

Nursery and Grow-out Techniques for Giant Clams (Bivalvia: Tridacnidae)

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Foreword

There is currently a wealth of information in print on the rearing of giant clams, including two excellent manuals (Heslinga et al., 1990; Braley, 1992; Calumpong 1992). In the years since these manuals were written, clam rearing methods have changed a great deal as have markets for these animals. The aim of this manual is not to contradict previous publications but to incorporate current information and up-to-date farming practices into a straightforward, step-by-step account of how to grow giant clams from their early life stages to market size and how to sell the final product. This manual follows on directly from CTSA publication #130 "Spawning and Early Larval Rearing of Giant Clams (Bivalvia: Tridacnidae)." Copies of CTSA publication #130 and additional copies of this manual can be obtained from:

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Introduction

Who is targeted by this manual?

The descriptions of nursery phases in this manual may be of interest to experienced culturists and novice farmers alike. Grow-out descriptions in this publication are designed to give prospective farmers all the necessary information to start a simple farm and to identify markets for their product.

Note: **Highlighted** words are described in the Glossary on page 90.

What are giant clams?

Giant clams have long represented a valuable resource to the people of the tropical Indo-Pacific in the form of a readily available and nutritious food source. However, in today's cash driven economies, giant clams have also come to represent a source of export income in many Pacific Island nations. Current uses for farm-produced giant clams include; stock enhancement, aquarium pets, biological specimens, food and shellcraft (see section Marketing and Economics on page 61).

Giant clams are **bivalve molluscs** of the family Tridacnidae with nine living species in two genera, *Tridacna* and *Hippopus*. They occur in association with coral reefs throughout the tropical Indo-Pacific region. While all species of giant clams have been cultured, six species remain the focus of most aquaculture activity today (Figures 2-7, page 5). The names and descriptions of the nine species follows:

1. *Tridacna gigas* is the true giant clam, growing to greater than 1.4 m in shell length. *T. gigas* is easily identified by its size and the triangular projections of the upper margins of the shell. The **mantle** is brown/green with blue or green dots (Figure 1, page 4 and Figure 2, page 5).
2. *Tridacna squamosa* (fluted or scaly giant clam) is easily identified by the large fluted scales on the shell. The mantle is generally mottled in blue, brown and green. Sizes reach up to 40 cm (Figure 3, page 5).
3. *Tridacna derasa* (smooth or southern giant clam) is the second largest species with a shell length of up to 60 cm. The shell is smooth, and the mantle has elongate brown, green and blue patterns (Figure 4, page 5).
4. *Tridacna maxima* (rugose or small giant clam) is the most wide-ranging giant clam species, being found from the east coast of Africa to the Red Sea and eastern Polynesia. It is recognizable by its brightly colored mantle (blue, green and brown) and boring habit (Figure 5, page 5).

5. *Hippopus hippopus* (horse's hoof or strawberry giant clam) has a heavy, thick shell composed of triangular **valves** with sharp, jagged teeth. The mantle is a dull yellow-brown and does not extend over the margin of the shell (Figure 6, page 5).
6. *Tridacna crocea* (crocus or boring giant clam) is similar to *T. maxima* in that it is a boring species and has a brightly colored mantle. This species is generally smaller and more triangularly ovate in shape than *T. maxima* (Figure 7, page 5).
7. *Tridacna tevoroa* (deep water devil clam) is a rare species that lives at depths of greater than 20 m in the northern Tonga Islands and eastern Fiji Islands.
8. *Tridacna rosewateri* is a newly described species that is very similar to *T. squamosa* and only occurs on the Saya de Malha Bank in the Indian Ocean.
9. *Hippopus porcellanus* (China clam) differs from *H. hippopus* by having a lighter, less ribbed shell although the mantle color is similar. The **incurrent siphon** of the China clam is lined with fringing **papillae**. *H. porcellanus* has a very limited range in the region of Indonesia, the Philippines and Palau.

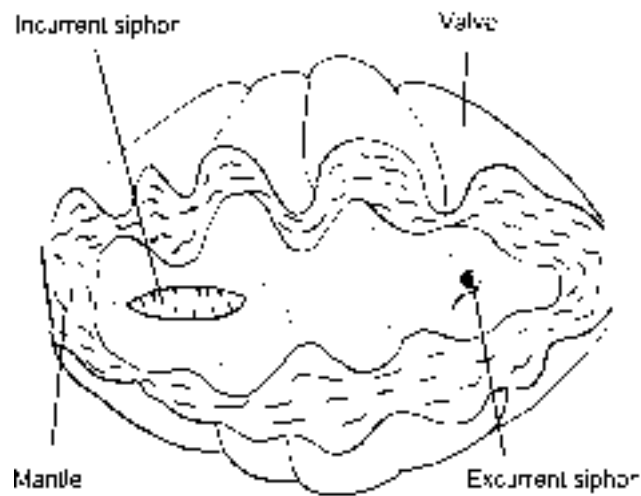


Figure 1. Schematic diagram of a giant clam

Note: Detailed descriptions with illustrations and photographs of giant clam species can be found in Lucas (1988), Braley (1992) and Knop (1996).

From a biological standpoint, giant clams are well suited for aquaculture. While they still filter food through their gills, they also derive a substantial portion of their nutrition from a **symbiotic** relationship with millions of **photosynthetic** algae called **zooxanthelle** (*Symbiodinium microadriaticum*) that live in their mantle. Zooxanthelle mainly produce complex sugars, but can also produce **amino acids** and **fatty acids**, a portion of which are released through the algal cell wall directly into the bloodstream of the clam. The direct benefit to clam farmers of this symbiotic relationship is that giant clams can be grown through their entire life cycle with clean seawater and sunlight as the only sources of input. Giant clams are also very **fecund**. The numbers of eggs spawned ranges from millions in small species such as *T. crocea* to hundreds of millions in larger species such as *T. gigas*.

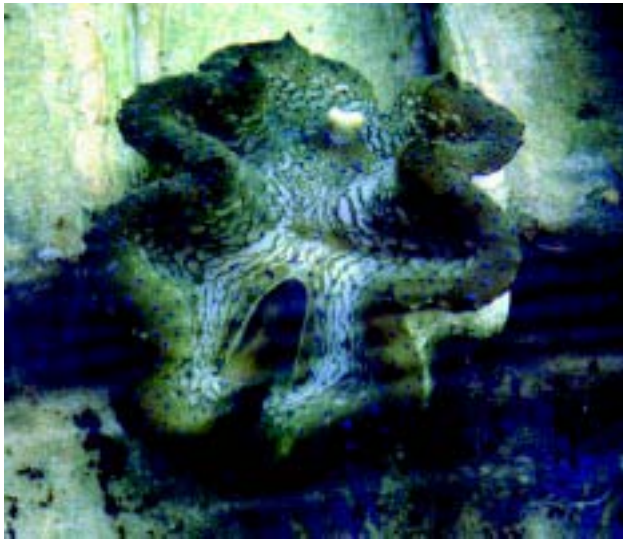


Figure 2. T. gigas (Simon Ellis)



Figure 3. T. squamosa (photo courtesy of CRRF, Palau).

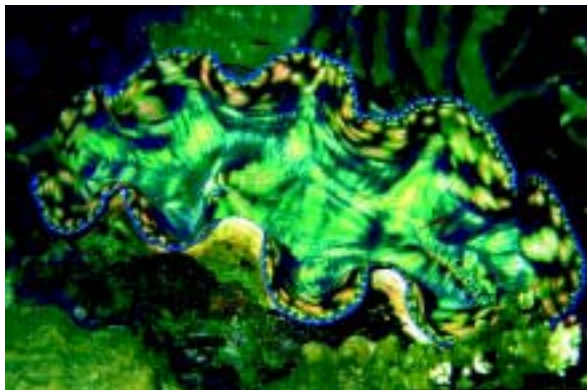


Figure 4. T. derasa (photo courtesy of CRRF, Palau).



Figure 5. T. maxima (photo courtesy of CRRF, Palau).



Figure 6. H. hippopus (photo courtesy of CRRF, Palau).

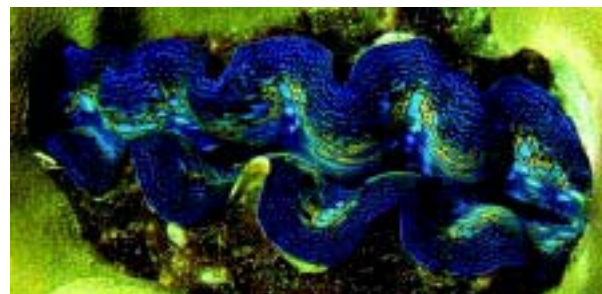


Figure 7. T. crocea (photo courtesy of CRRF, Palau).

Land-based nursery

This manual begins at the end of the **larval** phase of giant clams, which occurs at around 15 days of age. Regardless of the larval rearing method used, the juvenile clams will now be fully **metamorphosed** and settled on the tank floor. At this point, the rearing of giant clams becomes a two-dimensional issue and tank surface area becomes important. The land-based nursery phase is variable in length depending on the goals and operational protocol of the farm. Clams usually remain in the land-based nursery until they are at least 4 mm in length or for a period of 3-5 months. Some clam farms raise their animals entirely on land while others transfer their stock to the ocean at the earliest possible time. Advantages and disadvantages of land-based versus ocean-based nursery of giant clams are discussed in later sections of this manual.

Site selection

Land-based giant clam nurseries are almost always adjacent to the hatchery area and therefore the same site selection parameters apply to both. Parameters for proper site selection are as follows:

1. *Access to pollution-free seawater:* The nursery should not be situated close to point sources of pollution such as garbage dumps, sewage outfalls or dredging sites. Areas with excessive freshwater runoff should also be avoided.
2. *Proximity to a freshwater supply and electrical utilities:* While it is convenient to be located in an area with municipal utilities, many giant clam nurseries operate in remote locations by relying on rainwater catchment and using generators or alternative energy sources such as solar power to supply electricity.
3. *Proximity to main roads and airports:* While close proximity to sources of transport are preferred, this is not always possible.
4. *Land topography:* An area should be selected that is close to the seawater source but is high enough to avoid flooding during heavy rains or tropical storms.
5. *Security:* Both clams and equipment may go missing if security is not adequate at the hatchery site. Many nursery sites are fenced or have full-time security.

Environmental requirements

Giant clams require clear tropical seawater for optimum growth and survival. Water temperature should range from 25-30°C, salinity should range from 32-35 ppt and pH should range from 8.1 to 8.5. Sunlight is important for photosynthesis to occur, and only one species of giant clam, *T. tevoroa*, occurs at depths below 20 m. Giant

clams deprived of sunlight quickly die despite the presence of food in the water, indicating the importance of zooxanthelle to their survival. Mild siltation or **turbidity** can be tolerated by some giant clam species but clear, tropical, oceanic water is preferable. Giant clam nurseries should be equipped with a dissolved oxygen meter, a pH meter and a salinity refractometer* to monitor these water quality parameters.

* *Suppliers 1, 2, 3 and 4 in Appendix A.*

Nursery infrastructure

Seawater intake

One of the most critical parts of the nursery facility plumbing is the intake pipe. The need for access to clean, **pollution**-free seawater can result in the seawater intake being positioned in a awkward place (Figures 8 and 9). Pipes will be subjected to any wave action or currents in the area and must therefore be secured to the ground. How the pipe is attached will be determined by the level of wave action or



Figure 8. Seawater intake pipe at a giant clam hatchery in American Samoa (Simon Ellis).



Figure 9. Seawater intake pipe at the RRE clam farm in Majuro, RMI. Note the pipe has been coated with concrete to reduce damage from wave action on the reef flat (Eileen Ellis).

strength of current at the site. In some cases the intake pipe must be covered with concrete or secured with weights to eliminate any movement due to wave action. Schedule 40 PVC pipe, or the more flexible black HDPE (high density polyethylene) pipe, is generally used for the intake.

The intake pipe should be fitted with a **foot valve*** (also called a check-valve), which will assist with priming the pump in the event of a loss of suction. The foot valve need not be located at the end of the pipe but should be covered by seawater at low tide. An advantage to placing the foot valve at the end of the pipe is that it is easy to clean or replace if it becomes clogged or fouled.

** Suppliers 1, 2, 3 and 4 in Appendix A.*

A strainer should be placed at the end of the intake pipe. This is a box or piece of pipe that has a mesh screen over it to prevent small fish and debris from entering the pipe, and consequently, the foot valve and pump. Commercially available strainers can be purchased* or homemade versions can easily be constructed from available materials. The strainer's surface area should be large enough to allow for the required water flow to the tanks and should be inspected and cleaned regularly. The end of the intake pipe and strainer should be supported far enough off the bottom so that sand, mud and small rocks are not constantly being sucked into the pipe with the intake water.

** Supply sources 1 and 2 in Appendix A.*

Piping and plumbing

Schedule 40 PVC pipe and fittings are suitable for all aquaculture facilities. Assembly is easy, the pipe is nontoxic, and both the pipe and fittings are usually locally available*. If any other type of plastic pipe is used, it should be nontoxic and safe for marine life.

** Supply sources 1, 2, 3, 4 and 18 in Appendix A.*

Useful plumbing hints:

1. It is important to use the correct diameter pipe when plumbing any aquaculture facility. Using small diameter pipe increases head pressure caused by friction and increases pumping costs in the long-run. If there is any doubt about the correct pipe size, a larger diameter pipe should be used. The life span of schedule 40 PVC in the tropics is in excess of 10 years making the long-term investment in the facility minimal. The book, "The Aquaculture Desk Reference" (Creswell, 1992) can help pinpoint pipe and pump sizes for required flow rates.

2. A union should be placed on each side of every pump in use. In the event of a failure the broken pump can be easily replaced by unscrewing the unions and installing the new pump.
3. Use of elbows and bends in the pipe should be reduced wherever possible as this increases head pressure.
4. Ball valves should be placed at the junction of every tank or row of tanks. If there is a problem with the plumbing to one set of tanks, then the water flow can be turned off to that section of the facility without affecting the other areas.
5. Pipe on the suction side (between the pump and the ocean) of the pump should be regularly checked for leaks. Small holes cause air to be forced into the water under pressure – a process called super-saturation. When this occurs, tiny bubbles are visible in the water entering into the tank. Super-saturated water can be toxic to many species of fish and invertebrates and is the suspected cause of gas bubble disease in giant clams (see section Predators, Pests and Diseases on page 52).
6. Pure silicone caulk* should be applied to any threaded PVC fittings prior to threading, especially on the suction side of the pump.

* Supply sources 1 and 2 in Appendix A.

Each tank must be equipped with a drain and a standpipe that leads into a drain pipe or trough. A standpipe is a short piece of pipe that slots into the tank floor and determines the water level in the tank. Troughs can be made out of concrete and are often cheaper to construct than buying drainage pipe (Figure 10). In sandy areas, water is sometimes allowed to drain away into a hole in the ground (Figure 14, page 12). In muddy or easily corroded areas, concrete-lined troughs should be used.

Note: The point where water drains back into the ocean should not be near the end of the intake pipe as this may lead to recycling of dirty water through the tanks.



Figure 10. Drainage channel at the National Aquaculture Center, Kosrae, FSM (Eileen Ellis).

Pumps

Assuming a suitable coastal site adjacent to clean seawater has been found, pumping seawater should be relatively easy. The volume of seawater needed for a facility should be at least 3 times the total tank volume per day, though a target volume of 5 times the total facility tank volume per day is preferable. The type of pump selected will have some bearing on both peace of mind and facility operating costs. It is important to size the pump to the volume requirements of the facility. A pump that is too big for the facility's needs will waste electricity and a pump that is too small will not supply the water volume required. It is important to also consider site expansion when purchasing pumps as the facility volume may quickly outgrow the pump's capacity. Most catalogs publish "pump curves" that display volume of water output against head pressure, allowing selection of the most appropriate pump. Pump efficiency can also be increased in other ways. Three-phase pumps and pumps running on 220-240V tend to use less electricity than those using a single phase, 120V power supply.

Note: Head pressure is the pressure that a pump must work against that is a combination of the vertical height the water must be lifted and the friction caused by the water moving through the pipes.

Because water flow to the clams in the nursery facility is critical for good health and growth, having a reliable flow of seawater is essential. Clams held in a shaded area are able to withstand several hours without water exchange. In order to avoid long periods without water flow, an identical "backup" pump should be on hand to quickly replace the pump currently in use should it break down. A more reliable alternative is to operate two pumps in parallel. In a parallel system the intake line splits and water passes through two pumps placed side-by-side before rejoining a single pipe again. Each pump should be able to supply half the total volume so that if one pump breaks, the remaining working pump will continue to supply a diminished volume of seawater. A backup pump for parallel pump arrays is still recommended.

As mentioned previously, the type of pump required will depend on many factors such as volume of water needed and head pressure. Pumps must be able to operate continuously and withstand the corrosive effects of saltwater. Farmers must choose between submersible and non-submersible pumps. Submersible pumps are placed in the water at the end of the intake line and cost less to run than non-submersible pumps. However, submersible pumps for use in seawater must be stainless steel or titanium and tend to be more expensive. They can also be difficult to service or replace.

A popular pump in many aquaculture facilities is the centrifugal, self priming swimming pool pump*. These reasonably priced, non-submersible pumps are sized to accommodate many different head pressures and water volumes and are quite durable because the only part of the motor that comes in contact with the seawater is the corrosion-resistant impeller. The self-priming feature on these pumps also adds peace of mind as the pump will automatically start pumping water again after power outages.

**Supply sources 1, 2, 3, 4, and 5 in Appendix A.*

Tanks

Almost any tank that has a large surface area and is constructed of a nontoxic material is suitable for rearing giant clam juveniles. However, some tanks are better than others and the farmer must weigh factors such as cost, convenience and durability in deciding which tank to use. The following sections describe the different types of tanks used for nursery culture of giant clams and their relative advantages and disadvantages.

Fiberglass

Fiberglass* is one of the best materials to use for aquaculture tanks. This material is light, hard, smooth and durable with a life span of 15-20 years in the tropics (Figure 11, page 12). The overwhelming disadvantage to fiberglass is the cost. In almost all cases, except perhaps for small tanks, fiberglass is too expensive to use in rearing tanks for giant clams. Fiberglass tanks are rarely made on site but are usually ordered from a local or overseas source, making shipping expensive.

**Supply sources 1, 2 and 4 in Appendix A.*

Polyethylene

These tanks are similar to fiberglass but relatively new to the aquaculture scene. They are cheaper than fiberglass but have similar durability. They do not come in large sizes but are good for small nursery tanks. Because they are premoulded, they are bulky and often expensive to ship.

**Supply sources 1, 2 and 4 in Appendix A.*

Vinyl liners

Vinyl liners* are a remarkably versatile product to use in giant clam nurseries. They are cheap and easy to ship, which makes them ideal for use in remote areas of the tropical Indo-Pacific. Liners can be ordered to fit almost any size structure so tanks can be custom made depending on the site and materials available. Vinyl liners can be used in plywood, sheet metal, wire or log frames (Figures 12, 13 and 14, page 12). They must be laid on a smooth surface free of jagged objects such as glass,



Figure 11 (Left). Fiberglass grow-out tanks at the Lenger Island giant clam hatchery, Pohnpei State, FSM. The roof over the tanks is to protect the clams from the locally heavy rainfall. (Eileen Ellis).

Figure 12 (Right). Vinyl lined tank with coconut log sides at ICLARM-CAC, Solomon Islands (Simon Ellis).

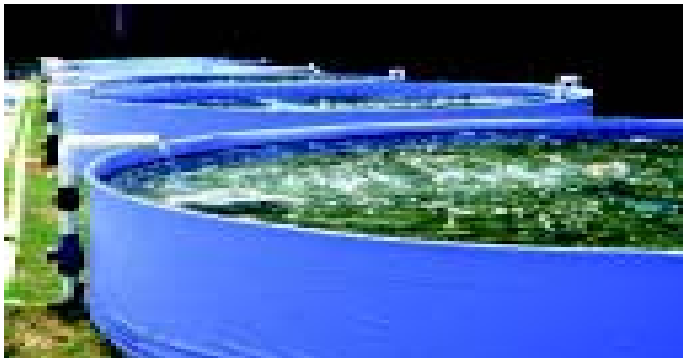


Figure 13 (Left). Vinyl lined pools at the Palu Mariculture Demonstration Center, Palau (Eileen Ellis).

Figure 14. Vinyl lined pools with plywood sides at the RRE Wau Mili Clam Farm, RMI. Note the holes in the ground for drainage. (Eileen Ellis).



shell or rock. The most common bed for tanks with vinyl liners is fine sand that has been sifted for sharp objects. While technology used in the manufacture of vinyl liners has improved markedly over recent years, their major disadvantage still lies in their life span. Liners are prone to sun damage and tears caused by the sharp edges of giant clam shells, resulting in a life span of only 3-5 years under normal use.

