo, who has lived in Falevai all his life (as did his father before him), told the survey team the village people were very happy to discover so many young clams on the reefs around Falevai, Nuku and A'a. He said they had never seen so many young clams before and the children had gathered and eaten many of them. In 1990, Mr. Fakatulolo said the people had found even more juveniles and the children had collected baskets of them. The numerous juvenile clams made the village skeptics into believers and provided strong support for the community sanctuary (Chesher 1991a).

While the survey teams did not find baskets of juvenile clams (perhaps because the children had collected and eaten them) there was, in 1989, an increase in both *Tridacna squamosa* and *Tridacna derasa* recruits on the reefs in the vicinity of the Falevai community clam sanctuary as compared to control sites further away from the site (Figure 4). In 1990, as Mr. Fakatulolo said, the number increased again.

Table 2 shows the total numbers of clams found per hour searching at all Vava'u stations from 1987 to 1990. Figure 7 shows the numbers of giant clams found per hour of searching over the four year period. The population of *Tridacna maxima* remained reasonably constant over the four year period. The large numbers of *Tridacna maxima* in Figure 7 obscure the increase in *Tridacna derasa* and *Tridacna squamosa* following the installation of the sanctuary in 1988. Figure 8 illustrates the data for only these two species.

Table 2.Total numbers of clams found per hour from all Vava'u stations 1987 to 1990.

YEAR	HOURS	MX/HR	SQ/HR	DR/HR
1987	64.35	18.38	2.05	0.00
1988	69.92	14.75	1.42	0.03
1989	64.75	20.63	2.49	0.69
1990	55.37	18.85	4.80	1.48
TOTAL	254.38	18.06	2.59	0.51

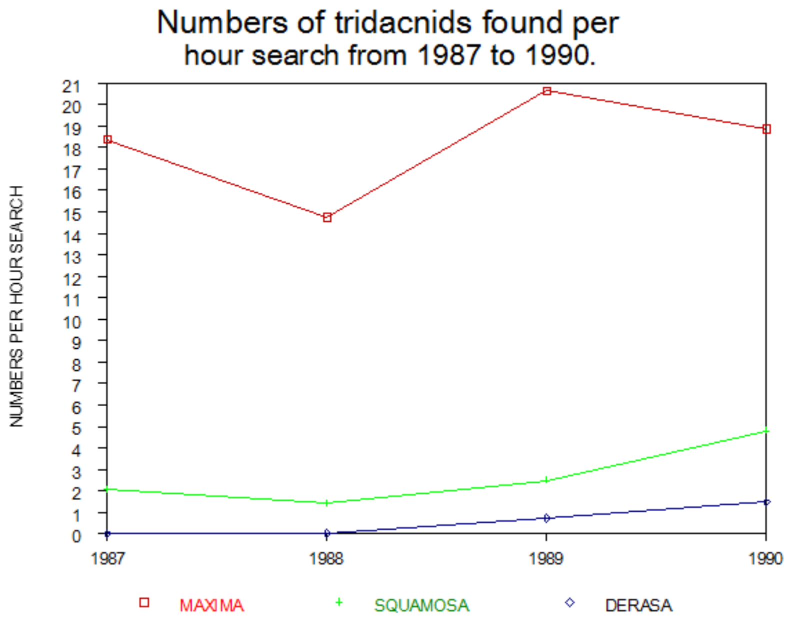

Figure 7. Numbers of giant clams found per hour of searching 1987 to 1990.

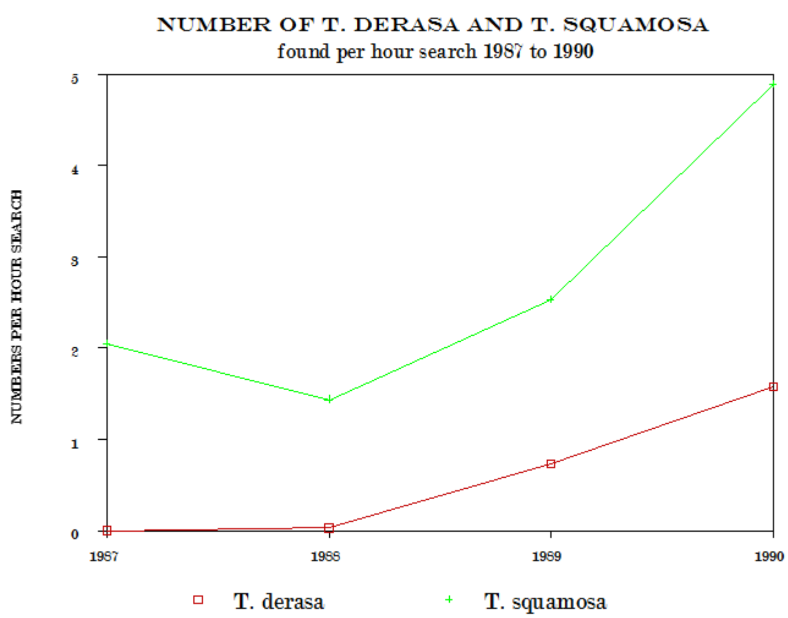

Figure 8. Numbers of Tridacna squamosa and Tridacna derasa per hour of search 1987 to 1990.

Settlement of juvenile *Tridacna derasa* and *Tridacna squamosa* increased in 1989 and 1990. But, did the juveniles come from the sanctuary or from an outside stock of clams?

The results of the six tests built into the experiment to determine this question strongly suggest they resulted from the sanctuary.

Test 1. Adult *Tridacna derasa* found in the inner island area were collected by local divers or the survey team and placed in the Sanctuary along with other breeding adults from south of the island group. Since no juveniles were found prior to late 1988 in the inner island area, the previous distribution of adults was not productive. Eight months after installation of the sanctuary, a 38-mm juvenile *Tridacna derasa* was found in a survey sites 500 meters to the south of the sanctuary. In October a second specimen, 44-mm in shell length was located 10 meters from the broodstock circles. It is unlikely any adults remaining in the inner island group outside of the Sanctuary became prolific at just that time.

Test 2. Many adult *Tridacna squamosa* were left outside the Sanctuary in the inner island group. They were scattered and living in depths over 10 meters. Yet the increase in juvenile *Tridacna squamosa* at stations near the sanctuary paralleled the increase of *Tridacna derasa* (Figure 4 and tables 6 and 7).

A revealing relationship was found by comparing recruitment at Mala, Port Maurelle and Falevai in 1989 and 1990. Two *Tridacna derasa* were found in Mala in 1990 large enough to have been present in 1989. No *Tridacna derasa* were found in Port Maurelle in 1989. Settlement of *Tridacna squamosa* was also poor at both these stations in these years. At Falevai, however, about one kilometer south of Port Maurelle, settlement of both species was good in 1989 (Figure 9). In 1990, *Tridacna derasa* did settle in Port Maurelle and increased in Mala and the settlement of *Tridacna squamosa* in these same areas also increased to the highest level measured during the survey (Figure 10).

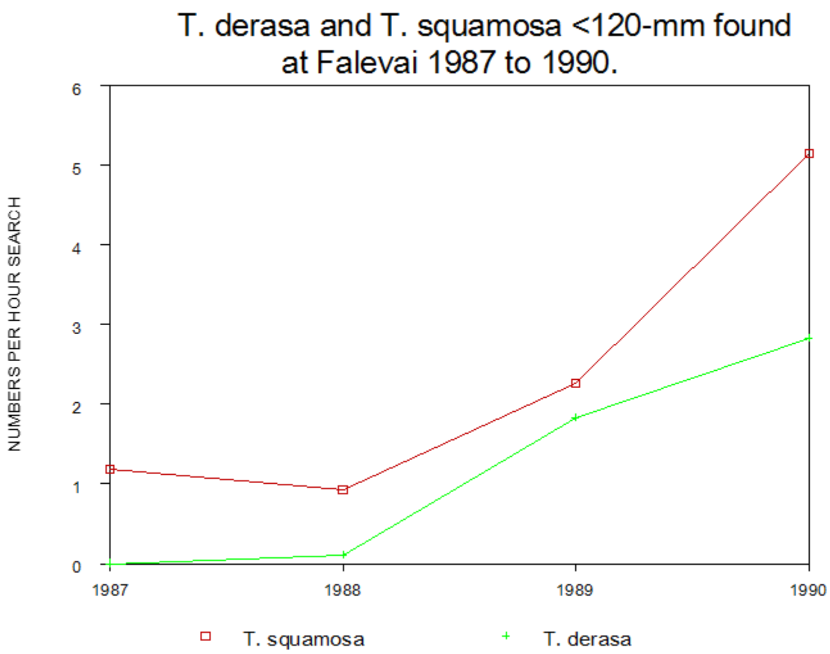

Figure 9. T. derasa and T. squamosa less than 120-mm found at Falevai 1987 to 1990

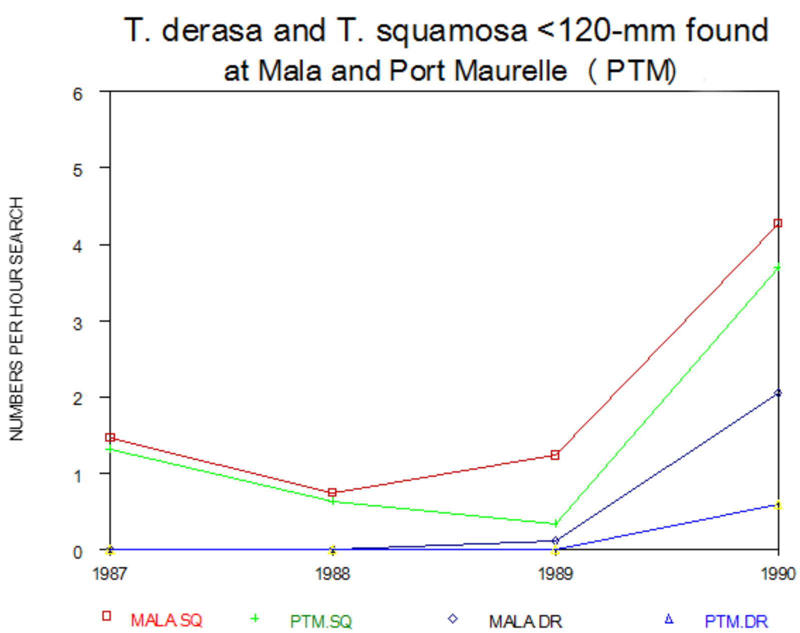

Figure 10. T. derasa and T. squamosa less than 120-mm found at Mala and Port Maurelle

Test 3. *Tridacna maxima* were not included in the sanctuary. Recruitment of *Tridacna maxima* did not increase in 1989, while the number of juvenile *Tridacna derasa* and *Tridacna squamosa* did increase. In 1990, there was a definite increase of *Tridacna maxima* recruitment similar to the increase in the other two species (Table 5). This indicates two things. First, the increase of recruitment for the species in the sanctuary happened, in 1989, in what was otherwise a poor year for recruitment. Second, 1990 was a good year for recruitment for all tridacnids and settlement of all clams increased together, indicating the brood stocks of *Tridacna derasa* and *Tridacna squamosa* were functioning as well as the more abundant *Tridacna maxima*.

