CTSA Publication No. 147

Recent Advances in Lagoon-based Farming Practices for Eight Species of Commercially Valuable Hard and Soft Corals - A Technical Report

Simon Ellis
Eileen Ellis

CENTER
FOR
TROPICAL
AND
SUBTROPICAL
AQUACULTURE

Recent Advances in Lagoon-based Farming Practices for Eight Species of Commercially Valuable Hard and Soft Corals - A Technical Report

Simon Ellis
Eileen Ellis

Center for Tropical and Subtropical Aquaculture
Publication No. 147

March 2002

Table of Contents

Acknowledgments **1**

Foreword **2**

Introduction **3**
About this publication 3
The world market for live corals 4
Coral species used in the study 5

Site selection **9**
Test sites 9

Advances in farm structure **11**
A modular approach 11
Use of cages 14

Broodstock **15**
Advances in broodstock collection and transport 15
Recommendations for the test species 16
Placing broodstock at the farm sites 17
Broodstock regeneration and the case for in situ collection versus on-site holding of broodstock 18

Culture techniques **26**
Substrates and their manufacture 26
Cutting 31
Attachment and planting methods 33

Growout and husbandry **37**
Growth rates and patterns 37
Positioning and stocking density 44

Diseases and pests **45**
Pests 45

Diseases 45

Harvest and transport 46
Holding in the land-based facility 47

Shipping 48
Specific packing instructions 48
Permits, CITES and shipping documents 49

Industry feedback 50
General comments 50
Specific comments 50

A revised economic model for coral farming in Pohnpei using recommendations from this study. 52
Capital costs 53
Operating costs 53

Species summaries 55
Lemnalia 55
Green polyped Sarcophyton 55
Long polyped Sarcophyton 56
Pachyclavularia 56
Acropora 57
Porites 57
Turbinaria 58
Euphyllia 58

References 59

Acknowledgments

This publication was prepared as part of the work under a project titled “Aquaculture Research, Extension and Training Support in the U.S. Affiliated Pacific Islands - Year 12.” Funding was provided by the Center for Tropical and Subtropical Aquaculture (CTSA) through a grant from the Cooperative State Research, Education, and Extension Service of the U.S. Department of Agriculture (grant #99-38500-7399). The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Department of Agriculture, the Center for Tropical and Subtropical Aquaculture or any staff of those agencies.

Thanks go to the following for their assistance and input to this project:

The staff of the Marine and Environmental Research Institute of Pohnpei (MERIP) for providing facilities and staff assistance for this work. In particular, Gregory Muckenhaupt S.J., Tyler McAdam, Stacy Maenner, Susan O’Connor and John Tomczuk.

Private sector individuals, Roderick Bourke of Robert Reimers Enterprises, Joy Meadows of Harbor Aquatics and Butch Almberg of Reef Rascals, for their advice and feedback.

The Australian Embassy Pohnpei for use of their boat to collect specimens from Pakin Atoll.

Dr. Philip Alderslade for coral identifications.

Kai Lee Awaya of CTSA for editing this manual and for printing assistance.

Foreword

The information presented in this publication was derived directly from a collaborative research project on lagoon-based farming of corals. Collaborators were CTSA, MERIP and the College of Micronesia - Land Grant Program. While farming practices for the species covered are not fully complete, information provided herein is designed to provide the reader with as much field derived data as possible for establishing a commercially viable coral farm. In addition, many of the farming techniques described can have direct application to other coral species with similar morphology and growth characteristics. This report assumes the reader to have some general knowledge of the benefits and basic aspects of coral farming as outlined in CTSA Publication #137 "The Culture of Soft Corals (Order: Alcyonacea) for the Marine Aquarium Trade." It is advisable to be familiar with this publication in order to fully utilize the information contained herein. Publication #137 can be downloaded from the CTSA website (http://library.kcc.hawaii.edu/CTSA) or ordered from the address below.

Center for Tropical and Subtropical Aquaculture
The Oceanic Institute
41-202 Kalanianaole Highway
Waimanalo, HI 96795, USA
Tel. 808-259-3168
Fax. 808-259-8395
e-mail: aclegg@oceanicinstitute.org

Introduction

About this publication

This publication reports directly on the results of an 18-month research study into the specific farming practices of eight species of commercially valuable hard and soft corals in Pohnpei, Federated States of Micronesia (FSM). Four species of hard coral and four species of soft coral were selected for the trial using the following criteria:

1. The corals are attractive and are regularly kept as aquarium specimens (as determined by reference to aquarist texts such as Puterbaugh and Borneman, 1996; Sprung and Delbeek, 1997; Delbeek and Sprung, 1994; Wilkens and Birkholz, 1992 and personal communication with aquarium wholesalers and aquarium hobbyists).
2. Corals that are hardy enough to be kept by aquarists with average experience and standard equipment.
3. Corals that are abundant enough in and around Pohnpei lagoon and its associated atolls to supply broodstock for an industry.
4. Corals that are photosynthetic.

Through a combination of field observations, growth and attachment trials, liaison with wholesalers and shipping and marketing trials this report strives to remove some of the unknown factors from coral farming, thereby making it easier for prospective farmers to enter this new field. Detailed for each species are the most efficient cutting and planting methods, survival and growth data, broodstock regeneration times, refined shipping methods, market acceptance information and a general price range derived from actual sales of the product in the United States. While this information is based on observations in Pohnpei, FSM it has wide ranging applicability to the rest of the Indo-Pacific region.

Throughout this report, reference will be made to CTSA publication #137 “The Culture of Soft Corals (Order: Alcyonacea) for the Marine Aquarium Trade”. Publication #137 provides much of the basic background and rationale for coral farming in general and is best used as a prefacing companion to this publication. Details of how to obtain CTSA publication #137 are given in the Foreword on page 2.

IMPORTANT NOTE: Before starting a coral cultivation project, it is critically important to become familiar with local and international laws regarding the collection, cultivation and possession of live corals. Please contact local government agencies to obtain information regarding current regulations.

The world market for live corals

Most of the live corals collected or farmed around the world supply the marine aquarium trade. Over 90% of live corals are shipped to the United States which had an estimated 560,000 tropical marine aquaria in 1999, a figure that is growing at 20% per annum. The growth in the marine aquarium hobby has been triggered primarily by vast improvements in aquarium technology which allow an increasing number of marine invertebrates to be kept alive in home aquaria. The percentage of live coral exports as a proportion of the total global trade grew from approximately 5% in 1991 to 53% in 1997 (Green and Shirley, 1999). It is currently estimated that there are some 1 million pieces of hard coral and 6 million pieces of soft coral residing in US marine aquaria.

In recent years there has been increasing concern over the effect that wild collection of corals is having on reef health in developing nations. It is not so much the effect of this one activity that is worrisome but rather that it is adding to manifold other pressures on coral reefs such as destructive fishing and development practices. As a standalone industry, wild collection of corals for the aquarium industry could be a highly sustainable practice, especially considering that it is a finite market and has one of the highest economic returns for the environmental impact.

Mariculture or farming of corals has the potential to reduce the number of corals being collected from the wild. Many corals reproduce using a process called fragmentation where a small piece of coral breaks away from the main colony and forms a new colony on its own (Highsmith, 1982). The majority of coral farming makes use of this simple procedure. Despite the large potential for farming of corals only 0.03% of corals sold for marine aquarium use today are estimated to be farmed and with those that are collected, demand currently outweighs supply (Green and Shirley, 1999).

The case for culturing corals rather than collecting them is one of conservation and sustainability versus economics. Wild collection offers an instantaneous return on investment whereas farming requires some investment and a period of time before harvest can begin. However, in the long-term, farming can offer more stable income, the ability to grow large quantities of rarer, high value species, reduced operating costs and a more sustainable future for the industry in general.

Coral species used in the study

Using the criteria listed on page 3, four species of hard coral and four species of soft coral were chosen for the study. These species were chosen as the most likely candidates for successful farming and also as a diverse group of corals that would provide a well rounded product line for a commercial farm based in Pohnpei. Because coral diversity is not as high in Pohnpei as it is in the Philippines, Palau, Indonesia and other parts of the Indo-Pacific, the corals that might be chosen in each area are likley to differ.

Species chosen were:

Soft corals

1. Long polyped leather or mushroom coral (*Sarcophyton spp.)**. This species is abundant in Pohnpei lagoon and surrounds. It is found primarily in areas with high water exchange such as channels and cuts. Color is brown/beige with large polyps that when extended are also beige in color and move in the current (Figure 1, page 6). Long polyp *Sarcophytons* generally resemble a mushroom or toadstool. They are hardy and are recommended for standard marine aquaria and beginners. Level of difficulty of care is 2 on a scale of 1 to 10 with 1 being easiest (Puterbaugh and Borneman, 1996).
* Soft corals in general, and members of the genus *Sarcophyton* and *Lobophytum* in particular, are notoriously difficult to identify and distinguish between. Identification of species to genus level for soft corals is usually acceptable for export permits and shipping documents.

2. Green polyped leather coral *(Sarcophyton spp.*). This species is much less abundant in Pohnpei than the Long polyp *Sarcophyton* and occurs in deeper parts of similar habitats. This species has a much shorter stalk and polyps than the Long polyp *Sarcophyton* but has bright green polyps that remain extended much of the time (Figure 2, page 6). It can tolerate low light levels and poor water quality making it suitable for beginners and expert hobbyists alike. Level of difficulty of care is 2 on a scale of 1 to 10 with 1 being easiest (Puterbaugh and Borneman, 1996).

Figure 1. Long polyp Sarcophyton *broodstock*

Figure 2. Green polyp Sarcophyton *broodstock*

Figure 3. Lemnalia broodstock

Figure 4. Pachyclavularia *broodstock*

Figure 5. Acropora *broodstock*

Figure 6. Porites *broodstock*

Figure 7. Euphyllia *broodstock*

Figure 8. Turbinaria *broodstock*

3. Brown tree coral (*Lemnalia spp.*). This species is abundant in Pohnpei lagoon and surrounding areas. It has a brown/beige color and a branching or arborescent appearance (Figure 3, page 6). Abundance is greatest on shallow, well flushed reef flats although it also occurs at depth in cuts and channels. A poor shipper, this coral thrives once established in aquaria. Level of difficulty of care is 5 on a scale of 1 to 10 with 1 being easiest (Puterbaugh and Borneman, 1996).

4. Green star polyps (*Pachyclavularia violacea*). This species is a stoloniferan coral in the family Tubiporidae (formerly classified as *Clavularia*). It is characterized by green/brown polyps protruding from an encrusting purple mat (Figure 4, page 6). This coral was located off Pakin Atoll (25 miles NW of Pohnpei) at a depth of 15-20 meters in very turbulent water. Although it has not been located in or around Pohnpei lagoon, it is quite abundant in the Pakin area. *Pachyclavularia* is a hardy species that does well in aquaria provided there is a strong flow of water. Unlike most other corals, *Pachyclavularia* is unable to repel filamentous algae and detritus from its skeleton, which can be problematic. Because it is an encrusting species it can encroach on other living corals in an aquarium and may need to be controlled (Sprung and Delbeek, 1997). Level of difficulty of care is 1 on a scale of 1 to 10 with 1 being easiest (Puterbaugh and Borneman, 1996).

Hard corals

5. Blue tipped *Acropora* (*Acropora nasuta*). This species is found in abundance on shallow reef flats and inner reef edges with high water movement and light intensity. It is characterized by a light brown color with bright blue growth areas on the tips and fringes of the base (Figure 5, page 7). In aquaria, it needs strong lighting and high water flow. It is not recommended for beginners and has a level of difficulty of care of 6-8 on a scale of 1 to 10 with 1 being easiest (Puterbaugh and Borneman, 1996).