**Supply sources 1 and 2 in Appendix A.*

Concrete

By far the most convenient and inexpensive material for constructing giant clam nursery culture tanks is concrete. It is cheap and easy to obtain throughout the Indo-Pacific region and is not easily destroyed by salt or UV light. Depending on the quality of construction, concrete tanks can have a useful working life of 10-20 years. The major disadvantage to concrete tanks is that they are not portable. Once constructed they must remain in place until destroyed.

Tank construction for the most part is based on residential house building techniques and almost any qualified construction company should be able to produce high quality concrete aquaculture tanks for a farmer. The following construction guidelines should be followed with all concrete tanks to ensure a long, trouble-free life span.

1. All types of concrete tanks should be placed on a poured concrete foundation at least 10 cm thick.
2. Iron reinforcing bar (rebar) with a minimum 15 mm diameter should be set in the concrete foundation and throughout the tank to provide stability. This is particularly important in tanks with high walls.
3. A drain pipe made from an 8-10 cm PVC pipe coupling and pipe should be placed so that it is flush with the tank floor at the time of pouring. The floor should also be sloped so that water runs toward the drain and the tank drains completely. This makes for easy cleaning and waste removal.
4. Sand that is free of salt and rinsed with freshwater should be used in the concrete during tank construction. This will prevent the rebar from rusting and breaking through the concrete.
5. If possible, epoxy coated rebar should be used for construction. While it is expensive, this will also help to prevent rusting and tank deterioration.
6. Tank walls should be covered with at least one coat of smooth concrete plaster. This prevents depressions and holes in the concrete finish where algae and dirt can accumulate, thereby making cleaning difficult. Buildup of dirt in these areas can also harbor disease.

7. Square or rectangular tanks should have common or shared walls wherever possible, thereby saving money in construction.
8. Fresh concrete is toxic and should be painted to prevent the poisons from leaching into the water. A light color epoxy based paint that is guaranteed nontoxic* is recommended. As epoxy paints tend to be expensive, Heslinga et al. (1990) recommended using 2-3 thick coats of a latex-based house paint and allowing it to leach before stocking with clams. While some clam facilities do not use painted tanks, bare concrete should also be allowed to leach prior to stocking with clams.

* *Supply sources 1 and 2 in Appendix A.*

Note: Leaching is the process of removing toxins from paints or concrete. To do this the tank is filled with seawater which is exchanged at least once daily for a period of 2-3 weeks. After this time, all water-soluble poisons should be dissolved out of the paint or concrete surface.

Types of concrete tank construction

There are three main types of concrete tank construction; ferrocement, poured cement and concrete block. All employ the use of concrete in conjunction with reinforcing wire or rebar.

Ferrocement tanks: Ferrocement tanks are possibly the easiest tanks to construct and are also the most likely to deteriorate quickly because of the amount of metal in the frame. A frame of rebar and reinforcing wire (such as chicken wire) is first made in the desired shape of the tank. This frame is then coated with concrete so that all the spaces are filled and the wire and rebar are completely covered.

Poured concrete: Poured concrete tanks are constructed using a form made of plywood that is built in the desired shape of the tank. The form is reinforced with rebar and then filled with concrete in one single pour. Poured concrete tanks are generally the most sturdy but also the most expensive type of concrete tank.

Concrete block: Concrete block tanks are the most convenient and cost-effective type of concrete tank. Blocks are cheap, readily available and tanks of all shapes, (including round) can be easily constructed. Blocks are arranged in the desired configuration and cemented together in the same manner as residential construction. Rebar is inserted into the spaces in the middle of the blocks, which are then filled with concrete to provide extra stability. The filled blocks are plastered to provide a smooth finish.



Figure 15 (Left). Round concrete pools at the ICLARM-CAC, Solomon Islands. (Simon Ellis).

Figure 16 (Right). Concrete block raceway at RRE Clam Farm in Majuro, RMI. Note the overhead shade cloth and epoxy coated walls. (Simon Ellis).



Figure 17 (Left). Concrete block raceways at the Palu Mariculture Demonstration Center, Palau. Note the low height and shared center walls (Eileen Ellis).

Figure 18. Concrete tanks with shade covers at the RRE Wau Mili Clam Farm, RMI (Eileen Ellis).



The following is a description, taken from the publication *Clamlines*, of the construction process for a 10 m² round concrete block tank (Figure 15, page 15) constructed at the ICLARM Coastal Aquaculture Center, Guadalcanal, Solomon Islands. These tanks use 75 standard concrete blocks and cost approximately US\$300 to construct.

1. The foundation of the tank is first raised to ensure positive drainage to a concrete drainage channel. This also allows for a net or screen to be put in place to sieve the effluent water.
2. The tank area is marked using the bottom course of blocks. A slope to the center drain is formed and an 80 mm drainpipe is put in place with an elbow protruding some 4 cm above the soil surface. Sixty centimeter lengths of 19 mm rebar are then hammered 20 cm into the ground in every alternate hole in the blocks.
3. The blocks are then removed and the concrete foundation of the tank poured to a depth of 10 cm, using a 3:1 sand:cement mix, and allowed to dry.
4. The 3 courses of blocks are cemented in place over the rebar.
5. The block holes are filled with a 4:2:1 sand:gravel:cement mixture and then coated with a 3:1 sand:cement mix.
6. A final layer of 2:1 sand:cement mix is plastered onto the base and sides of the tank.

Tank Shape

Tanks can be formed in almost any shape but some configurations are better than others. The following guidelines should be followed when designing tanks for giant clam nursery and grow-out:

1. *Surface area to volume ratio:* The most important aspect of the tank is the bottom surface area as this is what determines clam stocking density. Tanks that are shallow with a large bottom surface area are therefore preferred over tall tanks with a small bottom surface area.
2. *Self cleaning and water circulation:* Tanks should be designed to have a self-cleaning action where the pattern of water flow moves waste toward the drain. In addition, they should be designed to minimize “dead spaces,” which are areas of the tank where water does not easily flow. Dead spaces occur in the corners of square or rectangular tanks and along the bottom of all tanks unless corrective measures are used. Round tanks with a center drain and raceways (long narrow tanks) provide the best self-cleaning and circulation of all tank configurations.

Note: Self cleaning action of any tank can be improved by placing a large pipe over the drain pipe in the tank (sometimes called a venturi pipe). The larger pipe should be higher than the drain pipe and have one or two small notches cut in the bottom to allow water flow. Water leaving the tank is forced through the notches on the bottom of the pipe thereby drawing up waste materials from the tank floor.

3. *Conservation of materials:* Tanks should be constructed with the minimum of materials in order to keep construction costs down. Money saving methods include using low tank walls (60-90 cm), and shared center walls by building raceways in sets of two or three (Figures 16, 17 and 18, page 15).

Based on these criteria the most common tanks in use in giant clam facilities today are shallow raceways. These tanks are easy to construct, conservative on materials, have a self cleaning action and a high surface area to volume ratio.

Aeration

Aeration, while not essential to the success of a land-based nursery and grow-out facility, can provide a number of benefits to the farming operations. Aeration in giant clam facilities is provided more to improve water circulation in the tank than for bringing oxygen to the clams. Growth of giant clams in land-based culture is limited by the amount of nutrients available. Aeration assists growth by bringing fresh nutrients to the clams and eliminating dead spaces in the tank. Air is generally delivered to the tank through 15-30 mm PVC pipe with small holes drilled at intervals along its submerged length (Figure 17, page 15). For raceways, a single air line running down the center of the tank is adequate, while in round tanks, a square arrangement of pipe placed in the center area of the tank is often used.

Another benefit provided by an aeration system is that it can act as a backup in case of pump failure. Giant clams can live for long periods of time without fresh seawater providing the water is circulated and aerated.

Note: Heslinga et al. (1990) noted that aeration helped to keep juvenile *T. derasa* more evenly distributed in raceways, thereby helping to reduce stunting and improve growth and survival.

Because the tanks used for nursery and grow-out of giant clams are usually quite shallow, the best type of aerator to use is a regenerative blower*. These machines produce high volumes of air under low pressure. Because they have only one moving part, they are highly reliable and will last for many years. The bearings are the

only part that wears out on regenerative blowers. If a spare set is kept on hand at the farm they can easily be replaced by a local car mechanic. Because regenerative blowers produce air in high volumes, it is best to use 3.8 or 5 cm PVC pipe to deliver the air to the rearing tank.

** Supply sources 1, 2, 3 and 4 in Appendix A.*

Shade

Many facilities cover their tanks with 50% light-occluding shade cloth*. This helps to reduce algal fouling, especially during the early stages of development, and prevents overheating of the water in tanks with low water exchange. Photosynthetic capability of juvenile clams up to 2 months of age is unaffected by 50% shade cloth. After this time, shade cloth can be removed to increase growth rate. Because removing the shade cloth will increase algal fouling, the farmer must make a choice between the benefits of increased growth rate versus increased tank fouling and the subsequent cleaning and handling of the clams.

** Supply sources 1, 2 and 21 in Appendix A.*

One convenient method of using shade cloth is to cover the entire farm area with an overhead array (Figure 16, page 15). A system such as this protects the clams, tanks and workers from the sun, thereby increasing tank life span and creating a more pleasant working environment. Cheaper methods of using shade cloth include attaching it to an easily removable frame that fits over the tank (Figure 11, page 12 and Figure 18, page 15). This can then be removed when working in the tank.

Water filtration

Filtration of incoming water is necessary to remove excess debris and most importantly, the eggs and larvae of predatory snails and fish (see section Predators, Pests and Diseases on page 52). Polyester filter bags* (Figure 19) are the most widely used form of filtration. These bags, which are placed over the influent pipe, are cheap and durable with a life span of up to 6 months. Depending on water flow rate and the particulate load of the incoming



Figure 19. Polyester filter bag at giant clam hatchery in American Samoa (Simon Ellis).

seawater, bags have to be cleaned only once or twice daily by spraying them with clean water using a hose or pressure sprayer. Bags can be purchased with filtration capabilities of 1, 5, 10, 25, 50 and 100 μm .

* *Supply sources 1 and 2 in Appendix A.*

Husbandry

The time the clams spend in the land-based system depends on the operating protocol of the farm. The clams should be at least 4 mm in length before they are moved from the land-based nursery to an ocean-based system (Calumpong, 1992). The following procedures should be used to maximize growth and minimize mortality during the land-based nursery phase.

Tank maintenance

Most of the manual work in the land-based nursery revolves around the control of **biofouling**, in particular filamentous algae. During the first two months of culture, the clams are very sensitive to handling so cleaning of the tank is not recommended. During this time, the algal community on the tank floor and walls generally undergoes a succession from diatoms through to filamentous algae. It is this filamentous algae that can smother the clams and also compete for nutrients in the water, causing slow growth and excess mortality. The type of succession and the speed of colonization of filamentous algae varies greatly from tank to tank depending on environmental conditions. Excessive growth of algae is controlled in the early stages by using 50% shade cloth and maintaining the water flow at no more than 2 exchanges of the tank per day. A 10 μm filter bag is also used for the first 60-90 days of nursery culture to minimize debris in the tank and to prevent contamination by predatory snails.

After 2 months, the clams should now be visible to the naked eye and are quite strong. At this point, they will be attached to the substrate via the **byssus** and no attempt should be made to detach them until harvest. Every time a clam is dislodged from the substrate it ceases growing until it has reattached. A farm manager has to constantly balance the benefits of cleaning against its detrimental effect on growth whenever the clams are disturbed. Water flow can be increased to 2.5 (or greater) exchanges of the tank volume per day and the 10 μm filter bags can now be replaced with 25 μm bags. Algal control at this point is carried out by “fanning” it off the bottom to prevent dislodging the clams. Workers may need to put on a mask and snorkel and get into the tank to do this, making sure not to stand on the tank



Figure 20. Worker using the fanning method to remove algal fouling. (Simon Ellis).

bottom. Starting at one end or area of the tank the worker uses a paddle, broom or his/her hand to gently fan the bottom of the tank (Figure 20). Contact is not made with the tank floor but the fanning action creates a current that loosens the attached algae. The loosened algae is concentrated near the drain and then either allowed to pass out of the drain by gently removing the stand pipe or by siphoning it out of the tank. This cleaning process should be repeated every 10-14 days.

Algae can be collected on a 200-300 mm screen and any clams that came loose during cleaning can be reclaimed. The screen should be set up in a tub of seawater so that the clams are submerged on the screen during drainage or siphoning. To retrieve the clams, the algae containing the clams is rinsed into a high-sided bucket or tub and the clumps of algae are broken up using the fingers. A flow of clean seawater into the bucket washes away the algae while the heavier clams sink to the bottom. Similarly, a low-sided tub can be used and the water containing the lighter algal fragments can be decanted off and the tub refilled with clean seawater. This process is repeated until the water is clear.

After 2 months, biological algal control can be implemented. This is where **herbivorous gastropods** such as *Trochus niloticus* or fish such as surgeon fish (*Acanthurus spp.*) or rabbitfish (*Siganus spp.*) are placed in the tanks to graze on the algae. It is important to use small specimens when the clams are young. When they are first added to the tank of two-month-old clams, the fish should be only 3-5 cm long and *Trochus* only 1-2 cm in shell width. The feces from grazers will build up in the tank and must be removed during periodic cleaning.

“Feeding” using dissolved inorganic nitrogen (DIN)

The use of ammonium-based nitrogen compounds has been shown to significantly increase clam growth and improve conditions in land-based nursery and grow-out facilities (Heslinga et al., 1990; Belda et al., 1993; Fitt et al., 1993; Knop, 1996). However, recent results from ICLARM (Grice and Bell, 1998) indicate that an over-supply of DIN may actually have a negative effect on growth.

DIN should not be used until the clams are 5 mm in length. After this, a twice weekly addition of 50 mM ammonium nitrate (2 g per 1000 L of tank volume) should be added at the beginning of the day (Grice and Bell, 1997). This amount of fertilizer, in comparison to higher concentrations, has been demonstrated to significantly lower algal proliferation while still increasing clam growth.

Harvest

When the level of crowding or algal encroachment becomes too high, it is time to harvest the tank and redistribute the clams either to the ocean nursery or for further grow-out in land-based tanks. If the tank has been regularly cleaned of algae, the first harvest will usually not have to occur until 5-6 months after stocking. However, some facilities conduct the first harvest after 2-3 months. Harvesting should only be done this early to alleviate crowding or algal fouling. Juvenile clams are still quite fragile at 2-3 months and some mortality is likely to occur.



Figure 21. Technician harvesting giant clam juveniles (Simon Ellis).

A worker enters the tank equipped with a mask and snorkel (Figure 21) and harvests the clams using a sharp blade such as a filleting knife or paint scraper. Clams are dislodged from the bottom by pushing the blade along the surface at a low angle to cut their byssal threads. Clams can be siphoned out of the tank onto a screen submerged in a large bowl. Alternatively, they can be piled up on the bottom of the tank and periodically transferred by hand into a bowl or tub sitting on the bottom of the tank.

When using the siphon method, the scraper and siphon are employed simultaneously so that clams are sucked up by the siphon flow as soon as they are freed from the tank floor. They are then retained on an appropriate-sized screen that is submerged in a tub of seawater outside the tank. With both methods of harvest, any excess algal debris should be decanted off the heavier clams using the same method described on page 20. At the end of the harvest the clams should be stored in a bucket or tub with a light flow of clean seawater.

Counting the clams

It is important to use a quick but accurate method to count the harvested clams so that suitable numbers can be moved to the next rearing phase. Rather than counting each individual clam, a volumetric method is used to estimate clam numbers.

The procedure for volumetric estimation is as follows:

1. Select a container that will hold 100-200 juvenile clams. The container will depend on the size of the clams. For small clams this may be a glass vial and for larger clams a 100 ml beaker. The volume of the container is not important.
2. Fill the container with clam seed by scooping them randomly into the container until it is full to the top. The container should be filled underwater and care taken not to treat the clams roughly.
3. Count the number of seed in the container and record the number.
4. Repeat steps 2 and 3 at least four more times.
5. Calculate the average number of clams per full container.
6. Scoop the remaining clams into the container and transfer them to another bucket filled with seawater until all the clams have been moved. Keep count of the number of full containers being transferred.
7. Total number of clams is the average number of clams per container multiplied by the number of containers transferred.

Sample calculation:

1. The counts of clams in a 100 ml beaker were 123, 115, 132, 104 and 121.
2. Average number per beaker is $123 + 115 + 132 + 104 + 121 / 5 = 119$
3. The total number of full beakers of clams in the bucket was 42.
4. Total number of clams in the bucket is $42 \times 119 = 4998$

Recordkeeping and protocol

It is inevitable that technical and disease related problems will occur in any aquaculture grow-out system. For this reason it is important that each farm develop a rearing protocol that is strictly adhered to by all technical staff. As advances are made in rearing methods, the rearing protocol can then be changed accordingly and passed on to new staff. A daily log of rearing activities with written comments by the technicians is also essential. Many problems associated with culture methods or disease onset can often be easily traced to one particular activity or event that was recorded in the daily hatchery log.

Growth rates and survival are key indicators to the success of giant clam rearing strategies. Therefore, it is important that every time clams are moved to a new rearing area they should not only be counted but also measured to ensure adequate growth. Measurements are usually taken from a random sample of 100 individuals using plastic calipers*

** Supply source 1, 2 and 24 in Appendix A.**

Grow-out of clams after first harvest

After the initial harvest, a farmer must decide whether to continue growing the clams in a land-based system or to transfer them to an ocean nursery. Clams can be transferred to an ocean nursery at a size of 4 mm or greater. While there is substantial evidence to show that giant clams generally survive and grow better in ocean nurseries (Munro et al., 1993; Saquata, 1994; Foyle and Courtois de Vicose, 1995), some farmers may still prefer to grow their clams in land-based systems.

While ocean-based farms have obvious advantages, the economics of having both a land-based and ocean-based facility must be carefully considered. Ocean culture requires a range of field equipment, staff and an appropriate ocean site – which may not be located near the land-based facility. Therefore, for some markets where smaller animals are required (such as the aquarium trade) it may sometimes be more economical or convenient to grow clams onshore (Lucas, 1995).

Land-based grow-out of giant clams

Culture parameters such as tank type, water flow and filtration, level of shade, aeration and nutrient addition are kept essentially the same for land-based grow-out as during the latter stages of the land-based nursery phase.

Stocking density

Stocking density is extremely important for maximizing the resources of a land-based farm. If stocking density is too high, then the clams will quickly become crowded, resulting in decreased growth and survival rates. If the stocking density is too low, then valuable tank space and water will be wasted. To better manage tank stocking densities and to improve the ease of handling and cleaning of the clams, it is recommended to use nursery trays or some other form of container for holding the clams in the tanks. Nursery trays are widely used in the horticulture industry for holding seedlings. They come in many sizes and are generally made of black, UV-resistant polyethylene. Standard trays are 45 x 45 cm or 50 x 25 cm with sides 3-5 cm high*. Alternatives to nursery trays include any shallow plastic trays that can be used to hold clams. Commonly used are plastic mesh baskets or tubs (Figure 22, page 25) that are widely available in many countries for household purposes.

* Supply sources 21 and 22 in Appendix A.*

Nursery trays can be half-filled with gravel or a thin (1 cm) layer of concrete. This helps to weigh down the trays and provides an attachment substrate for the clams. Trays filled with gravel are convenient as the gravel can be discarded after one use. However, some farmers feel that the nooks and crannies created by the rocks in the tray can provide habitat for predatory snails, especially *Pyramedellids*. While concrete provides a smooth surface that is not conducive for these snails, clams tend to clump in the corners of the tray (Figure 23, page 25). To alleviate this, parallel or crisscross grooves are made in the concrete at the time of pouring, which allow the clams to settle and attach in a more uniform manner (Figure 24, page 25).

Note: Newly poured concrete trays should be left to leach in saltwater for 2-3 weeks prior to use.

The following are general guidelines for stocking giant clams in tanks:

Clams <1cm SL stock 2000/m²

Clams 1-2 cm SL stock 1000/m²

Clams 2-3 cm SL stock 500/m²

Clams >3 cm SL stock so that half the tray surface area is exposed



Figure 22 (Left). Giant clams being reared in locally purchased mesh baskets at the Lenger Island giant clam hatchery, Pohnpei, FSM. (Simon Ellis).

Figure 23 (Below). Juvenile clams clumped in the corners and along the grooves in the concrete base of a nursery tray at the RRE clam farm, Majuro, RMI. (Matt Harris).