Test 4. The geographic distribution of the juveniles agreed with the hypothesis that the spawn originated from the sanctuary brood stock. Numbers and sizes of each species found per hour of search are presented in Figure 4 and in tables 5 to 10.

Table 3. Numbers of tridacnids at the start of 1989 and the number of dead and recruits in 1990.

STATION	START 1989			NUMBER OF DEAD			RECRUITS		
	MX	SQ	DR	MX	SQ	DR	MX	SQ	DR
MALA+	180	28	2	83	18	0	38	32	24
PORTM	441	23	0	120	13	0	176	74	12
FALEVAI+	244	50	32	76	23	C	49	67	31
TAUNGA	67	8	11	17	7	4	9	14	10
FOEATA	57	1	0	12	1	0	3	0	0
TOTAL	974	111	45	308	63	4	275	187	76

Table 3 gives the numbers of tridacnids mapped at the start of 1989, the number of dead at each station and the numbers of recruits found in 1990. These stations were mapped coral heads (eg.

Fig 3 on page 29) and the numbers represent an absolute count of the entire population at the test sites. These coral patches were mapped with considerable accuracy. The survey teams were able, for example, to return and relocate clams of only 8-mm shell length and trace their growth from year to year (see part 3 of this report). Any juveniles missed in 1989, but found in 1990, are recorded in the tables as members of the 1989 stock.

Table 4 shows the percent recruitment from 1988 to 1989 and from 1989 to 1990 at the mapped stations. These data show the increase of juvenile *Tridacna derasa* and *Tridacna squamosa* at stations adjacent to the sanctuary. Foeata, a control station south of Hunga, showed no increase of these species during the survey period.

Table 4. Percent recruitment of tridacnids at mapped stations 1988 to 1989 and 1989 to 1990.

STATION	%RECRUITS 88-89			%RECRUITS 89-90		
	MX	SQ	DR	MX	SQ	DR
MALA+	7.9	14.0	200.0	21.1	114.3	1200
PORTM	12.4	13.5	0.0	39.9	321.7	1200
FALEVAI+	9.0	46.0	1550	20.1	134	96.9
TAUNGA	NO	SURVEY	1988	13.4	175.0	90.9
FOEATA	10.9	0.0	0.0	5.3	0.0	0.0
MEAN	10.1	10.4	437.5	19.9	149.0	430.9

The reef in front of Falevai was extensively surveyed in 1987 and 1988 and no specimens of *Tridacna derasa* were found. Except for the 38-mm specimen found in August and the 44-mm specimen found in October of 1988 at Falevai, no juvenile specimens of *Tridacna derasa* were located at any of the surveyed stations in 1987 or 1988.

In 1989, 32 juvenile specimens of *Tridacna derasa* measuring from 68-mm to 115-mm were located within one kilometer of the sanctuary. They were found on the shallow water fringing reefs around Falevai, on patch reefs in the pass between Nuku and Falevai, and the fringing reefs of A'a. 11 were found on the reefs at Taunga (4.4-km distant), and 2 at Luamoko (8.7-km distant).

In 1990, the range and numbers of juvenile *Tridacna derasa* increased. Specimens were found in Port Maurelle (12 specimens,1.6-km distant), Vaka'eitu (3 specimens 4.4-km distant), and Mala (26 specimens 6.7-km distant). Two of the Mala specimens were large enough to have come from the 1988 spawning (139 and 165-mm shell lengths) and are included in table 3 as 1989 specimens. The three specimens found at Vaka'eitu were also large enough to have been spawned in 1988 (144, 150, and 163-mm) and are included in the 1989 data in table 7. Specimens were again found at Falevai (31) and at Taunga (10). The total number of juvenile *Tridacna derasa* found in the survey sites in 1990 was 82.

Juveniles from the 1988 spawning, transplanted to the Sanctuary in 1989, ranged in size from 122 to 164-mm in shell length in 1990. Two other size ranges were found in 1990. A group between 78.5 and 115-mm in shell length which would have come from a 1989 spawning and a group from 32.5 to 59-mm probably spawned in late 1989 and early 1990.

<u>Test 5.</u> Size frequency analysis of the samples gives an indication of recruitment prior to 1987. The smallest *Tridacna derasa* found in the inner island group prior to the 1988 settlement was 310-mm in shell length. This indicated poor recruitment to that population for at least five years and (since the individual clam was found in a depth of 19 meters where growth may be slower) probably longer. The recruitment data in table 4 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 1987 and 1988.

A much greater area was surveyed and clams counted and measured without making detailed drawings of the position of each clam. Data from other stations, where individual clams were not mapped, can also give information about recruitment through a size frequency analysis. Tables 5, 6 and 7 summarize the number of juvenile tridacnids found in all stations per hour searching in each successive year.

<u>Test 6.</u> Despite the irregularity of tridacnid recruitment from year to year, (Tables 5, to 10) the number of juvenile *Tridacna derasa* and *Tridacna squamosa* increased steadily after the installation of the giant clam sanctuary (Figs. 8 and 9). The numbers of both species varied at specific locations over the three years, probably reflecting where larvae were carried or swam during this period (eg. Port Maurelle in 1989 and 1990, Fig. 10).

Table 5.Number of Tridacna maxima less than 60-mm shell length found per hour searching at Vava'u stations 1988 to 1990.

MAXIMA	1987	1988	1989	1990
FALEVAI	13.57	6.51	5.94	8.23
MALA	5.72	4.68	4.51	4.71
TAUNGA	5.07	NS	5.67	7.95
PORTM	5.89	8.57	7.18	12.03
VAKA'EITU	2.09	0.99	1.94	0.54
OVALAU	1.46	5.00	5.50	13.00
FOEATA	0.00	0.78	0.42	0.79
ANO	0.51	1.00	0.00	NS

Table 6.Number of Tridacna squamosa less than 120-mm shell length found per hour searching at Vava'u stations 1988 to 1990.

SQUAMOSA	1987	1988	1989	1990
FALEVAI	1.19	0.92	2.26	5.14
MALA	1.47	0.74	1.24	4.27
TAUNGA	0.85	NS	2.32	6.29
PORTM	1.31	0.62	0.33	3.69
VAKA'EITU	0.00	0.00	0.00	1.08
OVALAU	0.00	0.00	0.00	3.00
FOEATA	0.00	0.26	0.00	0.00
ANO	0.26	0.50	0.46	NS

Table 7. Number of Tridacna derasa less than 120-mm shell length found per hour searching at Vava'u stations 1988 to 1990.

DERASA	1988	1989	1990
FALEVAI	0.11	1.83	2.82
MALA		0.11	2.05
TAUNGA		2.83	1.29
PORT MAURELLE		0.00	0.60
VAKA'EITU		0.00	0.81
LUAMOKO		1.02	NS

Water currents within this area proved highly complex. Surface currents often ran in different directions than deeper water currents and depended on wind and tide conditions. Velocities varied from peaks of 43.4 Meters per Minute in the pass at Mala at mid falling tide to 0.21 Meters per Minute during slack tide at Falevai. Average surface currents were 6.3 Met/Min at Falevai for drogue casts during February, July and August. At this speed, larvae could travel 6 kilometers in about 16 hours. Shifts in wind direction and tides plus probable changes in depth at which larvae swam assured a 6-km voyage would certainly take longer than this. All of the stations where there was a marked increase in settlement of *Tridacna derasa* and *Tridacna squamosa* were within range of water currents passing over the sanctuary.

If no *Tridacna derasa* were found in 1990, as was the case prior to the construction of the giant clam sanctuary, the 1988 settlement found in the inner island survey sites might be a coincidental settlement from a natural stock. Finding increased recruitment of this species, representing three year classes, in 1990 argues very strongly for the hypothesis that the adults in the giant clam sanctuary were the major contributors to the increase.

DISCUSSION

The ACIAR/James Cook University Giant Clam hatchery project's Senior Scientific Liaison Officer, R. Braley conducted independent surveys of the Falevai site in April and October of 1990. According to fisheries personnel and village observers, he spent less than an hour in the water searching on each survey. He found three *Tridacna derasa* juveniles in April and two in October (Braley 1990 and letter dated 31 August 1990). In the Falevai area, our survey teams found 2.82 *Tridacna derasa* per hour of search so Braley's count of 5 in two hours matches our data. He also found 17 juvenile *Tridacna squamosa*, a level twice as high as our average search in the area.

RECRUITMENT IN OTHER PACIFIC AREAS

Hester and Jones (1974) surveyed a large portion of the Helen Reef atoll including eight transects with two areal surveys of 2,000 m^2 each. Although they found *T. crocea* and *T. maxima* less than 20-mm in shell length, they found no juvenile *Tridacna derasa*. The smallest *Tridacna derasa* found was 300-mm shell length.

Braley (1988) presents data on recruitment of *Tridacna derasa* in areas of high natural densities of adults on the Great Barrier Reef. In Watson's Bay, Lizard Island, 3 divers surveyed for two days and found one juvenile *Tridacna derasa*. It was 221-mm in shell length. Eight were located on a 1987 survey of unreported duration (presumably another two day period). At Palfrey-South Island Stations no juvenile *Tridacna derasa* were located during two months of 1983. Six were found during a two day survey in 1984. None were found in 1985 (3.5 days search) or 1986. In 1987 four juvenile *Tridacna derasa* were found.

At Escape Reef, another reef with high densities of adults, Braley surveyed for four weeks on two trips and found three juvenile *Tridacna derasa*.

At Michaelmas Cay, another reef with high densities of adults, Braley surveyed at nearly monthly intervals for two years and found one *Tridacna derasa* juvenile. He reports that Queensland Fisheries Service surveys at this reef from 1978 to 1985 (7 years) found a total of 9 juvenile *Tridacna derasa* at this reef.

At Myrmidon Reef, on four survey periods with 2 or 3 SCUBA divers, Braley found four *Tridacna derasa*.

Although the period of searching is not given for each survey, a conservative total is 70 days searching for 27 juvenile *Tridacna derasa* found. His find of five *Tridacna derasa* juveniles in two hourly snorkel dives at Falevai therefore represent a very high settlement for this species.

Adams et al (1988) reported similar low numbers of juvenile *Tridacna derasa* in an extensive survey of these giant clams in Fiji. Thinking they might be missing them during their surveys, they made several intensive searches in areas of high densities of adults. They found juveniles were often grouped together and sometimes attached to the inner surface of dead shells (we did not observe this in Vava'u although numerous dead shells were in the vicinity of the sanctuary and other sites).

