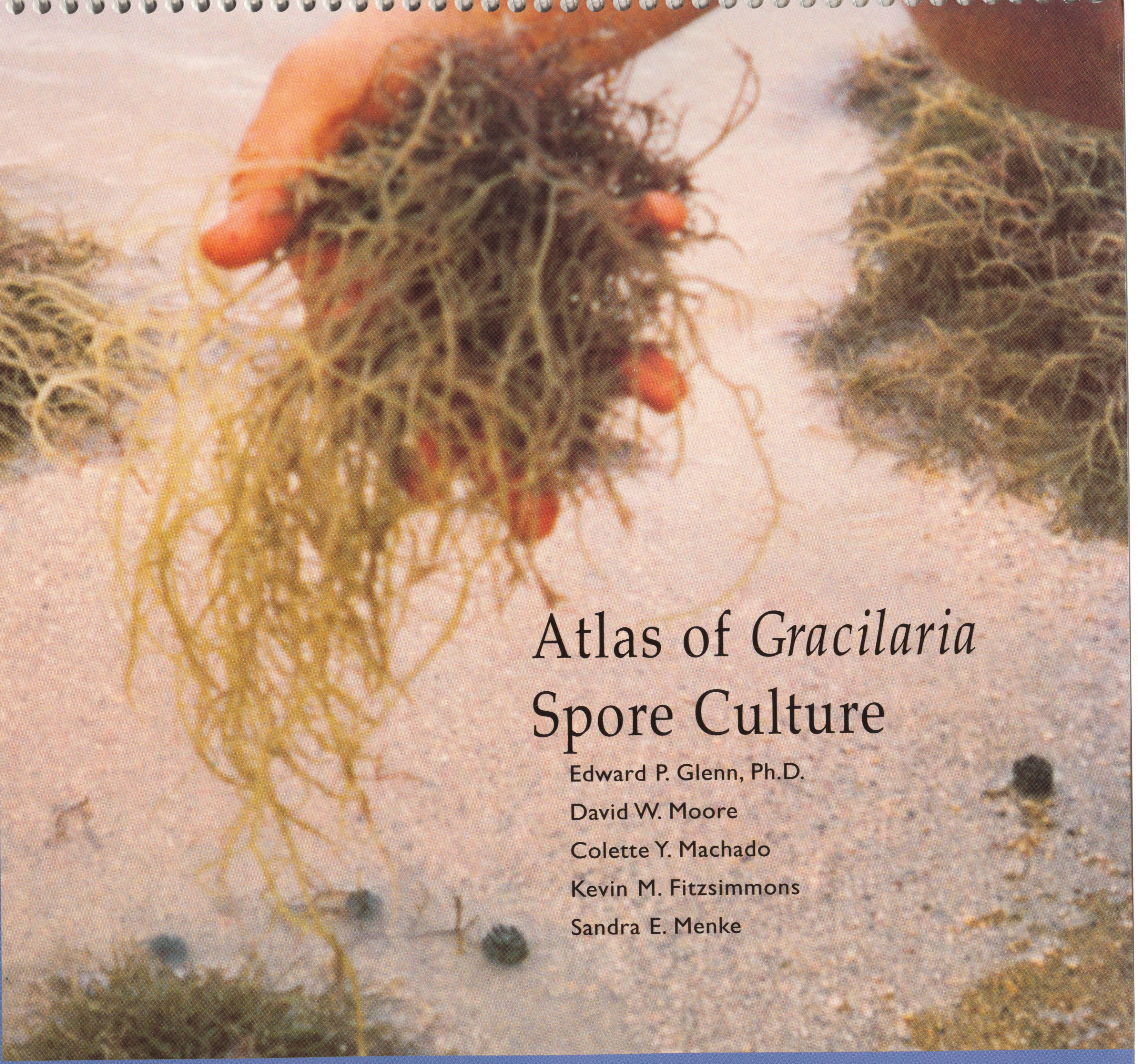

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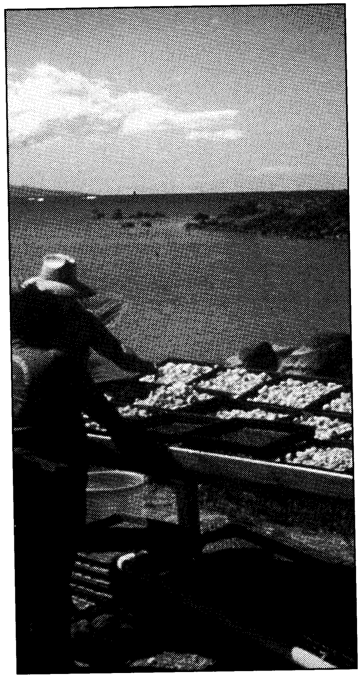

ATLAS OF *GRACILARIA* SPORE CULTURE

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The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies.

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Front Cover: Left inset: Hawaiian youth, Gandharva Ross, inspecting his *Gracilaria* crop grown from spores in a Moloka'i fish pond. Large Photo: Plants washed on shore, *Gracilaria parvispora* (long ogo). Back Cover: Cross section of cystocarp and spores.

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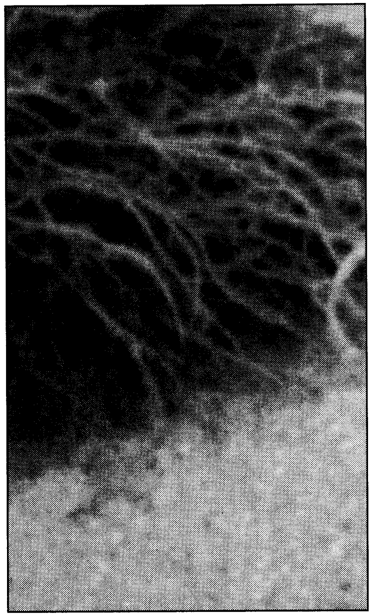

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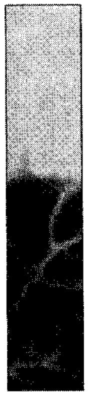


Introduction

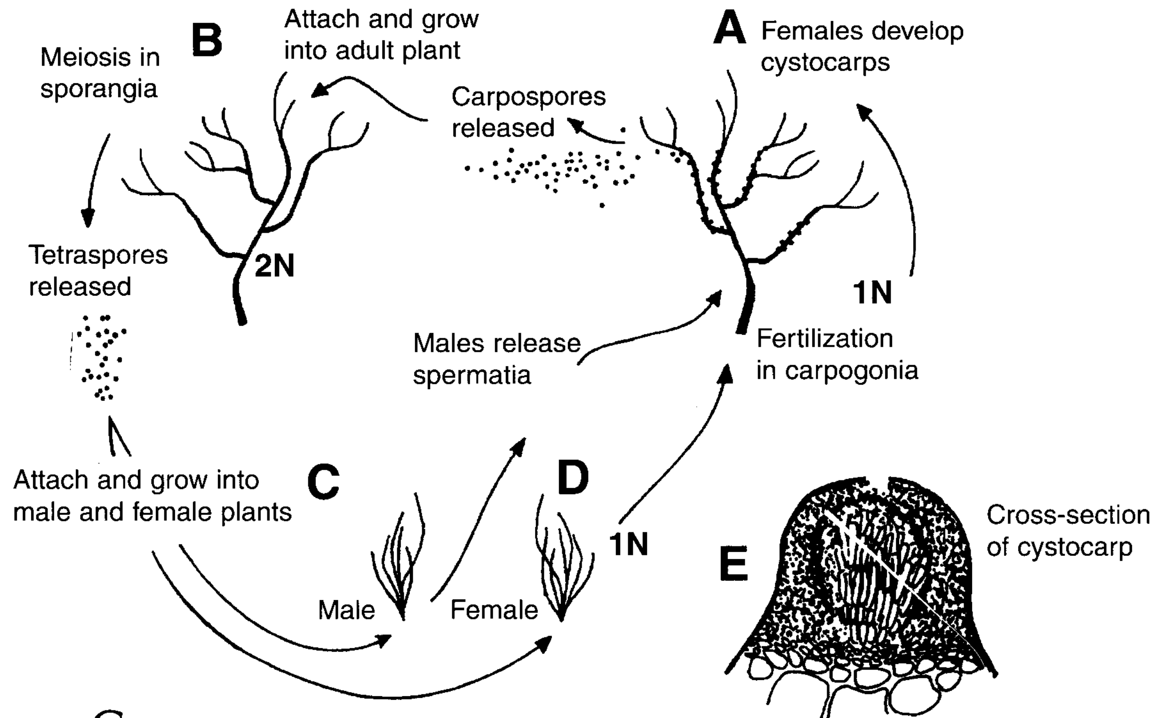
Gracilaria is a red seaweed sold as a high-value seafood in many parts of Asia and the Pacific. It is also the raw material from which the gel agar is produced. Agar is the main thickening agent used in Japanese cooking and is a common additive to prepared foods in the United States and Europe. Agar is also the familiar medium on which micro-organisms are cultured (agar plates).

The world supply of *Gracilaria* no longer meets the demand. Much of the supply still comes from the harvest of wild beds in Asia and South America, notably Chile, but these beds have been over-harvested. Increasingly, aquaculture supplies are supplementing the wild harvest. By 1991, one-third of the *Gracilaria* harvest came from aquaculture. As wild beds continue to be diminished, it is likely that the majority of *Gracilaria* will soon come from aquaculture.

Gracilaria aquaculture represents a new economic opportunity for coastal residents of tropical and subtropical coastlines around the world. The *Gracilaria* market is not limited by geography, but is served by countries as far apart as Chile, South Africa, France and Indonesia. Aquaculture methods are still being developed. There is no "best way" of growing *Gracilaria* - practitioners are still experimenting, developing methods that work at their location for their particular species of *Gracilaria*. The methods given in this atlas need to be modified by each grower to suit individual needs. Most *Gracilaria* farmers practice some form of vegetative culture. In vegetative culture, plants are not reproduced by spores. Instead, fragments of plants are grown in floating cages, on ropes, or broadcast into ponds or tanks, and are allowed to grow to harvest size. Vegetative methods have the advantage of simplicity. However, 20% or more of the harvest must be used to restart the cultures for the next round of growth. Vegetative methods are inefficient not only because a large amount of seaweed must be used for replanting, but because diseases and pest organisms become established on the plants. By replanting fragments of these plants, disease and pest populations soon become overwhelming and the farmer must restart his cultures using *Gracilaria* harvested from the sea rather than from his own farm. This can help deplete the local beds of *Gracilaria* which are generally already under stress from wild-crop harvesters.

This brief manual presents a "better way" to grow *Gracilaria*, using the natural spore shedding that occurs in most species. These spores, analogous to the seeds used to grow land crops, can be settled onto ropes, coral chips, fishing line, rocks or almost any other type of substrate, and grown into mature plants for harvest. The mature plants, in turn, provide a source of further spores to restart cultures, as well as *Gracilaria* for sale. Spore culture of *Gracilaria* is self-contained. It can be practiced even where *Gracilaria* does not grow naturally, or where the wild supplies have been depleted. Spore culture can also be used as an inexpensive method to repopulate natural stands of *Gracilaria* that have been over-harvested. Spore culture has been used for other types of seaweeds but is only recently attracting interest as a method for growing *Gracilaria*.

The manual relies on pictures as much as words to convey the message. The concepts are relatively simple and there is no single, right way of carrying out spore culture. Numerous modifications in methodology, utilizing local materials and suited to local conditions, are possible at each step. Pictures convey these alternate possibilities better than words. This manual is based on methods that we use to grow the edible species, *Gracilaria parvispora*, or long ogo, in Hawai'i. Our method makes use of the traditional Hawaiian fishponds on the fringing reefs of Moloka'i. However, the method can be adapted to other types of *Gracilaria* and other production systems.