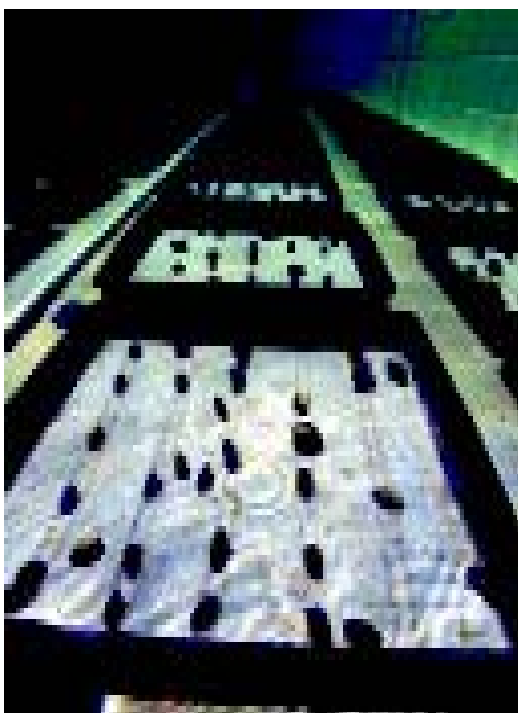


Figure 24 (Left). Recently cleaned clams quickly find and attach to the grooves in the concrete base of the nursery tray. RRE clam farm, Majuro, RMI.(Matt Harris).

As these stocking densities are only guidelines, it is important to observe the general rule of thumb that trays should be stocked so there is minimal contact between the clams and they have room to at least double in size before the next transplant. Giant clams cease growing for a 10-14 day period every time their byssal threads are severed for cleaning or transplanting. If clams are moved too often, this will lead to frequent stoppages in growth. Through the prudent use of stocking densities, biological fouling control agents such as *Trochus* and herbivorous fish, and sufficient water flow, clams should only have to be transplanted or “thinned” every 4-6 months.

Note: Clumping of clams together is generally a problem in all methods of grow-out. Management of this problem by cutting the byssal threads and redistributing the clams should not occur before scheduled transplanting unless the animals are so badly clustered that they are smothering each other (Figure 23, page 25). This can happen with younger clams where clumping can lead to stunting and shell deformities.

General husbandry

General husbandry practices during the land-based grow-out phase for giant clams are relatively simple. The following is a list of periodic chores that should be completed:

1. Water and aeration flow rates should be checked and adjusted daily. Water exchange should be kept at a minimum of 2 times the tank volume per day. Aeration levels should be heavy enough to keep the water circulating in the tank.
2. Filter bags should be cleaned as necessary. Filter bags quickly become clogged with debris and can overflow into the tank, thereby defeating the purpose of using the bag in the first place. Bags should be monitored regularly for signs of becoming clogged and replaced with a cleaned, dry bag when needed. Dirty bags should be turned inside out, cleaned with a jet of freshwater and left to dry before being used again. Bags can also be occasionally soaked in a dilute bleach solution but care must be taken not to destroy the fabric. At every cleaning, bags should also be inspected for holes and replaced when necessary. The life span of well treated polyester filter bags is about 6 months.
3. DIN should be added to tanks at a rate of 2 g per 1000 L each morning. DIN is added by dissolving the fertilizer in 1-2 L of filtered seawater and pouring it into the aeration stream of the tank.

4. Level of biofouling should be monitored to ensure that algal growth is not becoming too prolific. If excess algal growth is occurring, then more grazers (fish or *Trochus*) should be added to the tank.
5. Grazers, especially *Trochus*, produce large amounts of feces that build up in the tanks and should be periodically removed. One method of removal is to quickly drain the tank and wash the waste into the drain using a saltwater hose (Figure 25). Giant clams of >1 cm in size can withstand moderate air exposure. Another method is to lower the water level in the tank and stir up the waste using a high pressure jet of seawater. The suspended waste can then be washed down the drain by increasing the water flow rate to the tank.

Note: Clams do not respond well to being constantly disturbed. While studies have shown that survival is directly linked to cleanliness, excess handling depresses growth. Good clam husbandry, therefore, is a balance between maintaining relatively high levels of cleanliness while disturbing the clams as little as possible.



Figure 25. Technician cleaning debris from a tank of juvenile *T. derasa* with a saltwater hose at a giant clam hatchery in American Samoa. (Simon Ellis).

6. Tank cleanliness is an important issue when transferring clams. Tanks that have contained clams should be thoroughly scrubbed to remove any filamentous algae on the floor and walls. They should then be sterilized before restocking. The best way to do this is to hose the tank down with freshwater after scrubbing, then allow it to dry in the sun for at least two days. If a faster turnaround time is required, the tank can be scrubbed with a dilute bleach solution, hosed down with freshwater, then allowed to dry before being restocked. Care must be taken to ensure all bleach residue is gone by allowing the tank to dry for at least 2-3 hours.
7. Monitor the clams for clumping or crowding and thin them out as necessary.

Ocean-based grow-out of giant clams

Much of the tropical Indo-Pacific, especially the Pacific Islands, are characterized by clean, sheltered inshore waters that are ideal for growing giant clams. With this in mind, it seems practical to transfer the grow-out of giant clams to the ocean as soon as possible. After an initial investment in cages and perhaps a boat and diving gear, ocean-based giant clam farming is relatively less labor- and cost-intensive than land-based culture.

Aside from the long-term cost savings, the major advantage to ocean farming of giant clams is that they grow much faster than clams grown in land-based tanks. As an example, a study comparing growth of *T. gigas* in ocean and land-based nursery systems found growth rates in the ocean to be over three times that of the land-based tanks (Munro, 1985).

Until clams reach a size of about 20 cm, they must be kept in cages to protect them from large predators such as trigger fish, puffer fish and octopus. Cages come in many configurations and are selected based on the size of the clams and the topography of the site. A farmer must also decide whether to use floating or **benthic** cages.

Floating versus benthic cages

Many farms use floating cages, especially in the early stages of ocean-based grow-out. Clams kept in floating cages tend to grow faster and suffer less snail and fish predation than clams grown in benthic cages. Dalton et al. (1995) found floating cages generally easier to work on because the clams are suspended only 0.5 to 1 m below the surface. Settlement of predatory snails in floating cages was also found to be lower, as was the incidence of fish predation.

Floating cages have some disadvantages, the first being that they may require a larger initial capital investment than benthic cages. The main disadvantage to floating cages is their close proximity to the surface. Wave action or strong tidal currents may cause disruption of growth, and even mortality, in clams kept in floating cages. In addition, floating cages are more susceptible to damage by wave action during storms. Correct site selection and cage design is therefore essential when using floating cages.

Site selection

Site selection is paramount to the success of an ocean-based clam farm. Site selection for benthic cages is similar to that for floating cages except that the selection process takes on a more three dimensional aspect with depth and substrate becoming important factors. Factors to be considered in site selection are as follows.

Temperature

Giant clams grow best in water temperatures of 25-30 C, although they are able to withstand short periods of higher temperature exposure. Prolonged exposure to high temperatures will at the very least cause stress and inhibit growth. Other more serious effects include bleaching of the mantle and even death (see section Predators, Pests and Disease on page 52). Areas that are shallow enough to experience constantly elevated temperatures during low tide should be avoided when selecting both floating and benthic cage sites.

Note: Some giant clam species can withstand large amounts of air exposure and farms are sometimes intentionally located in the **intertidal** zone (see section Intertidal Giant Clam Farming on page 47).

Salinity

Giant clams do not respond well to prolonged exposure to salinities of less than 32 ppt. Constant exposure to low salinities will cause stress and inhibit growth with possible mantle bleaching and mortality. Areas close to river mouths and other areas of freshwater runoff should be avoided when siting benthic and floating cage farms. Areas that receive extremely heavy rainfall can often have a freshwater/saltwater interface close to shore that is several centimeters thick. Salinity profiles (measurements of salinity at different depths) taken after periods of prolonged rainfall will help a farmer to assess the suitability of an inshore site. This is particularly important when siting floating cages where clams are generally kept only 0.5-1 m below the surface. Salinity can be effectively and easily measured using a simple device called a refractometer*.

* *Supply sources 1, 2, 3 and 4 in Appendix A.*

Exposure

Exposure refers to the amount of wave action cages will experience during storms or windy periods. If possible, sites should be chosen that are protected from prevailing winds, especially when using floating cages. Coves, bays or areas close to lagoon islands are generally good sites. While sites with low exposure are preferred, water movement across the cages must be adequate. Stagnant, poorly flushed bays and inlets are not suitable.

Water movement

Water movement refers to tidal or wind-generated flow over the intended farm site. Studies have shown that clam growth increases with increasing water flow rates. Therefore, areas with stagnant or slow-moving water (poor flushing) should be avoided for farm sites. Water in areas with poor flushing rates will generally have less nutrients, may be turbid or cloudy, and can be prone to rapid fluctuations in salinity and temperature.

Turbidity

Turbidity refers to the cloudiness of the water. Cloudy or turbid water blocks sunlight to the clams. Because giant clams rely on sunlight to provide much of their nutrition through photosynthesis, excessively cloudy water should be avoided. Turbid water is often found in inshore or poorly flushed areas. Runoff from land clearing, quarrying, mining, agriculture or logging are leading contributors to turbidity. Turbidity is not as important in siting floating cages as it is for benthic cages because clams in floating cages are closer to the surface.

Pollution

Pollution can come from many sources, some of which are not immediately obvious. While turbidity of the water is often an indicator of pollution, many pollutants are invisible to the naked eye. One of the most common forms of pollution is organic matter in the form of human or animal waste and agricultural runoff. While pollution of this sort is rarely directly harmful to giant clams, it promotes growth of both macro and microalgae. Macroalgae settles on cages and quickly inhibits sunlight and water flow to the clams. Microalgae contributes to water turbidity which in turn

reduces sunlight to the clams. Clams contaminated with animal and human waste also cannot be eaten locally or exported as food (see section Marketing and Economics on page 61). For these reasons, farms should not be sited close to large areas of human habitation, sewage outfalls or large terrestrial farms.

Other sources of more acute pollution include pesticides from agricultural runoff, oil and gas from boat exhausts and leaching from anti-fouling paints. For this reason farms should not be sited close to harbors or mooring areas.

Substrate and biota

Sandy or coral rubble areas with isolated coral heads are preferable for both floating and benthic cage sites. While floating cages do not rest on the bottom, this type of substrate indicates an area of relatively low physical disturbance but with enough water movement to prevent siltation and turbidity.

Biota refers to the animals that are found around the prospective farm site. Heslinga et al. (1990) provide a list of species that might indicate the suitability of a farm site for growing clams. Listed as positive indicators are other giant clam species, stony corals such as *Acropora* and *Porites*, and seagrasses. Listed as negative indicators are mangrove trees and high densities of soft corals and sponges.

Seagrass beds are suitable for benthic farms only if the substrate is firm and sandy and the turbidity is low. Many seagrass beds are in a silty or muddy area which would make them unsuitable for clam culture (Calumpong, 1992).

Security

In many areas of the tropical Indo-Pacific, site security can be a problem. Aside from the clams themselves, ocean farms may have items that are of some value such as wire, floats, PVC pipe or rebar. From a security standpoint, the ideal place to site a farm is within sight of the farmer's house. This allows the farmer to constantly watch the farm for poachers or other problems. An alternative would be to site the farm close to the house of a friend or relative who can watch the farm.

A different but related issue is the distance the farmer must travel to the farm. A site just off the farmer's house can be serviced using a locally made canoe or raft, whereas a distant site may require a powerboat. Farmers will be more likely to visit the farm more frequently if it is cheap and convenient to do so. This factor is considered one of the most important influencing factors in whether or not a farm can be profitable (Heslinga, 1993).

Depth

Depth is very important in selecting both floating and benthic farm sites. Floating cages are best situated in 3-4 m of water primarily because this depth is usually far enough away from the shore to avoid rapid fluctuations in temperature and salinity. In addition, this depth is generally enough to deter predatory fish or octopus from venturing to the surface looking for clams.

The depth at which to situate a benthic farm is much more objective and must take into account many of the factors discussed above. Farms are generally placed in 1-5 m of water. A farm placed in shallow water (1-2 m) has the same advantages of a floating cage in that it is easy to work on. However, shallow cages are more likely to be affected by rough weather and by fluctuating salinity and temperature. Farms placed deeper (3-5 m) are more protected from the elements but then become harder to work on and maintain.

While most sites can be adequately operated and maintained with the use of only a mask, fins and snorkel, larger farms and/or farms located at depths of 3 m or more may be more effectively serviced using some form of underwater breathing equipment such as **SCUBA** or **hookah***. This equipment allows the farmer to work uninterrupted for long periods without constantly having to surface for air. The use of diving equipment should be carefully considered by each individual farmer. Small farms of 20-30 cages in depths of less than 3 m can easily be operated without the use of diving equipment. Larger farms or farms at deeper depths may be run more effectively with the use of diving equipment.

Supply sources 8 and 9 in Appendix A.

While there are obvious benefits to using SCUBA or Hookah, the following factors should be considered before making the decision to use diving equipment:

1. Buying diving equipment and undergoing the necessary training to use it represents a relatively large capital outlay. Equipment must also be regularly serviced and inspected to ensure safe operation.
2. Diving is a potentially dangerous activity which can be exacerbated by lack of training and poorly maintained equipment.
3. SCUBA equipment may only be appropriate for farms that have their own air compressor to fill tanks or that are located close to a dive outfit that can fill tanks. Hookah rigs are motor-operated breathing devices that require gasoline or diesel. Remote farm areas such as outer islands and atolls may not be appropriate places to keep and maintain diving gear without proper support.

The optimum farm site

Cages are best located in 2-4 m of water over a sandy or gravel bottom with isolated coral heads for anchoring floating cages. Sites should be protected from rough weather and prevailing winds and be in sight of the farmer's house. The site should be away from any sources of pollution or rivers and have a high flow of clear oceanic water. The back side of reef barrier islands or the lee side of coral atolls often make good clam farm sites.

Floating cages

Design and construction

Floating cages have three main design components; flotation, grow-out platform and anchorage. Two different cage designs will be described in this manual to illustrate different design options.

Flotation

The catamaran style cage (Figures 26 and 27, page 34), first described by Munro (1985) uses 15 cm PVC pipe capped at both ends for flotation. These floats are then lashed together using crossbeams made of wood or smaller diameter PVC. Alternatively, a series of smaller floats (Figure 28, 29, 30 and 31, pages 34 and 35) or locally available materials such as buoyant woods or bamboo can be used to provide buoyancy.

The central float style cage (Figures 32 and 33, page 36) was introduced at the ICLARM-CAC in the Solomon Islands in 1993 and consists of a platform suspended from a central flotation device such as one large or several smaller floats. This design can be used in a longline system where several floating cages are suspended on one line or in independent units.

Note: There is often an abundance of fishing floats from tuna longline vessels that wash up on the shores around the Indo-Pacific region. These floats are a free resource that can be used in the construction of floating cages for clam grow-out.

Figure 26 (Right). Older version of the catamaran floating ocean cage. (Taken from Munro et al., 1993).

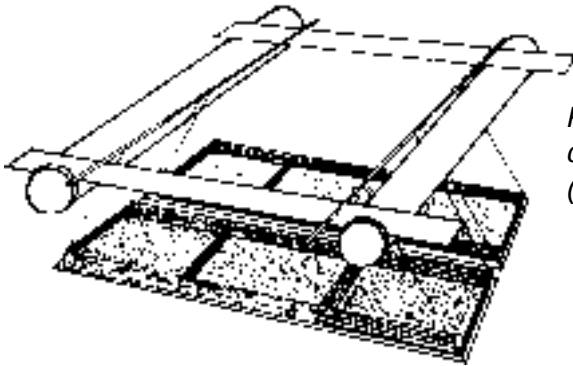
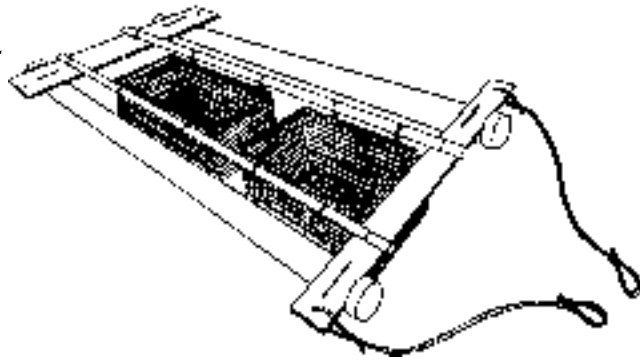


Figure 27 (Left). More recent version of the catamaran style floating cage. (Taken from Munro et al., 1993)

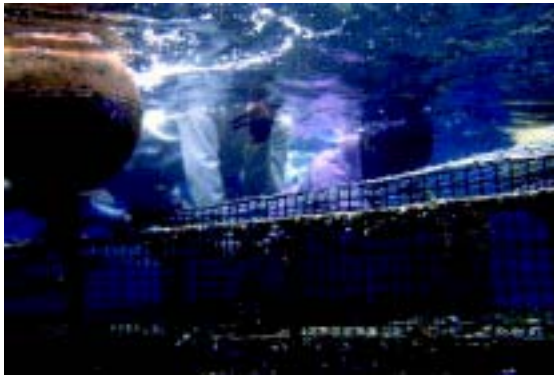


Figure 28 (Left). Floating cage showing farm workers conveniently cleaning the clams using snorkel gear.

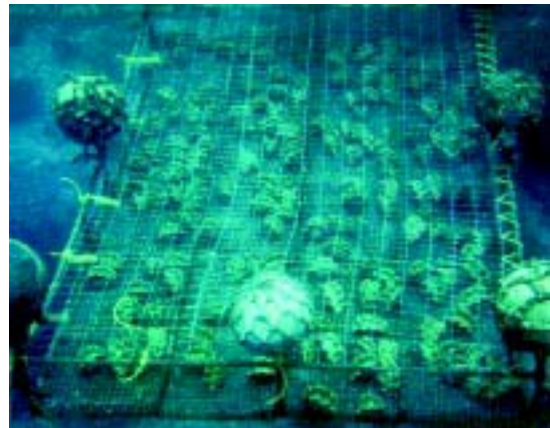


Figure 29 (Right). Floating cage tethered below the surface to avoid wave action. Note the flotation is provided by old tuna longline buoys.

Grow-out platform

The grow-out platform for floating cages must be rigid enough to support the weight of cages or nursery trays without being too heavy. A good material for the grow-out platform is the 14 gauge PVC coated, galvanized wire mesh* recommended by Heslinga et al. (1990) for construction of benthic cages (see section Benthic Cages on page 37). This mesh has a life span of 5 years in seawater and is rigid enough so that lightweight boxes or trays can be made for suspension below the flotation structure without any additional support.

* *Supply source 20 in Appendix A.*

Alternative designs include platforms made from welded rebar, galvanized steel pipe, PVC pipe, locally available hardwood poles or combinations of these (Figures 30 and 31) to which cages or trays can be attached. These platforms can be suspended from the flotation structure using either ropes or rigid struts. Rope is often a cheaper option and has the advantage of adding more flexibility to the system in rough weather.



Figures 30 (Left) and 31 (Right). Floating cages made with PVC pipe frame, PVC coated wire and rebar reinforcements at the RRE Wau Mili clam farm, RMI. (Simon Ellis).

Anchorage

How cages are anchored will depend on their configuration. Catamaran style cages can be anchored with ropes attached to one of the shorter sides of the cage. This allows the cage to swing freely in a full circle with the narrowest part of the cage always pointing into the wind. This reduces resistance on the cage during periods of high wave action. One drawback to this kind of anchoring is that water flow over

the clams may not be uniform. If both ends of the cage are anchored, it will not be able to swing into the wind and will remain in one position. A double anchor system has the advantage of extra protection in case one of the ropes snaps (Figures 32 and 33).

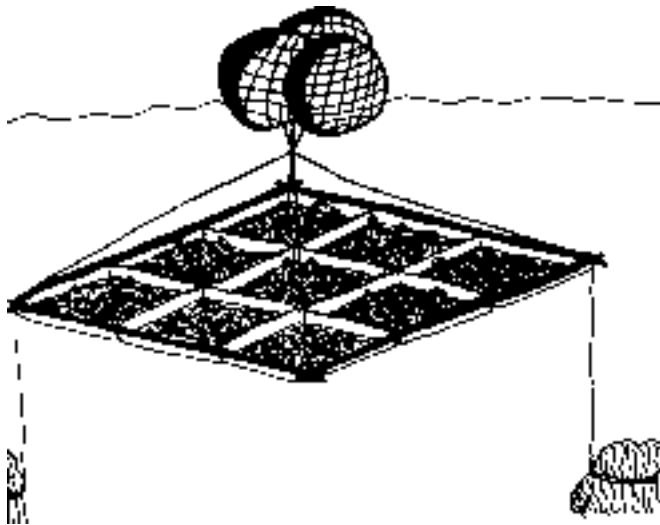


Figure 32 (Left). Drawing of floating cages made by outer island farmers in the RMI. (Taken from Dalton et al., 1995).