The data from the Great Barrier Reef and Fiji are not given in numbers of juveniles per hour of search. It is clear, however, that it is unusual to find reports in the literature of numbers as high as those found in the vicinity of the Falevai Community Giant Clam Sanctuary. Prior to the installation of the sanctuary, the numbers of juveniles was comparable to the findings of most surveys in low density areas of *Tridacna derasa* (zero recruits found by McKoy and our baseline surveys). During the 1989 survey, our teams found more *Tridacna derasa* juveniles than Braley (1988) reported from all the surveys of giant clams combined on the Great Barrier Reef. In 1990, we found even more.

No data is available on recruits of *Tridacna squamosa* from other areas. As with *Tridacna derasa*, the real measurement of success of the sanctuary is the increase in recruits from baseline surveys done before the installation of the brood stock and the numbers of recruits found in successive years following that installation.

The conservation strategy of community marine reserves of giant clams thus has merit. It is inexpensive, requires little maintenance, and includes the island community in a positive environmental improvement activity.

The six tests examined during this study argue a marine sanctuary of benthic invertebrates can improve recruitment of local stocks in surrounding areas. The behavior of the larvae, the movement of water through and around the sanctuary, and the length of the larval stage must be considered when siting a marine sanctuary. In the case of the Falevai Community Giant Clam Sanctuary, the location was a good one because adults were historically abundant in the area, proving it was biologically suitable for them. The central location of the sanctuary and recirculating water currents in the area also contributed to its success.

PART 3 GROWTH AND MORTALITY OF GIANT CLAMS IN VAVA'U, TONGA

ABSTRACT

The growth and mortality of wild stocks of *Tridacna derasa*, *Tridacna squamosa* and *Tridacna maxima* were studied in Vava'u, Tonga from 1987 to 1990. *Tridacna squamosa* was the fastest growing giant clam, producing the most meat during the first ten years. *Tridacna derasa* grew at the same rate (about 5-mm per month) but produced less meat than *Tridacna squamosa* of the same size. *Tridacna maxima* was the slowest growing giant clam (about 2-mm per month). The clams were determinate growers, reaching their full size in 15 to 20 years. The clams grew slower as they aged. After growth stopped, their shell thickened and slowly decreased in size through bioerosion.

There was considerable individual variation in growth rates but we found no significant correlations to explain it. Live coral formed a barrier for growth for *Tridacna maxima*. One color variety of *Tridacna maxima*, Black with tan or green spots, grew faster than other color varieties, perhaps because of a more efficient strain of zooxanthellae symbionts.

Mortality averaged about 30% of the standing stock of *Tridacna maxima* and 67% of the wild stock of *Tridacna squamosa*.

BACKGROUND

Declining stocks of giant clams in the Kingdom of Tonga prompted a 4 year environmental improvement project to revitalize the endangered species by establishing a community giant clam sanctuary (Chesher 1991a). Wild stocks of giant clams were surveyed and monitored in the Vava'u Island Group to provide data on the impact of the community giant clam sanctuary on surrounding reefs. Studies were made on the growth and mortality of the wild stocks of *Tridacna derasa*, *Tridacna squamosa* and *Tridacna maxima*. Overall distribution and recruitment of the tridacnids was discussed in Chesher (1991b).

Growth and mortality studies on tridacnid clams, especially *Tridacna derasa* and *Tridacna squamosa,* are based on relatively few field observations and a considerable body of information derived from hatchery work (Estacion 1988, Alcazar 1988, Bell and Pernetta 1988, Gomoz and Belda 1988, Crawford et all 1988, Munro 1988). Conditions in hatcheries and ocean nurseries might be expected to differ markedly from wild conditions (Beckvar 1981).

The Pacific wide interest in mariculture of giant clams (Heslinga et al 1984, Heslinga and Watson 1985, Munro and Heslinga 1983, Copeland and Lucas 1988) requires base-line information on the existing wild stocks of tridacnids so potential problems during grow-out of hatchery raised clams can be evaluated. In particular, information on wild stocks is needed to avoid potential damage to wild stocks of clams through the spread of nursery induced diseases.

METHODS

Figure 2 (Page 28) shows areas in Vava'u where clam surveys were made between June of 1987 until October of 1990.

75 specimens of *Tridacna derasa* and 75 specimens of *Tridacna squamosa* were tagged using rectangles cut from aluminum drink cans. We inscribed the length in millimeters and the date of tagging with a sharp nail. The tag edges were then folded and the tag glued to a cleaned area of the shell with underwater epoxy.

This method was impractical for tagging large numbers of *Tridacna maxima* or small specimens of any species. In addition to the time involved in tagging the clams, the tags attracted the attention of fishermen and fish, thus skewing the mortality data where the clams were unprotected. Also, recapture of specimens tagged at random in the field was difficult and we could not be sure if a tagged clam was overlooked or if it was dead or the tag lost.

We solved this problem by mapping the clams, individually, on the reef. Young clams of all species attach with a byssus and, after reaching a size where they could be detected by a diver, they did not change location. (Four *Tridacna derasa* did move a short distance after they were transplanted by divers to a sanctuary. One specimen rolled a meter down a slope after releasing its byssis at 245-mm shell length.)

Mapping the natural populations involved a three step process. Base maps of the survey sites were constructed by digitizing available charts and aerial photographs of Vava'u using a CAD/CAM program (Aegis Draw+) on an Amiga 1000 computer.

More detailed maps of individual coral patches were produced by dive teams. First, a sketch of the whole coral patch was copied onto a plastic slate from digitized aerial photographs (using carbon paper) or by simply sketching the patch from a boat. The position of the patch in the lagoon was determined using the two shore station azimuth intersection technique (Northrup 1987, Page 880).

Once in the water, divers improved the map with distinctive landmarks on the coral patch. They signaled the shore teams to take a bearing from each landmark (clam, coral head, patch reef, etc.) they drew on their slate. Two shore teams took bearings on dive teams with azmuths mounted on tripods. This gave a fix on each landmark within a small radius (Error increased with distance from the stations and the distance between shore teams. 500 meters was about the useful limit of distance from shore stations to divers for this technique).

When a clam was found, the divers signaled for a bearing and then drew the coral(s) and the position of each clam specimen on the coral. They noted the size and color of each clam, and the position of the coral on the overall patch.

Clams were measured in place using vernier calipers. 165-mm maximum length calipers were used for small specimens and 750-mm calipers for large specimens. Measurements were maximum overall shell length. If the specimen had projecting scales, these were included. *Tridacna maxima* burrows into the coral making measurement difficult. Gently tapping the clam prior to measurement caused it to close its valves, making it possible to see the shell ends and permit measurement to within 1-mm. In difficult cases, small pieces of coral had to be broken or moved. Where no exact measurement could be made, the clam was only used for mortality measurements, not growth.

At the end of a day's survey, the notes and drawings from the dive teams and the angles from the right team were entered into the left team notebook, synchronized by the signal times. Later, the data were entered into a database program. A MAP program, written in Basic, read these field data files and drew the exact location of every specimen of giant clam onto the Aegis Draw map of the area. A separate layer of the map was used for each species. The computer drew the exact path followed by each dive team (in different colors matching the color of the team's flag) on another layer of the drawing and calculated the number of meters surveyed by each team.

Using coordinates from previous surveys, shore teams guided the dive team to the same coral patch or coral head. The dive team matched the coral map with the relocated coral patch and resurveyed the patch using the reference map to find individual specimens.

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

Figure 3 gives an example of one of the reference coral maps.

A total of 4595 *Tridacna maxima*, 898 *Tridacna squamosa*, and 362 *Tridacna derasa* were found. Accurate growth data was obtained on 1153 *Tridacna maxima*, 217 *Tridacna squamosa*, and 231 *Tridacna derasa*. These figures include remeasurements of the same specimens from year to year.

GROWTH ANALYSIS

Growth curves were generated by a Basic program written by Munro *et al* 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 (the theoretical date of birth).

t_o was estimated by $t_o = -\ln((L_{oo} - L_t)/(L_{oo} - L_o))/K - t$

where L_t was taken as 0.1-mm (the size of the egg at fertilization) and L_o is the hypothetical zero size. t is taken to be zero at fertilization.

When clams were measured more than once, successive growth data, rather than cumulative growth were used.

Remeasurement data was also analyzed as millimeters growth per month for the average shell length during the interval between measurement and remeasurement. Linear regressions (Y = A + BX) were performed on the data.

McKoy's (1980) formulas were used to derive wet meat weight. Where L = maximum shell length and M = wet meat weight, the formulas are:

Tridacna maxima $M = (1.06 \times 10^{-4})\ L^{2.7218}$

Tridacna squamosa $M = (2.69 \times 10^{-6})\ L^{3.4102}$

Tridacna derasa $M = (4.14 \times 10^{-6})\ L^{3.2554}$

RESULTS

We surveyed favorable shallow water reef areas for specimens of *Tridacna derasa, Tridacna squamosa, Tridacna maxima* and *Hippopus hippopus*. The numbers of each species found are shown in Table 1 (Page 33). No *Hippopus hippopus* were located.

Fishermen, encouraged to bring in *Tridacna derasa* for the community clam sanctuaries, found an additional 233 *Tridacna derasa* and *240 Tridacna squamosa,* mostly in isolated reef areas south of the main island group during a long calm period in February of 1988 and in September of 1990, when they were able to fish reefs normally subjected to heavy surf. During 1990, a local diver captured five specimens of a new species, *Tridacna tevoroa* (Lucas et al 1990).

GIANT CLAMS GREW SLOWLY

In general, giant clams followed a pattern similar to most shelled mollusks. They grew quickly while young then slower after they reached sexual maturity and finally, growth stopped. When actively growing, the ends of the shells were sharp and thin. When growth stopped, the shells thickened and the edge of the ends became blunt and rounded through bioerosion.

Tables 8, 9 and 10 give growth data, plus K, L_{oo}, t_o and the number of specimens used for the curve analysis (N) for the three species investigated. Figure 11 shows the growth curves of all three species of giant clams found in Vava'u for the first 10 years. Figure 12 shows the calculated growth curves for all species for 40 years.