6. Yellow finger coral (*Porites cylindrica*). This species is extremely abundant in Pohnpei lagoon occurring primarily in shallow areas of the inner fringing reefs. It is tolerant of poor water quality and can be found in turbid and slow moving waters. *Porites cylindrica* is characterized by a branched, finger coral structure and a green/yellow color (Figure 6, page 7). Like the *Acropora* it requires strong light and is not recommended for novices. Level of difficulty of care is 8 on a scale of 1 to 10 with 1 being easiest (Puterbaugh and Borneman, 1996).

7. Hammer or anchor coral (*Euphyllia ancora*). This species is only moderately abundant in Pohnpei and occurs in poorly lit, turbid areas of the inner lagoon in large colonies. It is characterized by single large polyps with beige, hammer shaped tentacles on a skeletal stem (Figure 7, page 7). Because these corals favor lower light and water flow they are easier to keep in aquaria. Level of difficulty of care is 5 on a scale of 1 to 10 with 1 being easiest (Puterbaugh and Borneman, 1996).

8. Yellow lettuce or scroll coral (*Turbinaria reniformis*). This coral is moderately abundant in Pohnpei and surrounding areas, occurring mainly on well flushed shallow reef flats and at depth of up to 20 m in fast flowing channels and cuts. It is characterized by a bright yellow color and a curved or scroll like shape in larger colonies (Figure 8, page 7). These corals require high light intensity and water flow in the aquarium making them unsuitable for beginners. Level of difficulty of care is 8 on a scale of 1 to 10 with 1 being easiest (Puterbaugh and Borneman, 1996).

Site selection

Test sites

In order to evaluate how the eight test species would grow in conditions of varying light, current, turbidity and nutrient load, corals were grown under identical conditions at three different sites. Recommendations for growout sites for the test species are based on observations taken from these sites. Where species grew and survived well at one or more sites, general recommendations from all those sites are made.

Site conditions were as follows:

Site 1 was close to the mouth of a shallow eutrophic bay lined with mangrove forest. The substrate was a dark silt/sand mixture and coral cover was sparse consisting primarily of *Porites* heads, *Goniopora* and low light tolerant species such as *Plerogyra, Physogyra* and *Lobophyllia*. Of the species tested only *Turbinaria reneformis* was found in the general vicinity. Light penetration (mean 19,676 lux) was comparatively poor, and turbidity and nutrient load comparatively high. Average depth for growout was 4.61 m. While unidirectional water flow only averaged 2.04 cm/sec, this site also received wave surge in rough weather leading to increased water movement around the corals.

Site 2 was close to the barrier reef and received very high flows of fresh ocean water on the flood tide. Located in an open sandy channel running down the side of a barrier reef island it was quite protected on three sides from severe weather. Average depth for growout was 4.24 m. The substrate was a fine white sand. Light penetration was comparatively higher (mean 29,553 lux) and unidirectional water flow the highest of the three sites (mean 10.53 cm/sec). Surrounding coral cover consisted mainly of fire corals (*Millepora*). Of the corals tested only *Porites cylindrica* was found in the general vicinity.

Site 3 was midway between the barrier reef and the island of Pohnpei. This site was characterized by limited water movement (mean 1.62 cm/sec) and comparatively high light intensity (mean 50,484 lux). Average depth for growout was 3.84 m. Coral cover at this site was exceptionally high with large colonies of *Porites*, *Lobophyllia*, *Montipora*, *Goniopora*, *Pachyseris* and *Pavona*. Of the species tested only *Porites cylindrica* was found in the general vicinity.

Depth

All sites were in 3-5 m of water. A minimum depth of about 4 m helped in keeping the corals away from excessive light intensity, rapid changes in temperature and high wave action. This depth also made it easy to work on the farm using either snorkel or SCUBA equipment. Species kept in water shallower than 4 m showed a lightening in color or bleaching presumably caused by elevated temperature and light levels.

SCUBA or Hookah versus snorkeling

All facets of farm operation, with the exception of broodstock collections for deeper water species were designed so that diving equipment such as hookah or SCUBA is no longer necessary. However, the investment in diving gear should be considered carefully as it can save a substantial amount of time because workers are not interrupted by constantly having to surface for air.

Advances in farm structure

A modular approach

Previous recommendations for constructing farms has centered around the use of various forms of containment such as nursery trays, milk crates and PVC pipe placed on the substrate. This method has a number of pros and cons. The primary benefit to making farms in this way is that construction is quick and inexpensive.

However, in Pohnpei lagoon this method has a number of drawbacks that in the long run can waste time and cause coral mortality. Pohnpei lagoon is characterized by shallow reef flats that drop sharply to the lagoon floor. Consequently there is little flat area in the 4-5 m range to do coral farming. Those areas that are suitable are generally sandy or silty and have large populations of burrowing shrimp and polychaete worms. The mounds of sand produced by the burrows can either smother a tray or tilt it so that corals fall over or move to one side of the tray. In addition, trays placed on the sand in areas of high water flow quickly sink into the sand. Constant maintenance of these trays is troublesome and time consuming.

To overcome this problem and also to standardize the growout of the test species at each site, tables or trestles were constructed out of locally available 13.5 mm diameter iron reinforcing bar (re-bar). These tables allowed the farming of corals on sloping reef faces (Figure 9) as well as sandy and silty areas (Figure 10).

Figure 9. Tables placed on a sloping reef face.

Figure 10. Tables placed on a flat sandy bottom.

Figure 11. Concrete "boot" on table leg.

In sloping areas the legs were buried in the sand until the table surface was flat and in sandy areas concrete "boots" (Figure 11) were attached to the legs of the table to stop them from sinking. This proved highly effective even in very high flow areas. Boots were made by placing a piece of 10-cm diameter PVC pipe or the bottom of a plastic soft drink bottle approximately 25 cm long over the bottom of the leg and filling it with concrete.

The cost of manufacturing the tables was approximately US$25 each including labor and materials. Given a predicted 5-year life span and that each table can hold up to 160 corals the cost of manufacture was not considered excessive given the benefits of their use. The modular concept of using tables also allows streamlining of the farming process and less work to keep track of inventory.

Up to 4 tables could be carried on the work boat (Figure 12) during any one outing. Tables were easily deployed at the work site either by lowering them to the substrate from the boat or using floats to move them into place then lowering them to the bottom. This latter technique was particularly effective in areas of high coral growth. Tables could be lowered into small sand patches on the reef slope without impacting the surrounding coral.

Figure 12. Standard workboat common in Pohnpei.

Figure 13. Farm workers at a table.

Tables were constructed to fit 8 – 25 x 50 cm standard nursery trays which were each filled with 4 liters of basalt gravel. Gravel was pre-washed and measured into polyethylene bags (Figure 12) prior to deployment in order to reduce underwater working time. Gravel was placed in the trays even if another attachment substrate was being used for the corals. This added weight to the trays and allowed substrates to be nestled down in the gravel providing more stability to the corals in high currents or wave action. The tables also proved to be a comfortable and easy platform to work on, providing a stable area for divers to cut, plant and attach corals thereby improving working efficiency (Figure 13). A full table with trays, gravel and corals could also easily be picked up underwater and moved by two workers.

Use of tables had a number of environmentally beneficial effects. Firstly, the use of tables allowed coral culture to take place in areas that would otherwise be impractical for farming due to a sloping or poor substrate. This effectively removed the farming process from reef areas where it might impact the reef itself or otherwise interfere with cultural- or tourism-related reef activities such as fishing, snorkeling or diving. Secondly these tables form their own mini-reefs recruiting large numbers of reef fish to settle from the plankton and grow up in the area.

Table dimensions are as follows:

Legs – 0.9 m
Width – 1.1 m
Length – 1.1 m
Center struts – 27 cm apart
Curved ends – 27 cm apart

Use of cages

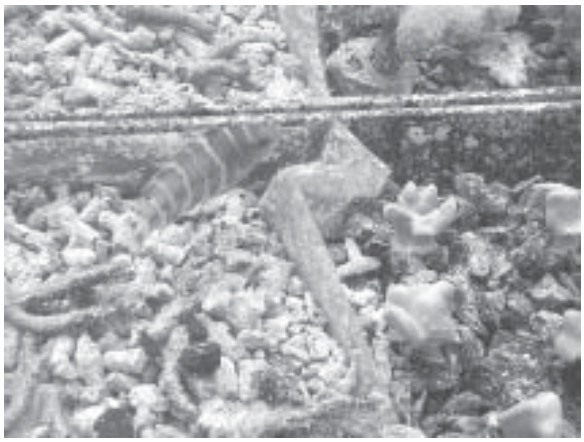


Figure 14. Fish foraging in coral trays.

While predation was rarely a problem during the study, seacucumbers, hermit crabs and large fish often interfered with the corals (Figure 14). Grazing activities of these animals tended to knock the corals over, causing blemishes, reduced growth and extra work to re-right them. To overcome this problem cages designed to house giant clams were tested (Figure 15). The use of the cages provided excellent protection for the corals reducing disturbance to a minimum. Cage tops were attached loosely so that access to the corals was easy. However, the cage tops do need to be scrubbed every two weeks to remove fouling, a job taking some 30-45 seconds per cage. Another advantage to using cages was that a simpler table design (also originally used with giant clams) could be employed (Figure 16). This table requires only 4 pieces of re-bar and can be made without the use of welding equipment. Details on design and construction of this trestle can be found in Ellis (2000) on page 43.

Figure 15. Square coral table equipped with predator exclusion cages.

Figure 16. Four piece trestle equipped with cages for holding corals.

Broodstock

Advances in broodstock collection and transport

Previous recommendations for broodstock collection detailed the use of polyethylene bags for collection. This has been replaced to a great extent by the use of simple baskets such as the one in Figure 17. Using baskets allows broodstock to be collected faster because the bagging time is eliminated from the process. In addition, collected colonies receive less handling and abrasion during the collection process. As long as colonies of the same species are placed in the same basket they can be packed at relatively high density without ill effects. Corals should always be collected by chipping away some of the substrate they are attached to using a hammer and/or cold chisel. Leaving the base of the animal attached to a substrate reduces the risk of infection and makes it easier to situate at the growout site.

Figure 17. Collection basket with anchor coral broodstock.

Depth is also an important consideration in broodstock collection. Taking the time to find shallow areas with dense populations of a particular species can save considerable time in the long run. Wherever possible, broodstock should be collected using snorkel gear or SCUBA gear in shallow water. This greatly reduces the cost of collection by saving time and the cost involved in filling more SCUBA tanks for deeper diving.

During collection, broodstock were brought back to the vicinity of the boat and were left submerged in the baskets until all the collecting was complete. At this point corals were quickly transferred to insulated ice chests filled with clean seawater. Previous recommendations included keeping the corals in bags or placing them in non-insulated containers. As thermal shock is one of the leading stressors that kill corals during transport, this recommendation has been revised so that only insulated ice chests are used and corals are removed from bags for the journey to the farm site.

Many corals have protective stinging mechanisms that can injure other coral species. For this reason corals should be placed in the coolers according to species. If possible only one species should be placed in a single cooler. If this is not possible then hard and soft corals should not be mixed as the hard corals can move around and squash or tear the soft corals. During transport to the farm site approximately 50% of the water should be exchanged in the cooler at least every 30 minutes.

Recommendations for the test species

For the purposes of the study, broodstock for each species were collected from the same general area and in the case of the *Euphyllia* from the same large colony. The *Turbinaria*, *Acropora*, *Porites* and *Lemnalia* were all collected from shallow water using snorkel equipment only. *Euphyllia*, Long polyp *Sarcophyton*, Green polyp *Sarcophyton* and *Pachyclavularia* were all collected from a depth of 10 – 20 m using SCUBA gear. Travel times from collection site to farm site were no more than 45 minutes with the exception of the *Pachyclavularia* which was collected from Pakin atoll, which is an approximate two hours boat ride from the test sites.