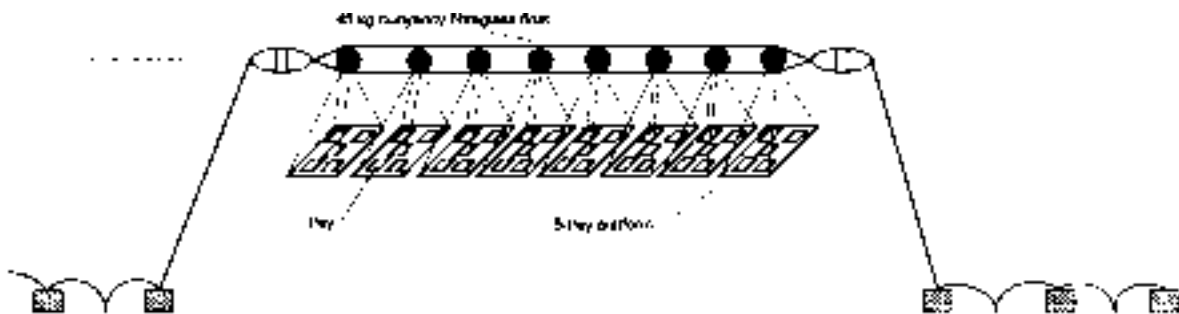


Figure 33 (Above). Longline system used for floating cages at the ICLARM-CAC in the Solomon Islands. (Taken from Lasi, 1993).

Throughout the Indo-Pacific, coral heads make excellent moorings for floating structures. While this may sound environmentally destructive, the coral quickly grows around the mooring rope and no harm occurs to the colony. If no coral heads can be found in the desired location, a good alternative is to use large blocks of concrete that are poured with a loop of rebar protruding for attachment of the mooring lines. Mooring lines and tackle should be checked regularly for wear and replaced as necessary. The use of 1-2 m of chain, shackled to the mooring block before the rope is attached, can significantly improve the effectiveness and durability of moorings.

Benthic cages

By far the most widely practiced form of ocean culture of giant clams is with the use of benthic cages. These are cheap to construct and, if sited properly, are easy to clean and maintain.

Design and construction

Like floating cages, benthic cages must be durable and able to keep out predators. The material used generally depends on local availability and the farmer's budgetary constraints.

Aside from using the appropriate materials, a farmer must consider how easy the cage is to work on and the most effective use of cage floor space. The lid of the cage must fit tightly enough to keep out predators while still providing easy access to the farmer. Cage floor space is optimally utilized by ensuring that the grow-out containers fit neatly into the cage without wasting space. For this reason, farmers often employ a modular cage design where all cages and grow-out trays are of a uniform size and shape. Figures 34-41 on pages 40 and 41 show some of the different types of cages used in giant clam farming. The following sections describe some of the more commonly used cage designs.

The MMDC cage

First put into use at the Micronesian Mariculture Demonstration Center* (MMDC) and described in Heslinga et al. (1990), this cage is constructed of 14 gauge PVC coated, galvanized wire mesh (mesh size 2.5 cm). Similar mesh is often available locally around the Pacific region as so-called "security wire" used on windows. The MMDC cage is one of the most simple and widely used designs employed in ocean farming of giant clams. Cages are constructed as two identical halves that fit together to form a cage 15 cm high and either 60 or 90 cm square (Figures 34, 35 and 40, pages 40 and 41). By using rolls of wire either 90 cm or 120 cm wide, time spent cutting is greatly reduced. The wire can be easily cut with a pair of heavy duty wire snips**. If large numbers of cages are needed for a farm, Heslinga et al. (1990) recommends using a pair of power shears**. The sides of the cage are made by simply bending the wire over a straight edge such as a sturdy table top. Life span of these cages is approximately 5 years in seawater.

*MMDC today exists as the Palau Mariculture Demonstration Center (PMDC).

** *Local purchase or supply source 23 in Appendix A.*

To construct the 90 cm square MMDC cage, two identical pieces of mesh are cut with dimensions of 60 x 90 cm. The sides of the cage are then made by bending the last 15 cm of each end of the longest sides of each section, at 90 degrees. The two halves of the cage are then hinged and closed using vinyl-coated brass wire.

The MMDC cages are designed to hold a certain size nursery tray. The 60 cm square cage houses two 51 x 26 cm nursery trays* and the 90 cm square cage houses four 45 x 42.5 cm nursery trays. This modular design makes it easier to place orders for materials and keep track of livestock inventory.

* *Supply sources 21 and 22 in Appendix A.*

The ICLARM-CAC cage

This cage design was developed at the ICLARM Coastal Aquaculture Center (CAC) to make use of readily available materials and is employed in their village based grow-out trials (Figures 36 and 37 on page 40). The cage is constructed from 18 gauge galvanized welded mesh with a mesh size of 19 mm. A concrete base is incorporated into the cage floor for holding the clams rather than the removable nursery trays. Like the MMDC cages, the wire in these cages is rigid enough to support its own weight, so a frame is not necessary. However, because the ICLARM-CAC cages are constructed of thinner (but cheaper) wire, their usable life span in seawater is only 2-3 years.

The following description of the construction of an ICLARM-CAC cage is adapted from Tafea (1993). The cage consists of two differently shaped pieces – a bottom tray and a lid. Because the cage is not designed to hold nursery trays, exact dimensions of the cage can vary and will be more dependant on the width of the roll of wire. Dimensions of the tray and the lid must be proportional in order for them to fit properly. Cages with sides of 60-80 cm are optimal because they can be easily transported and handled by one person.

As an example, the following wire dimensions would be needed to construct a cage with surface area of 0.4 m². The wire for the bottom tray would be 77 cm² and wire for the lid would be 68 cm². To form the bottom tray, a 13 cm square (7 mesh lengths) is cut from each corner and the sides are folded up at right angles using a piece of straight timber. The sides are then tied together with 1 mm galvanized tie wire. The lid is formed in a similar manner except that only 4 cm squares (2 mesh lengths) are cut from each corner before being folded down and secured with tie wire. The final step is to place the cage on a flat surface and pour a 2-3 cm concrete base into the tray for the clams to attach to.

Plastic and net cages

In many areas, soft plastic or netting is used to construct cages (Figure 38, page 41). One problem with cages of this sort is that predatory fish may be able to bite through the cage material and attack the clams. However, for areas that have few fish predation problems, these types of cages are a good option.

Plastic mesh is widely available* and can be purchased with the necessary UV inhibitors to provide a longer life span in seawater than most metal cages. Many types of plastic mesh are quite rigid and do not need a supporting frame. More flexible meshes and netting materials can be attached to a supporting frame made of locally available wood, PVC pipe or rebar. By far the more durable of these frame materials is PVC, although it may be expensive and difficult to obtain in some areas.

** Supply sources 1 and 2 in Appendix A.*

The following description of frameless plastic cages that are used at the Silliman University Marine Laboratory in the Philippines was adapted from Calumpong (1992). The cage top consists of a 1.2 x 0.6 m piece of 20 mm diameter mesh and the base consists of a 1 x 0.5 m piece of 12 mm diameter mesh. Cuts measuring 20 cm in length are made into the mesh 20 cm from the corner of the longest side of the mesh and the edges are folded up and secured using wire or electrical cable ties. The larger lid then fits over the base and the whole cage is secured to the substrate using iron bars.



Figure 34 (Left). MMDC style cage made of two identical parts. (Eileen Ellis)



Figure 35 (Above). Diver on SCUBA gear working on an MMDC style cage farm.



Figure 36 (Above). Farmers without diving gear working on an ICLARM-CAC style cage.



Figure 37 (Right). ICLARM-CAC style cages. (Simon Ellis).



Figure 38. A flexible plastic mesh cage on a PVC pipe trestle. (Simon Ellis).



Figure 39. Plastic mesh and MMDC style wire cages on a rebar trestle. (Simon Ellis)



Figure 40. MMDC style cages on a PVC pipe trestle.



Figure 41. Large T. derasa placed in nursery trays on open MMDC style cages.

Elevating cages above the substrate

Many farmers choose to elevate their cages above the substrate by using trestles or putting legs on the cages (Figures 38, 39 and 40 on page 41). Trestles generally house more than one cage while legs are used more commonly on large individual cages. Benefits of elevating cages are as follows:

1. Raised cages are less easily attacked by benthic predators such as snails. However, this does not prevent larval snails from settling in the cages. Excluders, such as inverted plastic bottles that have had the bottom cut away, are sometimes placed on the legs of trestles and cages so that snails cannot crawl up into the cages. Excluders are generally of varying effectiveness. Govan et al. (1993) described an effective trestle leg excluder design that also traps the snails (Figure 42).
2. Raising the cages allows farms to be placed in otherwise unsuitable areas such as fine sand substrates where clams would be easily smothered.
3. Use of trestles and legs allows cages to be placed in sloping areas where cages would otherwise be slanted and the clams pushed to one side of the cage. By altering leg lengths or burying the legs to differing degrees, cages can be kept more or less level.

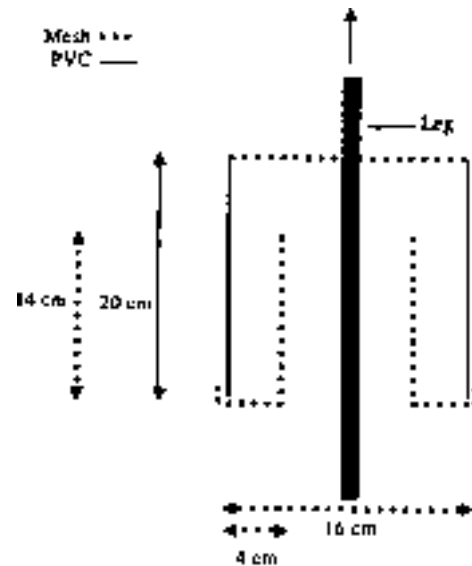


Figure 42. Diagram of an effective snail excluder which is placed on trestle or cage legs. (Taken from Govan et al., 1993).

Note: Constructing legs and trestles takes time and money and must therefore be carefully considered on a case-by-case basis using the criteria listed above.

Legs and trestles are generally constructed from the same materials used to make cage frames – rebar, PVC pipe and locally available wood. While PVC is the most durable, many farmers opt for using rebar, which is readily available, comparatively cheap and has a life span of 5-10 years in seawater, depending on the thickness used.

One simple trestle design documented by Tafea (1993) is constructed from two 6 m lengths of 12 mm rebar. Each length is cut using a hacksaw into a 2 m and a 4 m long section. Each length of rebar is then bent at a 90 degree angle 60 cm from each end. The rebar can be easily bent by holding it firmly in a vice 60 cm from the end and placing a sturdy piece of hollow iron pipe over the rebar for leverage while bending it. Each piece of rebar will now resemble a U shape. The shorter pieces are lashed approximately 70 cm from the ends of the longer pieces, which are held 60 cm apart, using strips of rubber inner tube. The resulting trestle is 2.8 m long, 0.6 m tall, has 8 legs and can hold up to 4 of the ICLARM-CAC cages described on page 38. Cages are then tied to the trestle so they do not fall off in rough weather.

Note: Rebar trestle can also be welded together if appropriate equipment is available.

Containment and substrates

Methods for containing clams and attachment substrates vary widely and are again influenced by the farmer's personal preference and the availability of materials. In the ocean environment, the clams must have a stable substrate for attachment so they are not constantly disturbed during rough weather. Clams are usually allowed to attach to the substrate prior to being transferred to the ocean. If this is not the case, then some form of containment must be provided so they are not washed away before they have time to attach.

Containment

As mentioned previously, horticultural nursery trays are a very common item for containing giant clams. They are widely used in the land-based nursery phase and also in ocean culture. While the sides of nursery trays are high enough to prevent the clams from being washed away before they can attach, they are not so high that they prevent water flow over the clams once they are established. Alternatives to nursery trays include any shallow plastic trays that can be used to hold clams. Commonly used are plastic mesh baskets or tubs that are widely available in many countries for household purposes.

Note: Nursery trays have the advantage of being of sturdy construction, uniform size and often are made of materials containing UV inhibitors that extend their useful life span in seawater.

If loose clams are moved into cages without any form of containment, a settlement ring can be used to protect the clams from currents and wave action (Bell et al., 1994; Foyle et al., 1997). This method has been widely used at the ICLARM-CAC village farming projects where loose clams are transplanted into cages with concrete floors. The settlement ring is simply a 6 cm strip of galvanized wire mesh (0.5 cm mesh size) which is fitted inside the perimeter of the cage (Figure 43). Clams are stocked within this ring and cannot be washed from the cage before they attach to the substrate. Water flow to the clams is still adequate during the settlement period. The ring is removed after approximately 2 weeks.

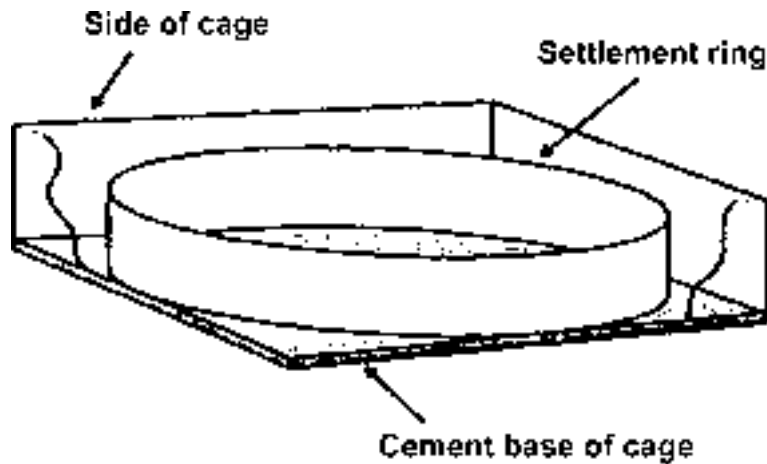


Figure 43. Diagram of a settlement ring. (Taken from Foyle et al., 1997).

Substrates

All species of juvenile giant clams secrete a **byssus**, which attaches them to the substrate. In addition, *T. maxima* and *T. crocea* have the ability to bore into calcareous substrates, which also protects the clam from predation. In ocean culture, clams should be allowed to attach to a substrate of some sort so that they are not rolled around in the cage during rough weather.

The best attachment substrate for ocean-based farms is concrete, which can be poured into containers or made into thin blocks. These blocks are made by pouring concrete over a wire base into a mould such as a sturdy nursery tray. Once dried, the block is removed from the mould. As with land-based systems, the concrete can have parallel or crisscross grooves made in it at the time of pouring to encourage faster and more uniform settlement of the clams. Alternatively, small rocks can be set into the concrete or small evenly spaced indentations made in the surface before the concrete dries. Both these methods also improve settlement success (Calumpong, 1992).

While it is better to let the clams attach to the concrete in the land-based nursery before moving them to the ocean, it is inevitable that they will need to be thinned out at some time during grow-out and allowed to reattach in the ocean environment. When using concrete substrate with no containment, some form of settlement ring may need to be used.

Some farms prefer using a gravel substrate for attachment in the ocean nursery. This method has some advantages in that gravel is cheap and easy to use. In addition, there is no need to cut the byssus during transplantation. The clam with the pieces of attached gravel can simply be moved to the next tray during thinning. However, clams attached to gravel are generally less stable under strong wave action and can easily tip over. They must then be righted by the farmer during routine inspections. Another problem with the use of gravel is that the crevices formed between the individual rocks may create hiding places for predatory snails. Heslinga et al. (1990) recommended changing the gravel in nursery trays periodically to prevent outbreaks of *Pyramidellid* snails. This does not solve the problem of *Cymatium* snails that can lurk undetected under the gravel for some time. Despite these problems, farms located in very calm areas should consider the use of gravel as a substrate for ocean farming of giant clams.

Exclusion areas

Giant clams will eventually reach a size where they can be left in the ocean without any form of protective enclosure. Depending on the species, this occurs at a size of 15-20 cm in length. At this point the clams will be resistant to almost all fish and snail predation (see section Predators, Pests and Disease on page 52). One alternative to cages for protecting larger clams (approximately 10-20 cm) from fish predation is the use of exclusion areas, also known as exclosures or enclosures (Figure 44).

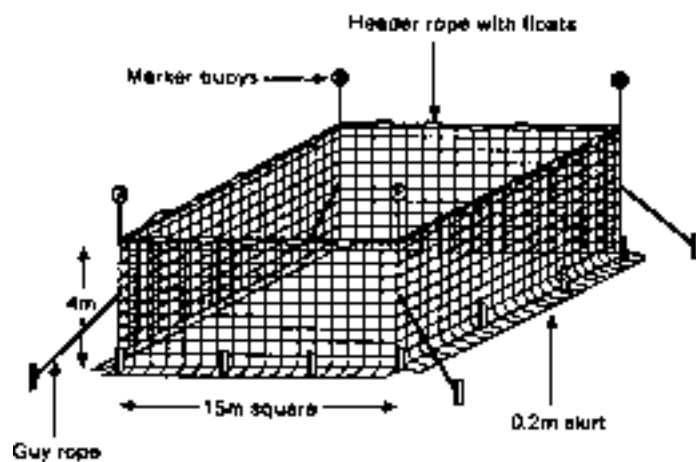


Figure 44. Diagram of an exclusion area (Taken from Barker et al., 1988).

Exclosures can be set up in the intertidal or **subtidal** zone and consist of a soft or rigid net or mesh that encircles an entire area, thereby eliminating the need for cages. Large numbers of clams can be housed in one enclosure. Exclusion areas increase the light intensity to the clams, making it easier to inspect them for signs of sickness or disease.

Disadvantages to clam exclosures are related mainly to the integrity of the structure. The enclosure must be meticulously maintained to prevent predatory fish such as trigger or puffer fish from getting inside the mesh. Just one fish may kill and eat hundreds of clams before being caught. Trigger fish, in particular, are known to routinely bite through plastic and cloth meshes to get to bivalves. For this reason, the enclosure should be routinely inspected for holes and any intruding predators speared. Efforts must also be made to prevent predators from entering the enclosure by going over or under the net. To protect the bottom of the net, a skirt approximately 1 m in length is generally used. This is anchored to the bottom with stakes and is also weighed down with piles of rocks. The top of the net is kept up by using enough floats so that the net does not sag down in any one place (Figure 45). Throughout the Pacific Islands, floats from tuna long liners and purse seiners are generally abundant and can be used on giant clam exclosures. Used netting from purse seiners can also be used to make enclosures. The top of the enclosure is kept in place by using guy ropes. This keeps the net from moving during periods of high wave action or current movement.



Figure 45. An exclusion area supported by purse seine fishing floats in American Samoa. (Simon Ellis).

A final note on the use of enclosures is the problem of algal fouling. Certain fish will graze algae off the mesh of the enclosure, but in areas that are overfished or with particularly heavy nutrient loads, algal fouling may be so heavy that water flow through the enclosure is eventually inhibited. In addition, the enclosure may become fouled with sponges, ascidians and even corals. When this occurs, the netting must be manually cleaned in place, or removed for cleaning and replaced with a clean net. The process of cleaning, repairing and monitoring an exclusion area can be extremely time consuming and, in some circumstances, may be more labor intensive than maintaining cages.

Intertidal giant clam farming

The types of ocean-based clam farming described so far in this chapter have dealt with the subtidal zone where the clams are always covered by water. Many species of giant clam in the wild are routinely exposed to the air during low tides and therefore the use of the intertidal zone for giant clam farming is biologically feasible. Giant clam farming in the intertidal zone is not widely practiced throughout the Pacific Islands but is used with success in the Great Barrier Reef area of Australia. This region is characterized by high tidal fluctuations (>3 m) and large expanses of otherwise unused, intertidal reef flats.

In a study comparing four methods of ocean culture of *T. gigas* on the Great Barrier Reef, intertidal culture was found to be the best overall rearing method (Crawford et al., 1998). Advantages and disadvantages of intertidal versus subtidal culture of giant clams are discussed below.

Advantages

1. *Equipment:* Cages for intertidal culture of giant clams are cheap and easy to construct and install.
2. *Access:* Giant clams grown in the intertidal region are easy to access without the use of SCUBA equipment or repeated breath-hold diving. Cages and animals are easy to inspect and maintain.
3. *Fouling and disease:* Because of the regular exposure of clams and cages to air in the intertidal, the degree of cage fouling and incidence of snail predation are less than in the subtidal region.