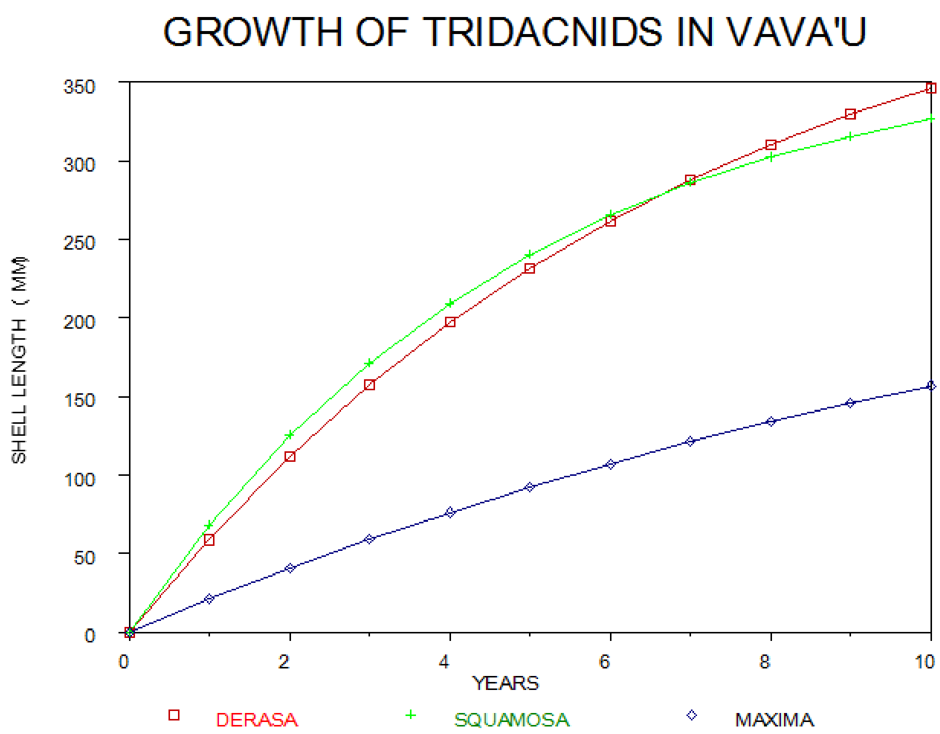

Figure 11. Calculated growth curves of Vava'u tridacnids for the first 10 years

On the average, to grow 200-mm long (about eight inches), *Tridacna squamosa* requires 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* requires just under 4 years, *Tridacna derasa* about 5 years and *Tridacna maxima* about 15 years of growth.

The longest *Tridacna derasa* found was 542-mm (21 inches) in shell length. The maximun length for *Tridacna tevoroa* was 560-mm (22 inches). The largest *Tridacna squamosa* was 415-mm (16 inches) and the maximum length for *Tridacna maxima* was 370-mm (14.5 inches).

Figure 11 shows the growth rates of *Tridacna derasa* and *Tridacna squamosa* were about the same until the seventh year, when *Tridacna squamosa* growth began to slow. *Tridacna derasa* continued rapid growth longer, reaching a larger size (Figure 12).

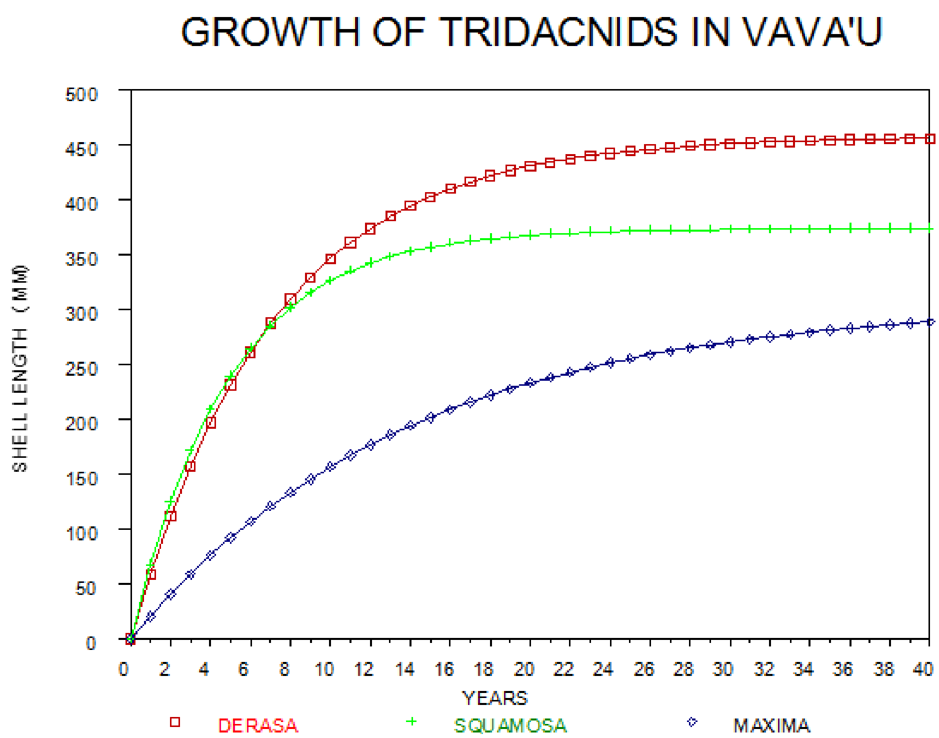

Figure 12. Growth curves for Tridacnid clams extrapolated to 40 years growth.

Insufficient data were collected to calculate a growth curve for the new species. From 26 September 1990 to 6 March 1991 neither the 560-mm *Tridacna tevoroa* nor a 423-mm specimen showed additional growth. A 314-mm specimen grew to 335-mm (3.97 mm/month), a 326-mm specimen grew to 345-mm (3.59 mm/month) and a 382-mm specimen grew to 387-mm (0.94 mm/month).

Table 8 Growth of Tridacna derasa from all stations, 1987 to 1990..

Tridacna derasa K=0.141934 L_{oo}=458 T_o=-.035 N=187				
YEARS	MM LONG	GM WET WT	INCHES	POUNDS
1	58.62	2.36	2.31	0.01
2	111.47	19.11	4.39	0.04
3	157.32	58.67	6.19	0.13
4	197.11	122.23	7.76	0.27
5	231.63	206.71	9.12	0.45
6	261.58	307.11	10.30	0.68
7	287.57	418.04	11.32	0.92
8	310.13	534.51	12.21	1.18
9	329.69	652.31	12.98	1.44
10	346.67	768.15	13.65	1.69

Table 9. Growth of Tridacna squamosa from all stations, 1987 to 1990.

Tridacna squamosa K=0.206956 L_{oo}=374 T_o=-0.035 N=217				
YEARS	MM LONG	GM WET WT	INCHES	POUNDS
1	67.71	4.71	2.67	0.01
2	124.97	38.04	4.92	0.08
3	171.52	112.00	6.75	0.25
4	209.37	221.09	8.24	0.49
5	240.15	352.92	9.45	0.78
6	265.17	494.85	10.44	1.09
7	285.52	636.72	11.24	1.40
8	302.06	771.54	11.89	1.70
9	315.51	895.11	12.42	1.97
10	326.44	1005.40	12.85	2.21

Table 10. Growth of Tridacna maxima from all stations, 1987 to 1990.

Tridacna maxima K=0.07128 L_{oo}=306 T_o=-0.035 N=400				
YEARS	MM LONG	GM WET WT	INCHES	POUNDS
1	20.34	0.39	0.80	0.00
2	39.99	2.43	1.57	0.01
3	58.29	6.78	2.30	0.01
4	75.34	13.62	2.97	0.03
5	91.21	22.91	3.59	0.05
6	105.98	34.48	4.17	0.08
7	119.74	48.07	4.71	0.11
8	132.56	63.40	5.22	0.14
9	144.49	80.16	5.69	0.18
10	155.60	98.07	6.13	0.22

These growth rates are within the range of growth variation for *Tridacna derasa* of similar sizes (Figure 13). The specimens were kept at a depth of 9 meters in the Falevai Community Giant

Clam Sanctuary. The shells of the three which grew showed a marked break in shell growth indicating the change from their normal habitat (or the trauma of transplantation) slowed or stopped their normal growth rate for a short interval. Several specimens transplanted from one area to another in Fiji died (Lewis and Ledua 1988).

Several *Tridacna derasa* over 350-mm shell length showed no growth at all in a 30-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. It appears likely *Tridacna derasa* grows to a certain age, perhaps between 15 and 20, and then stops growing. The considerable range of individual variation in growth (discussed below) determines the final size of the clam.

Like *Tridacna derasa*, growth appeared to stop at whatever size *Tridacna squamosa* reached after 15 to 20 years of growth. Specimens ranging from 320 to 390-mm shell length tended to show no growth at all, or a decrease in size, during the 30-month period of measurement.

All the calculated growth curves have poor correlations because of the wide range of individual growth rates in all three species. Growth variation between specimens of *Tridacna maxima* or *Tridacna derasa* from any one station in Vava'u were as great as differences in growth for the species from Australia to Palau to Tonga (see discussion). Simple scatter plots of the data give a more confused, and more realistic, picture of growth rates. Scatter plots of growth per month versus average shell length are presented in Figures 13, 14 and 15.