Long polyp *Sarcophyton*, Green polyp *Sarcophyton* and *Lemnalia* were collected as whole colonies by chipping away part of the attachment substrate with a hammer and chisel. *Porites*, *Euphyllia* and *Turbinaria* were collected by chipping large pieces of coral from the colony using a hammer. *Acropora* was collected as whole colonies where possible, leaving the stem to regenerate. Because of the mat-like structure of *Pachyclavularia* it was collected from areas of dead coral on which it had encroached. Whole pieces of the dead coral were chipped up using a hammer.

In all cases, simple rules of conservation were observed when collecting: areas were chosen where a species was abundant so that the impact of removal was minimal; only a fraction of the total amount of a species was ever removed from one area; collecting practices that limit damage to the environment were used; areas of outstanding beauty or areas where tourists regularly visit were avoided.

Placing broodstock at the farm sites

Broodstock were placed on nursery trays on tables at each of the test sites (Figure 18) with the exception of the *Euphyllia* and *Pachyclavularia*. *Euphyllia* were attached to the tables using wire (Figure 19) so that the colonies remained upright. It was discovered shortly after collecting the *Pachyclavularia* that this species would need special handling. Broodstock of this species left on nursery trays in the same way as other corals quickly became covered in filamentous algae that smothered the colony. To

Figure 18. Turbinaria *and* Green polyp Sarcophyton broodstock *held on tables*.

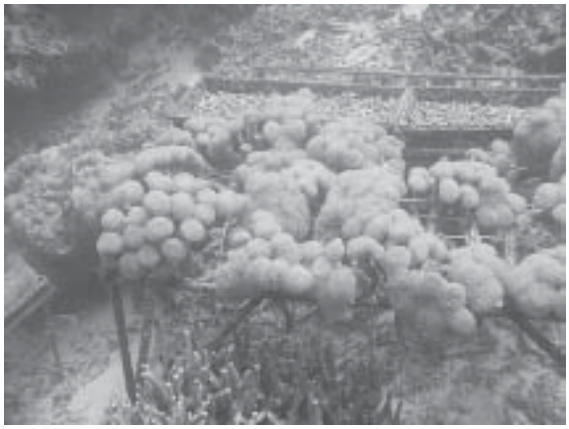


Figure 19. Euphyllia *broodstock held upright using wire on tables.*

Figure 20. Pachyclavularia *broodstock held under a coral outcrop.*

Figure 21. Pachyclavularia *broodstock held under a table covered with nursery trays.*

overcome this the collected broodstock were hung in a darker area under a coral overhang (Figure 20) or under tables covered with nursery trays (Figure 21). While this alleviated the problem somewhat, filamentous algae continues to be a problem for this species under farm conditions.

Broodstock regeneration

The sustainability of coral farming is an issue among prospective farmers, conservationists and industry regulators alike. It would be an ideal situation for all involved if broodstock were collected only once from the reef and placed in a farm after cutting where colonies would regenerate to their original size before being fragmented again. This one time removal would reduce impact to the reef, appease regulators and conservationists and cut farming costs and operating logistics.

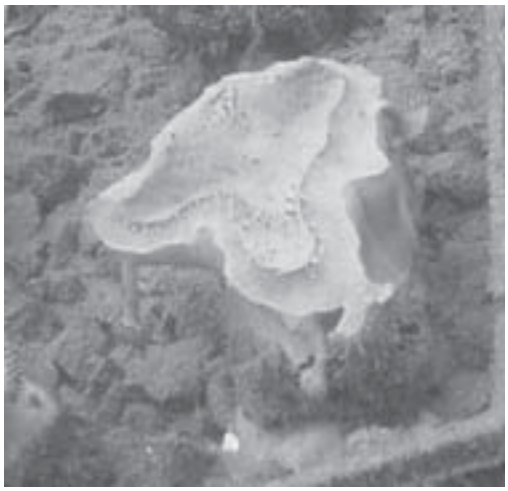
The realities of broodstock regeneration times are somewhat different. It would seem, that especially with hard corals, the long regeneration times would make it necessary to hold large numbers of broodstock colonies on the farm. These colonies would occupy tables and farm space and would need periodic maintenance. A rough estimate of the amount of space needed to house broodstock on the farm would be approximately half a table of broodstock for every table of coral fragments (approximately160). For example, a farm requiring 250 cuttings per month of a particular coral that has a regeneration time of 12 months would have to house enough broodstock to supply a years worth of cuttings. This would equate to approximately 10 extra tables just to hold broodstock for this one species.

The alternative is to leave the broodstock in place and travel periodically to an area and crop fragments from resident broodstock that are located in what is assumed to be an optimal area for their growth and survival. The cost of maintaining the broodstock on the farm versus the cost of traveling periodically to collect broodstock fragments must be carefully weighed in making a final decision. This will be influenced by, among other factors, the distance to the broodstock site, cost of fuel, sea conditions, local regulations and how hard the species is to collect.

Species regeneration rates and patterns

During the study broodstock were kept at the farm site so that a qualitative estimation of broodstock survival and regeneration times could be obtained. Estimated regeneration times, based on field observations and fragment growth rates are as follows:

Long polyp *Sarcophyton:* The relatively slow growth rate of fragments of this species (approximately 25% crown width over a 6-month growout period) and field observations of broodstock indicate that regeneration would be quite slow, taking 9-12 months. This species is quite abundant in Pohnpei and if large beds of broodstock could be located close to the growout site it would be recommended to collect cuttings from these sites rather than holding the broodstock on-site. Figures 22-24 show the progression of healing and growth during the 6-month trial for Long polyp *Sarcophyton*.



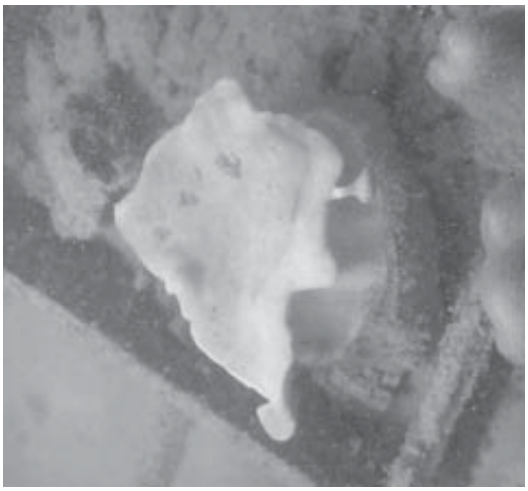
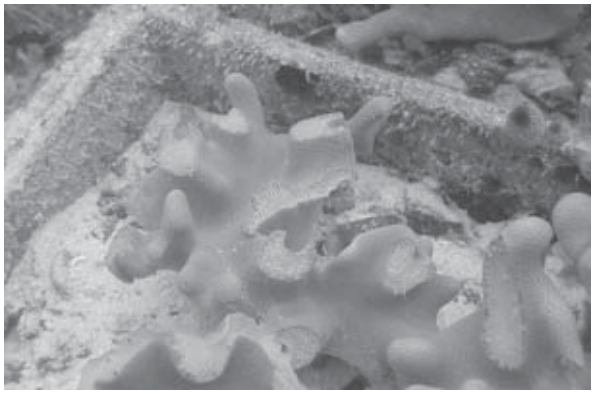


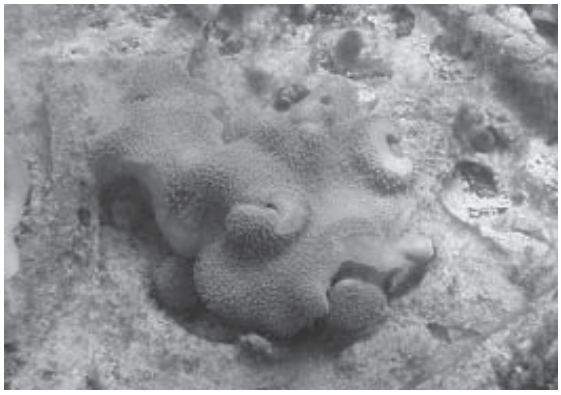
Figure 22. (*Top left). Long polyp* Sarcophyton *broodstock immediately after cutting.*

Figure 23.(*Top right). Long polyp* Sarcophyton *broodstock 2 weeks after cutting showing new polyp growth in the scar tissue.*

Figure 24. (Bottom left). Long polyp Sarcophyton *broodstock 6 months after cutting showing new tissue growth on the crown.*

Green polyp *Sarcophyton*: The relatively faster growth rate of fragments of this species compared to the Long polyp *Sarcophyton* (approximately 59% crown width over a 6-month growout period) combined with broodstock observations indicate that regeneration would be quite fast, taking 6-9 months. This species was relatively sparsely distributed in Pohnpei and had to be collected from a depth of 10-20 m using SCUBA gear. Given its fast regeneration time and the difficulty of obtaining broodstock it is recommended to keep broodstock of this species at the growout site. Figures 25-27 show an example of the progression of healing and growth during the 6-month trial for Green polyp *Sarcophyton*.





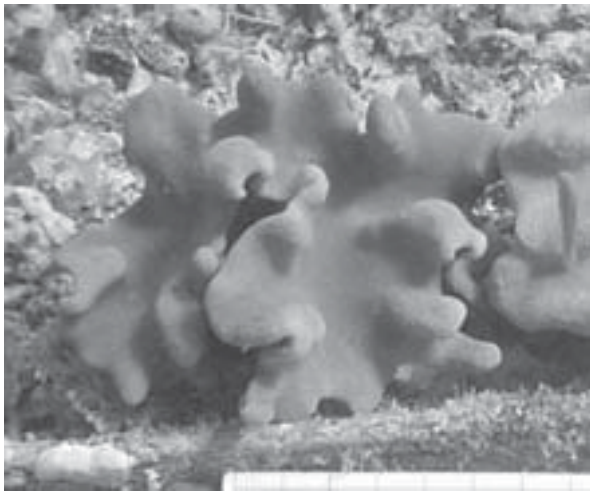


Figure 25. (*Top left). Green polyp* Sarcophyton *broodstock immediately after cutting.*

Figure 26.(*Top right). Green polyp* Sarcophyton *broodstock 2 weeks after cutting showing new polyp growth in the scar tissue.*

Figure 27. (Bottom left). Green polyp Sarcophyton *broodstock 6 months after cutting, showing new tissue growth on the crown.*

***Lemnalia*:** Fragments of this species grew very fast (89% increase in length in 6 months) and also regularly produced new stalks and buds. Estimated broodstock regeneration time is only 4-6 months. During the growth trials, inspection of broodstock for healing was not possible after 3 months because all the branches removed had regenerated. This species is quite fragile and difficult to transport. Given that it has such a fast regeneration time it is recommended to keep broodstock at the farm site whenever possible. Figures 28 and 29 show examples of *Lemnalia* directly after cutting and new buds appearing 2 weeks later.