Disadvantages

1. *Growth*: Clams in the intertidal do not grow as fast as those in the subtidal because they spend part of their time exposed to the air and therefore closed. However, growth rates reported by Crawford et al. (1988) were only slightly lower for intertidally grown clams than clams grown on subtidal trestles.
2. *Security*: Clams grown on the reef flat throughout the Pacific Islands would be more susceptible to poaching than clams kept in the subtidal. Even farms adjacent to a farmer's house would be easier to steal from because poachers could simply walk onto the reef flat at night rather than having to snorkel to obtain the clams.
3. *Weather*: Giant clams do not survive well in environments with rapidly fluctuating temperature and salinity. Torrential rains, rapid heating and regular cyclonic activity may pose a barrier to intertidal culture in some parts of the Pacific Islands.

Note: Smaller clams of < 5 cm are generally more susceptible to environmental fluctuations. Nash (1988) found that small *T. gigas* (< 5 cm) exposed to the air for longer than 6-7 hours per day did not survive in the intertidal zone. Therefore, species such as *T. maxima* and *T. crocea* grown for sale to aquarium markets may never attain a large enough size for intertidal culture. The decision on whether to use subtidal or intertidal culture methods, like most aspects of giant clam farming, will need to be decided on a site-by-site basis.

Cages for intertidal culture

Cages used for intertidal culture of giant clams are similar in construction to subtidal cages. Galvanized or PVC coated steel wire mesh is used to construct cages that are then attached to the substrate using rebar pegs. The cages are also weighed down using the gravel or concrete placed in the cage for clam attachment.

One type of intertidal cage used for its ease of construction and cost-effectiveness is called a "line" due to its long, narrow shape (Figure 46, page 49; Barker et al., 1988). The line cage is 30 m long by 1.1 m wide and is divided using mesh partitions into 15 individual cells, each 2 m long by 12 mm. The base and sides of the cage are made from 5 or 12 mm plastic mesh and the lids are made from 26 mm plastic mesh. Each cell has a separate lid. Galvanized steel wire mesh (100 mm mesh size) running the complete length of the line is used to support the structure and provide anchorage to the substrate by the use of steel pegs. These cages are filled with a gravel or concrete attachment substrate.

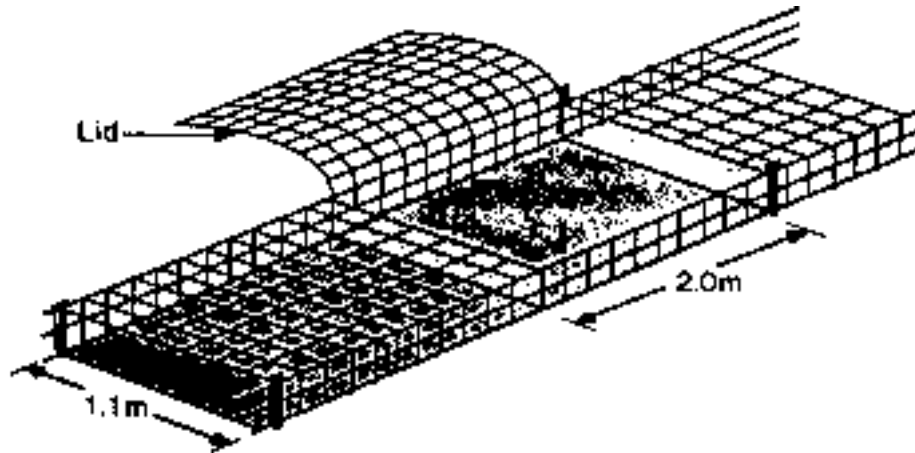


Figure 46. Diagram of a line of protective cages.
(Taken from Barker et al., 1988)

A structure similar to a line in length and width is called a “cover” (Figure 47; Barker et al., 1988). This consists simply of 40-60 mm plastic mesh that is anchored to the reef flat and bent over the clams, which are placed directly on the reef flat. This structure is used for larger clams (>12 cm) and has no partitions or base. Access to the clams is through a V-shaped opening that is wired shut when not in use.

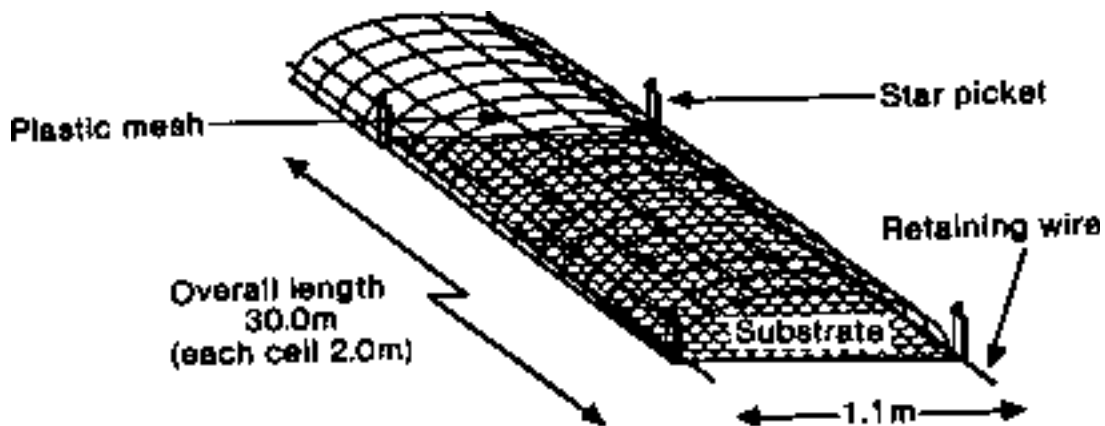


Figure 47. Diagram of a protective cover.
(Taken from Barker et al., 1988)

General husbandry during ocean-based grow-out

Giant clam care in the ocean is generally not labor intensive but requires constant diligence and care by the farmer. Cages should be visited at least once a week and the farm inspected for signs of damage, fouling, snail predation and disease. Constant visits to farms in remote locations will also help to deter unwanted visitors. The following is a list of husbandry tips to help farmers during ocean-based grow-out of giant clams.

1. *Stocking and cage densities:* When stocking clams into the ocean for grow-out, they should be allowed to attach to the substrate in the land-based system or some form of containment should be used to ensure they are not washed away before the byssus has time to attach. The stocking densities and protocols recommended for land-based systems should also be applied to ocean rearing to reduce overcrowding.
2. *Biofouling:* Cages and clams can quickly become fouled with algae, which inhibits clam growth by reducing ambient sunlight and water flow over the clams. However, in healthy, pollution-free environments, grazers such as fish and snails will quickly colonize cage areas and keep algal growth to a minimum. Cages should be inspected once weekly and, if necessary, the sides and top scrubbed to remove algae. When using cages with easily removable lids, such as the MMDC cages, fouled lids can be removed and sun-dried to kill fouling. The fouled lid is then replaced with a clean lid and the process repeated as necessary.
3. *Predation:* (See section on Predators, Pests and Diseases on page 52). Predation can be one of the major causes of clam losses during ocean farming if the farmer is not vigilant. Predatory fish should be speared if they are seen in the vicinity of the farm and the cages should be checked regularly for predatory snails or indicators of their presence.
4. *Clumping.* As in the land-based tanks, ocean-farmed clams will tend to clump in corners of trays and cages. If this becomes so bad that the clams are smothering each other, then they must be removed from the substrate and redistributed or thinned out.
5. *Cage inspection.* Cages and enclosures should be checked regularly for tears or structural damage and repaired immediately.

6. *Data collection and analysis:* Even small farmers should attempt to keep records of growth and survival of their clams during ocean rearing. Growth and survival of giant clams will vary between sites and with the rearing method used (cage or enclosure type, location, use of trestles, etc.). It is recommended that farmers monitor their cages as often as once a month to look for trends in growth and survival at each particular site. The time taken to do this will generally be rewarded by a faster diagnosis of health problems and determination of the optimum grow-out method and location for that particular farm. It will also give the farmer a good idea what clams are close to harvest size so that more seedstock can be ordered.

It is recommended that the following data be kept for each farm site:

1. Types of cages, trestles, etc. used.
2. Numbers of clams stocked and harvested along with monthly counts of clams remaining per cage.
3. Records of thinning and restocking dates.
4. Dates when predators or pests were encountered and removed from or around cages.
5. Clam growth should be monitored on a monthly basis by randomly measuring at least 10 clams from each cage . Clams should not be removed from the substrate during measuring and should be measured along their longest axis using a ruler or preferably an inexpensive caliper*.

* *Supply sources 1, 2 and 24 in Appendix A.*

Predators, pests and diseases

There are many documented predators, pests and diseases of giant clams. These are documented particularly well by Braley (1992), Calumpong (1992), Heslinga et al. (1990) and Knop (1996). Because sophisticated diagnostic techniques are rarely available for clam diseases throughout the Pacific Islands, this manual will limit its coverage of this topic to problems that cause the most mortality, are easily recognizable and that can be ameliorated or prevented through careful management.

Predators and pests

Ranellid snails

Description of the problem

Ranellid snails (gastropods) of the genus *Cymatium* (Figure 48, page 54) are probably the most consistently destructive predator of cultured giant clams and the hardest to control (Govan et al., 1993). These snails are ubiquitous throughout the tropical Pacific and have a planktonic larval phase that can last many months until the larvae encounter a suitable settling substrate. Most *Cymatium* infestations occur when larval snails settle in a cage of giant clams. Young snails enter the clam by crawling through the **byssal opening** where they start feeding. Larger snails can actually chew through the byssal threads to gain access to the byssal opening. The snail generally lodges itself between the shell and mantle (Perron et al., 1985) and grows rapidly as it consumes the clam. Eventually the clam will begin to gape and the mantle will retract inside the shell. Death follows very soon afterwards. The *Cymatium* will then move on to another clam. One adult or subadult *Cymatium* can attack and kill up to 10 juvenile clams per week (Calumpong, 1992).

Sizes and species affected

While all giant clams are susceptible to attack from *Cymatium*, clam size and species affects the level of predation. Clams of 15-17 cm in length appear to be able to repel *Cymatium* because their weight forces the byssal opening into the substrate so snails cannot easily get inside. In addition, large clams also seem able to expel snails that try to crawl over the top of the shell. All clams less than 17 cm should be considered susceptible to *Cymatium* attack.

Clam species with a large byssal opening such as *T. maxima*, *T. crocea* and *T. derasa* are more susceptible to attack by *Cymatium*. Species with a small byssal opening, especially *H. hippopus*, are relatively resistant. In a study on prey preference (Govan et al., 1993), *T. crocea* was the most preferred prey species for *C. pileare*.

Diagnosis and prevention

Clams infested with *Cymatium* will gape and the mantle will start to sag away from the shell. By the time this is noticed, the clam is unlikely to recover and should be removed from the tank or cage and sacrificed to look for snails. If the problem is *Cymatium*, the offending snail should be removed and killed. In addition, all clams in the tank or cage should be inspected for initial signs of *Cymatium* attack and the areas under and around the clams checked for the presence of snails.

Snail infestations can be prevented in land-based systems by screening the water to 25 µm using filter bags or some other form of filter system. If *Cymatium* do make it into the land-based system, affected clams should be removed and healthy clams moved to a clean tank. The infected tank should be drained and sundried before being used again. Filter bags in an infected tank should be thoroughly inspected for holes or tears.

Prevention of *Cymatium* infestation in ocean culture is not possible. The only known method for control of these animals is regular inspection and removal of visible snails. If inspection is carried out on a 1-2 week schedule, then mortalities related to this predator can be kept to a minimum. It should be noted that *Cymatium* outbreaks are episodic and have been correlated to high rainfall at the MMDC in Palau (Heslinga et al., 1990).

While it is not possible to prevent *Cymatium* outbreaks during ocean culture of giant clams, measures can be taken to prevent infestation by adults and subadults. Govan et al. (1993) reported the following information on *Cymatium* predation.

1. Cage mesh size can be important in preventing snail entry as smaller meshes will stop the larger, more devastating snails from getting into the cages.
2. Cages raised on trestles had less snail predation, reducing the presence of snails by 50%.
3. Trestle leg excluders had limited benefits aside from a design shown in Figure 42, page 42 that actually traps the snails.



Figure 48. *Cymatium* spp. snails.
(Simon Ellis)



Figure 49. *Pyramidellid* snails. (Simon Ellis).

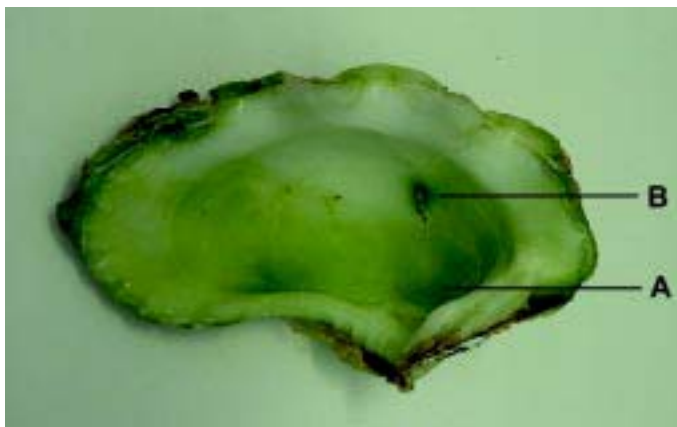


Figure 50. Inside of the valve of a *T. maxima* showing: A) boring algae infestation (green shading); B) a worm burrow that has penetrated the shell of the clam. (Simon Ellis).



Figure 51. A tray of “ultra” grade *T. maxima* destined for the aquarium market. (Satoshi Yoshi).

Note: There are a number of different snails and other animals that occur in giant clam cages. Most of these are not predators of giant clams and many can be beneficial to the clams by actually preying on the clam predators. Unless mortalities are being experienced in any particular cage, non-predatory snails and other animals should not be arbitrarily removed from the cages as they may be helpful.

Pyramidellid snails

Description of the problem

Pyramidellid snails of the genera *Turbonilla*, *Pyrgiscus* and *Tathrella* are another pest that occurs in both the ocean and land-based nursery and grow-out operations for giant clams. An unlikely parasite, these wide-ranging, small white snails have a fragile appearance and only grow to a maximum of 8 mm in length (Figure 49, page 54). However, the reproductive strategy of these snails allows them to build up to very high densities in a short period of time if left untreated. Pyramidellid snails lay their eggs on the shell of the clam. Larvae are non-planktonic and hatch from the egg in about 15 days, taking a further 100-120 days to reach sexual maturity. Thus, in a relatively short period of time, a light infestation can reach epidemic proportions. Cummings (1988) reported an initial population of 6 *Pyrgiscus* grew to 1700 individuals in just 6 months.

Pyramidellids feed primarily at night, by using a **proboscis** to suck fluid from the mantle of the clam. Effects of infestation range from slow growth and poor health to secondary infections and occasionally, death.

Sizes and species affected

All species of giant clam are susceptible to Pyramidellid infestations. Juvenile clams are affected more by the presence of these snails because of their relatively smaller body mass. Mortality in juvenile clams with Pyramidellid infestations is not unusual, while larger clams can withstand extremely high levels of infestation and rarely die.

Diagnosis and prevention

Presence of the snails on the underside of the clams is the first obvious indicator of infection. Other indicators of attack include blisters on the inner surface of the clam shell, shell thickening near the inner valve edges and a visibly retracted or scarred mantle.

During ocean culture of giant clams, Pyramidellids occur more frequently in cages raised above the substrate. The reason for this is thought to be that cages sitting on the substrate are inhabited by small benthic predators such as portunid crabs and fish that prey on these tiny snails (Crawford et al., 1988; Cummings, 1998; Heslinga et al., 1990). Biological control of this pest in land-based systems may also be possible using animals known to control them in ocean culture systems.

Note: While elevating the cages leads to a higher frequency of Pyramidellid infestation, leaving the cages sitting on the substrate generally increases *Cymatium* predation, which is a far more serious problem.

In land-based culture of giant clams, filtration of incoming water to 25 µm will prevent eggs and larvae of Pyramidellid snails from entering the tanks. If infestation in either land or ocean-based culture does occur, proliferation to epidemic proportions can be prevented by periodic scrubbing and transplanting of the clams. Because the life cycle of the snails is approximately 4 months, scrubbing the clams and moving them to a clean cage or tank every 3 months will prevent large numbers of these snails from establishing in the culture system. Regular cleaning also helps to reduce the growth of filamentous algae, a habitat where these snails live and lay their eggs.

Fish, crabs and octopus

Description of the problem

“Macro-predators” that are large enough to crush the shell of giant clams can be a serious problem in ocean-based culture of giant clams. Trigger fish, puffer fish, tusk fish, eagle rays and many other fish that regularly eat shellfish can quickly devour large numbers of giant clams. Other macro-predators include large crabs and octopus that can pry open the valves of giant clams.

In addition to macro-predators, fish can occasionally cause problems in other ways. There have been reports of *Thalassoma* wrasses attacking the byssal area of recently stocked and unattached *T. crocea* and *T. maxima* in ocean cages. This problem is easily overcome by attaching the clams in a land-based system prior to stocking.

One interesting observation by Heslinga et al. (1990) is that certain highly territorial damsel fishes of the genus *Dischustodus* will establish themselves on cage sites and prevent other algal grazers from removing algae from the cages, thereby increasing fouling on the cages. They recommended periodic removal of this species by spearing.

Sizes and species affected

Smaller clams are more susceptible to attack by macro-predators because of their thinner shell and weaker **adductor** muscle. Clams of 15-20 cm in length are generally large enough to withstand attacks by macro-predators. All species are susceptible to these attacks.

Diagnosis and prevention

Clams that have been attacked by fish will generally have bite marks on the top of the shell. Attacks by crabs and octopus are indicated by empty shells with very few other marks on the **valves**. Octopuses will often carry the shell away from the area.

Most cages used for giant clam culture were developed to prevent macro-predator attacks. Metal cages are more effective than plastic or soft mesh nets against fish and crabs. Octopus often gain access to cages through improperly closed lids or holes in the mesh. Octopus predation has been observed in intertidal clam covers housing *T. gigas* of >20 cm in length (Barker et al., 1988). Where macro-predators are a constant problem or presence, they should be removed from the area either by spearing or trapping. Cages placed on trestles are generally immune from attacks by crabs.

Diseases and disorders

Disease and the environment

As with all aquatic animals, there is a close relationship between environment and the onset of disease. Potentially infectious bacteria, viruses and other disease-causing organisms are constantly present in seawater. Giant clams will only get sick when they are stressed to the extent that their natural immunity to these disease-causing agents is lowered. Animals kept in intensive culture conditions that involve crowding, poor water quality and potentially unseen pollution are most susceptible to the onset of disease. Therefore the best way to treat disease in giant clam culture is to ensure that the clams never become overstressed. To do this the farmer should pay strict attention to avoiding crowding, tank and cage fouling, poor water quality and excessive handling.

Recorded and documented outbreaks of diseases in giant clams caused by bacteria, protozoans and viruses are remarkably few. This may be due to the generally limited ability to diagnose such outbreaks throughout the Pacific. Veterinary and pathology laboratories capable of making this kind of diagnosis are quite rare. However, just as rare are unexplainable mass die-offs of giant clams. Most mass mortalities can be traced to snail predation or stress linked to poor water quality, crowding or over-handling. For this reason, general disease descriptions will not be covered in this manual. Any farmers experiencing unexplainable clam mortalities should look carefully at their records for indicators of stress to the clams and take measures to remedy these. Sick clams should be removed from the tank and isolated as they may become a vector for the spread of pathogens. This will prevent rapid proliferation of the pathogen from overwhelming otherwise healthy clams. The few diseases and disorders described below can all be easily diagnosed by farmers and remedied using simple procedures.

Mantle bleaching

Description of the problem

Bleaching occurs in giant clams when a stressor triggers the animal to expel its **zooxanthelle** from all or part of the mantle, leaving it white and without pattern.

Sizes and species affected

All sizes and species of giant clam can be affected by bleaching.

Treatment and prevention

Bleaching events in giant clams are thought to be brought on by rapid fluctuations in environmental conditions, especially temperature and light. Elevation of temperature close to the lethal limit will cause clams to expel their zooxanthelle almost entirely. So-called central bleaching is the bleaching of the central part of the mantle which gets the highest level of light exposure. Bleaching of this sort tends to occur when the clam is exposed to very high UV light or to sudden changes in light intensity such as being removed from a shipping box into full sunlight or being brought from a deep ocean nursery into a shallow raceway. Bleaching is nearly always triggered by an increase in light intensity as lowering light intensity within the physiologically acceptable range simply stimulates production of higher zooxanthelle concentrations in the mantle tissue.

Bleaching can generally be avoided by paying attention to the environments between which the animal is being moved and avoiding rapid changes in light or temperature. For instance, if the clam is brought from deep water into a shallow raceway, it is good to cover the raceway with a 50% light-occluding shade cloth for a few days to allow the animal time to adjust to the new lighting. Likewise, temperature should be kept as constant as possible between the two environments.