Gracilaria Life Cycle

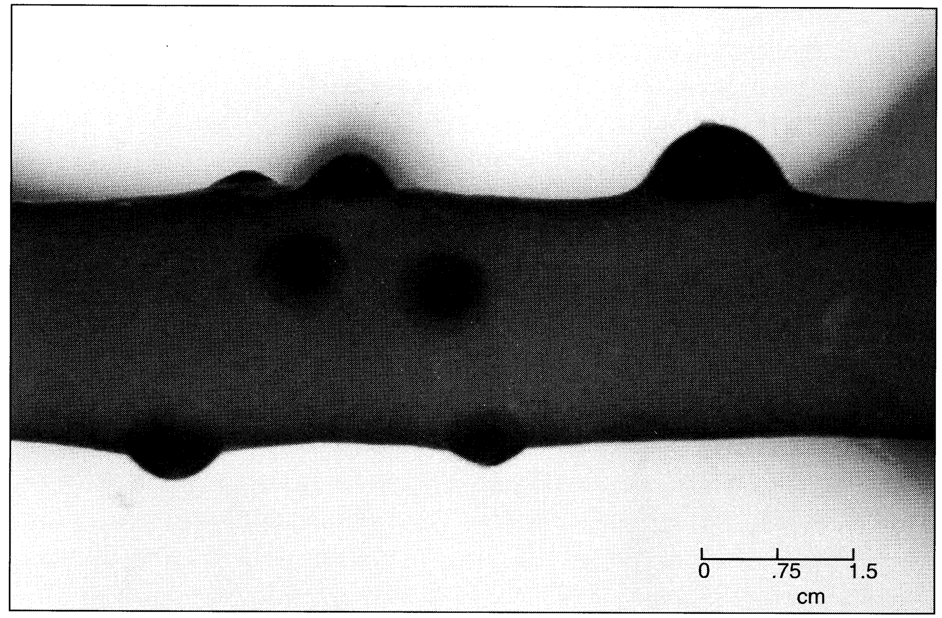
Red seaweeds have a type of life cycle called an isomorphic alternation of generations. Isomorphic means the different life stages look the same superficially. An alternation of generations means that a haploid generation of plants (containing one copy of each chromosome in the nucleus) gives rise through sexual reproduction to a diploid generation (containing two copies of each chromosome, one from the mother and one from the father). These life stages are designated 1N and 2N, respectively, for the number of copies of each chromosome. Unlike other seaweeds, red seaweeds such as *Gracilaria* have two diploid life stages rather than just one. One diploid stage does not look like the other stages: it consists of small bumps growing on adult (haploid) plants. Each bump is called a cystocarp, and it grows from a fertilized egg attached to a female plant.

A female plant usually contains hundreds of cystocarps distributed all over the thallus (A). Although they look like part of the parent plant, cystocarps are actually separate small plants growing on the mother plant (E). The cystocarps produce single-celled spores, called carpospores, which are released into the water. They are sticky, and as soon as they attach to an object in the water they begin to grow. They grow into mature, diploid plants called tetrasporophytes (the second diploid stage)(B).

Tetrasporophyte plants have single-celled, spore-producing bodies distributed over their surface (but not visible without a microscope). The spore-producing cells undergo meiosis and release haploid spores called tetraspores. The tetraspores attach and grow into male or female gametophytes (C,D). To the naked eye, male and female gametophytes are indistinguishable from tetrasporophytes. However, the males produce spermatia which are carried by the water current to the females, which bear eggs. The eggs are fertilized and grow into cystocarps, which release carpospores, thereby starting the life cycle all over.