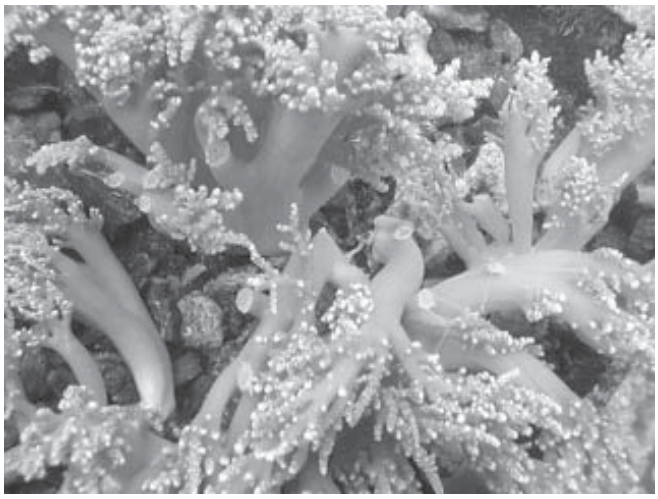
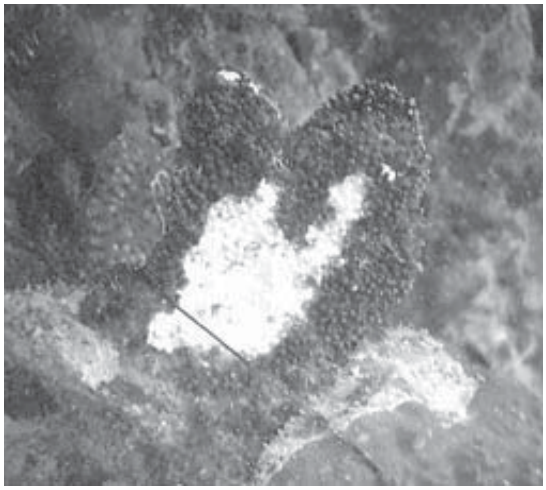
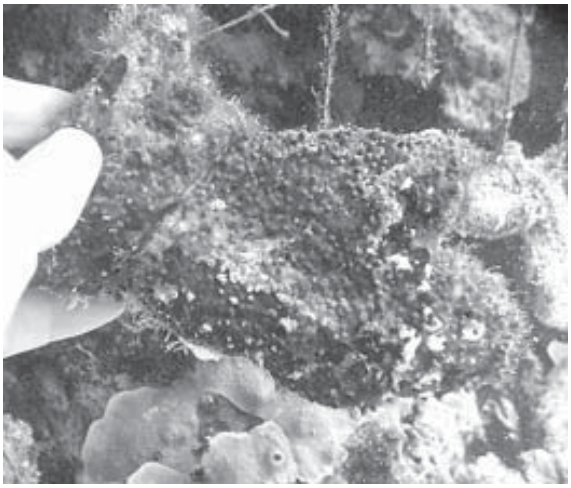


Figure 28. Lemnalia *broodstock immediately after cutting.*

Figure 29. Lemnalia *broodstock with new buds emerging from the scar tissue 2 weeks after cutting.*

***Pachyclavularia*:** Many problems occured with the broodstock of this species because it could not repel filamentous algae. Any area where tissue was removed from the broodstock substrate tended to be rapidly colonized by algae and other fouling organisms thereby preventing regeneration of the corals tissue. Despite this, *Pachyclavularia* grew relatively fast by putting out stolons that adhered to the substrate. In some instances it would grow up the pieces of string that suspended it. Because *Pachyclavularia* did not thrive at any of the test sites it is hard to estimate its regneration time. However, under optimal conditions it is likely to be 6-9 months. Figures 30-32 (next page) show regeneration patterns for *Pachclavularia*.





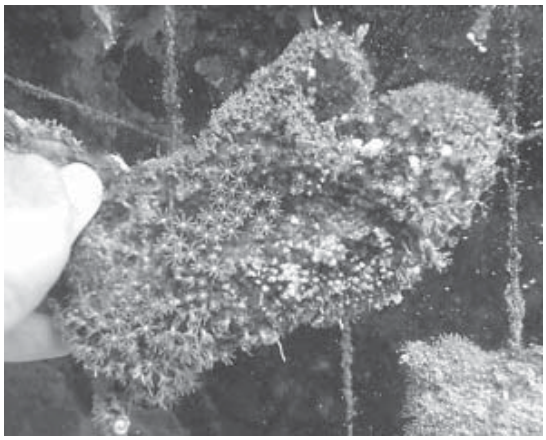


Figure 30. (Top left) Pachyclavularia *broodstock immediately after cutting.*

Figure 31. (Top right) Pachyclavularia *broodstock 3 months after cutting.*

Figure 32. (Bottom left) Pachyclavularia *broodstock 6 months after cutting.*

***Acropora*:** Fragments of this species were the fastest growing of the hard corals tested. Broodstock quickly healed and put out new buds in the areas that had been cut. Regeneration time is estimated to be 12-18 months. Given that this species is abundant in Pohnpei lagoon and has a relatively long regeneration time it is recommended to collect cuttings from the wild rather than keeping broodstock on site. Figures 33 and 34 show an example of broodstock regeneration over a 6-month period.

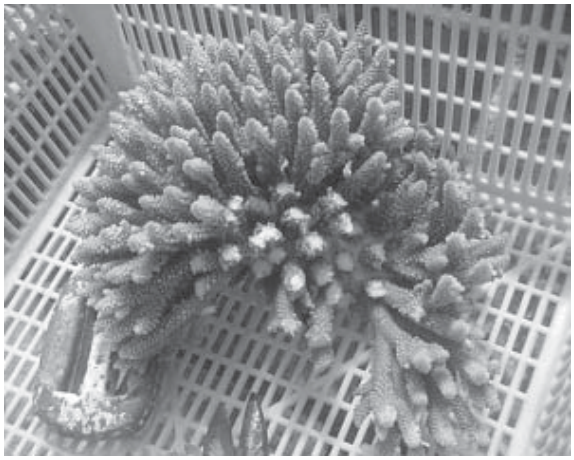


Figure 33. Acropora *broodstock immediately after cutting.*

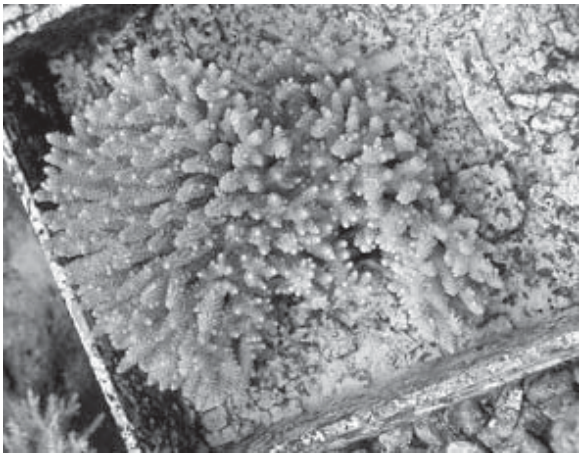


Figure 34. Acropora *broodstock 6 months after cutting.*

***Porites*:** While not a particularly fast growing species, broodstock quickly healed and put out new buds in the areas that had been cut. Regeneration time is estimated to be 18-24 months. Given that this species is abundant in Pohnpei lagoon and has a relatively long regeneration time it is recommended to collect cuttings from the wild rather than keeping broodstock on-site. Figures 35 and 36 show an example of broodstock regeneration for *Porites* over a 6-month period.

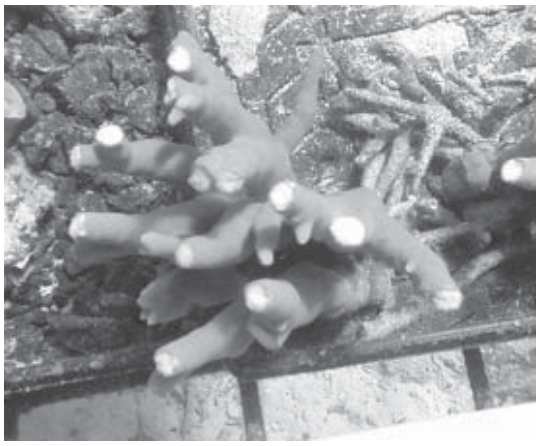


Figure 35. Porites *broodstock immediately after cutting.*

Figure 36. Porites *broodstock 6 months after cutting.*

***Turbinaria*:** While it survived well, fragments of this species were the slowest growing of all the animals tested. Regeneration time is estimated to be 24-36 months. However, cut areas quickly healed and rounded out with little sign of necrosis. Given that this species is abundant in Pohnpei lagoon and has a relatively long regeneration time it is recommended to collect cuttings from the wild rather than keeping broodstock on site. Figures 37 and 38 show an example of broodstock regeneration for *Turbinaria* over a 6-month period.

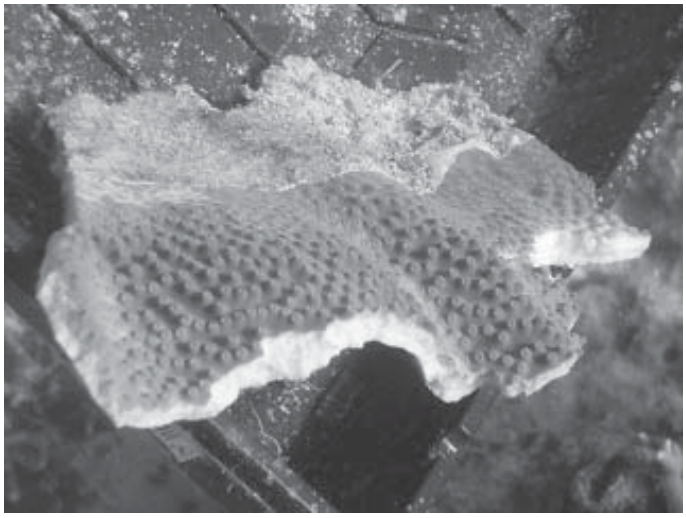


Figure 37. Turbinaria *broodstock immediately after cutting.*

Figure 38. Turbinaria *broodstock 6 months after cutting. Light areas around the edge indicate new growth.*

***Euphyllia*:** As the only large polyp stony coral tested in this study, regeneration patterns were different from the other species. Polyps that were removed did not regenerate from the cut stalk. Instead, polyps tended to split from existing polyps forming new polyps. This was evident from the growth trials where approximately 80% of single polyp fragments split into 2 or more polyps inside the 6-month growth trial. Regeneration time for this species is estimated to be 18-24 months. Although this species is not abundant in Pohnpei lagoon, the relatively long regeneration time and the difficulty of keeping the broodstock on tables indicate that it is better to collect cuttings from broodstock in the wild rather than keeping broodstock on-site. Figures 39 and 40 show an example of broodstock regeneration for *Euphyllia* over a 6-month period.

Figure 39. Euphyllia *broodstock immediately after cutting.*

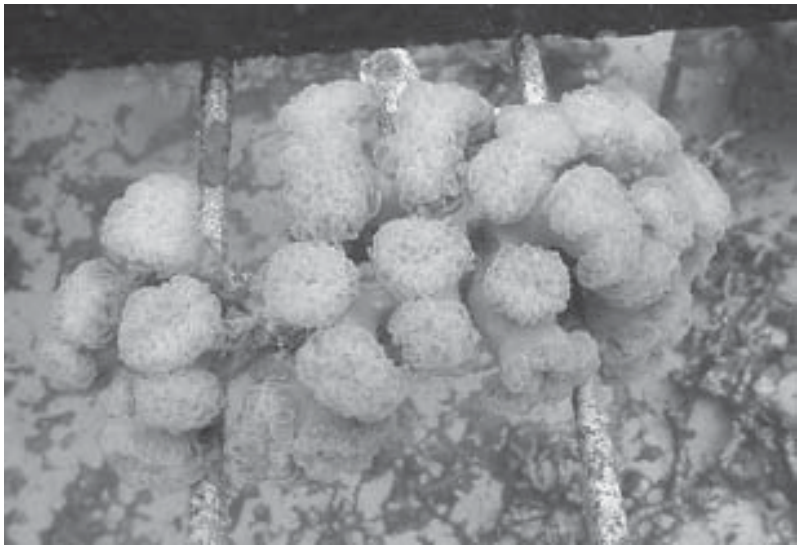


Figure 40. Euphyllia *broodstock 6 months after cutting.*

Culture techniques

Substrates and their manufacture

Substrates chosen for each species depended on their ability to attach naturally and also on feedback from wholesalers and hobbyists as to their preferences for cultured corals.

Gravel:

Locally available gravel products are generally good substrates for attaching soft corals. Depending on locality in the Pacific, coral or basalt gravels used in construction are generally cheap and readily available. Basalt gravel with an average diameter of 10.5-24.6 mm was chosen for these experiments because they easily identified the coral as being cultured. The gravel was ordered in bulk and was rinsed with freshwater to remove dirt and small grit prior to being used on the farms. Per each tray, 4 L of gravel was used.