One type of bleaching that rarely occurs in the culture of giant clams is due to a lack of nitrogen or other essential nutrients in the water. This condition would only occur in land-based systems that have an inadequate flow of seawater.

Gas bubble disease

Description of the problem

Gas bubble disease is caused by high levels of dissolved gases in the water of land-based systems. This usually occurs when air is entrained into the incoming seawater on the suction side of the pump. When the water and air pass through the pump together the air is forced into solution by the pressure. Excess gas pressure in the water causes air bubbles to form in the mantle, often causing smaller clams to float to the surface. Serious cases are fatal.

Sizes and species affected

All sizes and species of giant clam can be affected by gas bubble disease.

Treatment and prevention

Mildly affected clams can be transferred to another tank or area that does not have high levels of dissolved gas in the water. Care needs to be taken during transportation as temperature fluctuations and higher temperatures are known to exacerbate this problem.

This problem can generally be prevented by constantly checking the suction side of pumps for small leaks or cracks. A large number of tiny bubbles in the water as it comes out of the tank inflow pipe is a telltale sign of high dissolved gases in the water. Dissolved gases in seawater can also be measured using a satumeter* which will indicate high levels of dissolved gases. Land-based facilities with chronic dissolved gas problems can also use packed columns or degassing towers** to strip gases from the water before it enters the tank.

* Supply source 1 in Appendix A.*

** Supply source 1 in Appendix A.*

Boring sponges and algae

Description of the problem

Giant clams are susceptible to natural fouling organisms that bore into the shell. Of these, the boring sponge (*Cliona spp.*) and boring algae cause the most problems. Both types of organisms bore into the shell of the clam, often penetrating through the entire shell where subsequent tissue damage can occur. Boring sponges are far more destructive than boring algae and *Cliona* is known to be a significant pest in the pearl oyster industry. While rarely fatal, these boring organisms can weaken the shell and allow openings for other predators, parasites or secondary infection (Figure 50, page 54). Badly infected shells also have little or no value in the shell trade and a reduced value in the live aquarium trade.

Sizes and species affected

All sizes and species of giant clam can be affected by these boring organisms. However, older animals are sometimes more seriously affected because of the time it takes for these parasites to become a nuisance.

Treatment and prevention

There is no effective way to prevent attack by boring algae and sponges. Both are naturally occurring organisms that will eventually settle on clam shells. Settlement can be geographically specific. Both boring sponges and algae can be easily controlled by regularly washing the clam shell with an antifouling treatment. The most simple form of antifouling is freshwater, which quickly bursts the cells of the marine-dwelling algae and sponges by osmotic shock. Other treatments include scrubbing the shell with a 1% formalin solution (Braley, 1992; Knop, 1996) or hydrogen peroxide. It is important not to allow formalin or hydrogen peroxide to enter the clam. Exposure to freshwater should also be limited. Treating clams against boring organisms takes time and effort and a conscious decision should be made by the farmer based on whether this effort will impact the health or sale value of the clam.

Marketing and economics

The different uses for giant clams are briefly discussed in the introduction of this manual. The purpose of this section is to provide a more detailed description of the possible marketing channels for giant clam products and to provide information, where possible, on the potential economic returns of these marketing options. The options presented below are not mutually exclusive. Giant clam farmers must take every opportunity to sell their products with the result that some marketing strategies will overlap. It is extremely important for a farmer to have considered and chosen a marketing strategy before grow-out begins as this will affect the structure of the farm and the species chosen for grow-out.

One of the best examples of a facility that explored every possible marketing strategy was the MMDC in Palau. This fully integrated facility not only spawned and produced their own seed, but also conducted clam grow-out. This versatility allowed them to sell small clams as seed for other farms and for aquarium pets. Larger clams were marketed for meat, and shells of all sizes were crafted into jewelry or ornaments for sale in their on-site gift shop. While this may not be possible for every farm, it provides an excellent example of how farmers can combine marketing strategies to maximize profits.

Marketing giant clams as seedstock

The most logical place to start in a discussion of marketing giant clams is with the sale of seedstock. Currently, most giant clam seed are supplied to farmers via government hatcheries. However, the potential is there for private farms that could spawn and rear clams to either stock their own farm and/or to sell seed clams for grow-out by local farmers. There are any number of scenarios that exist for the nursery culture of giant clams that will vary according to species, culture methods, and target production. Economic analyses conducted on hatchery and nursery production for different geographical areas indicate that clam seed production prices could be kept low by keeping production numbers high (500,000 or more animals per year) – the so-called economy of scale (Hambrey and Gervis, 1993; Tisdell and Tacconi, 1993). However, a farmer must consider if a market exists for such large numbers of clams before entering into such production.

It should also be noted that operating costs can be kept low by utilizing extensive spawning methods and basic, no-frills rearing facilities. In addition, the level of skill attained by many Pacific Islanders in giant clam husbandry also removes the need for expensive expatriate labor to manage facilities, which substantially lowers operating costs. The following example demonstrates the operating and construction costs for a small hatchery and nursery operation.

Example 1. This model assumes the following:

1. The facility is located in a rural or low-cost area of Micronesia.
2. Land area is adjacent to a sheltered lagoon and is approximately 300 m in length.
3. There is a production goal of no less than 100,000 colored *T. maxima* per year for sale to farmers targeting the marine aquarium trade.
4. Clams are raised solely in a land-based system until approximately 1 year of age or 2.5-3 cm in length.
5. Broodstock are bought from local fishermen for \$5.00 each.
6. Extensive spawning methods are used thus bypassing the need for a hatchery facility.
7. Spawning occurs three times per year utilizing 2 raceways for each spawn. Survival from stocking until first harvest is 1-1.5%.
8. Young clams are harvested after 4 months and restocked in up to 5 tanks at a density of up to 4000/m².
9. A second harvest takes place at 8 months and clams with good color (40% of remaining total) are restocked into 5 tanks for further grow-out at a stocking density of up to 1000/m². Clams with poor color are discarded. Survival from first to second harvest is 75%.
10. Harvest takes place at 12 months. Survival from second to third harvest is 75%.
11. The average sale price of each clam is \$0.75.
12. All prices are in U.S. dollars.
13. The farm is operated by a single owner who manages the facility and takes salary from the profits.

The company's costs on a yearly basis are as follows:

Land lease - \$1,000 per month	\$ 12,000
Office, laboratory and storage area - \$20,000 (10 year dep.)	\$ 2,000
15 - 2 x 6 x 0.6 m concrete raceways - \$18,000 (15 year dep.)	\$ 1,200
Plumbing, security fencing and shade - \$15,000 (10 year dep.)	\$ 1,500
Pumps and aeration - \$1,700 with 2 year depreciation	\$ 850

Microscope and laboratory equipment \$1,500 (5 year dep.)	\$ 300
Utilities for 1 HP pump, 0.5 HP blower and basic lighting	\$ 2,400
Used pickup truck - \$4,000 (5 year depreciation)	\$ 800
2 full-time staff (\$3.00 per hour)	\$ 12,000
Supplies (filter bags etc.)	\$ 1,000
Miscellaneous expenses (fuel, etc.)	\$ 2,000
Computer \$2,000 (5 year depreciation)	\$ 400
Fax machine and photocopier - \$1,000 (3 year dep.)	\$ 330
Marketing materials and communications	\$ 1,200
Maintenance and insurance	\$ 3,000
TOTAL	\$ 40,980

With average sales of 100,000 clams p.a. @ \$0.75 per piece:

Gross revenue per year = \$75,000

Profit before taxes = \$75,000 - \$40,980 = \$34,020

Break-even point for this model = 54,640 clams per year @ \$0.75 per piece
or 100,000 clams at \$0.41 sale price per piece.

Marketing giant clams for the marine aquarium trade

The marine aquarium market

By far the largest and most lucrative market for giant clams at present is in the marine aquarium trade. Clams can reach market size in 1-2 years and sell for high prices per unit weight. Total world retail value of the aquarium industry in 1995 was estimated at between \$4 and \$15 billion \$US (Corbin and Young, 1995) with plant and animal sales alone estimated at \$900 million \$US (Bassleer, 1994). The United States is currently the world's largest importer and end user of aquarium livestock, importing approximately 90% of all live marine aquarium products (Dr. Edward Green, personal communication) However, large markets also exist in Japan and the European Union member countries.

Marine species make up only 9% of the volume of the aquarium pet trade but represent 20% of livestock revenues due to their high value (Bassleer, 1994). There are an estimated 10-20 million aquarium enthusiasts in the United States alone (Winfree, 1989). The keeping of marine aquaria, especially the "reef tanks" that contain live corals and giant clams, is a rapidly growing sector of the aquarium industry. This expansion is primarily attributed to increased public exposure and access to the tropical marine environment (Puterbaugh and Borneman, 1996)

coupled with greatly improved aquarium technology for marine species. Giant clams are currently one of the few marine animals that can be raised from the egg for the aquarium industry. While all giant clam species can be sold as aquarium pets, the demand, and price, is highest for the very brightly colored clams such as *T. maxima*, *T. crocea* and, to a lesser extent, *T. squamosa*.

Possible problems and constraints

Although the aquarium trade can be the most lucrative of giant clam markets, there are risks and concerns that a farmer must be aware of before choosing this as an option.

1. *The aquarium market for giant clams is limited.* Increasing competition in the market for aquarium clams in recent years has led to demand by the consumer for only the highest quality animals. Clams must not only be of the finest blue or green color (the so-called “Ultra” grade; Figure 51, page 54) but they must also be of the size required. Because so many producers are selling 3-6 cm clams, there is a greater demand for larger 6-15 cm clams that take longer than 3 years to grow. These clams are in shorter supply and can therefore command a higher price. Consequently, there may be a longer period of time before the farm can utilize its full potential and an added risk of maintaining the livestock for a longer period.
2. *Clams raised for the aquarium trade must be transshipped live to the buyer.* This process requires extensive paperwork, dealing with overseas buyers and a rigorous packaging process (see section Shipping on page 80). This part of the business is often very difficult for individual farmers and the decision to start a aquarium clam farm must take into account this important part of the process. One alternative is to find someone else to market the clams. Many areas have a resident marine wholesaler who transships live fish, corals and other invertebrates for the aquarium trade. They may be willing to supplement their product line with farm-raised giant clams. Because the local wholesaler is taking the responsibility for selling and transshipping the clams, a farmer should expect to receive substantially less for each sale than if the clams were being sold directly to a wholesaler in another country.
3. *The aquarium market is constantly changing.* While this industry is growing rapidly and there will always be a demand for giant clams, there is no way to accurately predict what size, species and color will be in demand in 2 or 3 years’ time. In all likelihood the larger, brightly colored clams will still be the most sought after animals. However, a farmer should keep in constant contact with wholesalers to identify changes in market trends.

The buyer

Most buyers will be wholesalers based close to major metropolitan areas around the world. (See Appendix C for a list of wholesalers of marine aquarium products.) Wholesalers are like any other business people, in that they want the best product for the least amount of money. Therefore, it is important to reduce the cost to the buyer wherever possible. This is possible not only by watching shipping costs (see section Shipping on page 80) and keeping product prices competitive, but also by making the farm visible to the buyer.

One of the best ways to publicize a farm is to post a stock list on the Internet. A simple Website will not only make the company visible to most buyers but will allow them to make purchases via e-mail, a substantial cost savings over using the phone in most Indo-Pacific nations. In places where access to the Internet is not available, marketing efforts can be made in more traditional ways. The best traditional method for advertising the farm's products is a simple brochure with a few color pictures of the product, a product list and accompanying price list that can be mailed to prospective buyers. The price list should not be printed directly on the brochure because the brochure may last for many years but prices constantly change.

Building a trusting relationship with a buyer is an important aspect of marketing giant clams. The farmer and the buyer are usually separated by huge distances and there is often a certain amount of initial distrust between the two parties. This mistrust is often well earned by both sides. A farmer should insist on prepayment on all shipments until there is a bond of trust with the buyer. Nurturing a long-term relationship with a buyer is beneficial for a number of reasons. Communication allows the farmer to receive feedback from the buyer on what products are selling, how the animals are doing after shipping and allows the farmer to structure farm inventory to future demand. At the same time, a reliable farmer should produce a consistently high-quality product, listen to the buyer's needs and promptly replace or give credit for an excessive amount of dead animals. Other good ways to nurture the relationship between buyer and farmer is for the farmer to occasionally send free samples or to offer discounts on certain items.

Note: Dead on arrivals (DOAs) are the animals that were shipped live but arrived dead. These should generally be a small percentage (less than 5%) of the total number shipped. If a buyer receives a shipment with an unusually high proportion of DOAs, then they may ask for replacement of the animals or credit on the next

shipment. Occasionally, an unscrupulous buyer will claim a large number of DOAs to boost profits. If the farmer suspects this is the case, then photographic or other evidence can be requested to verify the damage. A buyer who constantly files large DOA claims against the farmer should be dropped from the customer list.

Price structure

As mentioned previously, there are many sources of giant clams throughout the Indo-Pacific. Any new farm will be selling in direct competition with these other producers, so pricing must be attractive to the buyer. It is often hard to find out what other producers are selling their clams for but a general rule of thumb is to sell the product for 25% of the wholesaler's reselling price. Wholesalers will generally make their price lists available or post them on the internet. Selling a product for only 25% of the wholesalers list price may seem low but factors such as cost of shipping, losses due to mortalities and profit to the wholesaler must be considered.

Lagoon-based farm economics for aquarium clams

The economics of running any giant clam farm are affected by many variables, which are covered in other sections of this manual. The simple examples that follow are based on a typical lagoon-based cage farm growing *T. maxima* for the aquarium trade. Prospective farmers should look closely at all the costs involved in this operation to see what they would change for their own individual operation.

Example 2. This model assumes the following:

1. The farm is located in an area that meets the criteria listed in this manual for an adequate ocean farm site.
2. The farm is less than 1 km from the farmer's house and the farmer and an assistant make four 8-hour visits to the farm every month (48 visits per year).
3. The farm only stocks high quality, colored *T. maxima*.
4. In full production, the farm consists of 250 MMDC style cages with a grow-out area of 0.25 m² each.
5. Grow-out time is 18 months with an average harvest size of 8-10 cm (growth rate 3.5 mm per month). Production target after that time is 530 clams per month.
6. Seed clams are obtained from a local hatchery at a size of 2-3 cm for \$1.00 each.
7. Stocking density is 120 clams per cage with thinning to 60 clams per cage after 9 months.

8. Average sale price to a local transshipper of \$4.00 per clam. Transshipper can then resell the clams for \$6-7 each.
9. Clam survival from stocking to harvest is 80%.
10. All prices are in U.S dollars.
11. The farm is operated by a single owner who takes salary from the profits.

Basic stocking and harvest protocol would be as follows:

Month 1: Stock 50 cages (Cohort 1) with 6000 clams (120 per cage). These are spread into a further 50 cages (100 in total) at month 9.

Month 9: Stock 50 cages (Cohort 2) with 6000 clams (120 per cage). These are spread into a further 50 cages (100 in total) at month 18.

Month 18: Begin monthly harvest and sale of Cohort 1 clams (11 cages per month). Stock 50 cages (Cohort 3) with 6000 clams (120 per cage). These are spread into a further 50 cages (100 in total) at month 27 using empty cages from Cohort 1 harvest.

See Table 1 below:

Table 1. Planting and harvesting schedule for a lagoon-based giant clam farm growing clams for the marine aquarium trade.

Cohort	Month				
	1	9	18	27	36
1	Stock 50 cages	Thin to 100 cages	Begin harvest		
2		Stock 50 cages	Thin to 100 cages	Begin harvest	
3			Stock 50 cages	Thin to 100 cages	Begin harvest

After the first 18 months of operation, the operating costs on a yearly basis are as follows:

Hookah rig for 2 divers \$1,600 (5 year depreciation)	\$	320
Used boat and motor \$4,000 (5 year depreciation)	\$	800
Fuel (2 gallons per day, 4 days per month)	\$	220
Assistant (32 hrs/month @ \$3.00 per hour)	\$	1,152
Miscellaneous expenses	\$	500

Nursery and Grow-out Techniques for Giant Clams

250 MMDC style cages @ \$15 ea. (5 year depreciation)*	\$	750
500 nursery trays @ \$1.25 ea. (5 year depreciation)*	\$	125
6000 seedling clams @ \$1.00 ea.	\$	6,000
TOTAL	\$	9,867

* Taken from Shang et al. (1992).

With average sales of 530 clams per month @ \$4 per piece

Gross revenue per year = \$25,440

Profit before taxes = \$25,440 - \$9,867 = \$15,573

Break-even point for this model = 205 clams per month.

Example 3. This model uses all the assumptions of Example 1 (page 62) with the following exceptions:

1. The farm is located within paddling distance of the farmer's house so a boat is not required.
2. The farmer does not employ an assistant and maintains 150 cages.
3. The farmer does not use a Hookah rig.

Basic stocking and harvest protocol would be as follows:

Month 1: Stock 30 cages with 3600 clams (120 per cage). Spread these into a further 30 cages (60 in total) at month 9.

Month 9: Stock 30 cages with 3600 clams (120 per cage). Spread these into a further 30 cages (60 in total) at the end of the year.

Month 18: Begin monthly harvest and sale of month 1 clams (6-7 cages per month). Stock 30 cages with 3600 clams (120 per cage). Spread these into a further 30 cages (60 in total) at Month 27 using empty cages from month 1 harvest.

After the first 18 months of operation, the yearly operating costs are as follows:

Miscellaneous expenses	\$	500
150 MMDC style cages @ \$15 ea. (5 year depreciation)*	\$	450
300 nursery trays @ \$1.25 ea. (5 year depreciation)*	\$	75
Average of 4800 seedling clams @ \$1.00 ea.	\$	4,800
TOTAL	\$	5,825

* Taken from Shang et al. (1992).

With average sales of 320 clams per month @ \$4 per piece

Gross revenue per year = \$15,360

Profit before taxes = \$15,360 - \$5,825 = \$9,535

Break-even point for this model = 121 clams per month.

Marketing giant clams for the food trade

By far the largest potential market for giant clams is as a food item. However, this potential has been largely unrealized mainly due to transport, regulatory and time for grow-out constraints. Reports of meat production from mass grow-out of giant clams in otherwise unproductive areas, such as intertidal reef flats, are as high as 48 tonnes of meat per hectare (Lucas, 1995). Considering that giant clams only produce a 10-15% meat yield, total tonnage of production ranges from 320-480 tonnes/hectare. Meat yield also varies according to size, with larger animals having a proportionally higher meat yield.

Giant clams grown for food tend to be the larger, faster-growing species such as *T. derasa*, *T. gigas* and *H. Hippopus*. Even utilizing these fast-growing species, the economic analyses of clam grow-out for food indicate that clams would have to be held for 6-10 years before sale to attain maximum profitability (Munro, 1988; Watson and Heslinga, 1988; Tisdell and Tacconi, 1993; and Hambrey and Gervis, 1993). Notwithstanding the inherent disease, storm and other risk factors involved in keeping animals in ocean culture, this is a long time to wait until gains are realized, by almost any farming standards. To compound this problem the economics of growing giant clams for food on a truly mass scale are at best marginal. However, despite this somewhat bleak outlook, many farmed giant clams are sold for food worldwide, usually to niche or specialty markets.

How giant clams are eaten

Two main parts of the giant clams are eaten, the adductor muscle and the mantle. The adductor muscle is highly favored over the mantle which has a more bitter taste and chewy texture. Yields of adductor muscle from giant clams are deceptively small compared to the overall weight of the animal. For example, a three-year-old *T. derasa* that is 15 cm long and weighs around 500 g will only yield about 14 g of adductor muscle and a further 80 g of other edible meat (Watson and Heslinga, 1988). This is a matter for serious consideration if the animal is to be shipped whole over long distances since this high weight to meat yield ratio increases overall cost of the edible portion of the animal.

General methods of giant clam preparation are as follows:

1. *Sushi and sashimi dishes:* The giant clams used in almost all restaurant dishes and most home prepared meals are either raw or lightly marinated. Sushi and sashimi dishes using fresh clam meat are widely prepared because of their appeal to the Asian market and the high price they command. Aside from freshness, which is the most important aspect of serving raw clams, presentation is

paramount. The shell of the clam can play an important role in presentation, acting as a centerpiece or serving dish for the meal and also providing a souvenir for the diner. In some restaurants, the serving of a very large clam (greater than 30 cm) to a group of diners creates the center of attraction for the meal (John Gourley, personal communication).

Note: Giant clams are protected under CITES (see section Shipping on page 80) which regulates the trade in endangered species and therefore the use of the shell as souvenirs for overseas tourist diners may require certain documentation.