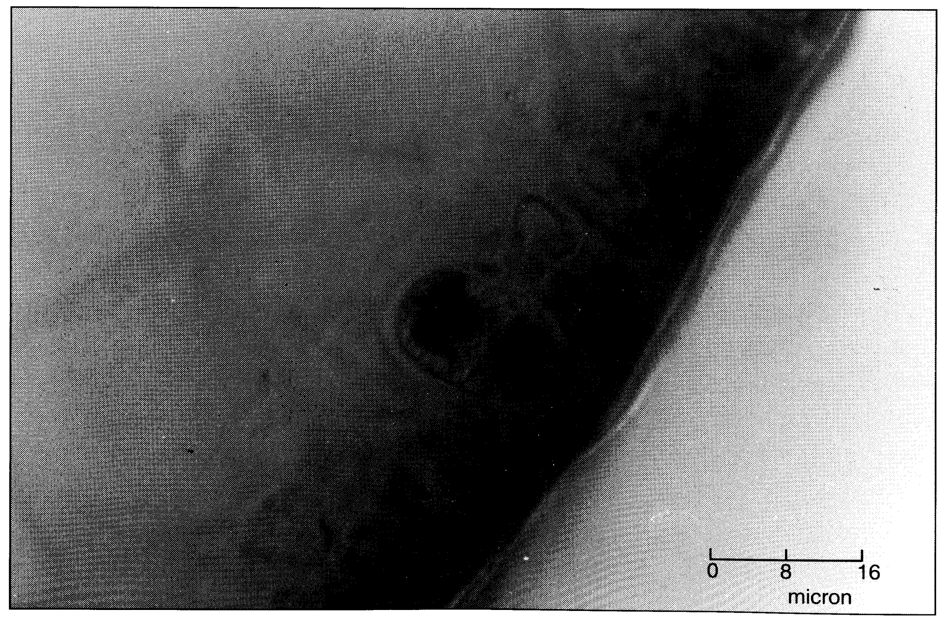
Cystocarpic Plant

Cystocarps

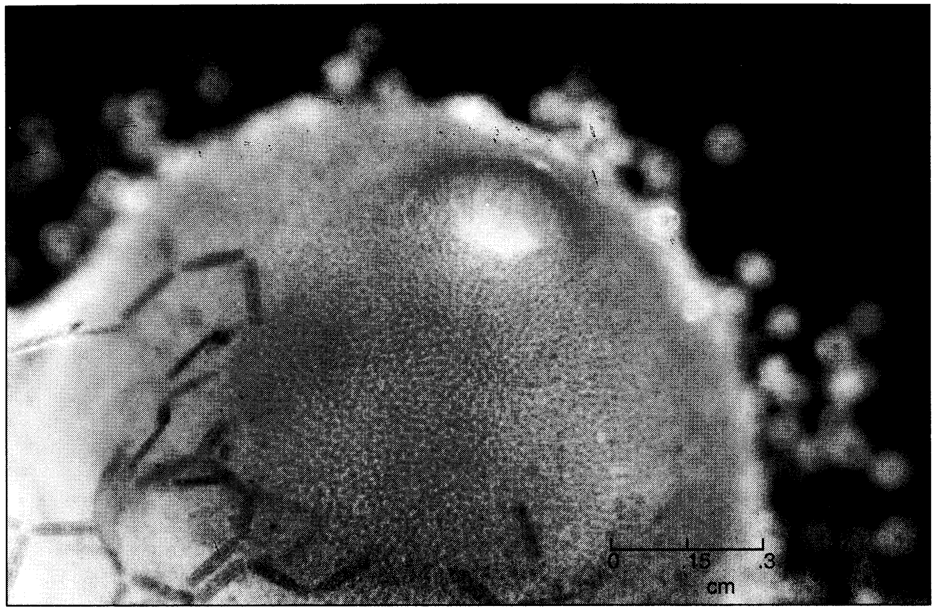


Tetrasporophyte

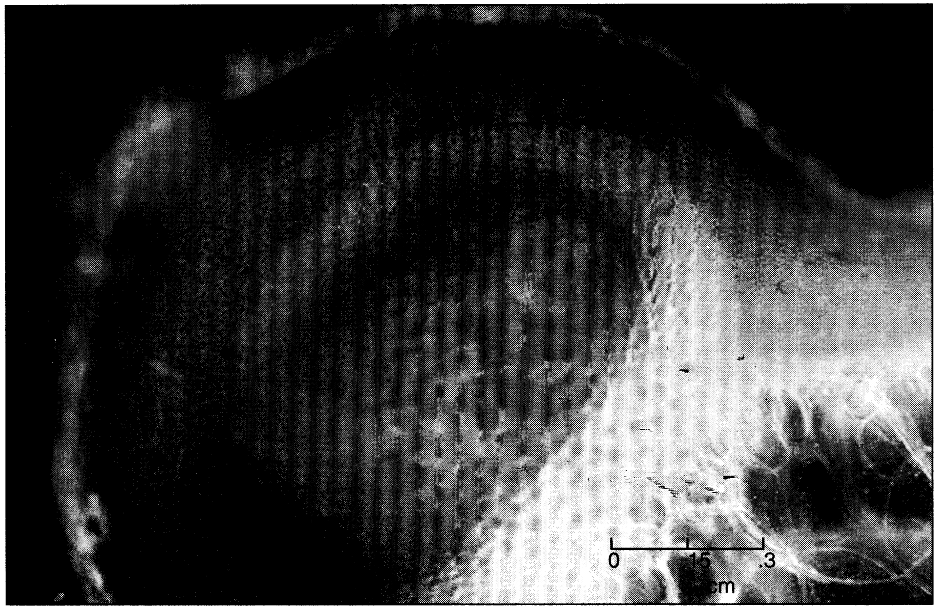
Tetrasporangium



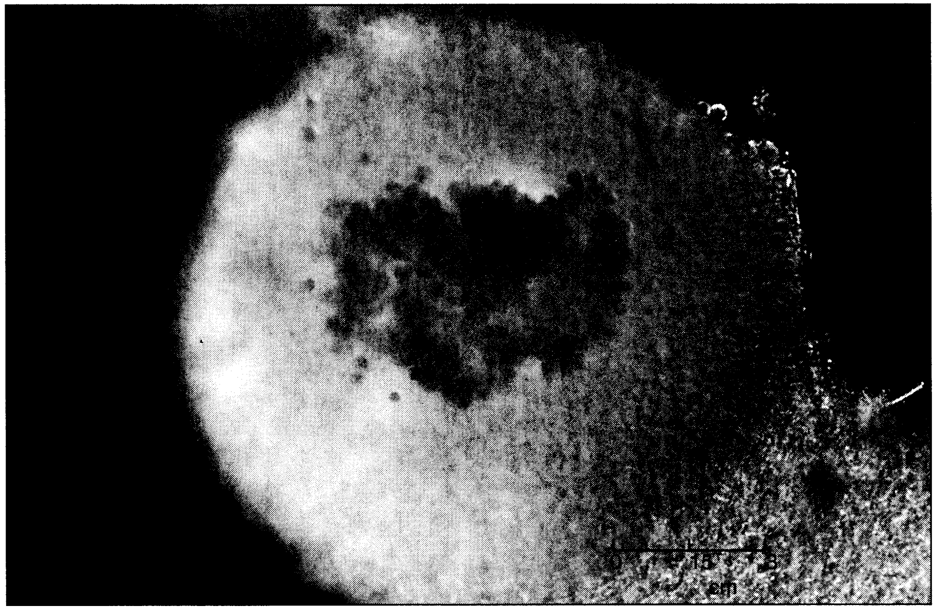
Cystocarps & Spores



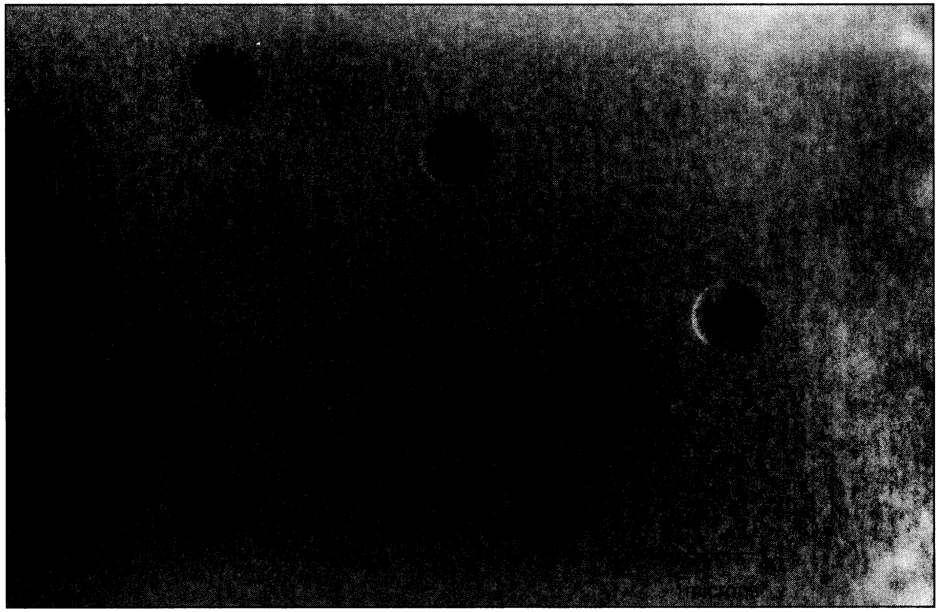
Cystocarps & Spores



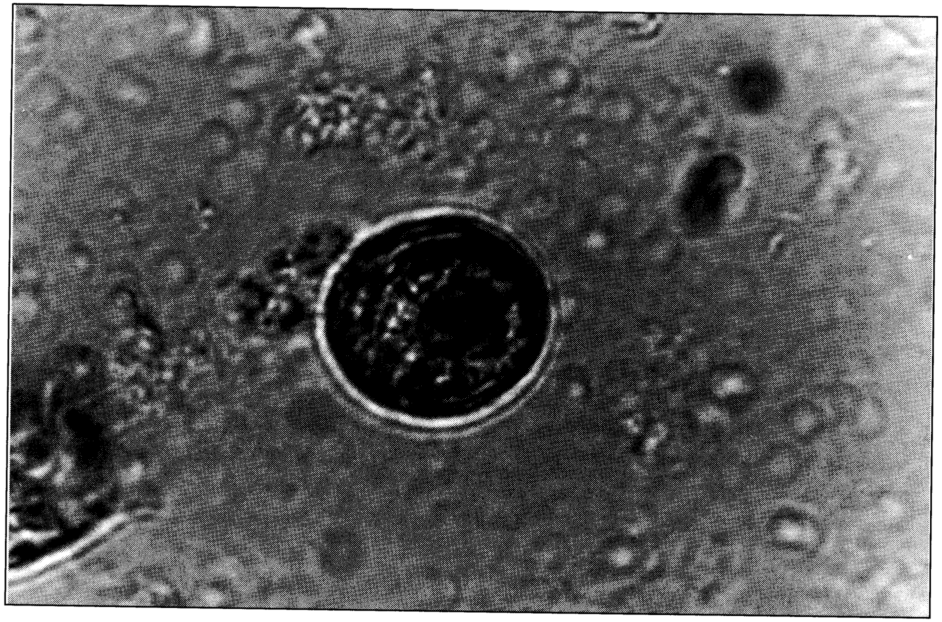
Cystocarps & Spores



One-Day-Old Spores

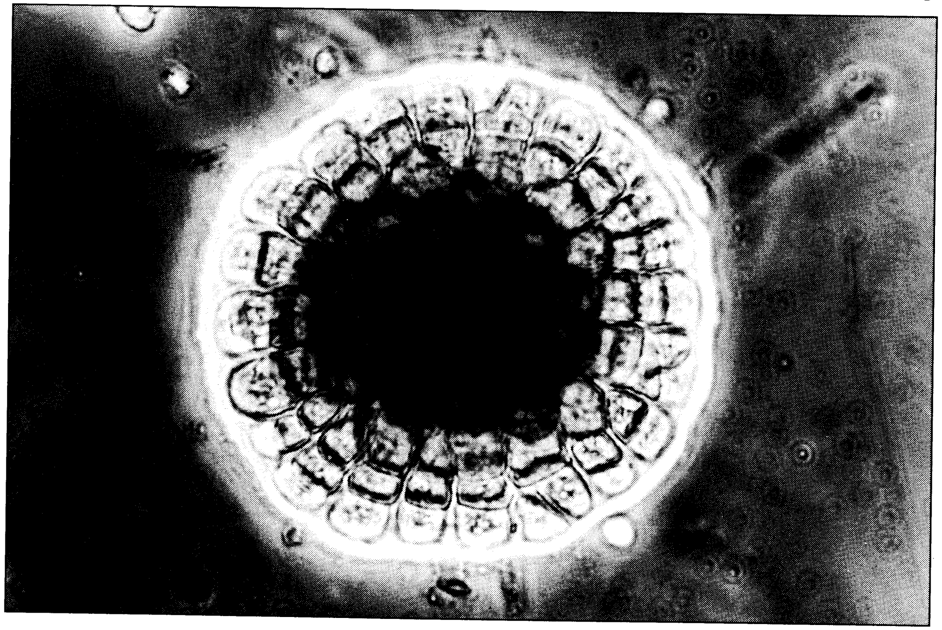


DIVIDING SPORES - 1 DAY

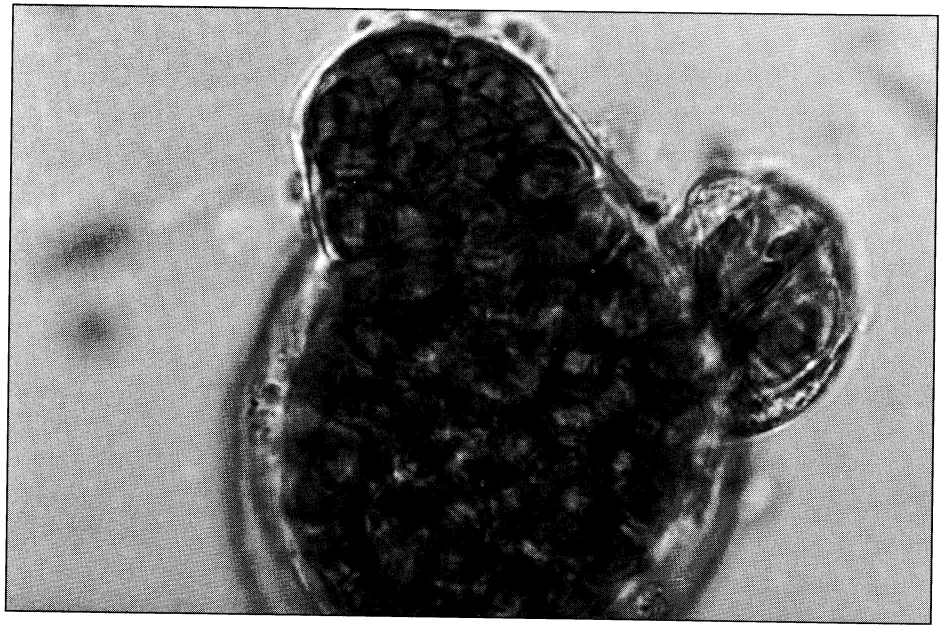


DIVIDING SPORES - 2 DAYS

DIVIDING SPORES - 7 DAYS



DIVIDING SPORES - 10 DAYS

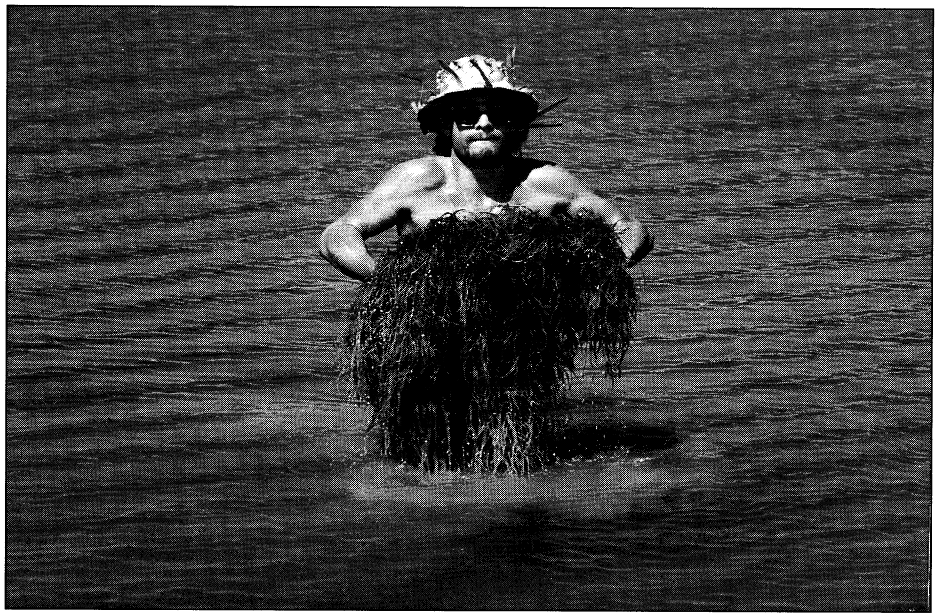


SPORLINGS - 21 DAYS

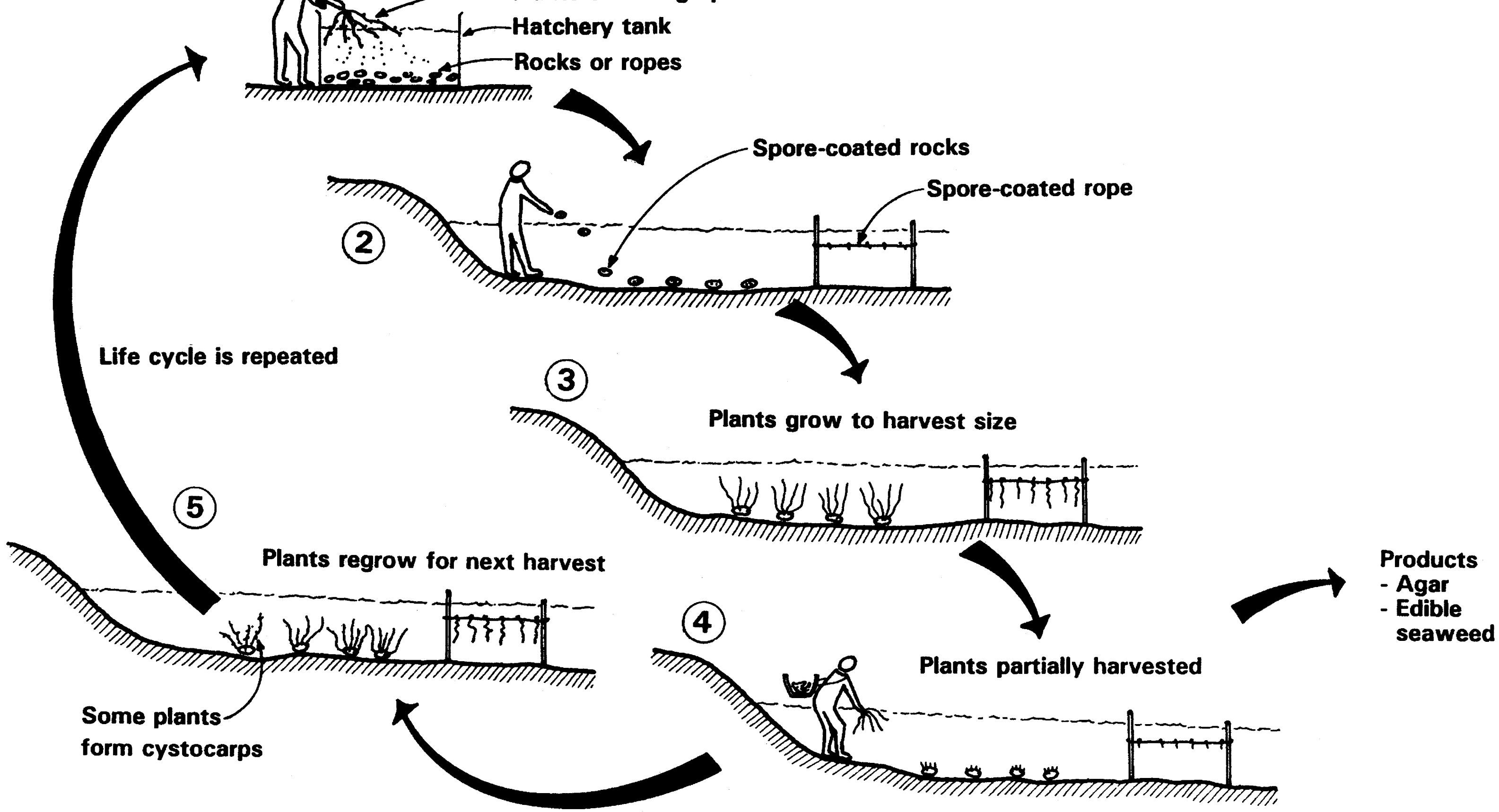
YOUNG PLANTS - 10 WEEKS

MEDIUM PLANTS - 40 WEEKS

LARGE PLANTS - 50 WEEKS



Steps in Spore Culture of *Gracilaria*



Completing the Life Cycle in Culture

Although the life cycle may seem complicated, completing the life cycle in aquaculture is not difficult. Only a few steps are involved:

1) Hatchery

A simple hatchery is needed to settle carpospores onto substrates that are then planted in the ocean to grow into harvest plants. Typically, the hatchery is a tank filled with seawater, with aeration to keep the algae alive and to distribute the spores. The substrates are any materials on which the farmer wants *Gracilaria* plants to grow. Spores will readily attach to any material that is not toxic. The farmer chooses the substrates based on convenience of planting and harvesting. Typical substrates are pebbles or coral chips which are broadcast onto pond bottoms or lines which are strung between stakes in the ocean.

Substrates are placed at the bottom of the hatchery tank, and female *Gracilaria* plants containing cystocarps are laid over the substrates. The tank is covered with shade cloth to keep competing organisms from growing and then incubated for 3-4 days. During this time, spores are released from the cystocarps and attach to the substrates.