Coral gravel was also tested as a substrate prior to the start of the growth trials as this is often the only substrate available in some areas, such as atolls. All the soft corals readily attached to coral rubble and no obvious differences were observed in attachment rates of corals on basalt versus coral gravel.

Of the species tested, *Lemnalia*, Green polyp *Sarcophyton* and Long polyp *Sarcophyton* are recommended for attachment to basalt or coral gravel.

Live rock disks:

When searching for a suitable disk-type substrate for attaching corals, both hobbyists and wholesalers preferred a non-concrete disk that still showed the coral to be cultured but did not look too artificial. One suggestion from Mrs. Joy Meadows, an aquarium wholesaler at Harbor Aquatics in Chicago, USA, was to use pieces of live rock that had been cut, using a saw, into flat disks (Figure 41). This type of live rock substrate was tested on all coral species used in the study and was adopted as the substrate of choice for *Pachyclavularia*, *Acropora*, *Porites*, *Euphyllia* and *Turbinaria*.

While the Long polyp *Sarcophyton* attached readily to basalt gravel (40.0%), percent attachment was higher on the live rock disks (63.3%). However, problems arose during the growout trials with the result that these disks are not recommended for growing soft corals. Once the toothpicks that were holding the soft coral cuttings onto the disks were removed, the corals had a tendency to migrate to the edge of the disk and often

attached themselves partially to the disk and partially to loose pieces of basalt in the trays (Figure 42) . The resulting corals appeared asymmetrical in appearance and many were deemed not saleable for this reason. In addition, the live rock disks with lightweight soft coral fragments on them had a tendency to flip over in strong currents or wave action, causing extra maintenance work, and again, rendering the fragment non-saleable.

Figure 41. Substrate disks made from live rock.

Figure 42. A Long polyp Sarcophyton *fragment that has migrated to the edge of the disk and attached to a piece of basalt.*

Live rock disk manufacture:

Live rock, usually from thick branching species such as *Porites* and *Goniopora*, was collected from Pohnpei lagoon and left for approximately one week on land to kill any sponges and algae. Minimum width of the branches for cutting was 40 mm (Figure 41). The dry branches were cut using a commercial band saw (Figure 43). The size and width of the disks varied depending on the species for which they would be used. For stemmed soft corals such as *Lemnalia*, Green polyp *Sarcophyton* and Long polyp *Sarcophyton* a base 40-60 mm in diameter and 10-mm thickness was used. A 2.4-mm hole was also drilled in the center of the base for attachment using a toothpick. For *Pachyclavularia*, larger disks with the

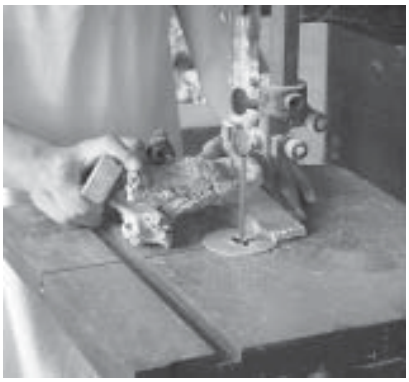


Figure 43. Cutting live rock disks using a bandsaw.

same thickness as the other soft corals but with diameters of 55-105 mm were used so that the animal could spread over the substrate's surface (Figure 41, third from left). *Turbinaria* disks averaged 14 mm in thickness and 49-70 mm in diameter and had a 9-mm channel across the middle which was made using a hand-held angle grinder (Figure 41, far right and Figure 44). Disks for the *Acropora*, *Porites* and *Euphyllia* averaged 19 mm in thickness and varied from 41-54 mm in diameter (Figure 41, second from left and Figure 45). A hole ranging from 13-18 mm was drilled approximately 10 mm deep in the center of each disk into which the stem of the fragment was glued. The size of the hole was chosen depending on the width of the stem. The *Euphyllia* were put into the disks with the largest holes (16-20 mm) and the *Porites* and *Acropora* into the disks with smaller holes (13-16 mm).

Figure 44. Live rock substrates used for planting Turbinaria.

Figure 45. Live rock substrates used for planting Acropora*,* Euphyllia *and* Porites*.*

While liverock disks were attractive they were relatively time consuming and expensive to make. A farmer interested in using these disks would have to buy a bandsaw, hand operated drill and angle grinder and constantly replace the blades and bits for this machinery. Average time to make 1 disk using a "production line" method of cutting all pieces at one time, drilling all pieces at one time etc. was estimated at 53 seconds. Average cost of manufacture of each disk, taking into account labor costs of US$1.35 per hour, depreciation on machinery, the cost of electricity and the cost and expected life of saw blades, drill bits etc. in Pohnpei was US$0.06.

To overcome the cost and investment related to having to cut the live rock disks some experimentation was done with simply chipping appropriate pieces of live rock with a hammer and attaching the corals into natural crevices and dips that result from the breaking of the live rock (Figure 46). This has a more natural appearance and is also cheaper and faster per substrate. The major disadvantage to this method is that it is often hard to recognize the substrate as being man-made.

Figure 46. Substrate made by chipping live rock with a hammer.

Concrete disks:

During discussions with aquarium wholesaler and hobbyists it was determined that concrete disks were generally disliked and that many hobbyists simply break the coral from the concrete disk prior to putting them in the tank. Primary complaints about concrete disks were the fear of them leaching chemicals into the water and a distinct man-made appearance. Despite these concerns it was decided to still test concrete as a substrate. To overcome customer concerns a growout time of 6 months was adopted so that the disks could leach properly and disks were made in less uniform shapes to make them look less man-made. The primary advantages to concrete disks is that they are cheap and quick to produce requiring very little materials and equipment. In addition, their manufacture does not require electricity.

Concrete disk manufacture:

All concrete disks were made using a table filled with beach sand as shown in Figure 47. The sand was first smoothed out on the table. Concrete was then made by mixing 70% beach sand with 30% cement and water and was scooped out into small, irregularly shaped mounds on the sand and appropriately sized holes (12-20 mm) or channels (8-10 mm) were formed in the wet concrete using a finger or small spatula (Figure 48-50). An experienced technician can easily make 75 disks per hour at an estimated cost of US$0.028 per disk (concrete and labor). After the disks had set they were submerged in freshwater for a minimum of 3 days, prior to being used, to allow preliminary leaching.

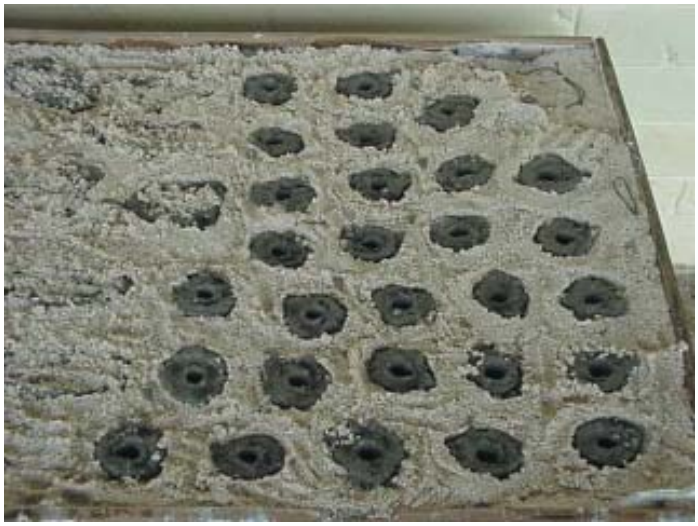


Figure 47. (Top left). Sand filled table used for making concrete substrates.

Figure 48. (Top right). Freshly poured concrete substrates.

Figure 49. (Middle). Concrete substrates used for planting Pachyclavularia *and* Turbinaria*.*

Figure 50. (Lower). Concrete substrates used for planting Euphyllia, Porites *and* Acropora*.*

Cutting

Cutting always took place adjacent to, but not on, the planting area. All the soft corals were cut using a pair of stainless steel scissors available at most hardware or craft stores. *Lemnalia* were fragmented by removing whole 40-60 mm branches from the colony (Figure 51). The Long polyp *Sarcophyton* and Green polyp *Sarcophyton* were fragmented by cutting the loose flesh off the crown, close to the stem leaving only the central tissue over the stem (Figures 52-54). The removed tissue was then cut into 20-30 mm squares for planting. Cutting took place in an open basket so that fragments were consolidated in one area. Cuttings were then placed in a covered basket or plastic bag filled with clean seawater for transport to the planting area.

Figure 51. Taking Lemnalia *cuttings using scissors.*

Figure 52. Taking Long polyp Sarcophyton *cuttings using scissors.*

Figure 53. Strips of Long polyp Sarcophyton *tissue removed from the crown.*

Figure 54. Green polyp Sarcophyton *after cutting removal.*

The tissue of the broodstock *Pachyclavularia* adhered very strongly to the substrate making fragments hard to collect. Where loose edges were present on the broodstock, cuttings were made using scissors (Figure 55). When scissors could not be used fragments were removed using a sharp knife or scalpel (Figure 56). Average size of a cutting was 10-20 mm^2.

Figure 55. Taking cuttings from loose edges of Pachyclavularia *using scissors.*

Figure 56. Taking Pachclavularia *cuttings using a scalpel .*

Hard coral cuttings were taken primarily using a pair of aviation snips (Figures 57-60). For *Turbinaria*, the back of the coral was also lightly tapped with the head of a cold chisel to aid fragmentation. Ideal starting sizes for fragments are 70-80 mm^2 for *Turbinaria* (Figure 59), and 30-60 mm for *Acropora* and *Porites* (Figures 57 and 58). One single polyp was used to start the *Euphyllia* colonies (Figure 60). Hard coral cuttings were also made in open baskets.

Figure 57. Acropora *cuttings being taken using aviation snips .*

Figure 58. Porites *cuttings being taken using aviation snips.*

Figure 59. Turbinaria *cuttings taken using aviation snips and a cold chisel.*

Figure 60. Euphyllia *cuttings being taken using aviation snips.*

Attachment and planting methods

Toothpicks:

A number of attachment methods were experimented with depending on the species in question. All soft corals tested showed the ability to reattach to the substrate once fragmented. For the *Lemnalia*, Long polyp *Sarcophyton* and Green polyp *Sarcophyton* the best method for attaching was to use a wooden toothpick to hold the fragment close to the substrate until it had time to attach (Figures 61-63). This method proved

Figure 61. Lemnalia *cuttings attached using toothpicks.*

Figure 62. Green polyp Sarcophyton *cuttings attached using toothpicks.*

Figure 63. Long polyp *Sarcophyton cuttings attached to live rock disks using toothpicks.*

more effective (Long polyp *Sarcophyton* 40%, Green polyp *Sarcophyton* 83% and *Lemnalia* 93%) than simply nestling the cutting into the substrate (Long polyp *Sarcophyton* 27%, Green polyp *Sarcophyton* 77% and *Lemnalia* 96%) for all three species.

To plant in basalt gravel a cut end of the fragment was nestled into the gravel and a toothpick forced through the cutting into the gravel at an angle of approximately 20-30 degrees from the perpendicular. To plant on liverock disks the cutting was again placed so that one of the cut edges was in contact with the substrate and a toothpick was used to pin it to the disk After the fragment had attached adequately (2-4 weeks) the toothpick was removed. It was better to remove the toothpick as soon as the fragment was loosely attached to the substrate because the cutting often adhered so strongly to the toothpick that it could not be removed without tearing the fragment from the substrate.

Rubber bands:

The *Pachyclavularia* showed the best rate of attachment when held to the substrate using a rubber band (57%) (Figure 64) rather than a toothpick (37%). Rubber bands were placed on the substrates prior to hanging them so that planting was quickly and easily accomplished by tucking the fragment under the rubber band with the

Figure 64. Pachyclavularia *planted using a rubber band on live rock disk.*

flat side (the side originally in contact with the broodstock substrate) touching the disk. The band was removed between 2 and 4 weeks after planting.