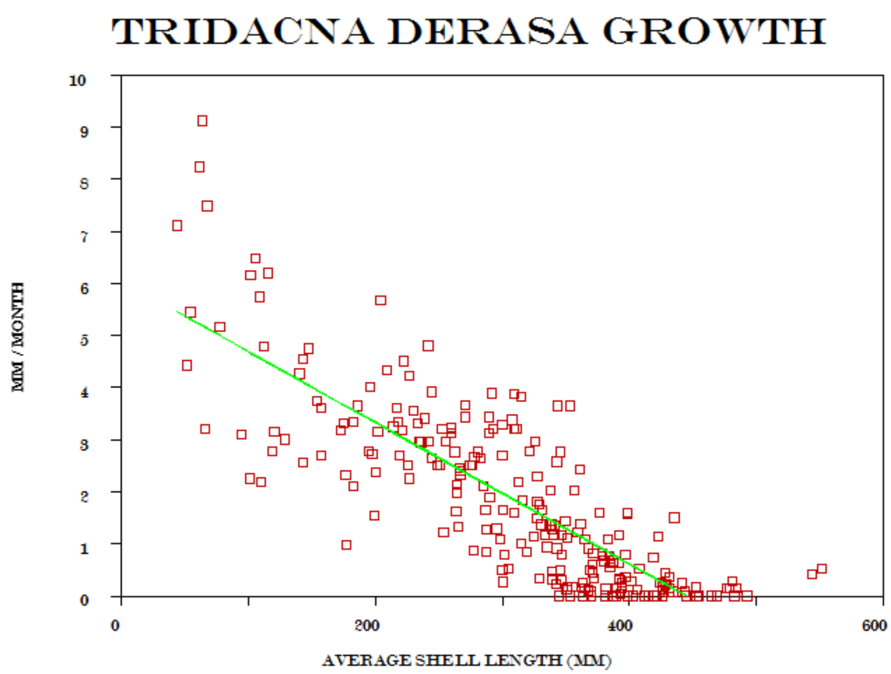

Figure 13. Growth per month of Tridacna derasa in Vava'u 1987 to 1990

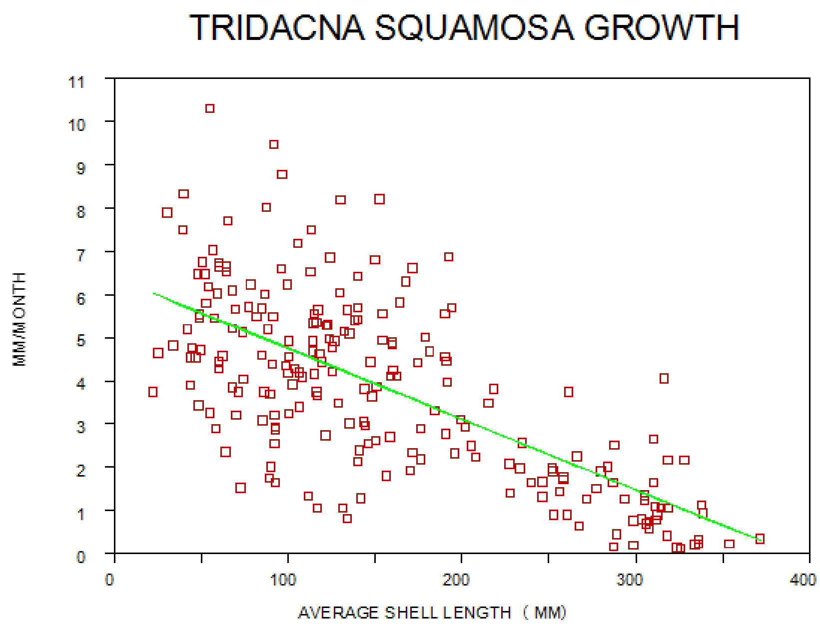

Figure 14. Growth per month of Tridacna squamosa in Vava'u 1987 to 1990

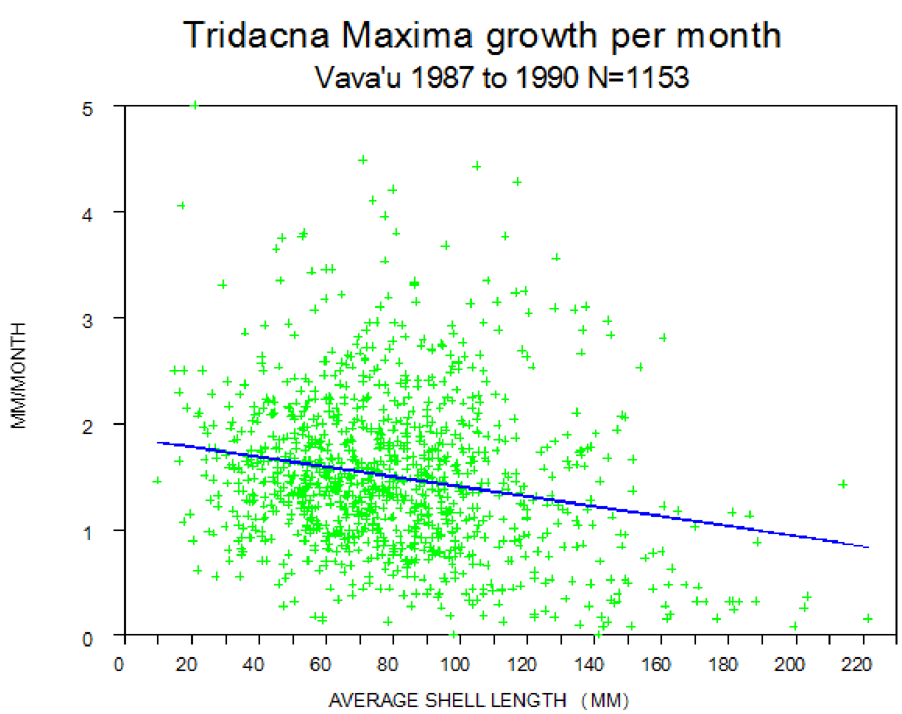

Figure 15. Growth per month of Tridacna maxima in Vava'u 1987 to 1990

Table 11 gives the data for the regression analysis of the scatter plots.

Table 11. Regression analysis for growth per month in Vava'u tridacnids (Y = A + BX)

Regression	*T. derasa*	*T. squamosa*	*T. maxima*
A	6.046031	6.413724	1.872783
Std Err A	0.987058	1.553473	0.707151
R squared	0.674453	0.477252	0.043340
B	-0.01357	-0.01653	-0.00467
Std Err B	0.000623	0.001179	0.000647
Number	231	217	1153
Avg Size (mm)	43.5 to 552	22 to 371.5	9.75 to 221.5

VARIATIONS IN GROWTH

We could not find any clues as to the range of individual variation in growth for *Tridacna derasa* or *Tridacna squamosa*. The majority of *Tridacna derasa* and many specimens of *Tridacna squamosa* were transplanted into the sanctuary when found and their growth monitored in this single locality. Each specimen was placed on the bottom in similar conditions, about two meters from the next clam, so crowding was not a factor. Depth, salinity, temperature, wave exposure, sun exposure, attacks by fish and other environmental factors did not vary within the sanctuary.

Heslinga et al (1984) presents growth data for cultured *Tridacna derasa* in Palau and these, too, show the same degree of individual variation in growth despite their being siblings raised in culture conditions.

HARRASSMENT BY FISH

One specimen of *Tridacna squamosa*, kept in a wire cage in Neiafu Harbor for six months, exhibited the fastest growth of any specimen (10-mm per month). The difference in growth rate was evident in the greater spacing between the scales of the shell and in the thinness of the shell compared with *Tridacna squamosa* grown in wild conditions. Specimens of *Tridacna squamosa* growing in exposed locations on the tops of coral heads where algae was present grew slower than specimens in less exposed conditions where algae was not abundant. The slower growing specimens had heavier shells, few and smaller scales, and the shell was less inflated (flatter) than those growing in more protected niches.

Herbivorous fish fed on the algae growing on the exposed, algae-covered *Tridacna squamosa.* Each time a fish nibbled on the algae attached to the clam, the clam retracted its mantle and partly closed its valves. Since clams grow by secreting calcium carbonate from the edges of their mantle when it is expanded, and since tridacnids depend on their symbiotic zooxanthellae for nutrients, the slower growth and abnormal shell shape may well have resulted from fish harassment. The specimen inside the cage was not bothered by fish and thus had its mantle fully extended all day. When removed from the cage and placed in the sanctuary, its growth slowed.

COLOR VERSUS GROWTH

Trench et al (1981) suggested some of the observed growth variation in tridacnids might result from different strains of symbiotic zooxanthellae. Since the colors of giant clam mantles result from the zooxanthellae it is reasonable to assume clams with markedly different colors might have different strains of zooxanthellae.

The greatest amount of growth data was gathered for *Tridacna maxima* (Figure 15). An analysis of color versus growth showed no significant growth differences for *Tridacna maxima* with blue, brown, gold, green or gray mantle colors (Figure 16). Both fast and slow growing clams appeared in all size/color categories, and the clams tended to grow at the same rate at all sizes.

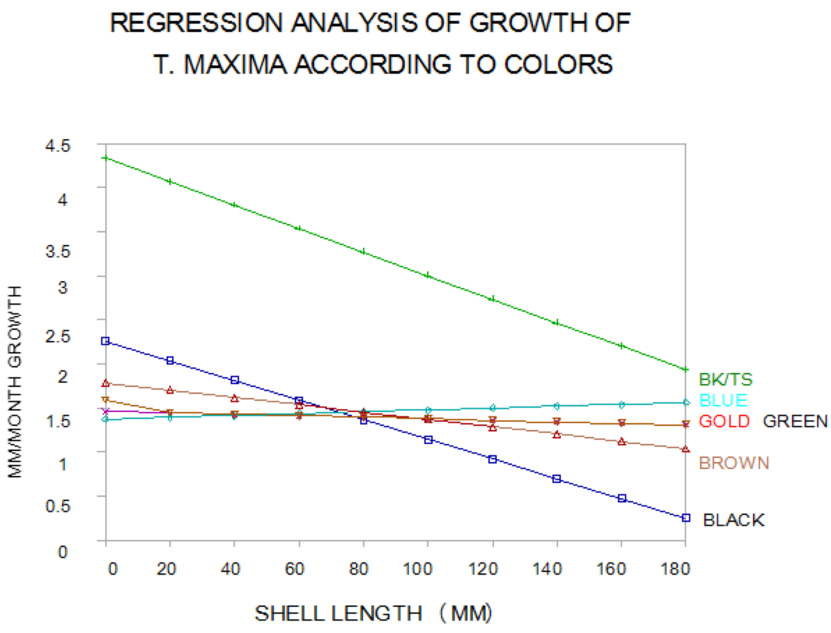

Figure 16. Growth rates of different colors of Tridacna maxima 1989 to 1990

Black combinations (ie. black and white, black and yellow, either striped or spotted) showed a markedly different slope to the regression line, indicating a more definite decrease in growth with increasing size, but the actual growth per month fell within the range of the other color patterns (Figure 16 and Table 12).

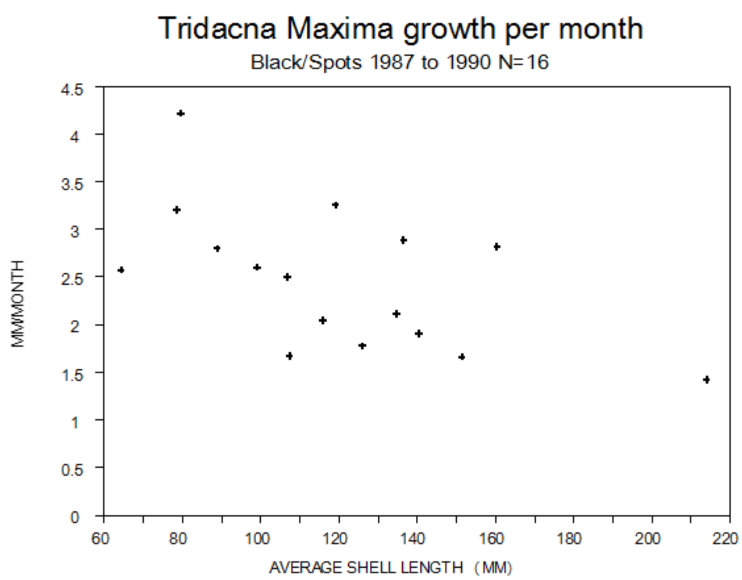

Figure 17. Growth of Black with Tan or Green spot Tridacna maxima 1987 to 1990

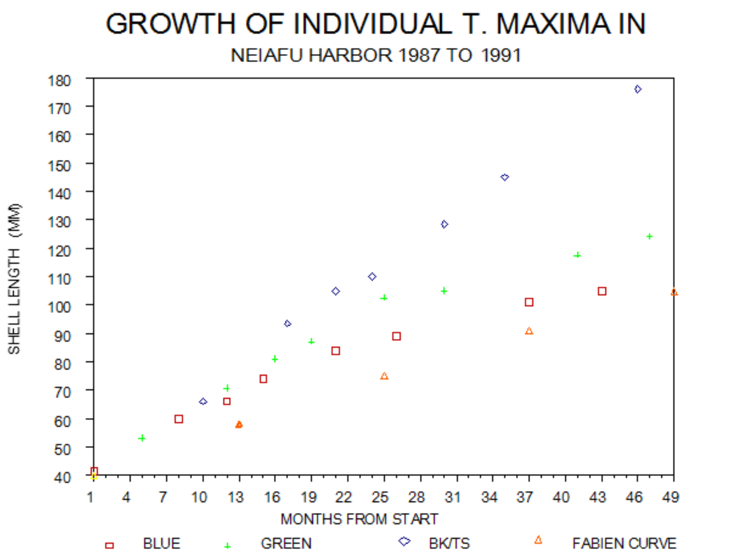

Figure 18, Growth of three specimens of Tridacna maxima transplanted into Neiafu Harbor