2) Planting

The spore-coated substrates are removed from the tank and are planted in the ocean as quickly as possible (to avoid stressing the young sporlings). In the illustration, two types of plantings are shown: spore-coated rocks are broadcast onto the pond bottom; and spore-coated lines are tied between stakes. Sporlings and mature plants resist drying out and can be exposed to air for several hours without dying. They can even be transported in coolers without water.

3) Growout

The sporlings grow slowly at first, but many eventually become mature plants. Since the rocks and lines are inexpensive and do not require any maintenance during the growout period, a less-than-perfect success rate is acceptable. Plants are ready for first harvest approximately 25-50 weeks after planting out, depending upon their growth rate. Growth rate is determined by time of year (faster in summer than winter), amount of water motion, nutrients and water clarity.

Sporlings may enter a period of dormancy after they reach approximately 0.5 mm in length (barely visible to the naked eye). They can remain in this dormant state for weeks or months, until growth conditions are right. Sporlings then may grow rapidly to harvest size in just a few weeks. Fertilizing the sporlings may help break the dormancy.

4) First Harvest

At first harvest, plants are cut back to within 5 cm of the holdfast, leaving enough material behind to produce a second crop. Nearly all the plants at the first harvest will be tetrasporophytes (smooth plants without cystocarps), since they all grew from carpospores.

5) Regrowth and Subsequent Harvests

Plants require 4-10 weeks to grow back to harvest size after they are cut back. The farmer watches his crop, and schedules his harvests accordingly. There is no fixed number of harvests that can be taken, since *Gracilaria* plants will continue to grow indefinitely. However, with time the rocks or lines become covered over with competing organisms and the quality and quantity of the harvested material declines. After 2-3 years, most substrates will need to be replaced with fresh material from the hatchery. The farmer can broadcast new rocks or attach new lines over top of the old ones which may still be producing a harvest, minimizing the time between harvests. When the old substrates need to come out, the new ones will already be in place producing a harvest.

The hatchery operation requires a continual supply of cystocarpic plants. Over time, the farmer will notice that approximately 10% of his harvest plants are females bearing cystocarps. These arise as second-generation plants, from the release and growth of tetraspores by the tetrasporophytes which are the majority of plants. The tetraspores settle and grow on the same substrates that are already growing plants. The tetraspores grow into male and female gametophytes, and the females produce eggs which are fertilized and grow into cystocarps. The farmer culls these cystocarpic plants from each harvest, and uses them to start new hatches. A more efficient method, described in a latter section, is to dedicate part of the hatchery to producing cystocarpic plants so a supply of spores is always available.

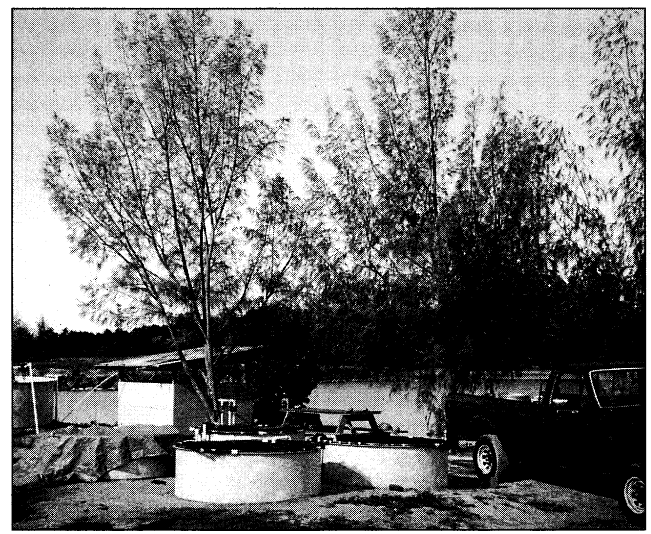
Hatchery Details & Alternatives

A tank hatchery using 4, 1000 liter tanks (1.5 m diameter, 0.6 m depth), can accommodate 48 plastic trays (40 x 40 cm) each containing 100-200 pebbles or coral chips to be coated with spores. This hatchery can produce approximately 3600 spore-coated rocks or chips per week, enough to plant 1-2 ha of pond per year. The substrates to be coated are washed in bleach solution and sun-dried prior to use, and placed in a single layer in trays. Hatch tanks are scrubbed with bleach solution, rinsed, and filled with filtered seawater prior to use. Since the seawater is not changed during a hatch, very little intake capacity is needed to support a hatchery. The illustrations show an intake capable of supplying 200 liters/minute of water. This intake is used to support fish cultures as well as the hatchery and is far larger than is needed for the hatchery alone. The hatchery could be served with a portable, submersible pump capable of delivering 10-20 liters/minute, similar to a garden hose. The sand filter removes large particles but not microorganisms. Aseptic techniques are not necessary.

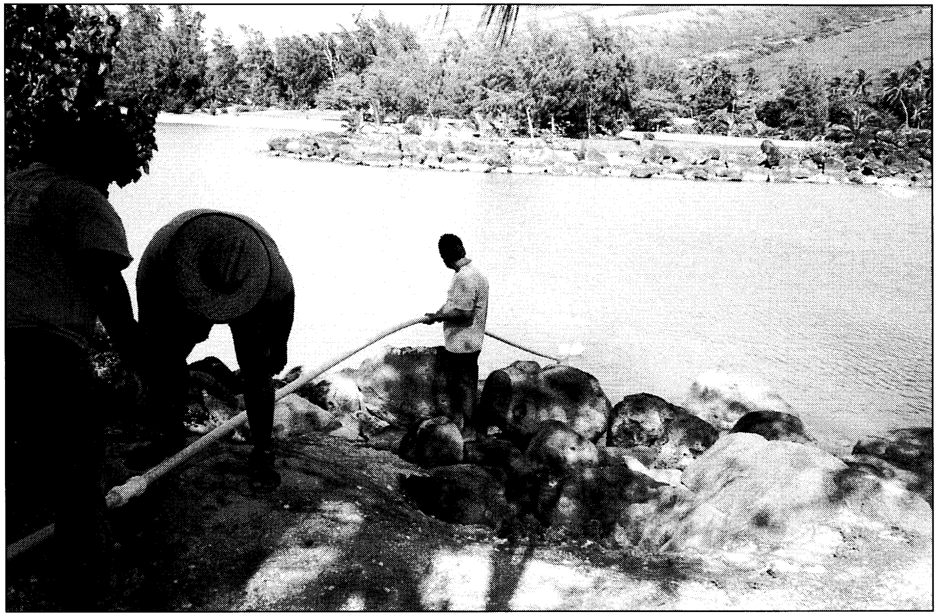
Trays are placed in a single layer in the bottom of tanks, and overlaid with cystocarpic plants that release spores into the water. The cystocarpic plants are hand-cleaned before use, to remove other algae, sponges or other contaminating organisms. Approximately 2 kg of plants per tank is sufficient (100-200 g per tray). A clean microscope slide is placed in each tray to estimate the success of spore settling. The tanks are aerated sufficient to keep the water moving but not so much that the plants are moved off the trays. This can be accomplished using a small air blower and several airstones per tank, of the type used in home aquaria. Shade cloth is used to block out 75% or more of the sunlight.

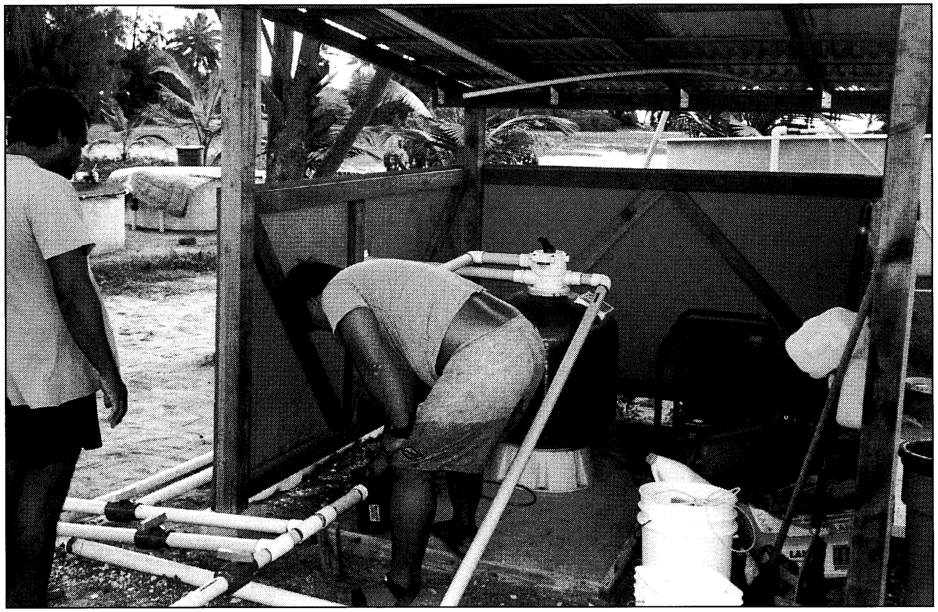
After 3 days the slides are counted for spores under a compound microscope. Spores are visible as red, dividing cells attached firmly to the slide (slides can be washed in seawater to remove some of the contaminating organisms). Spore density should range from 200 to 7,000 per cm^2 - even the lowest density is sufficient to indicate that all the rocks or chips were well coated with spores. Nearly every hatch produces numerous spores, but occasionally only a few spores are found on the slides. These hatches should be repeated using fresh cystocarpic material.

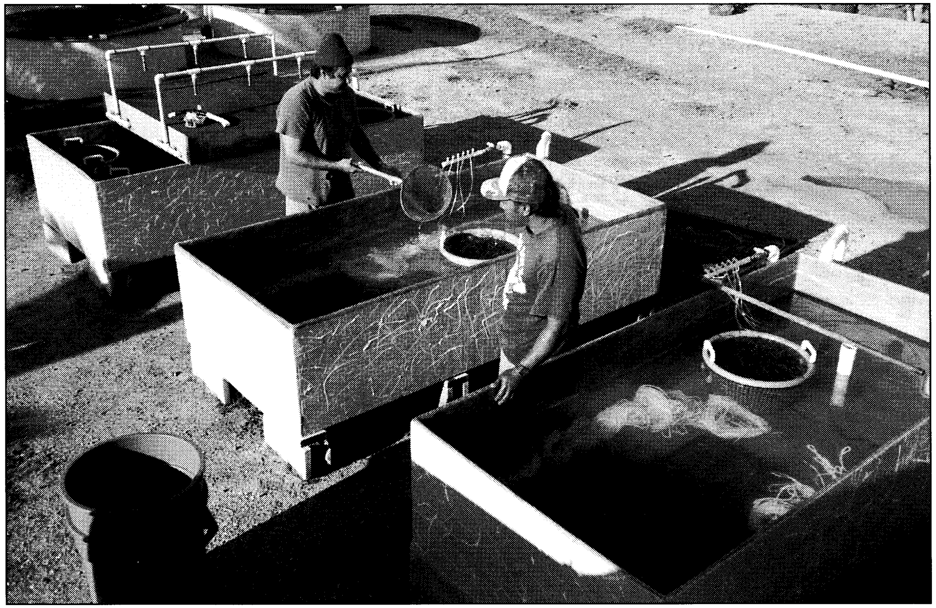
As the pictures show, hatches can be carried out in square tanks, or ropes can be substituted for rocks and chips. Ropes can be coiled loosely in tanks and turned every day during the hatch, or they can be strung on frames to ensure even spore coating. Thin nylon rope (0.5 diameter) is inexpensive and durable. The hatchery procedure can even be carried out in the pond, using floating baskets to hold the trays, which are overlain with cystocarpic thalli.