Epoxy glue:

All the hard corals were attached to the appropriate substrates using an epoxy glue. While *Porites* and *Acropora* will attach passively given time, the use of epoxy allowed mass production of corals at very little added expense. Prior to the start of experiments *in situ* trials were conducted using a variety of commercially available two-part epoxy glues. Glues were rated on working time, ease of use, cost per unit and how well they held the fragment in place. The overall winner by far was a two part epoxy manufactured by Z-Spar called 788 Splash Zone Epoxy. The two parts are black and

Figures 65. (Top left). Putty underwater in jars prior to mixing.

Figures 66. (Top right). Putty being mixed in two equal parts.

Figures 67. (Bottom left). Putty when fully mixed into an unobtrusive olive color.

mustard colored which when mixed form an unobtrusive olive color (Figures 65-67). Pot life is approximately 40 minutes and it can be mixed and applied entirely under water. Price per coral planted was also the lowest at approximately US$0.035 per piece. Care needed to be taken directly after planting not to disturb the corals until the epoxy had set properly. Corals planted using this epoxy showed almost 100% attachment at the end of the growth trials approximately 6 months after planting.

Figure 68. Turbinaria *fragments being planted using epoxy putty.*

Figure 69. Turbinaria *fragments attached with putty being left to harden prior to transfer to the grow-out site.*

To expedite planting of hard corals the prepared disks were loaded into open baskets and carried to the work site (Figure 50, page 30). Fragments were taken from broodstock by one worker while other workers laid out the disks in baskets or trays and/or mixed the glue. Fragments were then planted by matching the stem of the fragment to the appropriate hole or slot and adhering it with a small amount of epoxy (Figures 68). Newly planted fragments were then left for about 1 hour to allow the glue to set before being carried to the growout tables (Figure 69).

Planting was most time effective for all species when done on a mass scale using a production line method. Up to 300 cuttings could be made and stored in open, well flushed baskets prior to planting.

Growout and husbandry

Corals require very little attention once planted but each table should be checked at least every two weeks. Corals were easily knocked over by grazing fish, sea cucumbers, fast currents and wave action. This was alleviated somewhat by using cages (see Section “Use of cages” on page 14) to prevent animal activity and to prevent corals being washed off the tables. However, the tops of the cages needed to be scrubbed with a brush every two weeks to remove algal fouling.

Growth rates and patterns

Under optimal conditions growout times varied dramatically depending on species. Growth rates reported below are presented as percent increase of original size, also called relative growth rate.

Lemnalia: Of all the corals tested, *Lemnalia*s grew fastest and performed best in the environment with fast flowing oceanic water. At this site their height increased by an average of 89% over the 6-month growth trial from a starting size of 45 mm (Figure 70, page 38). They also grew well at the turbid, eutrophic site (58% increase in height) but did not grow well at the mid-lagoon site with poorer water exchange (-9.5%). They reached a recommended harvest size of approximately 60-80 mm in 4 months under optimal conditions. This species also spawned many new stems and branches (Figures 71, page 38), becoming much thicker and bushier in appearance. At the optimal site, survival and number of saleable* corals at harvest were both 62%.

* Saleable corals for all species tested were specimens that fell within a reasonable size range for sale that did not have any blemishes or scars.

Long polyp *Sarcophyton*: This coral grew the best at the fast flowing, oceanic site, registering a 16.7% increase in crown diameter over the 6-month growing trial. While this seems quite low the morphology of the animals changed significantly during the trial indicating a high growth rate. The original cuttings, with a crown diameter of 42 mm (Figure 72, page 38) started by differentiating into a stem and crown at approximately 2 months (Figure 73, page 38) after planting. The crown then rounded out to form the final product (Figure 74, page 38). Growth at the eutrophic site and mid-lagoon sites was negligble and the corals showed a decrease in crown diameter of –20% and –29% respectively. Primary problems with this species planted on the live rock substrates at the fast flowing and eutrophic sites were currents and wave action overturning the corals. Optimum initial fragment size for this species is 60-70 mm. At the fast flowing, oceanic site, survival was 76% from planted cuttings and 60% were deemed saleable.

Figure 70. (Top left). Representative picture of Lemnalia *cuttings at the start of the growth trials.*

Figure 71. (Top right). Representative picture of a Lemnalia *cutting at the end of the growth trials.*

Figure 72. (Middle left). Representative picture of a Long polyp Sarcophyton *cutting at the start of the growth trials.*

Figure 73. (Bottom left). Representative picture of a Long polyp Sarcophyton *cutting 2 months after the start of the growth trials.*

Figure 74. (Bottom right). Representative picture of a Long polyp Sarcophyton *cutting at the end of the growth trials.*

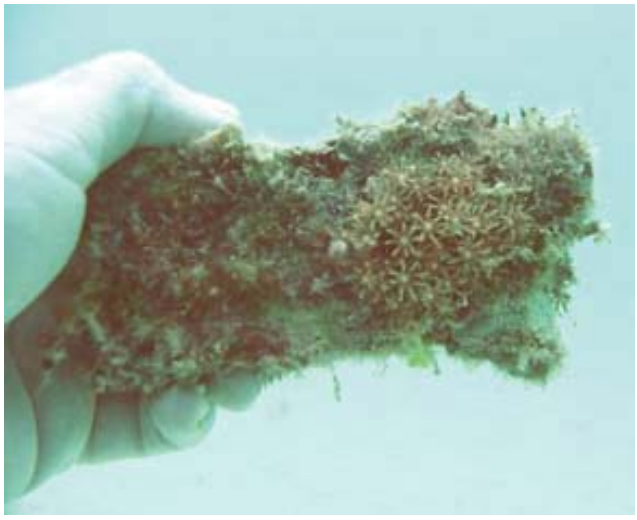
Figure 75. (Top left). Representative picture of a Green polyp Sarcophyton *cutting at the start of the growth trials.*

Figure 76. (Top right). Representative picture of a Green polyp Sarcophyton *cutting 1 month into the growth trials.*

Figure 77. (Middle left). Representative picture of a Green polyp Sarcophyton *cutting at the end of the growth trials.*

Figure 78. (Bottom left). A Pachyclavularia *cutting showing new stolon growth.*

Figure 79. (Bottom right). A Pachyclavularia *cutting after 6 months covered by filamentous algal growth.*



Green polyp *Sarcophyton*: This coral grew best at the fast flowing site showing a 58.7% increase in crown diameter over the course of the trial. This compared to a crown size increase of only 7.5% and –5% at the eutrophic and mid-lagoon sites respectively. Initial fragments with a crown diameter of 32 mm (Figure 75, page 39) began differentiating into a stem and crown within one month of planting (Figure 76, page 39) and reached a minimum marketable size (50-mm crown diameter) by the end of the 6-month growing period (Figure 77, page 39). Survival was highest at the fast flowing and eutrophic sites (88% and 90% respectively). However, poor health of corals, manifested as small lesions and areas of necrosis resulted in only 10% being deemed saleable from the eutrophic site as opposed to 82% from the fast flowing site. Estimated optimum initial fragment size of this species, based on wholesaler feedback, is 50-70 mm crown diameter.

***Pachyclavularia*:** The *Pachyclavularia* performed worst of all the corals tested. Optimum growth of 37% increase in width and 52% increase in length were recorded at the fast flowing, oceanic site but these figures are misleading because the animal grew outward by extending thin stolons across the live rock disk that only covered a small fraction of the disk surface area (Figure 78, page 39). In addition, the disks and the corals rapidly became overwhelmed by filamentous algae making them unsightly (Figure 79, page 39). At the mid-lagoon site the corals shrank by an average of 29% and at the eutrophic site no animals survived. Survival at the other sites was 32-34% and no specimens from either site were deemed saleable.

***Acropora*:** The *Acropora* grew fastest at the fast flowing, oceanic site showing a 101% increase in width and 31% increase in height during the growout period. From the initial planting at a size of about 16 mm (Figure 80, page 42), growth followed a distinct pattern at each site starting with a spreading of tissue over the substrate within 1 month of planting (Figure 81, page 42). At the fast flowing and eutrophic sites the substrate became covered in 3-4 months and corals began budding. By the end of the 6-month growout period the corals had totally covered the base and were showing significant budding both from the original stem and also from the newly formed base tissue (Figure 82, page 42). Minimum time to market size for this species is 4 months. Survival was highest at the mid-lagoon and fast flowing sites (96% and 90% respectively). At the eutrophic site survival was only 72% primarily because wave action kept overturning the corals. The number of saleable corals at the fast flowing site was 88% compared to only 66-68% at the other sites. Corals at the latter sites were either too small or had poor color by the end of the trial. Corals from the eutrophic site were very brown in color with none of the characteristic blue tissue on growing tips. When specimens from the this site were moved to the fast flowing site, blue growth areas became apparent within 4 weeks of transfer. Optimum initial fragment size for this species is 30-40 mm.

***Porites*:** Results from the *Porites* growth trial indicated that this species might be grown with relative ease at any of the three sites tested. While growth was highest at the mid-lagoon and fast flowing, oceanic sites (88-89% increase in width and 44-51% increase in height from a starting height and width of 32 mm and 19 mm respectively), corals at the eutrophic site had a greater spreading of tissue onto the substrate (Figure 84, page 42) and had a higher percentage of saleable animals (66%) than the other sites (46-48%). Corals that had not covered the portion of the base where the glue showed (Figure 83, page 42) were classified as non-saleable. Therefore corals at the fast flowing and mid-lagoon sites may have had a greater percentage of saleable animals had the growout period been longer. This species was also prone to small blemishes and necrotic areas at all sites that reduced the number of saleable specimens.

***Turbinaria*:** Percent increase in height ranged from 4 to 10% with the highest increase coming at the mid-lagoon site. Percent increase in width was highest at the eutrophic site and ranged from 7 to 11.5% between the sites. Starting heights and widths averaged 31 mm and 45 mm respectively (Figure 85, page 43). While growth rates appeared relatively slow for this species the results were somewhat distorted by the fact that the edges of the fragments began to curl as they grew making the relative growth rates seem less than they actually were (Figure 86, page 43). The fast flowing site was once again deemed the best site for growing this species with a survival rate of 98% with 92% of fragments deemed saleable (Figure 87, page 43). Corals at the eutrophic site also fared well but corals grown there had a much browner color which reduced their potential marketability. Specimens moved from this site to the fast flowing site at the end of the growth trials did NOT turn a more attractive yellow color within 4 weeks of transplant. Growout time for this species should be a minimum of 6 months and optimal initial fragment size should be 70-80 mm based on wholesaler feedback.

***Euphyllia*:** The eutrophic site was the best overall site for growing this species. Percent increase in width was 64% and 79% of corals planted as a single polyp (Figure 88, page 43) split to become 2 or 3 polyps by the end of the trial (Figure 89, page 43). In addition, corals at the eutrophic site looked healthier than at other sites as evidenced by the extension of soft tissue down the stem of the coral (Figure 89). Survival was high at all sites, ranging from 92-100% and the percentage of saleable animals was highest at the eutrophic and fast-flowing sites (94% and 96% respectively). Growout time for this species should be a minimum of 6 months and the optimal initial fragment size is a single polyp on a stalk approximately 40-70 mm long.