Table 12. Regression analysis for growth per month in various color forms of Tridacna maxima (Y = A + BX)

Regression	Black	BK/TS	Brown	Blue
A	2.259	4.333	1.784	1.372
Std Err A	0.560	0.744	0.580	0.558
R squared	0.182	0.295	0.047	0.002
B	-0.0112	-0.013	-0.004	-0.001
Std Err B	0.004	0.005	0.002	0.002
Number	43	20	109	109

Regression	Gold	Green	Gray
A	1.462	1.590	1.344
Std Err A	0.563	0.678	0.573
R squared	0.182	0.295	0.047
B	-0.0112	-0.013	-0.004
Std Err B	0.004	0.005	0.002
Number	43	20	109

While growth varied considerably from one specimen to the next, it was consistent for any one individual (ie. Figure 18). Ambient nutrients did not seem to make any difference in growth rates. Neiafu Harbor had an enriched environment with considerable plankton development. *Tridacna maxima* in the same depth range at Ano Beach showed similar growth rates although the water off Ano Beach was consistently clear and low in plankton.

Tridacna maxima growth was influenced by the nature of the substrate in which the clam burrowed. Specimens burrowed into dead sections of living coral heads stopped growing when both ends of their shell were within a millimeter of live coral, especially *Porites lutea* or *Lobophyllia* sp. There was no evidence of attack or injury to the clam by the mesenterial filaments of the corals but evidently the corals were able to prevent the clam from extending its mantle onto or even over its polyps. *Tridacna maxima* in branching coral areas or not embedded in the coral grew more rapidly. Fastest growth of *Tridacna maxima* was obtained by transplanted specimens which were not deeply embedded in the coral substrate (Figure 18).

MEAT PRODUCTION

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, we obtained growth in wet meat weight from the calculated length/age curves to produce the wet meat weight curves shown in Figures 19 and 20.

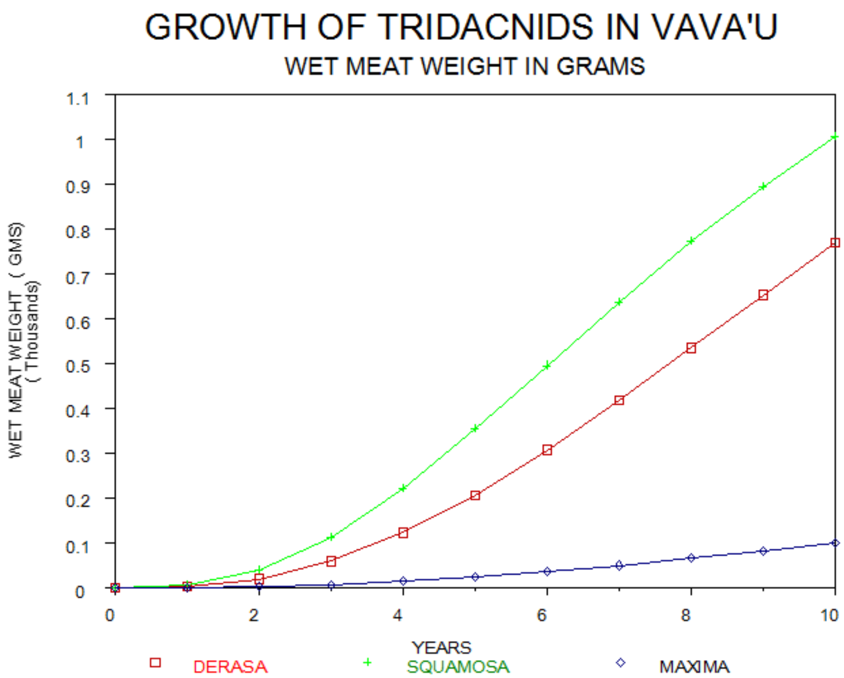

Figure 19. Wet weight of meat produced by Vava'u tridacnids in the first ten years of growth

Although *Tridacna derasa* and *Tridacna squamosa* grow at the same rate for the first 8 to 10 years, *Tridacna squamosa* has a more inflated shell and produces more meat than a comparable sized *Tridacna derasa*. Figure 20 gives the increase in wet weight of the Vava'u tridacnids for the first ten years of life. *Tridacna squamosa* was clearly the fastest meat producer in the first decade of life.

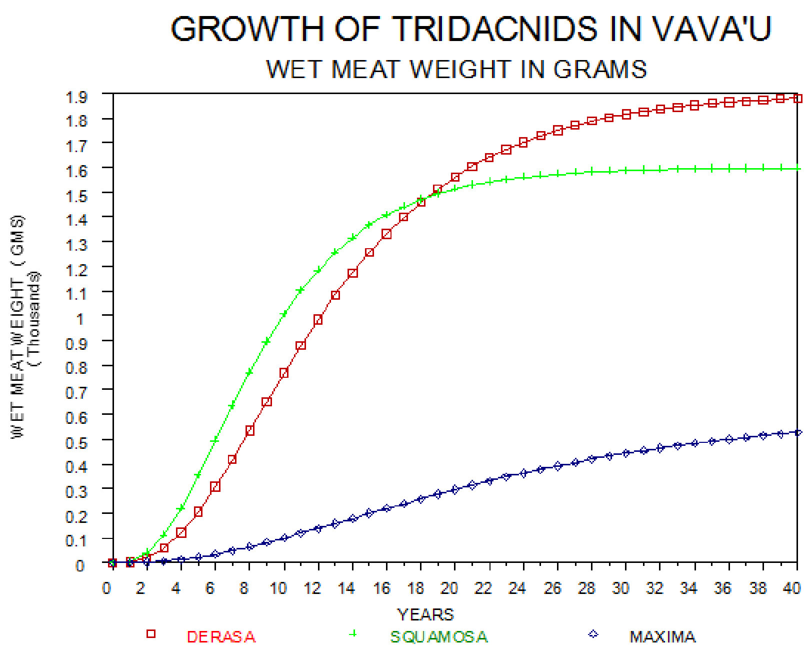

Figure 20. Growth in wet meat weight (milligrams) for tridacnids in Vava'

MORTALITY

Mortality of all species of Tridacnids was determined directly by mapping whole discrete populations and counting exactly how many clams died in a one year period from this known population. Table 13 shows the percent mortality for *Tridacna maxima* and *Tridacna squamosa* at different areas in Vava'u between 1988 and 1989 and from 1989 to 1990.

Table 13. Percent mortality of tridacnids at mapped stations 1988 to 1989 and 1989 to 1990.

STATION	%DEAD 1988-89		%DEAD 1989-90	
SPECIES	MAXIMA	SQUAMOSA	MAXIMA	SQUAMOSA
MALA+	29.5	78.6	46.1	64.3
PORTM	27.0	70.0	27.2	56.5
FALEVAI+	31.0	69.0	31.1	46.0
TAUNGA	NO 1988	SURVEY	25.4	87.5
MEAN	29.2	72.5	32.5	63.6

Between 1988 and 1989 *Tridacna maxima* mortality rates ranged from a low of 27.0% in Port Maurelle to a high of 31% at Falevai with a mean mortality of 29.2%. Between 1989 and 1990, *Tridacna maxima* mortality increased from a low of 25.4% at Taunga to a high of 46.1% at Mala with a mean of 32.5%. For all stations (including Foeata with 21.4% mortality) over the two year period the yearly mortality averaged 29.8% (S.D. = 6.83 95% confidence limits 24.08-35.51, S.E. of Mean = 2.58).

Mortality of *Tridacna squamosa* was much greater than for *Tridacna maxima*. Between 1988 and 1989, mortality averaged 72.5% per year from all stations and ranged from a low of 69% at Falevai to a high of 78.6% at Mala. Between 1989 and 1990, mortality ranged from 46% at Falevai to 87% at Taunga. The mean mortality rate was 63.6%. For both years, the yearly mortality averaged 67.4% (S.D. 12.67, 95% confidence limits 55.7% to 79.1%, S.E. of Mean = 5.7).

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 indicated some of the observed mortality was from fishing. Mortality rates were, however, equally high in specimens below the size of first entrance into the fishery (<40-mm shell length).

Mortality figures of adult *Tridacna derasa* (L>240) were limited to observations in the sanctuaries. No adults were found in the mapped survey areas and those found in deeper water or remote locations were collected and placed in the community clam sanctuary. These were still alive at the end of the project in 1990 and no natural mortality of adults was observed after they had been placed in the sanctuary.

38 juvenile *Tridacna derasa* found in 1989 were collected and placed in the community sanctuary at Falevai. 15 Juvenile *Tridacna derasa* were taken for exhibition purposes in 1989 and were not returned. An octopus slithered off with another 5. Three died from unknown causes (the shells were broken along the edges). Villagers from Falevai took numerous juvenile specimens of *Tridacna derasa* and *Tridacna squamosa* from the reefs at Falevai and Nuku in 1989 and 1990. Most of these were taken by children and no records were kept. Of the 45 specimens found in 1989, only 15 remained in 1990 (66% mortality).

DISCUSSION

GROWTH

***Tridacna derasa*:**

Growth rates of giant clams are an important consideration in calculating the potential productivity of these animals in aquaculture operations (Munro 1988, Watson and Heslinga 1988). *Tridacna gigas* is generally accepted as the most rapidly growing giant clam and therefore preferred for culturing (Munro 1988). Preliminary tests of this species in Fiji, however, have been disappointing. Growth rates of imported Australian seed in lagoon conditions were only 2.4mm per month (Ledua and Adams 1988). In the Philippines, *Tridacna gigas* imported from Australia grew 7.3mm per month.