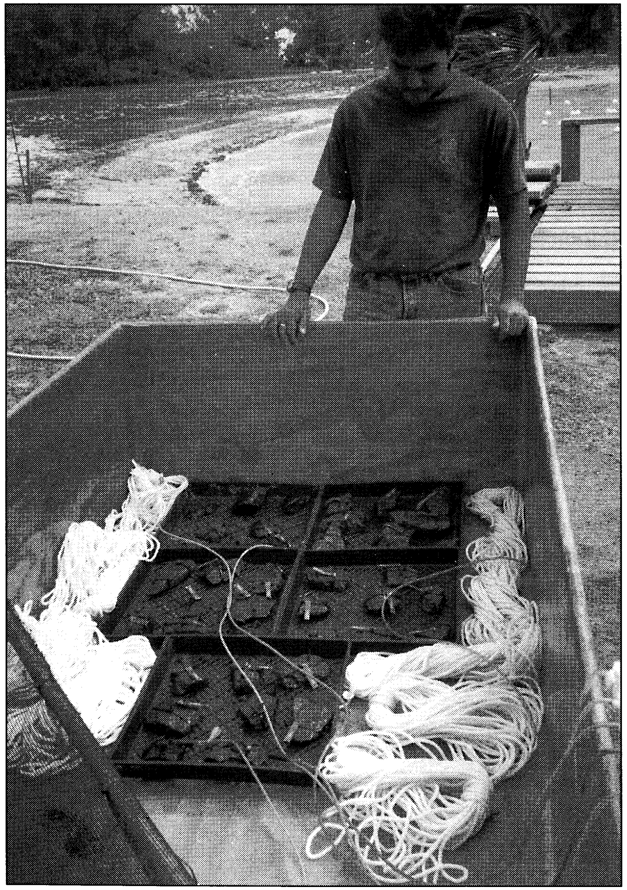


Setting Up a Hatchery



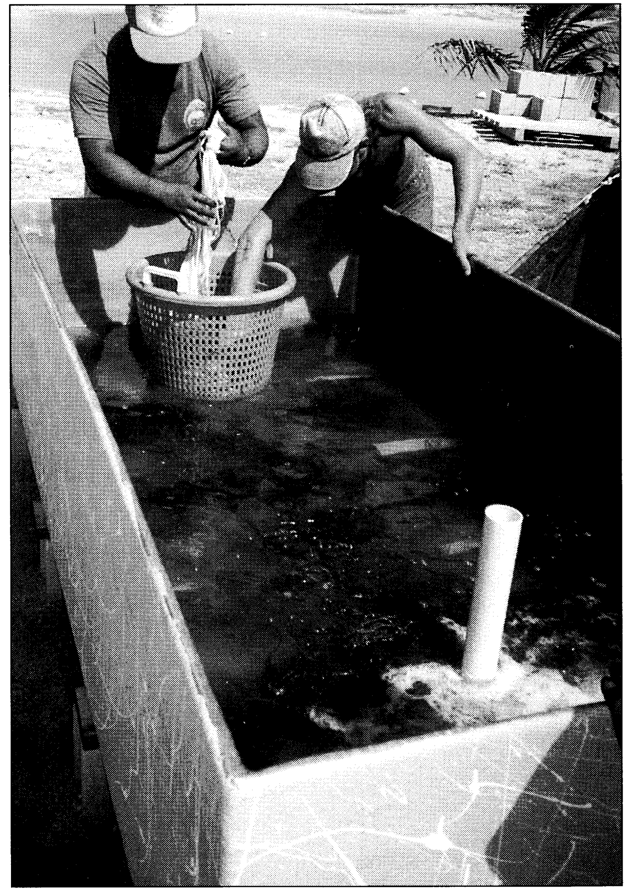






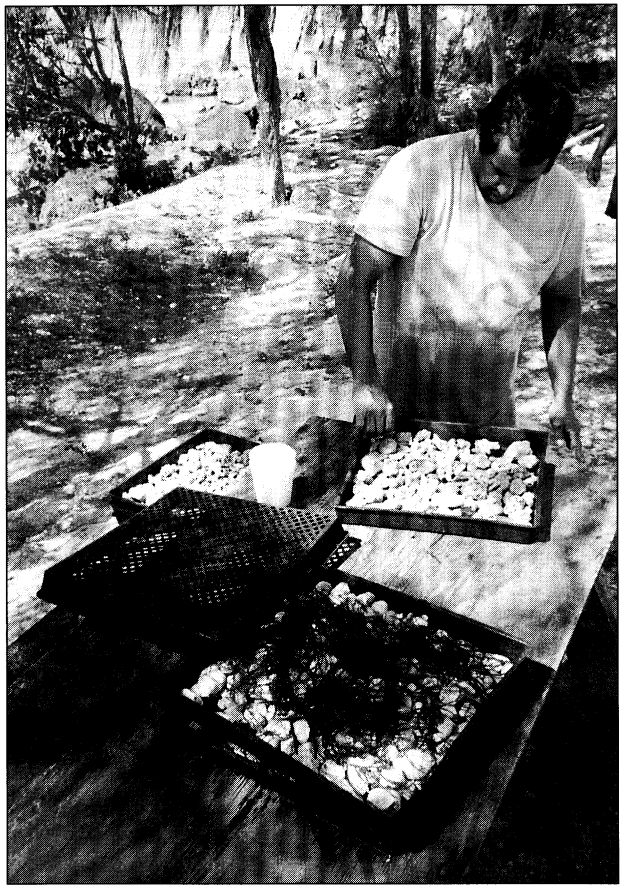
ROCKS AND ROPES TO BE COATED WITH SPORES

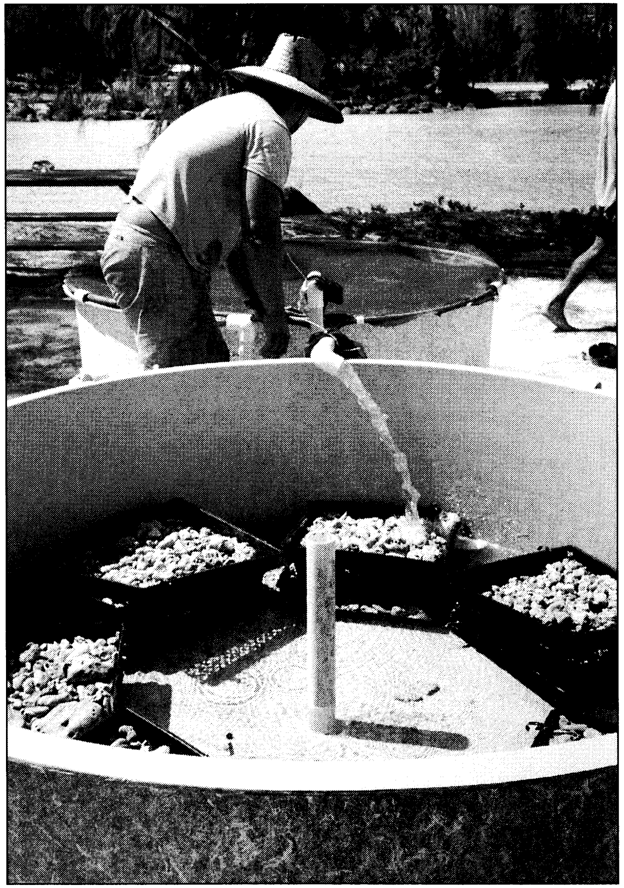
CYSTOPCARPIC PLANTS

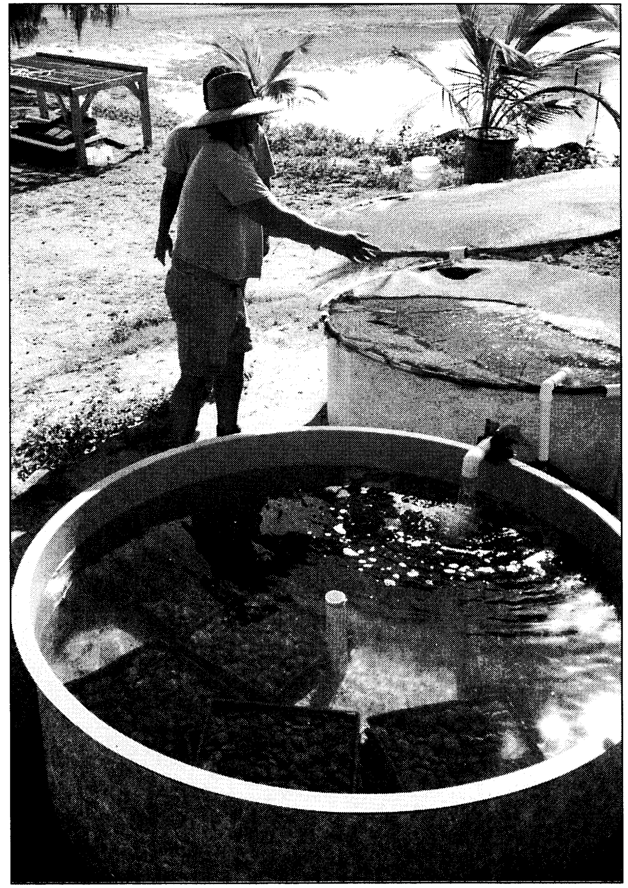


HATCH IN PROGRESS

Setting Up a Coral Chip Hatch in Trays



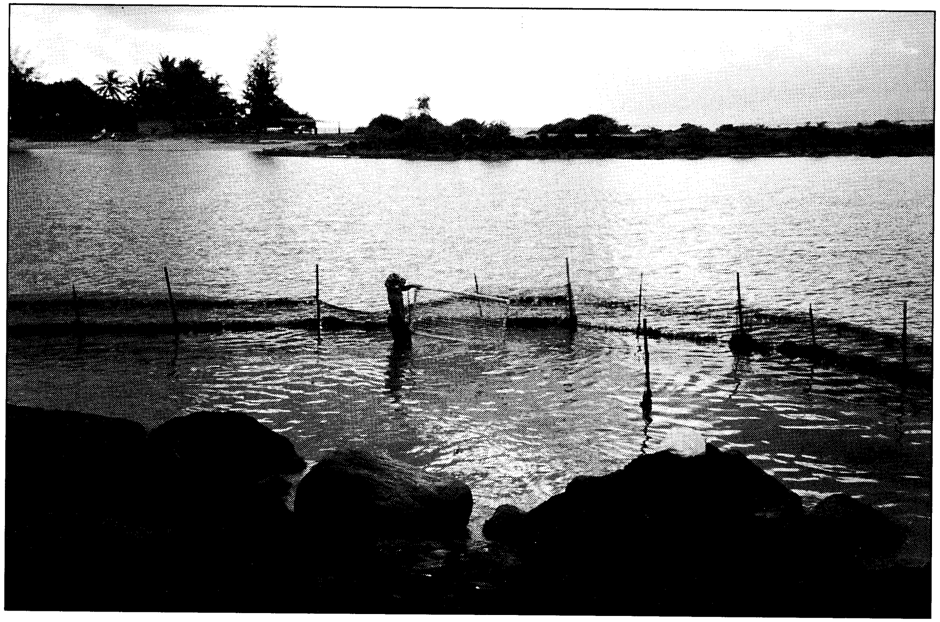




Setting Up a Hatchery – *Cont.*

Rope hatch using frame

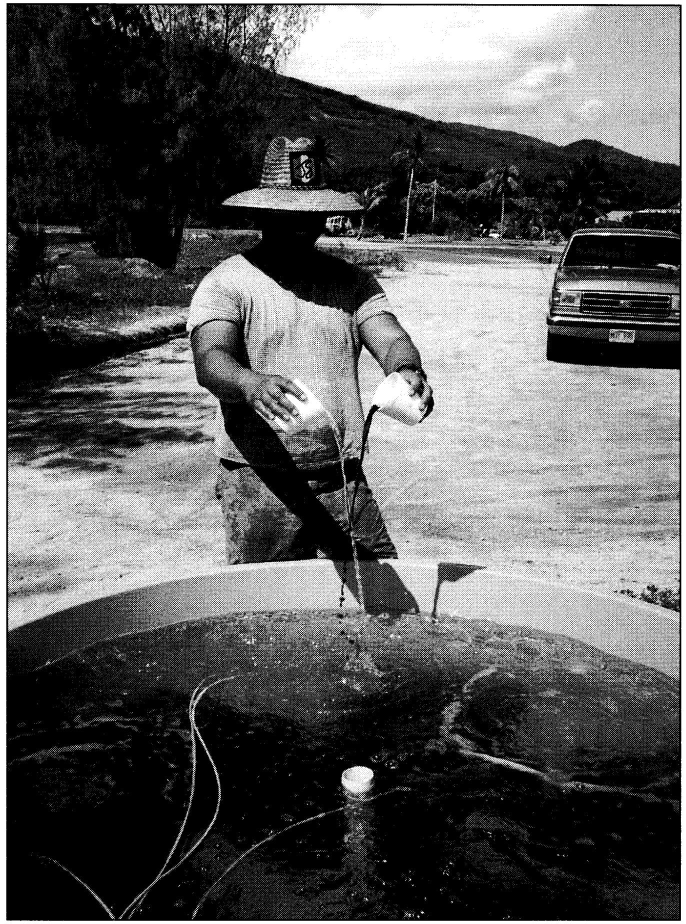
Frame with spores placed in penned section of pond



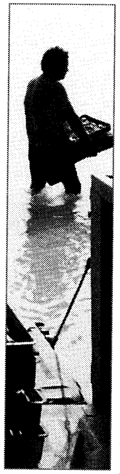
Fertilizing Sporlings & Larger Plants

Like most crops, *Gracilaria* responds positively to nitrogen and phosphorous fertilization. As a red algae, *Gracilaria* has a special ability to take up nitrogen and store it for latter use to support growth. The red pigment in red algae is a protein that is involved in nitrogen storage as well as light absorption. When exposed to fertilizer for 24 hours in tanks, *Gracilaria* plants (sporlings as well as large plants) absorb and store enough nitrogen and phosphorous to last for several weeks once they are removed from the tanks and placed in the ocean. The plants develop an intense red color within a week after fertilization, which gradually turns to a tan color as the plants grow and redistribute the nitrogen within the plant.