Figure 80. (Top left). Representative picture of an Acropora *cutting at the start of the growth trial.*

Figure 81. (Top right). Representative picture of an Acropora *cutting 1 month into the growth trial.*

Figure 82. (Middle left). Representative picture of an Acropora *cutting at the end of the growth trial.*

Figure 83. (Bottom left). Porites *cutting with no tissue growth over the base after 6 months.*

Figure 84. (Bottom right). Porites *cuttings with basal tissue growth after 4 months.*

Figure 85. (Top left). Representative picture of a Turbinaria *cutting at the start of the growth trial.*

Figure 86. (Top right). Natural curling of the Turbinaria *cuttings during the growth trial.*

Figure 87. (Middle left). Representative picture of a Turbinaria *cutting at the end of the growth trial.*

Figure 88. (Bottom left). Representative picture of single Euphyllia *polyps at the start of the growth trial.*

Figure 89. (Bottom right). Representative picture of a Euphyllia *cutting that has split into 3 individual polyps by the end of the growth trial.*

Positioning and stocking density

For all the species tested with the exception of the *Pachyclavularia*, corals were grown in the nursery trays on the table top. Stocking density was 20 corals per tray or 160 corals per table (Figure 90). During initial trials with *Pachyclavularia* it was observed that cuttings quickly became overrun with filamentous algae when they were placed facing the water surface in a nursery tray. To overcome this problem the disks were hung vertically underneath the tables (approximately 50 can be hung under each table) so they were shaded by the nursery trays (Figure 91). While this cut down on algal growth, the *Pachyclavularia* cuttings did not grow well and most specimens were not fit for the market after a 6-month growout.

Figure 90. Culture table stocked with 8 trays at 20 corals per tray. Corals were randomly distributed in groups of 10 among the tables for the growth trial.

Figure 91. Pachyclavularia *cuttings were hung under the tables to minimize growth of filamentous algae.*

Pests and diseases

Pests

Primary pests to corals on the trays were fish, sea cucumbers and hermit crabs. While these animals rarely attacked or harassed the corals, their feeding activity and foraging in the trays knocked corals over and made soft corals contract their polyps. This was addressed by introducing the use of cages at sites where this was a problem (see section titles “Use of cages on page 14). At the fast flowing oceanic site, substrates and trays became colonized by a variety of ascidians. These animals did not kill the corals but would start to grow up the stem of the hard corals causing blemishes and localized bleaching. Time had to be taken to periodically remove these fouling organisms from the coral substrates.

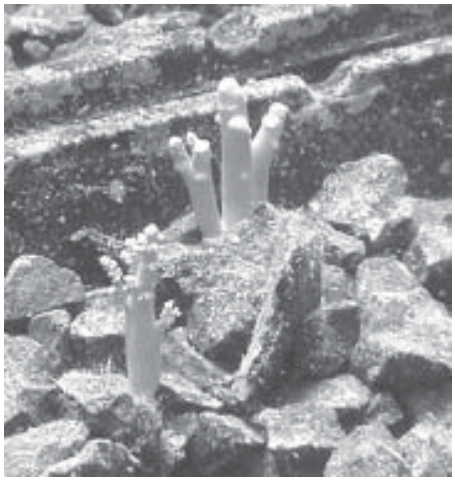


Figure 92. Lemnalia *fragments showing signs of fish predation.*

The only evidence of predation on any of the corals tested was with the *Lemnalia*. In this case, it appeared that the corals were being eaten by fish (Figure 92). As most soft corals are regarded as toxic to marine fish, incidences of attack were sporadic and corals quickly regenerated.

Diseases

For corals kept in optimum conditions there was rarely any sign of disease. Green polyp *Sarcophyton* and Long polyp *Sarcophyton* that were kept in less than optimum conditions showed signs of bleaching and small areas of necrosis on the crown. Long polyp *Sarcophyton* held at the eutrophic site, which often had heavy wave action and siltation, showed signs of bleaching and atrophy, possibly due to the heavy silt load in the water.

Harvest and transport

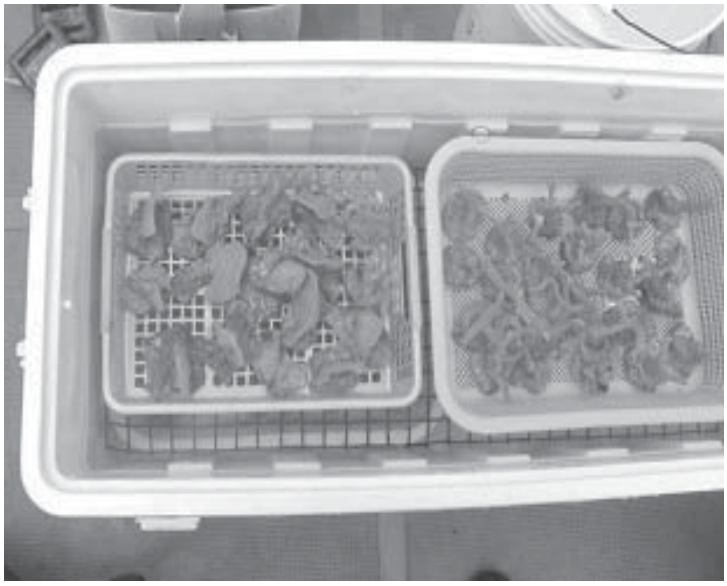


Figure 93. Open-sided plastic baskets stacked inside an ice chest used to transport corals.

Harvesting of the corals was simply a case of picking them out of the trays and transporting them to the site of shipping. Prior to transport, substrates were cleaned to remove any fouling organisms with a knife or brush. As with the broodstock it is important to minimize the amount of time the corals are out of the water and also to reduce the possibility of thermal shock. Harvested corals were placed in open-sided baskets (Figure 93) for carrying to the boat.

Corals were transported in ice chests filled with fresh seawater. To optimize space, plastic baskets with lids containing the corals can be stacked on top of each other in the ice chests (Figure 93). Baskets used to collect corals in the water were the same as the ones used in ice chests, thereby eliminating the need to transfer corals at the surface. Because the *Lemnalia* were so sensitive to air exposure they were collected in closed-sided tubs that were also placed directly into the coolers so that the corals were never exposed to air (Figure 94). Approximately 100-120 corals could be transported in a standard 120-liter capacity ice chest. For journeys longer than 30 minutes, water exchanges were done in the ice chests.

Figure 94. Closed sided tub used for transporting Lemnalias.

Holding in the land-based facility

Corals were held in land-based, concrete raceways with a 50% light occluding shaded cloth overhead (Figure 95). Water depth was kept at 40-50 cm and water in the raceways was exchanged at least three times per day with 25-σm filtered seawater (Figure 96). Corals kept in this manner remained healthy with little loss of color. It is recommended to hold the corals for approximately one week in the land-based facility prior to shipping to allow them to recover from the stress of transport from the field.

Figure 95. Concrete raceways used to hold corals prior to shipping.

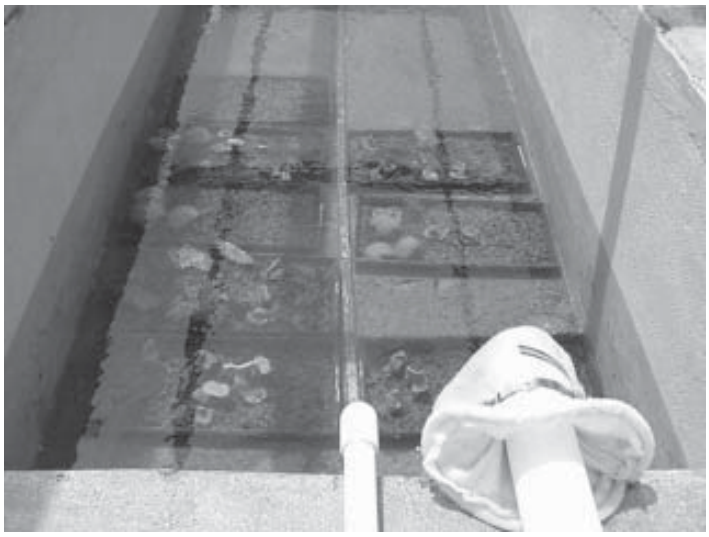


Figure 96. Corals being held in shallow water prior to shipping.

Shipping

Specific packing instructions

All corals were packed for shipping in double bags with an intermediate layer of newspaper filled with seawater and oxygen as described in Ellis (2000) and Ellis and Sharron (1999). Bags had a thickness of 3 mm. *Pachyclavularia* were shipped in bags 23 cm in width. All other corals were shipped in bags 15 cm in width. Bags were placed into Styrofoam lined cardboard boxes (Figure 97). Prior to shipping to the wholesaler all corals underwent 24 and 48 hour simulated shipping trials to test these standard techniques. Different methods of packing recommended for the different species of corals are detailed below.

Figure 97. Newspaper lined double bags inside a Styrofoam insulated shipping box.

Figure 98. Coral suspended on Styrofoam in preparation for packing.

All hard corals were suspended upside down on a piece of Styrofoam approximately 5-6 cm^2 and 1.5 cm thick by rubber bands for shipping (Figure 98). This prevented the corals from touching the side of the bag and also protected the bag from sharp areas of the substrate or coral itself. The bag was filled with water so that the suspended coral would remain at least 3 cm clear of the bag bottom. At least half the bag volume was oxygen.

Soft corals were not attached to Styrofoam for shipping but were placed directly into the bag and were allowed to contact the bag sides. Enough water was used to cover the specimen by at least 3-4 cm and at least half the bag volume was oxygen. The only species to fare badly using this method of shipping was the *Lemnalia*. For this species between 65-75% of the bag volume was filled with water and the remainder with oxygen.

Permits, CITES and shipping documents

Of the species tested, only the hard corals (*Acropora*, *Porites*, *Turbinaria* and *Euphyllia*) and one species of soft coral (*Pachyclavularia*) are currently listed under Appendix II of the Convention on the International Trade in Endangered Species (CITES). Procedures for using and examples of necessary export permits, shipping documents and CITES permits are detailed in Ellis and Sharron (1999) and Ellis (2000).

Industry Feedback

To get a better idea of the saleability and quality of the cultured corals in this experiment, feedback was sought from individuals in the marine aquarium industry. Shipments of approximately 100 corals were air freighted to two independant wholesalers/retailers of marine invertebrates in the United States (Reef Rascals in Indialantic, Florida and Harbor Aquatics in Valpraiso, Indiana). Feedback was given on the health of the corals after they had been shipped, their size and color, customer satisfaction and the type of substrate that was used. Wholesalers were also asked to give an approximate price they would pay for the product as presented. In addition, Mr. Roderick Bourke, manager of Robert Reimers Enterprises Wau Mili Giant Clam Farm in Majuro, Republic of the Marshall Islands, was asked to provide input on general product quality and pricing.

General comments

Substrates: Both wholesalers preferred live rock over the concrete discs although one commented that customers had not indicated a preference. Mr. Bourke of RRE commented that many customers remove the coral fragment from the substrate prior to putting it into their tank anyway. Basalt gravel was not the choice of one wholesaler who preferred to use live rock or coral rubble instead.

Price: Estimated farm gate prices the 2 wholesalers would pay for individual specimens varied drastically with one estimating only between US$1.50-4.00 per coral and the other US$5.00-10.00 per coral. Mr. Bourke of RRE recommended a minimum farm gate price for cultured corals in general of US$5.00 per piece based on his own sales experience.

Size: Both wholesalers made general comments that the corals sent were smaller than the wild collected specimens they sell and they would pefer larger cultured specimens in order to be able to compete better.

Specific comments

***Lemnalia*:** This species shipped very poorly with 80-90% mortality within 1 week of arrival. Other comments included that they were popular with customers (average 6.5 on a scale of 10) but that a brighter color variant would be preferred. Price range $1.50-$5.00.

Green polyp *Sarcophyton*: This species had 100% survival during shipping and was extremely popular with customers (average 9 on a scale of 10) due to the green polyps. Both wholesalers commented that the size was a little small. Price range $2.50-8.00.

Long polyp *Sarcophyton*: This species had 100% survival during shipping and was popular with customers (average 8.5 on a scale of 10) due to the long polyp extension. Both wholesalers commented that the size was a little small. Price range $2.00-8.00.

***Pachyclavularia*:** This species shipped poorly and although normally popular the poor coverage of the substrate and infestation with filamentous algae in the shipped specimens made them unsaleable.

Acropora: This species had 80-90% survival during shipping and was very popular (average 9 on a scale of 10) because of its color. One wholesaler really liked the size but the other generally sells larger colonies but commented that the smaller fragments often acclimate better. Price range $4.00-10.00.