In Australia, average growth rates of 8.35mm per month are claimed by Barker, Crawford et al (1988) yet Barker, Lucas and Nash (1988) show subtidal growth of this species is much less, and not much different from Tongan *Tridacna derasa* of a similar size. At Orpheus Island, for example, subtidal growth was 5.67mm per month. At John Brewer Reef it was 4.41 mm per month in one test and 5.97mm per month in another. These data, when compared to the growth of *Tridacna derasa* in Vava'u shown in Figure 9, fall within the growth rate of subtidal specimens of similar sizes. The 4.41mm per month growth mean from John Brewer Reef is, in fact, on the regression line for *Tridacna derasa* of 125-mm average length.

Heslinga et al 1984 compares growth between *Tridacna gigas* and *Tridacna derasa* (his Fig. 8) and there is no significant difference until the fourth year.

Tridacna derasa growth from Australian aquaculture facilities is much slower than *Tridacna derasa* growth from other areas. At Orpheus Island, Crawford et al 1988 reports growth rates of only 2.4mm per month for *Tridacna derasa* aged between 18 and 24 months, and grown in lagoon subtidal trays . At Lizard Island, growth of 2.1 mm per month was measured for 25 to 35 month old *Tridacna derasa*. Gomez and Belda likewise report low culture growth rates of *Tridacna derasa* (3.3 to 3.6mm/month) in the Philippine Islands.

Cultured *Tridacna derasa* between 70 and 170mm imported from Palau grew about 5mm per month in American Samoa (Buckely and Itano 1988) and in Yap (Price and Fagolimul 1988). Growth rates reported by Watson and Heslinga for Palauan cultured *Tridacna derasa* were similar and all these data match the data for wild *Tridacna derasa* in Vava'u almost exactly.

Little data is available of growth of wild *Tridacna derasa* from other areas. In Australia, Braley (1988) measured growth rates of recruits found at Lizard Island and Myrmidon Reef. Two lizard island specimens grew at the high end of the Vava'u growth data for comparable sizes

(5.75mm/month for a 185.5mm average length, 4.4mm/month for a 233mm average length) while one specimen 155mm average length grew at the low end of the Vava'u data spread (2.5mm/month). At Myrmidon reef a specimen 135mm average length grew at 7.2mm/month which was, again, at the high end of the Vava'u growth range. A second specimen was reported to have grown at 27mm/month (200 to 310-mm in four months, a 55% increase) but clearly this is a mistake and must be 2.7mm/month, a rate fitting the Vava'u data almost on the regression line for a 205-mm long specimen.

Adams *et al* 1988 obtained growth data for *Tridacna derasa* from Fiji and it matches the Vava'u growth curve with no significant difference (K=0.134, L_{oo}=473 compared to K=0.142, L_{oo}=458 for our data). The calculated growth curve from Palau is slightly higher than the wild stock growth curve (K=0.187, L_{oo}=500) (Munro 1988), but because of considerable individual variation, this curve may not be significantly different. Munro has recalculated McKoy's 1980 data of *Tridacna derasa* from Tongatapu, Tonga and the curve (K=0.132, L_{oo}=500) is about the same as the growth measured elsewhere.

The natural growth rates of *Tridacna derasa* do not vary much between different parts of its range. In fact, there seems to be greater individual variation in growth for *Tridacna derasa* in any one locality than in the range of the species. A graph of *Tridacna derasa* growth shown by Heslinga et al (1984) shows the spread of individual growth varies about the same for cultured *Tridacna derasa* grown in Palau as we found for wild *Tridacna derasa* in Vava'u. This is interesting since the Palau clams were siblings raised in apparently identical conditions while the Vava'u clams were wild and on open reef conditions.

***Tridacna squamosa*:**

Unlike our data, most growth measurements of *Tridacna squamosa* have shown it to be a poor performer. Beckvar (1981) thought this might be due to culture conditions. Growth rates of cultured *Tridacna squamosa* in Palau presented by Heslinga et al 1984 show these animals did poorly in raceway culture compared to *Tridacna derasa*. They grew at about 2.7mm per month for the first year. In the Philippines, Gomez and Belda (1988) showed growths of only 1.1mm per month for cultured *Tridacna squamosa* in raceways and, when put onto a reef flat in cages, the species grew at 2.3mm per month at a mean size of 31-mm average length.

Bell and Pernetta (1988) found *Tridacna squamosa* grew only 2mm per month in a raceway in Papua New Guinea but when placed in 3 meters of water on an open reef they grew at 6mm per month at an average length of 38-mm (about the same rate as Vava'u wild specimens). In Madang, PNG, they measured 3.3mm month growth for 97-mm average length *Tridacna squamosa (*Low, but within the range of variation found for growth of this species in Vava'u. See Figure 14).

Gomez and Belda (1988), reported wild stock (number not given) *Tridacna squamosa* in the Philippines grew at 2.1mm/month at average length of 87-mm and 1.9mm month at length 112-mm. Both these rates are at the very low end of the individual growth found in Vava'u wild stock.

***Tridacna maxima*:**

The growth curve of *Tridacna maxima* (K=0.07, L_{oo}=306) calculated from Vava'u agrees closely with that calculated by Radtke (198?) for *Tridacna maxima* from Rose Atoll (K=0.065, L_{oo}=294). Radtke derived his growth estimate from growth rings in shells and checked it with tagged data. McMichael's (1975) growth data for *Tridacna maxima* from Australia also match the Vava'u data within the limits of error (K=0.132 L_{oo}=220). McKoy's (1980) tagged *Tridacna maxima* grew at comparable rates in Tongatapu. Again, individual variation in growth was greater in Vava'u populations than growth differences between populations of other island areas.

Gomez and Belda (1988) demonstrated that, unlike other tridacnids, juvenile *Tridacna maxima* showed excellent survival and good growth when placed onto a reef flat without protection at a mean shell length of 11.2-mm.

Contrary to McKoy's 1980 statement that *Tridacna maxima* would not reburrow and survive transplantation, we found they did very well in Vava'u, reattaching within 24 hours and growing more rapidly than non-transplanted specimens.

Tridacna maxima is found in very dense natural populations in the Cook Islands and in French Polynesia and appears to have no mass mortalities despite being so thick on some reefs it is impossible to walk without stepping on them.

Tridacna maxima showed much lower mortality rates in Vava'u than *Tridacna squamosa* or *Tridacna derasa*.

The variety of *Tridacna maxima* with black mantle and tan or green spots grew nearly as fast as *Tridacna derasa*, reaching 178-mm shell length in about 4 years. It may be this is the animal for giant clam aquaculture in Tonga. It could eliminate or minimize the disease hazards and expense of ocean nurseries and could, if Gomez and Belda's observations can be repeated in Tonga, be seeded out onto intertidal and subtidal reef flats by the thousands.

MORTALITY

McKoy (1980) used the slope of the size frequency distributions in Vava'u to estimate mortality of Z=0.35 for *Tridacna maxima*. 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). McKoy's (1980) estimate of mortality Z=0.35 derived from the analysis of size frequency, was not unrealistic at all. Our direct measurement of 29.8% average mortality (Z=0.35) matched his estimate.

Radtke (undated MS) examined an unfished population of *Tridacna maxima* at Rose Atoll and determined a natural mortality rate of 15.4% (Z=0.16). This would indicate about half of the observed *Tridacna maxima* mortality in other Vava'u stations was the result of fishing.

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The Hon. Baron Tuita, recently retired from the position of the Minister of Lands, Survey and Natural Resources, gave the approval for the first giant clam sanctuary and instructed that 100 Tokanoa molemole be placed on a reef in Nuku'alofa Harbor during Environmental Awareness Week of 1986.

The Hon. Akau'ola, Minister of Police, spent considerable time discussing the project and gave his support to the concept from its start. He arranged for several radio programs to tell the public about the need for Giant Clam circles and saw to it that the police force looked after the community giant clam circles in Falevai.

The Hon. Tu`i'afitu, Governor of Vava'u has expressed a continuing interest in the community giant clam sanctuary project and has offered sage advice on several occasions.

Sione Tongilava, Secretary of the Ministry of Lands, Survey and Natural Resources first asked the question, "What can we do to improve the sea during Environmental Awareness Week." Mr. Tongilava and Uilou Samani, Environmentalist for the Ministry, arranged for the installation of the first giant clam circle in Nuku'alofa during Environmental Awareness Week of 1986. They were also the instigators and supervisors of this project; designed to spread the idea of giant clam reserves into the public sector and to other islands of the Kingdom and eventually throughout the Pacific.

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Dr. Fatai Koli, Methodist Church, Neiafu, Vava'u

Father Aliki Langa, Catholic Mission, Neiafu, Vava'u

Uasi La'a, Bishop, Morman Church, Neiafu, Vava'u

Semisi Tupou, Manager, MH, Neiafu, Vava'u

Siosi Musika, Vava'u High School

Carter Johnson, Paradise Hotel

Tasi Afeaki, Tonga Maricultural Development Centre

Davita Leonati Motuliki, Artist

Thomas Waters, Manager of the Moorings

Mikio and Lena Filiatonga of the Vava'u Guest House

Peter Goldstern, Vava'u Water Sports

Denny Swan and Rosy Smith, Vava'u Water Sports

Tu'uta Galu, a Fisherman from NuaPapu, Vava'u

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APPENDIX SURVEY DATA

Table 14. Tridacna maxima found at Vava'u stations 1987 to 1990

FALEVAI + NUKU + AA								
SIZE	N 1990	MX/HR	N 1989	MX/HR	N 1988	MX/HR	N 1987	MX/HR
<30	32	2.74	13	0.80	10	0.55	14	1.04
<60	64	5.49	84	5.14	109	5.96	169	12.53
<90	62	5.31	152	9.30	134	7.32	131	9.72
<120	35	3.00	98	5.99	42	2.30	77	5.71
>120	9	0.77	23	1.41	30	1.64	73	5.41
TOTAL	202	17.31	370	22.63	325	17.76	464	34.41
	METER	MINS	METER	MINS	METER	MINS		MINS
	1607.9	700	3264	981	5067	1098		809
MALA + UTANGAKE								

SIZE	N 1990	MX/HR	N 1989	MX/HR	N 1988	MX/HR	N 1987	MX/HR
<30	23	1.97	12	0.68	17	0.79	11	0.73
<60	32	2.74	68	3.83	84	3.89	75	4.99
<90	26	2.22	86	4.84	65	3.01	58	3.86
<120	29	2.48	65	3.66	31	1.43	31	2.06
>120	24	2.05	51	2.87	31	1.43	28	1.86
TOTAL	134	11.45	282	15.87	228	10.55	203	13.52
	METER	MINS	METER	MINS	METER	MINS	METER	MINS
	2944	702	2951	1066	5427	1297	7955	901
PORT MAURELLE								
SIZE	N 1990	MX/HR	N 1989	MX/HR	N 1988	MX/HR	N 1987	MX/HR
<30	119	5.87	29	1.60	33	1.72	16	0.87
<60	125	6.16	101	5.58	131	6.85	92	5.02
<90	112	5.52	144	7.96	87	4.55	95	5.19
<120	82	4.04	84	4.64	45	2.35	59	3.22