During the last 24 hours in the hatch tanks the new sporlings (as well as the fertile thalli that released the spores) can be fertilized by adding 0.1 gram per liter each of ammonium nitrate and diammonium phosphate to the tanks. These are ordinary farm or garden fertilizers available in large or small bags from farm chemical suppliers or retail garden centers, respectively. Commercial liquid algae fertilizers can also be used in the hatch tanks. Plants and sporlings can also be returned to the tanks for refertilization, especially if they are grown in water of low natural fertility.



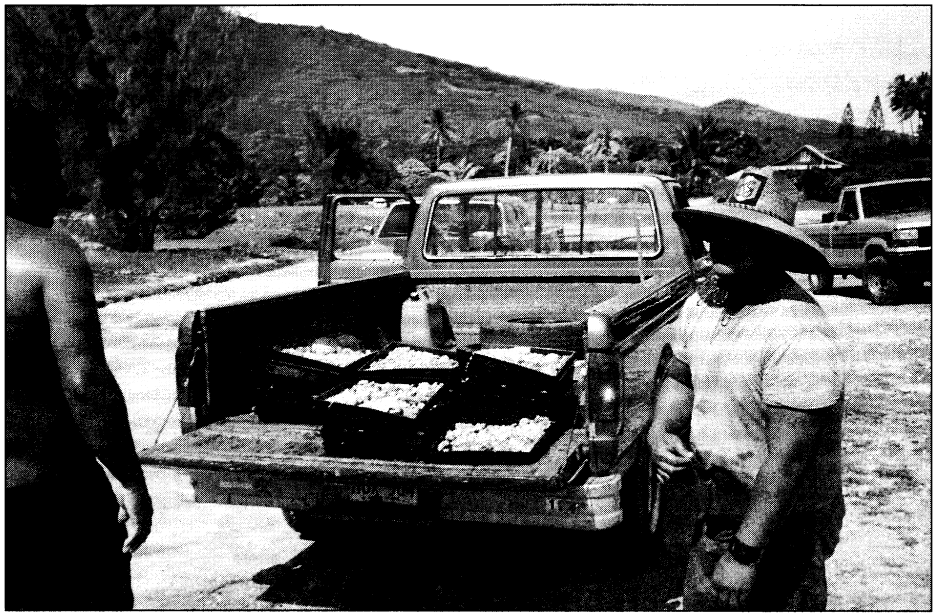
ADDING CONCENTRATED, COMMERCIAL ALGAE FERTILIZER TO HATCH TANK



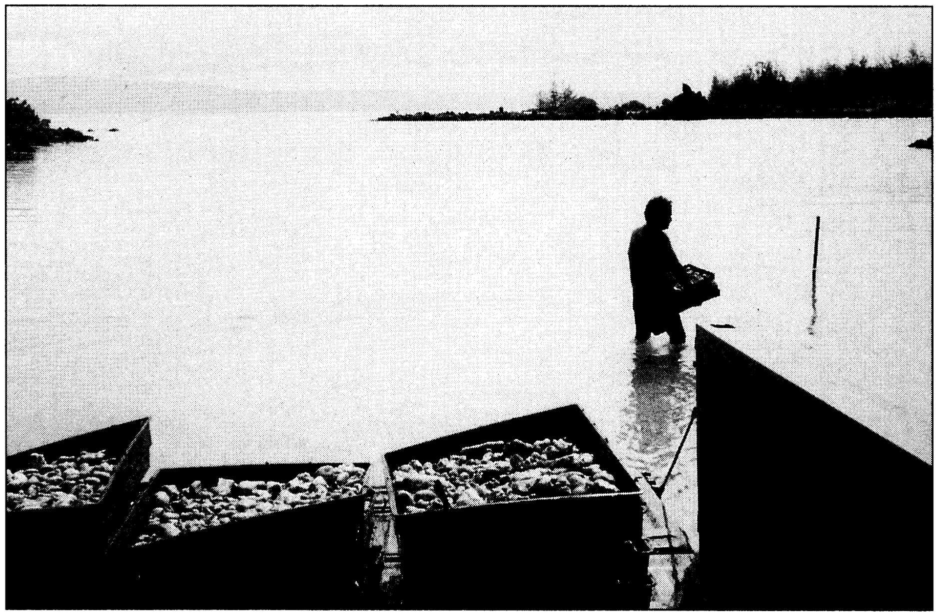
Growout of Plants on Rocks and Ropes

When it is confirmed that spore settling is adequate, the trays or ropes are removed from the tanks and hauled to the planting area. The sporlings can be exposed briefly to air without dying, hence the trays can be hauled dry in a pickup truck bed as illustrated. If they are to be out of the water for more than a few minutes, they should be moistened with seawater occasionally to prevent their drying. Ropes can be hauled in plastic garbage cans partially filled with seawater.

Rocks or chips are broadcast into a penned section of pond (to keep out fish and turtles that eat *Gracilaria*) and the trays are returned to the hatchery, where they are washed in bleach prior to reusing. The cystocarpic material from the hatch can be reused for subsequent hatches, but should be replaced after 3-4 weeks as the plants tend to lose vigor over time and produce fewer spores. Approximately 10 rocks or chips per square meter is the minimum density that will produce a good crop. The density can be much higher if sufficient rocks or chips are available. *Gracilaria* grows best when plants are crowded together to form a closed cover in which competing organisms have difficulty establishing.



PLANTING TRAYS IN A POND

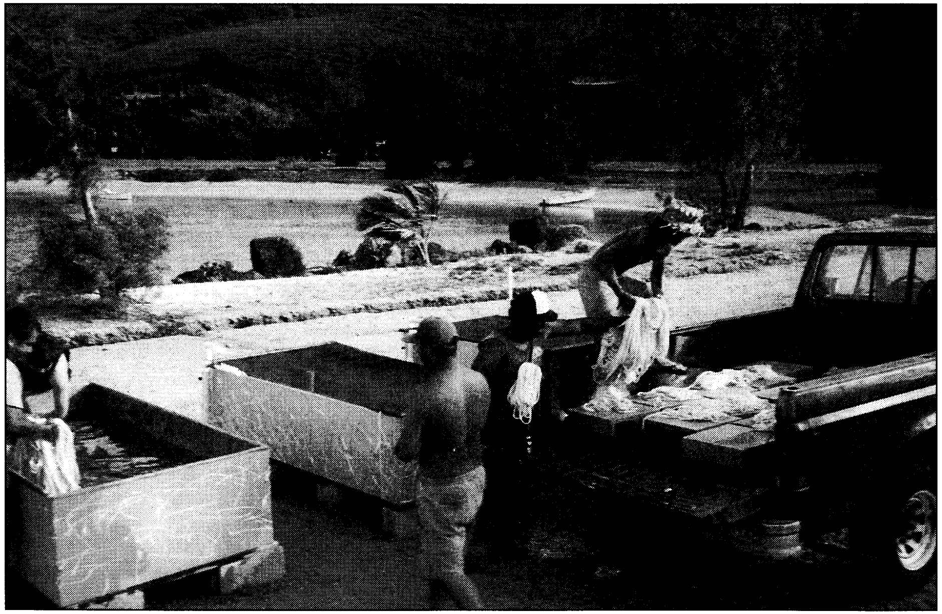


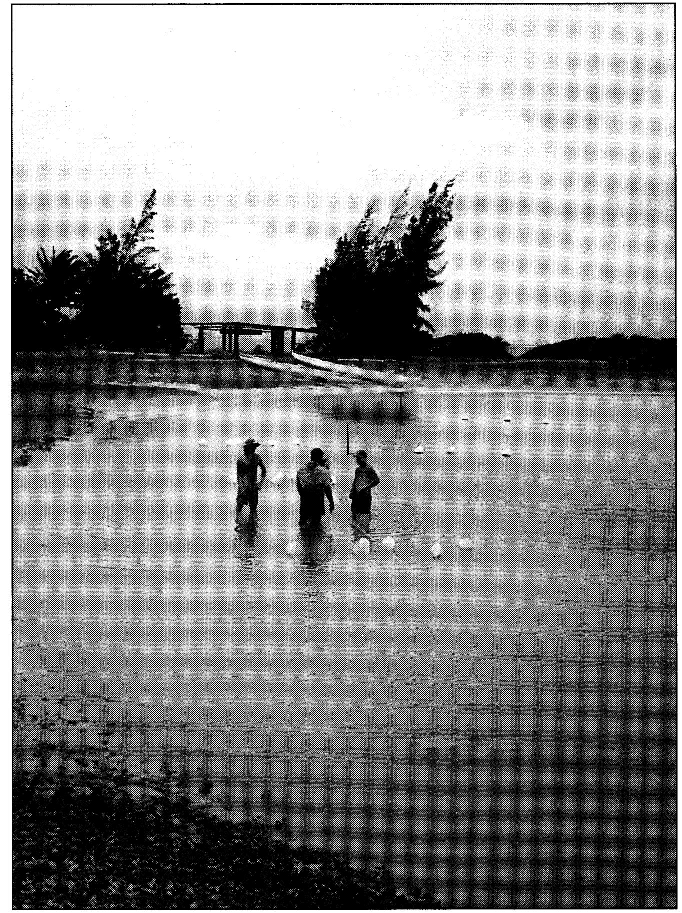
Ropes or lines are strung between stakes driven into the pond bottom, or stretched between concrete blocks that anchor each end. Lines 10-30 m long are convenient to handle, and a spacing of 1 m between lines allows room for harvesting and tending the lines.

Gracilaria will grow under a variety of water conditions. It responds positively to water motion, yet the best place to grow the crop may be in an area of reduced water motion. These areas tend to have lower growth of competing organisms. Shallow water (less than 1 m) is easiest to use if rocks or chips are broadcast onto the bottom, but lines can be stretched out in deeper water, using plastic milk jugs as floats. Growth is fastest in clear water, due to better light penetration, but good crops can also be produced in very murky water (visibility under 0.3 m). Murky water tends to discourage the growth of competing organisms.

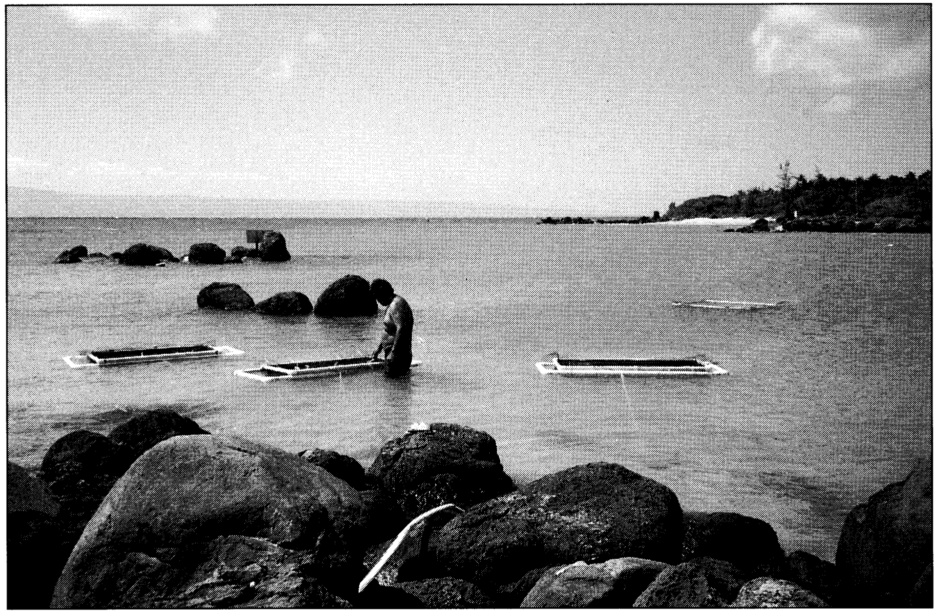
Depending upon water conditions, lines require 20-25 weeks to produce their first crop. Rocks and chips are slower, since they are on the bottom of the pond where they become partly covered with sand and silt, and they require 40-50 weeks before they can be harvested. In general, attempting to do weekly maintenance on the plantings is impractical. The most important single step a farmer can do to encourage a successful crop is to surround the planting area by an enclosure to keep out fish and turtles, which can completely eliminate a crop. A plastic fence using 2 cm mesh is sufficient. Inexpensive materials can be used, and it should be expected that the fence will need to be replaced or repaired following storms. The farmer will have to experiment to find the best locations in a pond or on the reef to plant out a crop.