***Porites*:** This species had 70-90% survival during shipping but was not particularly popular (average 3 on a scale of 10). Price range $2.00-8.00.

***Turbinaria*:** This species had 100% shipping survival. Popularity was mixed (3 and 10 on a scale of 10) with the price range varying accordingly at $2.00-10.00.

***Euphyllia*:** This species had 80% survival in shipping and were very popular (average 9 on a scale of 10). One wholesaler commented that these were the most popular of the corals sent. Both wholesalers commented that the cultured specimens were smaller than the wild collected specimens they usually sell but this did not hinder sales. Price range $2.00-12.00.

A revised economic model for coral farming in Pohnpei using recommendations from this study

Description:

This model is based on a fully integrated farm that produces only corals for the marine aquarium industry. The farmer has three full-time employees and takes a salary from the profits. The model assumes that a loan was taken to start operations and includes servicing of debt at approximately 30% of operating costs.

Assumptions:

1. All farming is ocean-based using metal trestles, nursery trays and cages.

2. The growout site is similar to the fast flowing site described in this study.

3. All production figures are based on growth and survival rates obtained in this study.

4. A small land-based facility is used for office space and holding and packing corals for air transport.

5. The land-based facility is approximately 4 km from the growout site and the broodstock is collected from within a 4 km radius of the growout site.

6. The farm grows 6 of the species tested (Long polyp *Sarcophyton, Lemnalia,* Green polyp *Sarcophyton, Acropora, Euphyllia* and *Turbinaria*). *Pachyclavularia* is discarded as a culture species due to poor test results and *Porites* is discarded due to poor marketability. While *Lemnalia* had poor shipping results it is assumed that with perseverance a reliable shipping method could be determined for this species.

7. A single owner/operator takes a salary from the profits.

8. All costs of packing and air transport are passed onto the buyer.

Capital costs

Fixed

Land and buildings	$ 15,000
Boat and motors	$ 14,000
Truck	$ 4,000
Diving gear	$ 1,500
Construction labor	$ 6,000
Subtotal	**$ 40,500**

Semi-variable

Office equipment (desks, chairs, air conditioner etc.)	$ 5,075
Land-based tanks (8)	$ 2,400
Ocean tables (130)	$ 3,250
Cages	$ 1,300
Equipment (saws, drills, hammers etc.)	$ 3,825
Pumps and plumbing	$ 1,500
Construction labor	$ 2,000
Subtotal	**$ 19,350**

Grand total capital costs	**$ 59,850**

Operating costs

Fixed

3 full-time employees @ $2 per hour	$ 12,000
Office (supplies, telephone, website, utilities)	$ 4,000
Maintenance and insurance (10% of capital)	$ 4,050
Capital charge (9% on 5 year loan)	$ 10,125
Land lease	$ 3,600
Subtotal	**$ 33,775**

Semi-variable

Maintenance and insurance (10% of capital)	$ 1,950
Capital charge (9% on 5 year loan)	$ 4,838
Subtotal	**$ 6,788**

Variable

Fuel	$ 3,500
Supplies (gravel, epoxy etc.)	$ 1,300
Tank fills	$ 3,600
Subtotal	**$ 8,400**
Grand total operating expenses per annum	**$ 48,963**

	Price per coral			
Pieces of coral sold per month	Breakeven price per coral	$5.00	$7.50	$10.00
2000	$2.04	$120,000	$180,000	$240,00
1500	$2.72	$90,000	$135,000	$180,000
1000	$4.08	$60,000	$90,000	$120,000
500	$8.16	$30,000	$45,000	$60,000

Table 1. Predicted revenues for varying coral prices and production volumes. (Note: lower production volume will lower operating expenses and therefore breakeven price. However, for the purposes of this model operating costs will remain constant).

Species summaries

Lemnalia

Broodstock location: keep broodstock on farm.
Estimated broodstock regeneration time: 4-6 months
Optimal initial fragment size: 40-60 mm tall
Best growing conditions: fast flowing with oceanic water exchange
Preferred substrate: basalt or coral gravel
Time to harvest: 3-4 months
Percentage of saleable animals from planting: 66%
Expected increase in height during growout: 89%
Optimal harvest size: 80-100 mm
Expected farm gate price: $5.00
Ease of handling and shipping: poor
Market acceptance: 6.5 on a scale of 10
Aquarium hardiness: medium
General comments: Once established this species is extremely hardy and grows rapidly. It cannot withstand rough handling and quickly succumbs to excessive contact. Further work is needed to improve shipping survival.

Green polyp *Sarcophyton*

Broodstock location: keep broodstock on farm.
Estimated broodstock regeneration time: 6-9 months
Optimal initial fragment size: 40-50 mm square
Best growing conditions: fast flowing with oceanic water exchange
Preferred substrate: basalt or coral gravel
Time to harvest: 5-6 months
Percentage of saleable animals from planting: 82%
Expected increase in crown diameter: 59%
Optimal harvest size: 60-80 mm
Expected farm gate price: $5.00-8.00
Ease of handling and shipping: excellent
Market acceptance: 9 on a scale of 10
Aquarium hardiness: high
General comments: This species is a fast grower with bright green polyps. It can withstand handling and transport well. It is not abundant in the wild so it is recommended to maintain broodstock on the farm.

Long polyp *Sarcophyton*

Broodstock location: keep broodstock on farm unless available locally
Estimated broodstock regeneration time: 9-12 months
Optimal initial fragment size: 60-70 mm square
Best growing conditions: fast flowing with oceanic water exchange
Preferred substrate: basalt or coral gravel
Time to harvest: 5-6 months
Percentage of saleable animals from planting: 60%
Expected increase in crown diameter: 17%
Optimal harvest size: 70-80 mm
Expected farm gate price: $5.00
Ease of handling and shipping: excellent
Market acceptance: 8.5 on a scale of 10
Aquarium hardiness: high
General comments: This species grows more slowly than the Green polyp *Sarcophyton* but cuttings differentiate into a definite stalk and crown that rounds out over time. Use of live rock disks for the growout trial was a mistake and it is likely that an increased percentage of saleable animals can be obtained using gravel as a substrate. This species is resilient to handling and general aquarium condition and is abundant in Pohnpei lagoon and broodstock should be available locally.

Pachyclavularia

Broodstock location: collect cuttings from the wild.
Estimated broodstock regeneration time: 6-9 months
Optimal initial fragment size: 10-20 mm square
Best growing conditions: fast flowing with oceanic water exchange
Preferred substrate: live rock disk
Time to harvest: 5-6 months
Percentage of saleable animals: 0%
Expected increase in length: 44.5%
Optimal harvest size: when covering at least half the disk
Expected farm gate price: not available.
Ease of handling and shipping: poor
Market acceptance: poor (wild collected specimens have high market acceptance)
Aquarium hardiness: medium
General comments: This species proved unsuccessful as a culture candidate due to its inability to repel filamentous algae and live in relatively calm lagoon conditions. The finished product was not attractive although it was hardy in the aquarium. Broodstock for this species were also hard to obtain.

Acropora

Broodstock location: collect cuttings from the wild
Estimated broodstock regeneration time: 12-18 months
Optimal initial fragment size: 30-40 mm tall
Best growing conditions: fast flowing with oceanic water exchange
Preferred substrate: live rock disk
Time to harvest: 4-6 months
Percentage of saleable animals from planting: 88%
Expected increase: width - 101%, height - 31%
Optimal harvest size: greater than 60 mm in height
Expected farm gate price: $5.00-10.00
Ease of handling and shipping: very good.
Market acceptance: 9 on a scale of 10
Aquarium hardiness: high
General comments: This species grows fast by first spreading over the substrate then putting out new buds. The characteristic blue color of the tips can be lost if it is not kept in the proper light. It sheds a lot of mucus when handled but is resilient to shipping and aquarium conditions. Different color morphs and species could diversify a farm's product line dramatically.

Porites

Broodstock location: collect cuttings from the wild
Estimated broodstock regeneration time: 18-24 months
Optimal initial fragment size: 30-60 mm tall
Best growing conditions: mid-lagoon site or fast flowing with oceanic water exchange
Preferred substrate: live rock disk
Time to harvest: 6 months
Percentage of saleable animals from planting: 66%
Expected increase in width 90% and height 51%
Optimal harvest size 60-70 mm tall
Expected farm gate price: $5.00
Ease of handling and shipping: very good
Market acceptance: 3 on a scale of 10
Aquarium hardiness: high
General comments: This is a very abundant species in Pohnpei and can nearly always be collected locally. It is resilient to handling, shipping and aquarium conditions but has poor market acceptance, which will limit sales.

Turbinaria

Broodstock location: collect cuttings from the wild.
Estimated broodstock regeneration time: 24-36 months
Optimal initial fragment size: 70-80 mm square
Best growing conditions: eutrophic or fast flowing with oceanic water exchange.
Preferred substrate: live rock disk
Time to harvest: 6-8 months
Percentage of saleable animals from planting: 92%
Expected increase in width 8-11% and height 7-10%
Optimal harvest size: 90-100 mm
Expected farm gate price: $5.00-10.00
Ease of handling and shipping: excellent
Market acceptance: range of 3-10 on a scale of 10
Aquarium hardiness: high
General comments: This is a relatively abundant species in Pohnpei and can nearly always be collected locally. While it is a slow grower, it rounds out well after fragmentation and starts to curl attractively at the edges after 5-6 months of growth. It is resilient to shipping and aquarium conditions but has a tendency to turn brown in low light conditions.

Euphyllia

Broodstock location: collect cuttings from the wild
Estimated broodstock regeneration time:18-24 months
Optimal initial fragment size: single polyp 40-50 mm tall
Best growing conditions: eutrophic or fast flowing with oceanic water exchange
Preferred substrate: live rock disk
Time to harvest: 6-8 months
Percentage of saleable animals from planting: 94%
Percentage split >1 polyps: 79%
Expected increase in width: 63%
Optimal harvest size: when split to 2 or 3 polyps
Expected farm gate price: $5.00-12.00
Ease of handling and shipping: very good
Market acceptance: 9 on a scale of 10
Aquarium hardiness: high
General comments: This species is quite rare in Pohnpei but because of the difficulty of keeping broodstock should be collected locally. It was the only species to thrive, grow and survive significantly better at the eutrophic site. It is resilient to handling, shipping and aquarium conditions.

References

Delbeek, J.C. and J. Sprung. 1994. The reef aquarium. A comprehensive guide to the identification and care of tropical marine invertebrates. Volume one. Ricordea Publishing, Florida 33133, USA. 544 pp.

Ellis, S. C. and L. Sharron. 1999. The culture of soft corals (order: Alcyonacea) for the marine aquarium trade. Center for Tropical and Subtropical Aquaculture, Publication Number 137. Waimanalo, Hawaii, USA. 73 pp.

Ellis, S. C. 2000. Nursery and grow-out techniques for giant clams (Bivalvia: Tridacnidae). Center for Tropical and Subtropical Aquaculture, Publication Number 140. Waimanalo, Hawaii, USA. 103 pp.

Green, E. and F. Shirley. 1999. The global trade in coral. WCMC Biodiversity Series No. 9. 70 pp.

Highsmith, R.C. 1982. Reproduction by fragmentation in corals. Marine Ecology - Progress Series 7:207-226.

Puterbaugh, P. and E. Borneman. 1996. A practical guide to corals for the reef aquarium. Crystal Graphics, Lexington, Kentucky, USA. 112 pp.

Sprung, J. and J.C. Delbeek. 1997. The reef aquarium. A comprehensive guide to the identification and care of tropical marine invertebrates. Volume two. Ricordea Publishing, Florida 33133, USA. 546 pp.

Wilkens, P. and J. Birkholz. 1992. Marine invertebrates: organ-pipe and leather corals, gorgonians. Karl-Heinz Dahne Publishing, Germany. 134 pp.