>120	26	1.28	27	1.49	28	1.46	52	2.84
TOTAL	464	22.88	385	21.27	324	16.93	314	17.14
	METER	MINS	METER	MINS	METER	MINS	METER	MINS
	1330	1217	2329	1086	2817	1148	5403	1099
VAKA'EITU								
SIZE	N 1990	MX/HR	N 1989	MX/HR	N 1988	MX/HR	N 1987	MX/HR
<30	1	0.27	0	0.00	0	0.00	0	0.00
<60	2	0.54	4	1.94	3	0.99	4	2.09
<90	16	4.32	12	5.81	15	4.97	9	4.70
<120	7	1.89	18	8.71	16	5.30	7	3.65
>120	1	0.27	20	9.68	16	5.30	4	2.09
TOTAL	27	7.30	54	26.13	50	16.57	24	12.52
		MINS	METER	MINS	METER	MINS		MINS
		222	1519	124	1799	181		115
TAUNGA								

SIZE	N 1990	MX/HR	N 1989	MX/HR	NO SURVEY 1988		N 1987	MX/HR
<30	9	2.57	2	0.52			4	1.13
<60	19	5.43	20	5.15			14	3.94
<90	15	4.29	34	8.76			10	2.82
<120	24	6.86	26	6.70			11	3.10
>120	14	4.00	14	3.61			7	1.97
TOTAL	81	23.14	96	24.72			46	12.96
	MINS		METER	MINS			METER	MINS
	210		1227	233			1128	213
OVALAU +								
SIZE	N 1990	MX/HR	N 1989	MX/HR	N 1988	MX/HR	N 1987	MX/HR
<30	9	4.50	1	0.50	0	0.00	0	0.00
<60	17	8.50	10	5.00	10	5.00	2	1.46
<90	10	5.00	28	14.00	15	7.50	9	6.59
<120	21	10.50	17	8.50	7	3.50	6	4.39

>120	16	8.00	18	9.00	12	6.00	13	9.51
TOTAL	73	36.50	74	37.00	44	22.00	30	21.95
	MINS		MINS		MINS		MINS	
	120		120		120		82	
FOEATA								
SIZE	N 1990	MX/HR	N 1989	MX/HR	N 1988	MX/HR	N 1987	MX/HR
<30	0	0.00	0	0.00	1	0.26	0	0.00
<60	2	0.79	1	0.42	2	0.52	0	0.00
<90	3	1.19	10	4.17	15	3.90	5	1.69
<120	12	4.77	12	5.00	9	2.34	2	0.68
>120	31	12.32	34	14.17	28	7.27	14	4.75
TOTAL	48	19.07	57	23.75	55	14.29	21	7.12
	MINS		MINS		MINS		MINS	
	151		144		231		177	
ANO BEACH BAY								

SIZE	NO SURVEY 1990		N 1989	MX/HR	N 1988	MX/HR	N 1987	MX/HR
<30			0	0.00	0	0.00	0	0.00
<60			0	0.00	2	1.00	2	0.51
<90			11	5.04	3	1.50	12	3.08
<120			5	2.29	1	0.50	9	2.31
>120			2	0.92	0	0.00	3	0.77
TOTAL			18	8.24	6	3.00	26	6.67
			MINS		MINS		MINS	
			131		120		234	

Table 15. Tridacna squamosa found at Vava'u stations 1987 to 1990.

FALEVAI + NUKU + AA								
SIZE	N 1990	SQ/HR	N 1989	SQ/HR	N 1988	SQ/HR	N 1987	SQ/HR
<60	28	2.40	7	0.43	1	0.05	4	0.30
<120	32	2.74	30	1.83	16	0.87	12	0.89
<180	11	0.94	19	1.16	14	0.77	5	0.37
<240	4	0.34	11	0.67	2	0.11	5	0.37
>240	0	0.00	0	0.00	2	0.11	1	0.07
TOTAL	75	6.43	67	4.10	35	1.91	27	2.00
	METER	MINS	METER	MINS	METER	MINS		MINS
	1607.9	700	3264	981	5067	1098		809
TAUNGA								
SIZE	N 1990	SQ/HR	N 1989	SQ/HR	NO SURVEY 1988		N 1987	SQ/HR
<60	12	3.43	1	0.26			0	0.00

<120	10	2.86	8	2.06			3	0.85
<180	8	2.29	5	1.29			4	1.13
<240	0	0.00	2	0.52			0	0.00
>240	0	0.00	0	0.00			0	0.00
TOTAL	30	8.57	16	4.12			7	1.97
	METERS	MINS	METER	MINS			METER	MINS
	971	210	1227	233			1128	213
MALA AND UTANGAKE								
SIZE	N 1990	SQ/HR	N 1989	SQ/HR	N 1988	SQ/HR	N 1987	SQ/HR
<60	26	2.22	11	0.62	2	0.09	7	0.47
<120	24	2.05	11	0.62	14	0.65	15	1.00
<180	9	0.77	22	1.24	14	0.65	7	0.47
<240	5	0.43	7	0.39	5	0.23	5	0.33
>240	0	0.00	0	0.00	0	0.00	2	0.13
TOTAL	64	5.47	51	2.87	35	1.62	36	2.40

	METER	MINS	METER	MINS	METER	MINS	METER	MINS
	2944	702	2951	1066	5427	1297	7955	901
VAKA'EITU								
SIZE	N 1990	SQ/HR	N 1989	SQ/HR	N 1988	SQ/HR	N 1987	SQ/HR
<60	0	0.00	0	0.00	0	0.00	0	0.00
<120	4	1.08	0	0.00	0	0.00	0	0.00
<180	3	0.81	2	0.97	1	0.33	3	1.57
<240	1	0.27	1	0.48	1	0.33	0	0.00
>240	0	0.00	0	0.00	0	0.00	0	0.00
TOTAL	8	2.16	3	1.45	3	0.99	3	1.57
	MINS		METER	MINS	METER	MINS		MINS
	222		1519	124	1799	181		115
PORT MAURELLE								
SIZE	NUMBER	SQ/HR	N 1989	SQ/HR	N 1988	SQ/HR	N 1987	SQ/HR
<60	52	2.56	2	0.11	2	0.10	5	0.27

<120	23	1.13	4	0.22	10	0.52	19	1.04
<180	8	0.39	9	0.50	8	0.42	20	1.09
<240	0	0.00	4	0.22	4	0.21	10	0.55
>240	0	0.00	0	0.00	0	0.00	0	0.00
TOTAL	83	4.09	19	1.05	24	1.25	54	2.95
	METER	MINS	METER	MINS	METER	MINS	METER	MINS
	1330	1217	2329	1086	2817	1148	5403	1099
OVALAU								
SIZE	N 1990	SQ/HR	N 1989	SQ/HR	N 1988	SQ/HR	N 1987	SQ/HR
<60	3	1.50	0	0.00	0	0.00	0	0.00
<120	3	1.50	0	0.00	0	0.00	0	0.00
<180	0	0.00	2	2.00	0	0.00	1	0.73
<240	0	0.00	0	0.00	0	0.00	0	0.00
>240	0	0.00	0	0.00	0	0.00	0	0.00
TOTAL	6	3.00	2	2.00	0	0.00	1	0.73

	MINS		MINS		MINS		MINS	
	120		120		120		82	
ANO BEACH BAY								
SIZE	NO SURVEY 1990		N 1989	SQ/HR	N 1988	SQ/HR	N 1987	SQ/HR
<60			0	0.00	0	0.00	0	0.00
<120			1	0.46	1	0.50	1	0.26
<180			1	0.46	0	0.00	0	0.00
<240			0	0.00	0	0.00	0	0.00
>240			0	0.00	0	0.00	0	0.00
TOTAL			2	0.92	1	0.50	1	0.26
			MINS		MINS		MINS	
			131		120		234	
FOEATA								
SIZE	N 1990	SQ/HR	N 1989	SQ/HR	N 1988	SQ/HR	N 1987	SQ/HR
<60	0	0.00	0	0.00	0	0.00	0	0.00

<120	0	0.00	0	0.00	1	0.26	0	0.00
<180	0	0.00	1	0.42	0	0.00	0	0.00
<240	0	0.00	0	0.00	0	0.00	0	0.00
>240	0	0.00	0	0.00	0	0.00	1	0.34
TOTAL	0	0.00	1	0.42	1	0.26	1	0.34
	MINS		MINS		MINS		MINS	
	144		144		231		177	

Table 16. Tridacna derasa found in Vava'u 1987 to 1990

FALEVAI + NUKU + AA						
SIZE	N 1990	DR/HR	N 1989	DR/HR	N 1988	DR/HR
<60	13	1.11	4	0.24	2	0.11
<120	20	1.71	26	1.59	0	0.00
<180	2	0.17	2	0.12	0	0.00
<240	0	0.00	0	0.00	0	0.00
>240	0	0.00	0	0.00	0	0.00
TOTAL	35	3.00	32	1.96	2	0.11
	MINS		MINS		MINS	
	700		981		1098	

TAUNGA				
SIZE	N 1990	DR/HR	N 1989	DR/HR
<60	5	1.43	0	0.00

VAKA'EITU		
SIZE	N 1990	DR/HR
<60	0	0.00

<120	3	0.86	11	2.83
<180	2	0.57	0	0.00
<240	0	0.00	0	0.00
>240	0	0.00	0	0.00
TOTAL	10	2.86	11	2.83
	MINS		MINS	
	210		233	
MALA AND UTANGAKE				
SIZE	N 1990	DR/HR	N 1989	DR/HR
<60	14	1.20	2	0.11
<120	10	0.85	0	0.00
<180	2	0.17	0	0.00
<240	0	0.00	0	0.00
>240	0	0.00	0	0.00
TOTAL	26	2.22	2	0.11

<120	0	0.00
<180	3	0.81
<240	0	0.00
>240	0	0.00
TOTAL	3	0.81
	MINS	
	222	
LUAMOKU		
N 1989	DR/HR	
0	0.00	
2	1.02	
0	0.00	
0	0.00	
0	0.00	
2	1.02	

	MINS		MINS			MINS		
	702		1066			118		

PORT MAURELLE

SIZE	N 1990	DR/HR
<60	6	0.30
<120	6	0.30
<180	0	0.00
<240	0	0.00
>240	0	0.00
TOTAL	12	0.59
	MINS	
	1217	