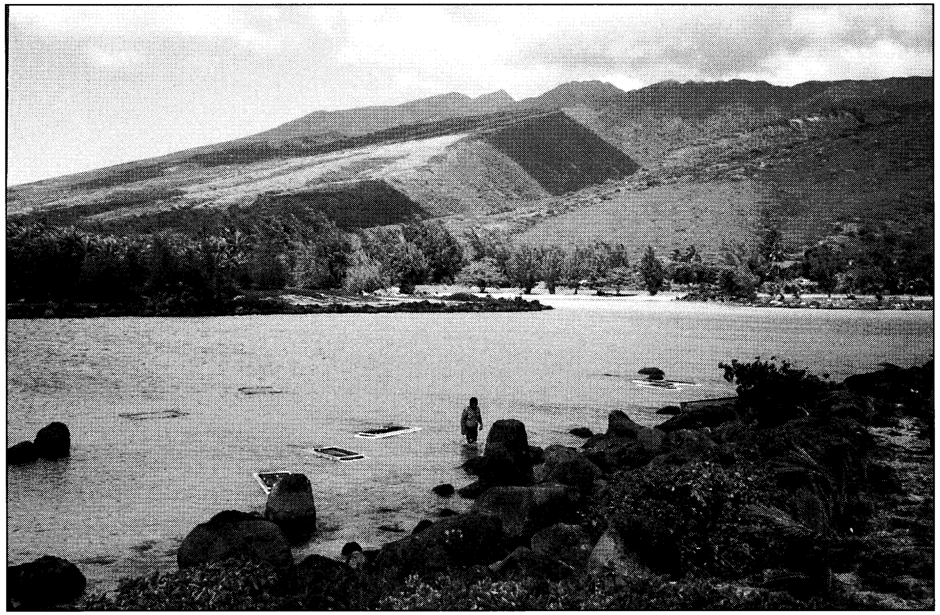
Planting Out Spore-Coated Ropes

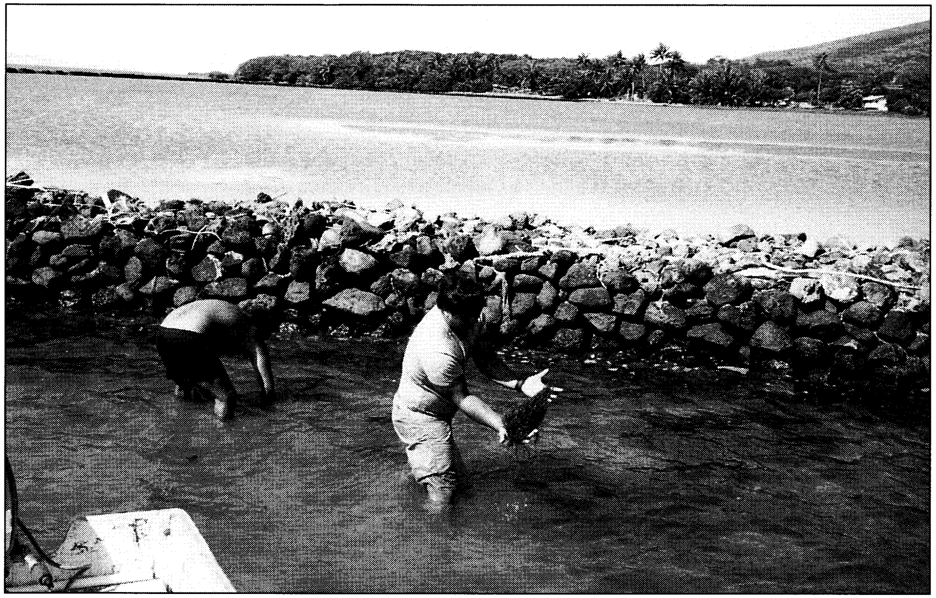


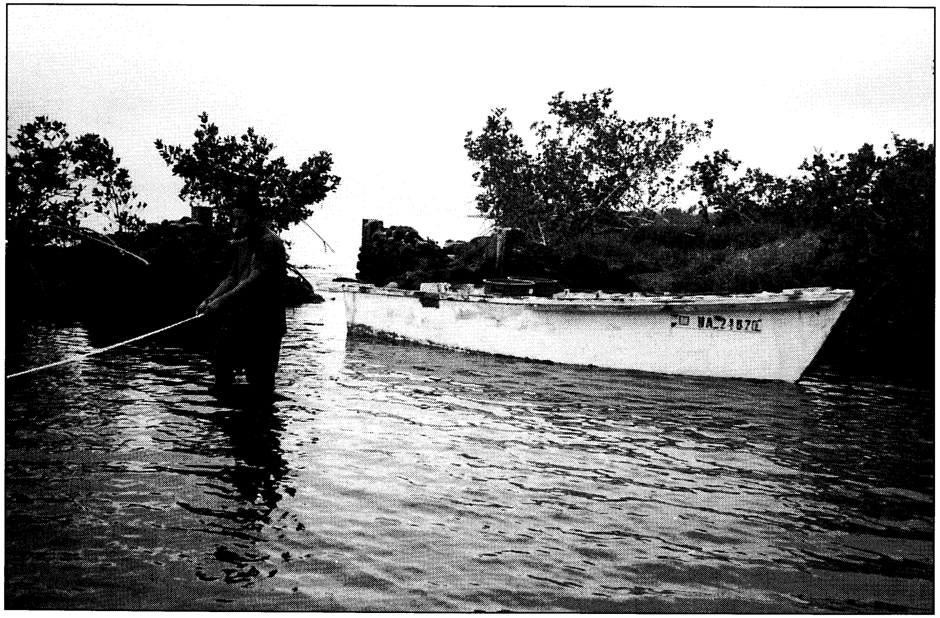


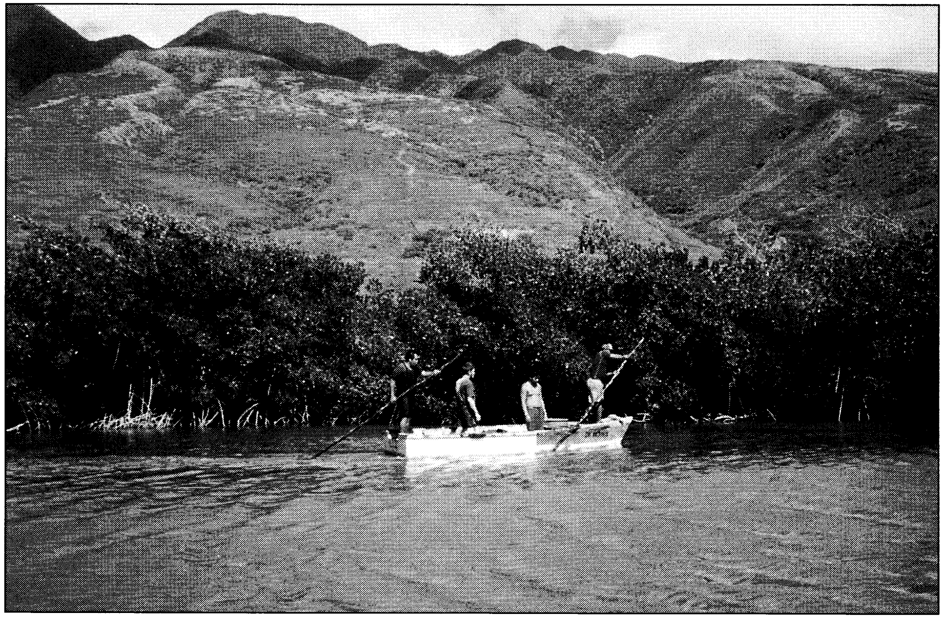
Setting Out Baskets to Multiply Stocks



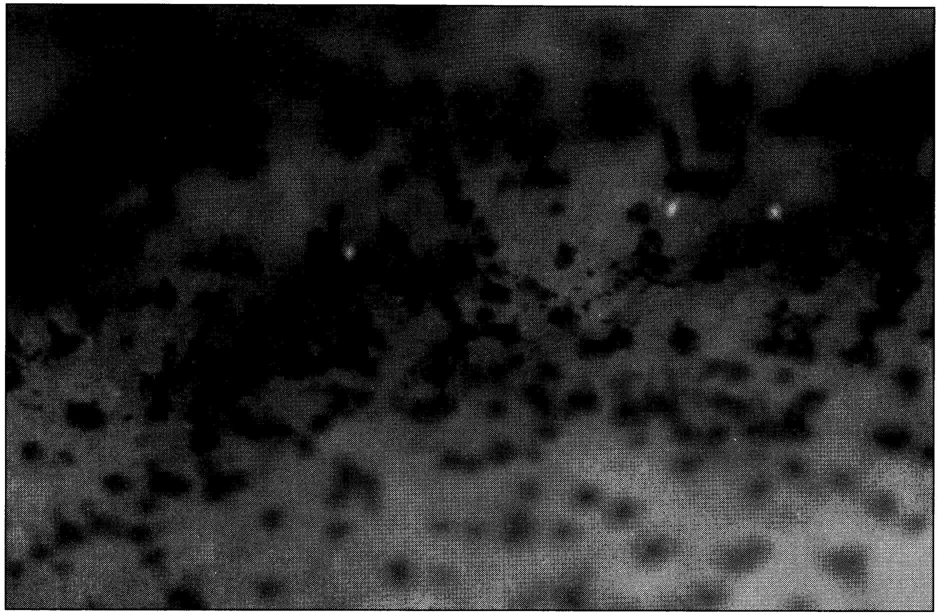




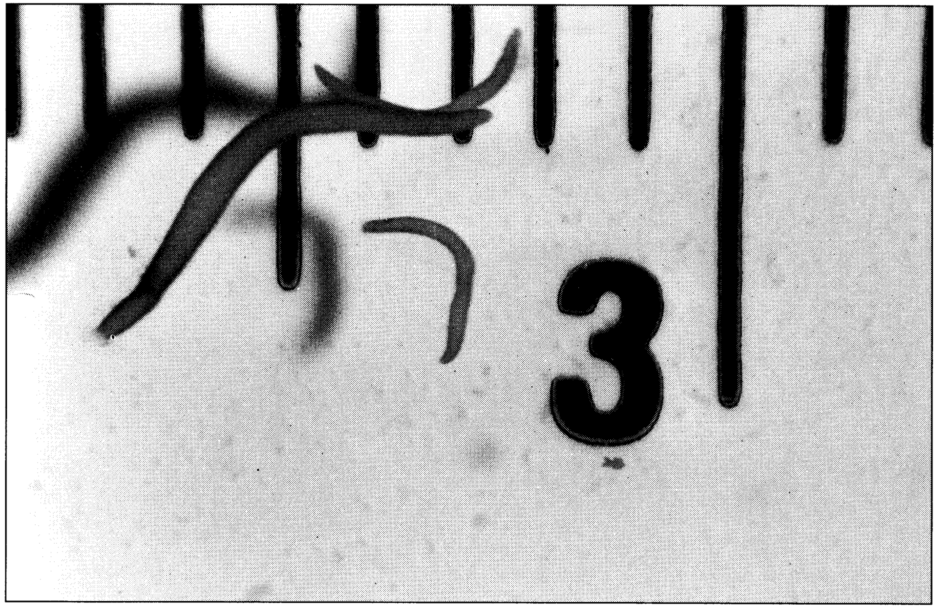


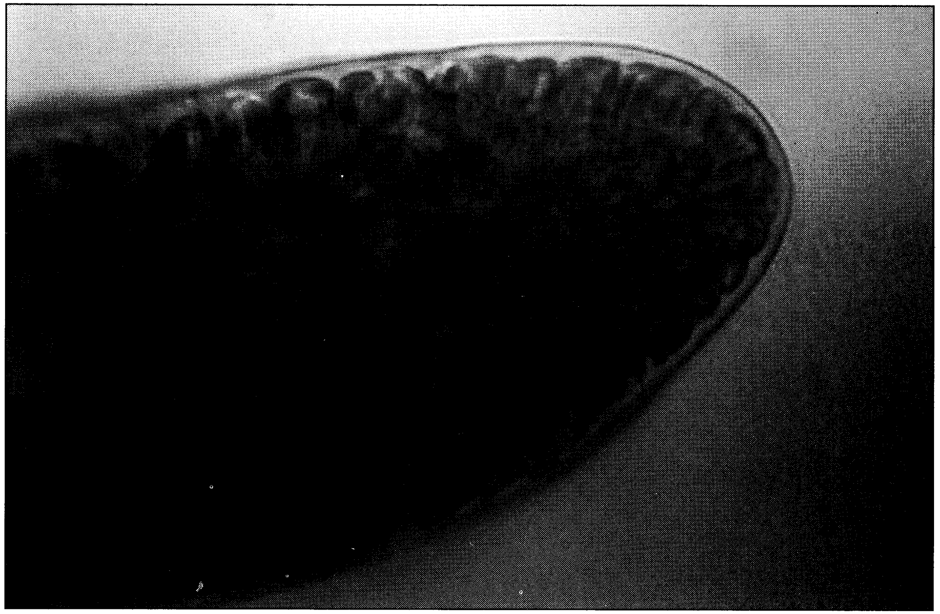


Sporlings on Rocks

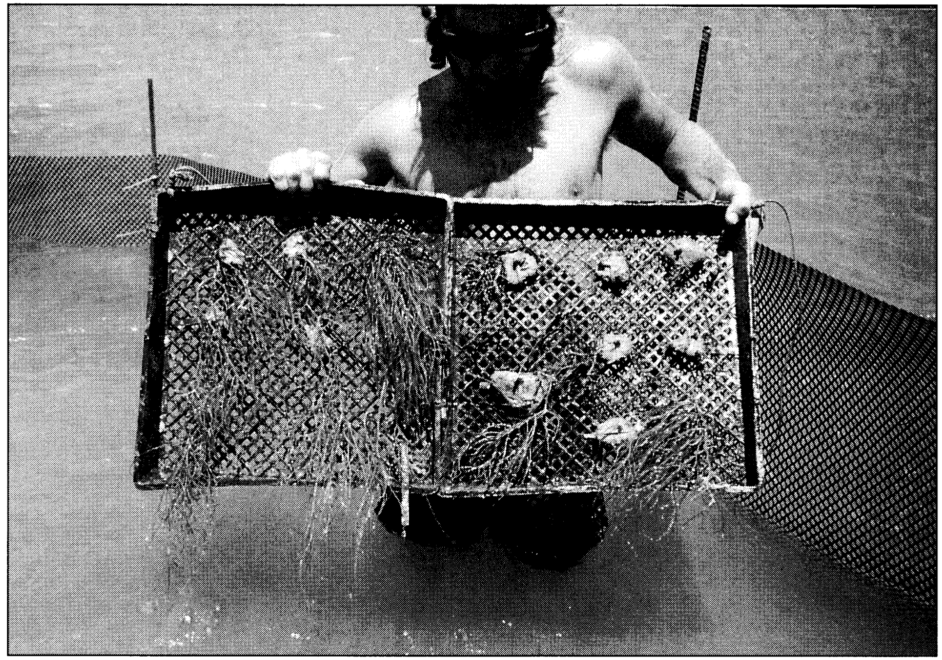


21-Day-Old Sporlings



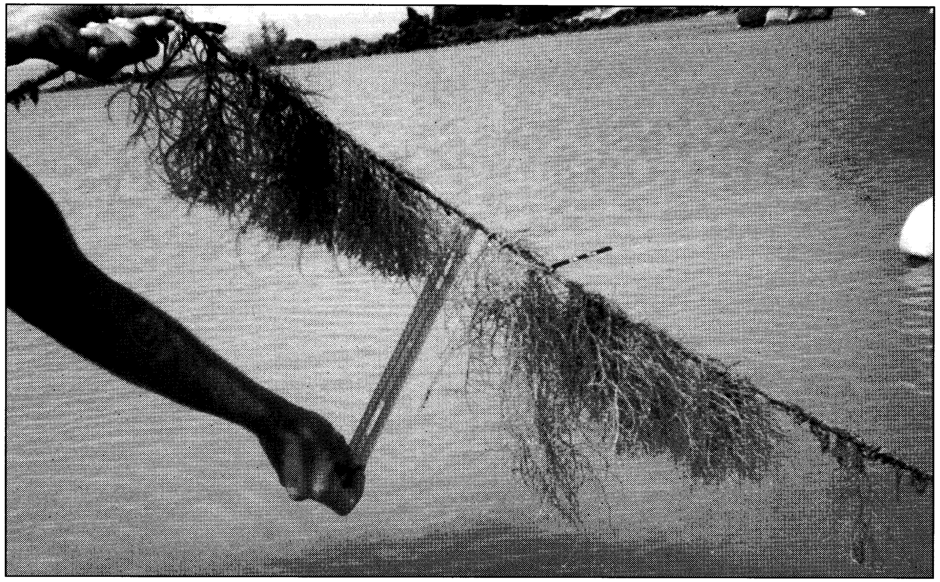


GROWTH ON ROCKS



40-WEEK-OLD PLANTS

Growth on Ropes

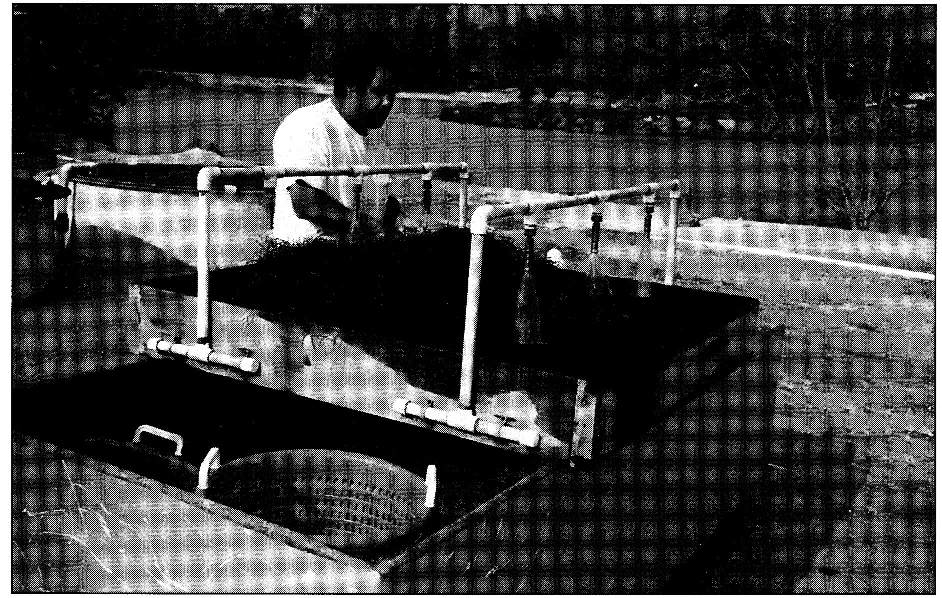


10-Week-Old Plants

20-Week-Old Plants

First Harvest, Subsequent Harvests & Gathering Cystocarpic Material to Complete the Life Cycle

Approximately 40-60% of rocks and chips develop harvestable plants (the rest are lost in the sand, overgrown with fouling organisms, or the sporlings are lost to predation). The success rate with lines is lower - approximately 30-40% of lines produce harvestable crops. The attrition rate of individual sporlings is high. Substrates may have several thousand sporelines per cm^2 to start, but have only 2-5 at harvest. This is enough to produce a dense growth of plants. At first harvest, plants are 30-50 cm long and are cut back to 5 cm. The remainder is allowed to regrow for a subsequent harvest.



The yield of *Gracilaria* is in the range of 500-1,000 grams (fresh weight) per square meter of pond at first harvest. In Hawai'i, the wholesale price for long ogo is $5 per kilogram, so the return at first harvest is $2.50-5.00 per m^2. If a farmer wished to gross $50,000 per year in sales, 1-2 ha of planted area would be required based on the return from the first harvest. However, the rocks, chips and ropes develop new crops much more quickly than the first crop, because the amount of starting material is greater for subsequent crops. Individual substrates can remain productive for two to three years. This is partly from regrowth of plants from their holdfasts after they are harvested, and partly from spore recruitment from shedding plants.

If plants are to be sold as seafood, they are hand-cleaned under a jet of seawater, to remove contaminating organisms, sand, silt and dead portions of plants. Cleanliness and freshness are the most important factors influencing the price a farmer can obtain for *Gracilaria*. *Gracilaria* harvested for agar production is handled differently. It is usually washed to remove sand and gross contaminants, and then dried in bulk on the shore. The factors controlling price are gel content, gel quality, and degree of contamination.

HARVEST PLANTS WASHED ONTO BEACH...

GROWING ON NETS...

ON CONCRETE BLOCKS...

OR UNATTACHED

Tetraspore Cultures to Regenerate Cystocarpic Plants

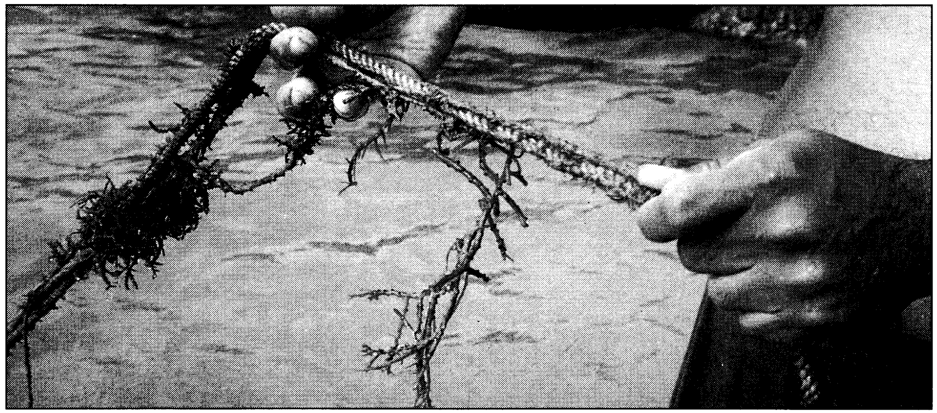