2. *Marinated dishes:* Cowan (1988) described a number of dishes where raw clam meat is soaked in vinegar or soy based marinades before being served with traditional garnishes of seaweed, ginger and carrot. Again, the use of the shell for serving can greatly enhance the presentation of such dishes.
3. *Cooked dishes:* Fresh giant clam meat can be used in stews, soups and also deep fried or sauteed. Use of fresh meat in this way is far less common because of the premium price placed on the raw product.
4. *Processed products:* Treating giant clam meat either by drying, smoking or pickling makes it easy to ship and can add value to the product (Trachet, 1989). In many parts of Asia and the Pacific, products of this nature using squid, shrimp and fish are regularly eaten as snacks giving instant recognition to similar products using giant clam meat. These products can also be used to flavor soups and stews.

Note: Giant clams sold in restaurants are often marketed through the use of display aquariums. Diners can select their own clam, which is removed from the tank and prepared fresh for eating.

Fresh versus frozen meat

Because of the remoteness of many clam farms from their intended market and the high price to air freight fresh product, there is an obvious niche for frozen meat that can be conveniently and cheaply shipped to its destination. While fresh meat sells at a premium to frozen meat, there is a distinct market for frozen meat for use in all types of clam cuisine. However, there are distinct differences in quality between frozen and fresh clam meat. In a sensory evaluation of fresh and frozen clam meat, fresh meat was found to be slightly preferable to frozen meat (Peavey and Riley,

1993). During the study, the frozen meat was found to have a distinct unpleasant odor upon thawing that had to be removed by rinsing the meat in seawater prior to serving. This could have a significant effect if frozen meat were not rinsed properly before use.

Domestic food markets for giant clams

Selling food clams in a local market greatly reduces many of the problems of exporting the product such as transportation and permitting. In many Indo-Pacific nations, the potential local market for giant clam meat is very large and is often related to the level of disposable income in the region (McConnaughey and S'ua, 1995). Alternatively, the presence of a tourist industry, especially from Asian countries, often means that giant clams can be sold in restaurants for higher prices than they would be sold for at market. Before a farmer decides to target a local food market, a number of factors must be considered:

1. *What is the demand by the general public for giant clams and how much are they willing to pay?* In many places, giant clams are still plentiful in the wild and thus have little value in the marketplace. Even if clams are difficult to obtain in an area, local people may not have the disposable income to pay a premium price for a farm-raised item that can take 2-6 years to reach market size.
2. *What is the tourist and restaurant demand for giant clams?* While there may not be a high demand for clams by the general public, farmers may find a good market for their clams in restaurants that cater to tourists or high paying customers (Peavey and Riley, 1992). For example, in Palau, the abundance of wild populations of clams results in little local demand, but demand remains high in the tourist market, which caters primarily to Asians.
3. *What is the optimum size and species required by the market?* Size and species chosen is important depending on the market. Some species do not occur in an area and are therefore less acceptable to the public. For example, the giant clam food trade in Japan is heavily reliant on *T. crocea* from the region of Okinawa. While *T. crocea* is a small, slow-growing species better suited for the aquarium industry, it accounts for 90% of the clams landed for food in Okinawa because of its regional acceptability (Okada, 1997).

The size of the local market for giant clams can be surprisingly large as illustrated by a study conducted in American Samoa. This territory receives very few tourists but has a relatively high per capita income and a shortage of clams in the local fishery. McConnaughey and S'ua (1995) estimated the annual demand for food clams in American Samoa to be at least 80,000 animals. This demand may be equally high in other areas of the Pacific Islands.

T. derasa is reportedly the fastest growing and most commonly used species for food in the Pacific Islands (Table 2). Although *T. gigas* has shown similar growth rates, they generally do not survive as well as *T. derasa*. *H. hippopus* is also a relatively fast growing species but has a slightly lower market acceptability than *T. derasa* (McConnaughey and S'ua, 1995).

Table 2. Expected sizes of *T. derasa*, stocked at a length of 5 cm, after different grow-out times in ocean culture.

Grow-out period (months)	Clam length (cm)
6	7-8
12	10-12
18	12-14
24	16-18
36	23-25

As with farming clams for the aquarium trade, the economics of running a food clam farm will be affected by a number of variables, not the least of which are the sale price and preferred sale size. The following simple example gives some basic information on potential returns for a lagoon-based operation growing *T. derasa* for local restaurant consumption.

Example 4. This model assumes the following:

1. The farm is located in an area that meets the criteria listed in this manual for an adequate ocean farm site.
2. The farm is located within paddling distance of the farmer's house so a powerboat is not required.
3. The farmer does not employ an assistant and maintains 150 cages.
4. The farmer uses a Hookah rig to maintain his clams.
5. The farmer spends 32 hours per month tending the farm.
6. The farm stocks yearling *T. derasa*, 5 cm in length, obtained from a local hatchery for \$1 each.
7. In full production, the farm consists of 150 MMDC style cages with a grow-out area of 0.25 m² each.

8. Grow-out time is 12 months with an average harvest size of 10-12 cm (growth rate 5 mm per month). Production target after 12 months is 320 clams per month.
9. Stocking density is 50 clams per cage with thinning to 25 clams per cage after 6 months.
10. Clams are marketed directly to local restaurants and delivered live in the shell for a wholesale price of \$3.00 each.
11. Clam survival from stocking to harvest is 80%.
12. All prices are in U.S. dollars.
13. The farm is operated by a single owner who takes salary from the profits.

Basic stocking and harvest protocol would be as follows:

Month 1: Stock 50 cages (Cohort 1) with 2500 clams (50 clams per cage). These are spread into a further 50 cages (100 cages in total) at month 6.

Month 6: Stock 50 cages (Cohort 2) with 2500 clams (50 clams per cage). These are spread into a further 50 cages (100 cages in total) at month 12.

Month 12: Begin monthly harvest and sale of month 1 clams (16-17 cages per month). Stock 50 cages (Cohort 3) with 2500 clams (50 clams per cage). These are spread into a further 50 cages (100 cages in total) at month 18 using empty cages from month 1 harvest.

See Table 3 below:

Table 3. Planting and harvesting schedule for a lagoon-based giant clam farm growing clams for local sale as food.

Month					
Cohort	1	6	12	18	24
1	Stock 50 cages	Thin to 100 cages	Begin harvest		
2		Stock 50 cages	Thin to 100 cages	Begin harvest	
3			Stock 50 cages	Thin to 100 cages	Begin harvest

After 6 months of operation, the operating costs on a yearly basis are as follows:

Hookah rig \$1,600 (5 year depreciation)	\$	320
Used pickup truck \$4,000 (5 year depreciation)	\$	800
Fuel for clam delivery (8 gallons per month)	\$	192
Miscellaneous expenses	\$	500
150 MMDC style cages @ \$15 ea. (5 year depreciation)*	\$	450
300 nursery trays @ \$1.25 ea. (5 year depreciation)*	\$	75
5000 seedling clams @ \$1.00 ea.	\$	5,000
TOTAL	\$	7,337

* Taken from Shang et al. (1992).

With average sales of 320 clams per month @ \$3 per piece:

Gross revenue per year = \$11,520

Profit before taxes = \$11,520 - \$7,337 = \$4,183

Break-even point for this model = 204 clams per month.

Export food markets for giant clams

There are a number of recognized, large export markets for giant clam meat as well as a number of smaller niche markets that could be filled. Any farmer wishing to target the export meat market for giant clams must consider many factors, some of which are listed below:

1. *What type of meat preparation is required?* Each market will require either adductor muscle, other soft tissue, whole clams with the shell or a combination of these. In addition, the preparation of the meat must be considered – live, fresh, frozen, dried, pickled or smoked.
2. *What is the size of the market?* Some markets for giant clam meat are extremely large. Any farm or country entering this market must consider whether they can supply all that market or just part of it. Importers in some countries will only consider buying minimum quantities of products such as clam meat. These minimum orders can be quite large. Consistency of supply is another issue to consider here. Importers often require a consistent supply of meat in order for them to be able to supply their own customers. Alternatively, a large amount of meat may be required at certain times of the year during festivals or holidays.
3. *What are the regulations on import of giant clam meat?* All giant clams are listed in Appendix II of CITES which requires certain documentation prior to import (see section Shipping on page 80). In addition, many countries unilaterally impose their own restrictions on import of giant clams. Health regulations must also be considered. Some countries require that imported shellfish (giant clams included) must meet certain health requirements. One such country is the United

States, which has stringent regulations on imported shellfish imposed by the U.S. Food and Drug Administration (Crawford, 1992). These regulations include monitoring the water where clams are grown and the clam processing facilities for bacterial and biotoxin contamination. Approximate costs for establishing such a program and operating it annually in a Pacific Island Nation are US\$48,000 and US\$25,000 respectively (Crawford, 1992). Despite these costs, the benefits of such a monitoring program could be large and extend further than just giant clam export. The United States represents one of the world's largest import markets for shellfish in general and a monitoring program for giant clams could also be used for the export of other shellfish. In addition, although many other importing countries do not have the same stringent regulations as the U.S., they will be much more willing to buy shellfish from a country that has a monitoring program in place.

4. *What is the cost of exporting the clams?* Depending on the desired preparation of the clams, shipping costs will vary dramatically. Live animals are the most expensive to ship because they must be air freighted. Frozen, dried or smoked meats can be cost-effectively shipped via surface routes.

Major markets for giant clam meat

Japan. Japan, with its large number of avid seafood consumers, represents the largest potential market for giant clam meat. However, giant clam meat is eaten almost exclusively in the southern island of Okinawa where small species, especially *T. crocea* are sold live, mainly to sushi bars. This market is estimated to be in excess of 500 tonnes/annum of whole clams. Giant clams are rarely eaten in mainland Japan but it is likely that marketing efforts in this area could open up a large demand for giant clam meat.

Like most of the Japanese seafood trade, a premium is put on freshness and presentation, requiring that the whole, live animals be air freighted into Japan. This is a major consideration for any exporter because the cost may be prohibitive. It is possible that there may be a market for air freighted meat without the shell as long as it is kept extremely fresh.

Note: Japan is one country that has imposed strict regulations on the import of giant clams. In 1992, Japanese authorities decided to allow importation of giant clams only from CITES member nations or from countries that have a certified government agency to act as a CITES office. Most Pacific Island nations are not signatory countries to the CITES treaty. Currently, Fiji, Tonga, Solomon Islands and Kiribati are the only Pacific Island Nations that can export giant clam products to Japan (Okada, 1997).

Taiwan. While the estimated market for clam adductor muscle in Taiwan is around 240 tonnes/annum, there is a preference for only large adductor muscle. As a result, the required long grow-out period combined with the price for the muscle alone would not make it feasible to grow clams for this market. However, by marketing the other products of the clam (shell and other edible tissue) this market may be viable. In 1988, Fiji exported 38 tonnes of clam meat, sending the adductor muscle to Taiwan and the mantle to New Zealand for consumption by Pacific Island immigrants (Tisdell and Tacconi, 1993). Export of wild clams from Fiji was later banned over concerns of excessive harvest depleting natural stocks. To supply this amount of adductor muscle using farmed clams, about 275,000 six-year-old *T. derasa* would have to be harvested each year in Fiji.

New Zealand, Australia and USA. A large amount of clam meat is imported into New Zealand, Australia and the USA to meet the demand from Pacific Island immigrants living there. It is estimated that a potential market of 1-3 thousand tonnes/annum exists for giant clam meat in New Zealand alone. Approximately 50% of the giant clams fished in Tonga are exported to Tongans living overseas (Tacconi and Tisdell, 1992).

Niche markets for giant clam meat

Niche markets occur for giant clams in many areas and it is hard to predict what may be a viable market. Positive indicators tend to be areas where there are large numbers of Asian visitors or residents. One such niche market is in Saipan, Commonwealth of the Northern Mariana Islands, which receives approximately 500,000 Asian tourists every year. Since Saipan has no giant clam fishery of its own, live clams were imported from farms in Palau and the Federated States of Micronesia to supply the restaurant trade. *T. derasa* (13-15 cm) were displayed in aquaria and sold for sushi and sashimi plates at a price of US\$21 per clam. The wholesaler received US\$10.50 per clam but had to cover the cost of buying and importing the clams from that sum (John Gourley, personal communication).

Marketing giant clam shells

The shells of many species of giant clams, especially the genus *Hippopus*, are more valuable than the meat. Nearly all giant clam shells have some commercial value as jewelry, dishes, planters, lamps or simply as an ornamental shell (Figures 53-55, page 78). A manual by Heslinga (1996) details the variety of ways to earn income from giant clam shells. While it is unlikely that a farmer or hatchery would grow giant clams purely to sell the shell, the extra income from utilizing the entire animal may be the deciding factor on whether or not a clam farm is viable.

One of the finest examples of the income earning potential from giant clam shells was the MMDC gift shop in Palau. Giant clam shells were manufactured into many different items, from lamps to earrings. These items were sold to a mainly Asian clientele in a gift shop that also marketed other tourist items such as t-shirts, books and maps.



Figure 52. T. derasa shells await cleaning before being used for ornaments at the PMDC in Palau. (Eileen Ellis).

Marketing shells need not involve the construction of a gift shop. In any area that has a tourist or gift trade, giant clam shell products can be added to an existing gift shop's product line. Another alternative to producing a finished item is simply to clean the shell and sell it to someone else to do the craft work. One market for shells can be found in the Philippines, which produces huge amounts of high quality shell craft very cheaply but often cannot get the raw shell because of chronic overharvesting of their own natural resources. The shell alone has many different uses such as decorative packaging for holding soaps or other toiletries, which are then wrapped in clear plastic.



Figure 53 (Left). Cleaned *T. derasa* shells are sold as household decorations at the PMDC in Palau. (Eileen Ellis)

Figure 54 (Right). Decorative lamp made from a pre-assembled base and a cleaned *H. hippopus* shell. (Simon Ellis).

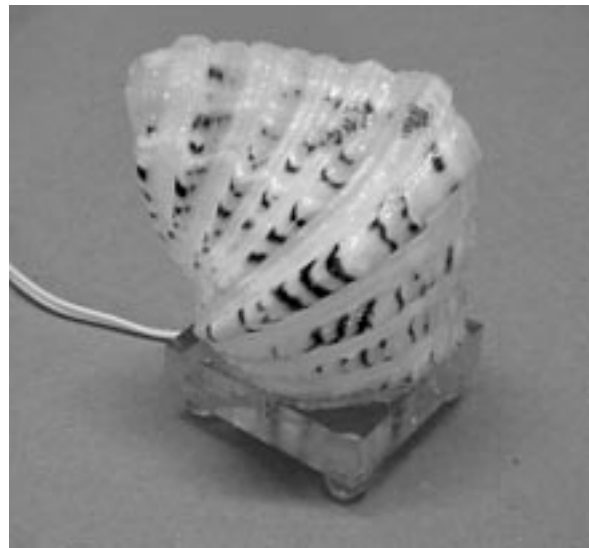


Figure 55 (Left). Wasabi dishes made from *T. derasa* shells target an Asian clientele at the PMDC gift shop, Palau. (Eileen Ellis).

Because of the global increase in tourism, especially in coastal areas, the world demand for souvenir shells is increasing. From the results of one marketing study (Shang et al., 1992), it appears that about 100,000 to 120,000 giant clam **valves** are sold annually in Australia. These are primarily sold as tourist souvenirs. During this study, *H. hippopus* was recorded as the most attractive shell having an estimated farm gate value of \$1.55 (both valves) for a 15-20 cm shell.

Marketing giant clams for stock enhancement

The initial interest in culturing giant clams stemmed from concerns related to the decline of wild stocks. Increasing coastal populations, pollution and improved harvesting efficiency (with powerboats and diving gear) are just some of the factors that have contributed to the collapse, and in some cases extinction, of local stocks of giant clams throughout their range. The initial intent of hatchery development was to reseed depleted reefs and reduce pressure on wild stocks by culturing the clams as a food source. While stock enhancement is primarily a goal of government run hatcheries at present, raising giant clams for this purpose may be of interest to conservation organizations and other non-government organizations in the future.

Since stock enhancement usually involves the supply of smaller animals, it will have the most income generating potential for organizations involved in the nursery phases of giant clam culture. A recent review of giant clam stock enhancement by Bell (1999) shows that results are highly variable depending on how the animals are stocked and cared for. Major sources of failure in enhancement efforts were attributed to predation, disease, poaching and lack of care. Despite extensive efforts in some countries, the success of stock enhancement efforts are still uncertain, mainly due to a lack of genetic markers that could identify progeny as having come from the restocked clams. One recommendation of the review was to put the stock enhancement effort in the hands of local clam farmers. By providing the care and protection for clam broodstock that farmers apply to their usual clam “crops,” there is an increased chance of sustained reproduction and recruitment to the reef of larvae from the protected clams.

Shipping

Permits, CITES and shipping documents

Many marine species have been assigned legal protection, both in their countries of origin and destination, that are designed to protect them from over-exploitation. The most wide-reaching of these conservation measures exists in the form of the Convention on International Trade in Endangered Species (CITES). While CITES is not a law in itself, any country that is a member of CITES must comply with standardized import and export documentation in order to monitor the trade in endangered species.

CITES has three appendices that provide varying degrees of protection to the species listed in each appendix. **All members of the giant clam family Tridacnidae are protected under Appendix II of CITES**, which provides protection for species that are not currently threatened with extinction but are regarded as being in danger of extinction if protection is not provided. Appendix II protects not only the living animal but any recognizable part of it, including the shell (Killelea-Almonte, 1992). Before exporting any species listed in Appendix II, an export permit must be issued stating the following:

1. The export will not be detrimental to the survival of the species.
2. The species was not obtained in contravention to the laws of the exporting State.
3. The method of export of living species will minimize the risk of injury, damage to health or cruel treatment.

Member countries of CITES are expected to comply with these specified levels of protection and ensure that nonmember countries comply in regard to any product imported or transshipped through a CITES member country. Most countries where giant clams are shipped are CITES member countries, including the USA, Japan and member countries of the European Union.

Nonmember countries of CITES (which include many Pacific Island and Pacific rim nations) must include an “in lieu of CITES” document with any export of a listed species to a CITES member country. This document is produced by the appropriate marine resource and management authority in the nonmember country.

An “in lieu of CITES” document must contain the following statement:

I _____, (signing official) hereby certify that the shipment of wildlife or plants covered by this document is in accordance with the laws of _____ (country), will not be detrimental to the survival of the species in the wild, and, if living, will be transported in a manner which will minimize the risk of injury, damage to health, or cruel treatment.

Note: While CITES provides minimum guidelines for import and export of endangered species, many countries choose to unilaterally impose more stringent protective measures. For example, in 1992, Japan stopped accepting “in lieu of CITES” documents from nonmember countries unless the exporting country had a suitable government agency to act as a CITES office. Of the Pacific Island Nations, only Fiji, Tonga, Solomon Islands and Kiribati are currently authorized to ship giant clams to Japan.

Further information can be obtained from:

The Office for Management Authority
U.S. Fish and Wildlife Service
4401 N. Fairfax Drive, Room 432
Arlington, Virginia 22203,
USA

OR

CITES Secretariat
6, Rue du Maupas
Casse Postale 78
CH-1000 Lausanne
Switzerland

It is extremely important that before targeting any particular giant clam market, thorough research be conducted into the local and international laws protecting that species. This applies not only in the country of origin but also in the target country for export. The local marine resources division of the country of origin should be able to supply the necessary information on what permits are required for exporting giant clam products. The buyer or importer of the clams will also be responsible for contacting the appropriate authorities to ensure that necessary permits accompany the shipment. Failure to send the proper permits and documents normally leads to impoundment or confiscation of the shipment.

Laws and regulations sometimes only apply to the wild collection of marine organisms. It is important to form a close relationship with local marine resources and management personnel so they are aware that the clams are farmed. Inviting marine resource personnel to periodically visit the farm is a good way to develop a cooperative and working relationship between the regulating agency and the farmer.

The following are documents that may need to accompany any export shipment of giant clams:

1. Original invoice listing the genus, number of animals in each genus, and the value of each animal. (A sample invoice is included in Appendix B.)
2. Export permit. (A sample export permit is included in Appendix B.)
3. Quarantine or veterinary inspection permit.
4. CITES or “in lieu of CITES” permit. (A sample “in lieu of CITES” document and a CITES permit are included in Appendix B.)
5. Airway bill.

Packing and shipping giant clams

Equipment

Shipping bags (1*, 10, 16, 13 and 26)
Shipping boxes (1 and 11)
Insulating, polystyrene sheet or boxes (1 and 12)
Oxygen cylinder (local rental from welding or medical supply company)
Oxygen regulator (1, 2 and 3)
12 mm ID polyethylene tubing (local and 1, 2, 3 or 4)
Rubber bands (local)
Tubing clamp or air nozzle (1, 2, 3, or 4)

* See Appendix A for supply sources.

General packing procedures

Giant clams are shipped overseas in plastic bags placed in insulated boxes to prevent large temperature fluctuations. There are two recognized methods for shipping giant clams, dry and wet packing. Dry packing is used for short journeys of up to 12 hours and wet packing for journeys of 12-48 hours.

Wet packing

Wet packing refers to submerging the clams in seawater for shipping. Each clam is packed individually in a plastic bag filled partially with clean seawater and pure oxygen. A general rule of thumb is to use a bag at least twice the



Figure 56. Shipping bag with newspaper insert. (Simon Ellis).



Figure 57. Farm technician filling a shipping bag with oxygen. (Simon Ellis).

size of the clam. For example, when shipping a clam 5 cm long, the sealed bag should be at least 10 cm x 10 cm. Two bags are used for each clam with a double-folded sheet of newspaper inserted between each bag (Figure 56, page 82). The newspaper helps to prevent tearing of the outer bag if the inner bag is punctured by a sharp piece of the shell.

Note: Some shippers will place more than one clam in a bag. This method reduces bag use and packing time but increases the risk of death by asphyxiation during shipping.

Approximately 1-3 hours prior to packing, the clams are removed from the grow-out tank to a separate tank and their valves are scrubbed with a stiff brush to remove any algae or other fouling organisms. This is very important as these fouling organisms consume oxygen or can die and foul the water. Care should be taken not to damage the byssal opening when scrubbing the clams by placing the thumb over the opening during cleaning.

Packing should take place as close to the time of the flight departure as possible. With practice, a packing crew can time the process to be completed within 1-2 hours of the airline's cargo acceptance cutoff time.

The clam is placed into the plastic bag and enough water is poured into the bag to barely cover the animal. The bag is now deflated and the end of the oxygen hose or nozzle is inserted into the neck. The opening of the bag is twisted around the tube or nozzle (Figure 57) and a jet of oxygen is squirted into the bag until an airspace has been created equivalent to approximately twice the water volume. The



Figure 58. Recommended oxygen nozzle shape and size. (Larry Sharron).

oxygen hose or nozzle is quickly removed and the top of the bag is twisted to keep the oxygen inside the bag. The neck is then secured with 2 to 3 rubber bands and the bag is placed in a cool place or directly into the shipping box. A thin, smooth nozzle such as the one shown in Figure 58 (page 83) makes filling the bags easier.



Figure 59. Cardboard shipping box showing polystyrene insulation, and sealed bags inflated with oxygen. (Simon Ellis).

Note: When shipping large numbers of animals, a production line approach is recommended. For example, with a crew of three people, one person should put the clams into the bags, one person should add the water and the third person should inflate the bags with oxygen and seal them.

When enough bags have been packed they are placed into the shipping box. These are made of corrugated cardboard and are generally cube shaped with 40-60 cm sides (Figure 59). The box is lined either with 19 mm sheet polystyrene or individual polystyrene

shipping boxes. In each case, a double tier of bags are packed in each cardboard box. If sheet polystyrene is used for insulation, a median sheet is placed on top of the first layer of bags and the next tier of bags is added. If polystyrene boxes are used, two boxes, half the height of the cardboard box, are inserted into the shipping box. An outer polyethylene bag is placed either inside the polystyrene sheeting or around the polystyrene shipping boxes before they are placed into the cardboard shipping box. This is simply an extra precaution against leakage and is often required by the airlines. Depending on the size of the clams, each shipping box should hold between 20 and 50 bags.

Note: If a buyer makes repeated complaints of excessive mortalities, some shipping trials should be conducted. During a shipping trial, the clams are packed as if for export but remain at the packing facility. Different packing methods such as oxygen:water ratios and hours in transit can then be tested to determine the best shipping method for the species in question.

Dry packing

Dry packed animals are packed in the same way as wet packed clams with the exception that they are not immersed in water. Instead, a pad of wet newspaper or tissue paper is placed in the shipping bag. This keeps the air moist but greatly reduces the water weight of wet packing. Dry packing is often used for short air journeys of larger food clams.

The buyer's role in shipping

Clam farmers will generally sell to an aquarium wholesaler, who buys large amounts of clams and resells them to retailers and sometimes other wholesalers. The buyer always pays the shipping costs on an order and therefore it is important to ensure that costs for transport are kept as low as possible. Shipping costs per animal are usually about the same price as the animal itself, so helping the buyer to get the cheapest shipping cost will help to ensure repeat business.

The first place to save money is on weight, which comes mainly from water. Keeping shipping water to a minimum while ensuring enough depth for healthy transit is therefore important.

Note: If there is any doubt as to how well clams will ship, then pack conservatively using slightly more water and a larger bag. A dead animal that was shipped cheaply is no good to anyone.

The second place to save money for the buyer is in the size of the shipment. Most carriers give reduced freight rates for cargo shipments of greater than 250 kg. This will equate to 12-15 boxes or 500-700 small clams in each order. It is important that the buyers know where the cutoff points for freight cost reductions are so that they can place a large enough order to save money. Helping buyers save money in this way helps to ensure future purchases from the farm.

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Glossary

Amino acids: the basic components of protein.

Benthic: referring to the ocean floor.

Biofouling: living organisms that encrust or clog thereby becoming a nuisance.

Bivalve mollusc: animal of the mollusc family with two shells that are hinged dorsally.

Byssal opening: area underneath the clam where it secretes threads that attach it to the substrate. This is area where predatory snails can enter the clam. The byssal opening is particularly large in *T. maxima*, *T. crocea* and *T. squamosa*.

Byssus: a tuft of long, tough filaments that certain bivalves use to attach themselves to the substrate.

Excurrent siphon: opening where water flows out of the clam after passing over the gills.

Fatty acids: one of the basic components in fats or lipids.

Fecund/fecundity: pertaining to the reproductive capability or number of eggs an animal can produce.

Foot valve: also called a check-valve, a spring-loaded valve placed in an intake pipe that closes when suction is lost and traps the remaining water in the pipe. This is used to assist in priming pumps after power outages and pump maintenance.

Gastropod: member of a large group of animals including snails.

Herbivorous: eating only plant material.

Hookah: a diving apparatus where the diver is supplied with air through a hose from a surface based compressor.

Incurrent siphon: opening where water is drawn into the clam.

Intertidal: occurring above the low tide mark and below the high tide mark.

Larval: referring to the earliest stages of an animal's development.

Mantle: portion of the animal responsible for secreting the shell; in the case of Tridacnids it is also the colored fleshy tissue that houses the zooxanthelle.

Metamorphosis: the physical transition of the clam from a larva to a juvenile.

Papillae: small protrusions on the skin.

Photosynthetic: pertaining to the ability to convert sunlight into energy, as in the case of plants.

Pollution: foreign matter that can cause harm in the environment to which it is introduced.

Proboscis: long flexible organ used for feeding purposes.

Reef tank: a home or commercial closed system tank display, designed to replicate life on coral reefs. These generally contain soft and hard corals, fish, live rock and other invertebrates.

SCUBA (Self Contained Underwater Breathing Apparatus): a diving apparatus where all the equipment needed for breathing underwater is attached to the diver, including a tank containing pressurized air.

Subtidal: occurring below the low tide mark.

Symbiotic: pertaining to the intimate living together of two different species, which is generally mutually beneficial to both parties.

Trochophore: a free-swimming ciliated larval stage typical of many marine invertebrates.

Turbidity: not clear or lacking in transparency.

Valve: one side of the shell of a bivalve.

Zooxanthelle: group of symbiotic dinoflagellate algae that live inside the cells of other animals such as giant clams and corals.

Appendix A. Suppliers listed in this manual

IMPORTANT NOTE: The following information is provided for convenience only and is not intended as an endorsement of any company or its products.

1. Aquatic Eco-systems Inc.
1767 Benbow Court
Apopka, FL 32703-7730, USA
Tel. 407-886-3939 or 1-800-422-3939
Fax. 407-886-6787
e-mail: aes@aquatic-eco.com
Website: <http://www.aquaticecosystems.com>
Comments: Suppliers of a large range of aquaculture and laboratory products.
2. Aquaculture Supply
33418 Old Saint Joe Road
Dade City, FL 33525, USA
Tel. 352-567-8540
Fax. 352-567-3742
e-mail: ASUSA@Aquaculture-Supply.com
Website: <http://www.Aquaculture-Supply.com>
Comments: Suppliers of a large range of aquaculture and laboratory products.
3. AREA
P.O.Box 901303
Homestead, FL 33090-1303, USA
Tel. 305-248-4205
Fax. 305-248-1756
e-mail: areainc@aol.com
Comments: Suppliers of a large range of aquaculture products.
4. Southern Aquaculture Supply
P.O. Box 326
931 Saint Mary's Street
Lake Village, AR 71653, USA
Tel. 1-800-850-7274
e-mail: sasi@cei.net; Website: <http://www.searkansas.com/aquaculture/index.htm>
Comments: Suppliers of a large range of aquaculture and laboratory products.
5. Pacer Pumps
41 Industrial Circle
Lancaster, PA 17601-5927, USA
Tel. 1-800-233-2861 or 717-656-2161
Fax. 717-656-0477
e-mail: pacer@success.net
Comments: Suppliers of a broad range of high quality pumps.
6. Advanced Aquatanks
525 West 130th Street
Los Angeles, CA 90061, USA
Tel. 310-538-4282
Fax. 310-538-9249
Comments: Suppliers of aquarium supplies.
7. West Marine (a.k.a. E + B Marine)
P.O. Box 50070
Watsonville, CA 95077, USA
Tel. 1-800-262-8464
Fax. 831-761-4421
Comments: Suppliers of a full line of fiberglass and marine products.
8. Performance Diver
One Performance Way
Chapel Hill, NC 27514, USA
Tel. 1-800-933-2299
e-mail: service@performancediver.com
Website: www.performancediver.com
Comments: Suppliers of a full range of dive equipment.
9. Brownies Third Lung
940 N.W. 1st St.
Fort Lauderdale, FL 33311, USA
Tel. 954-462-5570
Fax. 954-462-6115
Comments: Supplier of hookah rings.
10. Koolau Distributors
1344 Mookaula St.
Honolulu, HI 96817, USA
Tel. 808-842-3701
Comments: Suppliers of plastic transport bags.

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| <p>11. Pacific Allied Products
91-110 Koami Loop
Ewa Beach, HI 96782, USA
Tel. 808-682-2038
<i>Comments: Suppliers of transport boxes.</i></p> | <p>12. Marnika's Packaging Company
2370 Research Drive
Livermore, CA 94550, USA
Tel. 510-373-0283
Fax. 510-449-9146
<i>Comments: Suppliers of insulation foam sheeting for shipping.</i></p> |
| <p>13. Memphis Net and Twine Company
2481 Matthews Ave.
P.O. Box 8331
Memphis, Tennessee 38108, USA
Tel. 901-458-2656
Fax. 901-458-1601
e-mail: memnet@netten.net.
<i>Comments: Suppliers of plastic mesh, heavy duty fish baskets and polyethylene shipping bags.</i></p> | <p>14. Carolina Biological Supply Company
2700 York Road
Burlington, NC 27215, USA
Tel. 1-800-334-5551
Fax. 1-800-222-7112
<i>Comments: Suppliers of basic laboratory equipment and animal specimens.</i></p> |
| <p>15. Chemaqua
P.O. Box 2457
Oxnard, CA 93033, USA
Tel. 805-486-5319
Fax. 805-486-2491
<i>Comments: Suppliers of chemicals for shipping and treatment.</i></p> | <p>16. U.S. Plastics Corp.
1390 Neubrecht Road
Liima, OH 45801-3196, USA
Tel. 1-800-769-1157
Fax. 1-800-854-5498
e-mail: usp@usplastic.com
website: www.usplastic.com
<i>Comments: Suppliers of a wide range of plastic products including shipping bags.</i></p> |
| <p>17. Quill Corporation
P.O. Box 94081
Palatine, IL 60094-4081, USA
Tel. 1-800-789-1331
Fax. 1-800-789-8955
web site: http://www.quillcorp.com
<i>Comments: Suppliers of a wide range of office equipment.</i></p> | <p>18. Barnett
P.O. Box 2317
Jacksonville, FL 32203-2317, USA
Tel. 1-800-288-2000
Fax. 1-800-288-2828
<i>Comments: Suppliers of a wide range of plumbing, electrical and hardware supplies.</i></p> |
| <p>19. Koolau Distributors
1344 Mookaula St.
Honolulu, HI 96817, USA
Tel. 808-842-3701
<i>Comments: Suppliers of plastic transport bags.</i></p> | <p>20. E. C. Shepherd Co. Inc.
2221 Canada Dry Street
Houston, TX 77023, USA
Tel. 713-928-3763
Fax. 713-928-2324
e-mail: cesco@main.com
<i>Comments: Suppliers of vinyl-coated wire for cage building.</i></p> |
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Nursery and Grow-out Techniques for Giant Clams

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| <p>21. E. C. Geiger
P.O. Box 285
Harleysville, PA 19438, USA
Tel. 1-800-443-4437 or 215-256-6511
Fax. 215-256-6110
e-mail: dsalettel@hortnet.com
Website: www.hortnet.com/ecgeiger
<i>Comments: Suppliers of horticulture supplies such as nursery trays and shade tarp.</i></p> | <p>22. AFCO Plastics Inc.
P.O. Box 5492
Fullerton, CA 92635, USA
Tel. 714-773-4046
Fax. 714-688-0263
e-mail: afcoplastics@worldnet.att.net
<i>Comments: Suppliers of nursery trays.</i></p> |
| <p>23. Harbor Freight Tools
3491 Mission Oaks
P.O. Box 6010
Camarillo, CA 93011, USA
Tel. 1-800-423-2567
Fax. 1-800-905-5220
e-mail: cs@harborfreight.com
Website: www.harborfreight.com
<i>Comments: Suppliers of a full line of professional tools.</i></p> | <p>24. Forestry Suppliers Inc.
P.O. Box 8397
Jackson, MS 39284-8397
Tel. 1-800-647-5368
Fax. 1-800-543-4203
Website: www.forestry-suppliers.com
<i>Comments: Suppliers of field supplies such as calipers and waterproof paper.</i></p> |
| <p>25. Microwarehouse
47 Water Street
Norwalk, CT 96854-9958, USA
Tel. 1-800-696-1727
Fax. 1-201-855-1386
Website: www.warehouse.com
<i>Comments: Suppliers of a complete range of computers (Mac and PC), peripherals and software.</i></p> | <p>26. Plastic Bagmart
Tel. 1-800-833-3751
e-mail: bagmart@mindspring.com
Website: www.bagmart.com
<i>Comments: Web-based suppliers of a wide range of plastic bags for shipping.</i></p> |

Appendix B: Examples of shipping documents

Sample invoice showing necessary shipping information:

From:	Address of shipper	To:	Address of buyer
e.g.	Pleasant Clam Farm	e.g.	Contented Clam Buyer
	Tropical Paradise Way		110 Main Street
	Pohnpei		Anytown
	Federated States of Micronesia		USA
	Tel. 691-555-4329		Tel. 987-320-FISH
	Fax. 691-555-2657		Fax. 987-320-CLAM
			Attention: John Doe

Quantity	Common name	Scientific name	Price (US\$)	Total (US\$)
130	Giant clam (7-10 cm)	<i>Tridacna derasa</i>	3.00	390.00
210	Giant clam (5-7 cm)	<i>Tridacna derasa</i>	2.50	525.00
80	Giant clam (5-7 cm)	<i>Tridacna maxima</i>	4.00	320.00
105	Giant clam (7-10 cm)	<i>Tridacna maxima</i>	7.00	735.00
15	Giant clam (10-13 cm)	<i>Tridacna maxima</i>	10.00	150.00

Total livestock		\$2,120.00
Box charge ^a	15 boxes @10.00 per box	\$ 150.00
Handling ^b		\$ 50.00
Freight ^c	405 kg @ \$4.00/kg	\$1,620.00

^a Box charge includes the cost of the box, polystyrene insulation, bags, shipping, chemicals and oxygen.

^b Handling charge includes cost of labor for extra packers.

^c Note how much the shipping costs are relative to the livestock. This cost must be included in the buyer's reselling price.

Sample combination export permit and "in lieu of CITES" document issued with clam shipments from the FSM National Aquaculture Center in Kosrae:

	FSM NATIONAL AQUACULTURE CENTER DEPARTMENT OF RESOURCES & DEVELOPMENT P. O. BOX 11 KOSRAE STATE, FSM 96944
NATIONAL AQUACULTURE CENTER EXPORT DOCUMENT <i>and</i> CERTIFICATE OF ORIGIN	
This shipment contains _____ giant clams from the National Aquaculture Center (NAC) located in Tofol, Kosrae State, Federated States of Micronesia (FSM). The production and support of giant clam culture is an approved FSM Government project and is in compliance with all the laws and regulations of the Federated States of Micronesia, as verified by the authorized signature identified below.	
SHIPMENT DATA SUMMARY	
1. SHIPMENT and/or INVOICE NUMBER	_____
2. SHIPMENT DATE	_____
3. DESTINATION	_____
4. SPECIES	C O P Y _____
5. NUMBER SENT	_____
These giant clams have been inspected by National Aquaculture Center personnel and to the best of our knowledge are FREE of disease, pathogens and parasites.	
I hereby certify that the shipment of giant clams covered by this document is in accordance with the laws of the Federated States of Micronesia, will not be detrimental to the survival of the species in the wild, and if living, will be transported in a manner which will minimize the risk of injury, damage of health, or cruel treatment of this animal, and will not be detrimental to the survival and economic well being of the Federated States of Micronesia.	
Approved by:	
Kevan Charley, Acting Manager National Aquaculture Center	OR Moses A. Nelson, Administrator Marine Resources Division

Appendix C. Buyers of invertebrates for the marine aquarium trade

IMPORTANT NOTE: *The following information is provided for convenience only and is not intended as an endorsement of any company or its products.*

Black Coral Hawaii, 2941 W. Central Ave., Bldg A and B, Santa Ana, CA 92704
Tel. 714-754-6368, Fax. 714-754-5432, e-mail: coralfish@aol.com

Caribbean Creatures, 112 Peace Ave., Tavernier, FL 33070
Tel. 305-852-3991, Fax. 305-852-3149, e-mail: drfish@bridge.net
website: caribbeancreatures.com

Dynasty Marine Associates, 10602 7th Ave. Gulf, Marathon, FL 33050
Tel. 305-743-7666, Fax. 305-743-9063

Fish Collection, Miami, USA. Tel. 305-944-3416, e-mail: fishguys2@aol.com

Global Fish Net
Tel. 714-229-9910, Fax. 714-229-9919, e-mail: gfn@earthlink.net

Golden Generation Inc., 13033 Yukon Ave., Hawthorne, CA 90250
Tel. 310-219-0215, Fax. 310-219-0401, e-mail: saltfish1@aol.com

Harbor Aquatics, 927 N. 200 W, Valparaiso, IN 46385, USA
Tel. 219-764-4404, Fax. 219-763-4866, website: www.harboraquatics.com

Holiday Coral and Fish, 334 Fir Rd., Niles, MI 49120, USA
Tel. 616-684-3380, Fax 616-684-3244

Living Seas Wholesale, 2081 S.W. 70th Ave., H20-21, Davie, FL 33317
Tel. 954-452-2977, Fax. 954-452-5977

Reef Sciences International, 3494 Camino, Tassajara Rd., Suite 322, Danville, CA 94506, USA. Tel. 510-735-3258, Fax 510-735-6289, website: www.reefscience.com, e-mail: feedback@reefscience.com.

Sea Dwelling Creatures, 12583 Crenshaw Blvd., Hawthorne, CA 90250, USA
Tel. 310-676-9697, Fax. 310-676-9699, e-mail: sdcinc@earthlink.net

Total Marine Aquarium, 615-A North Avenue, New Rochelle, NY 10801
Tel. 914-632-0889, Fax. 914-632-0652, e-mail: 102403.1354@compuserve.com

Underwater World Enterprises, 5242 W. 104th St., Los Angeles, CA 90045
Tel. 310-670-1502, Fax. 310-216-2948

Walt Smith International Ltd., P.O.Box 4466, Lautoka, Fiji Islands
Tel. 679-665-045, fax 679-667-591, e-mail: wsi@is.com.fj

Wayne's Ocean World, 99-899 Iwaena St., Unit 103, Honolulu, HI 96701
Tel. 808-484-1144, Fax. 808-484-1145

World of Aquatics, 525 Jubilee St., Emmaus, PA 18049
Tel. 610-967-1456, Fax. 610-967-4228

World Wide Pet Supply
Tel. 888-800-PETS, website: mailorderpetsupply.com