A supply of spore-releasing plants can usually be obtained within the culture system. About 10% of the cultured plants develop cystocarps. These are second-generation plants, formed from tetraspores released from the tetrasporophytes. These tetraspores are formed in invisible sporangia on the smooth tetrasporophyte plants (see Life Cycle Diagram). Some of the tetraspores land on substrates and grow into male and female gametophyte plants, which are also smooth. The female plants, however, develop eggs, which are fertilized by male spermatia. The fertilized eggs grow into cystocarps on the mother plant, producing the familiar "plants with bumps" that are used to start hatches.

A special hatchery procedure can be set up to produce cystocarpic plants. In Hawai´i, it is illegal to collect wild cystocarpic plants. In other locations, finding wild cystocarpic plants can be difficult, and in some seasons they cannot be found at all. Hence, getting a supply of cystocarpic plants for the hatchery can become a production bottleneck. A controlled production method will help keep a hatchery and growout operation productive year round.

The hatchery procedure to grow tetraspores into carposporophytes is nearly identical to the procedure already described to grow carpospores into tetrasporophytes. There are two differences. First, tetrasporophytes release fewer spores than carposporophytes, so approximately 5 times more material must be placed over the substrates to get good spore settling. Second, the culture products will be a 50:50 mix of male and female plants, and they must be placed out in close proximity to each other to ensure that the females are fertilized by the males when they reach sexual maturity. So a special planting area is needed for growing male and female gametophytes together.

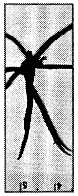
For a tetrapore hatch, collect large, smooth plants from the culture products (these can be removed from the weekly harvest collected for sale). Even though not all smooth plants are tetrasporophytes, it is not necessary to examine them microscopically. A few male or unfertilized female gametophytes in the hatch tanks will not make a difference to the final outcome. Set up a hatch with rocks or coral chips, laying at least 10 kg of smooth *Gracilaria* plants per tank over the trays of substrates (500-1000 g plants per tray). Place test slides in the trays and carry out the hatch exactly as for carpospores. Tetraspores are indistinguishable from carpospores under the microscope (they are 10% smaller on average but individual spores of both types vary more than this so they cannot be identified by size). However, if only smooth plants were used, any spores on the slides should be tetraspores, not carpospores.

If the slides show that at least some spore settling occurred, the substrates should be planted out in a common location designated as the "gametophyte patch", an area where plants grow well and all the trays contain rocks or chips on which tetraspores were settled. The substrates should be left in their trays, and the trays spaced 1 per m^2 on the pond bottom (leaving enough space to walk among the trays). In 25-50 weeks, about half the plants develop cystocarps, and these can be harvested and used to initiate new hatches to keep the production system going.



Cystocarpic plant produced in culture (note bumps)

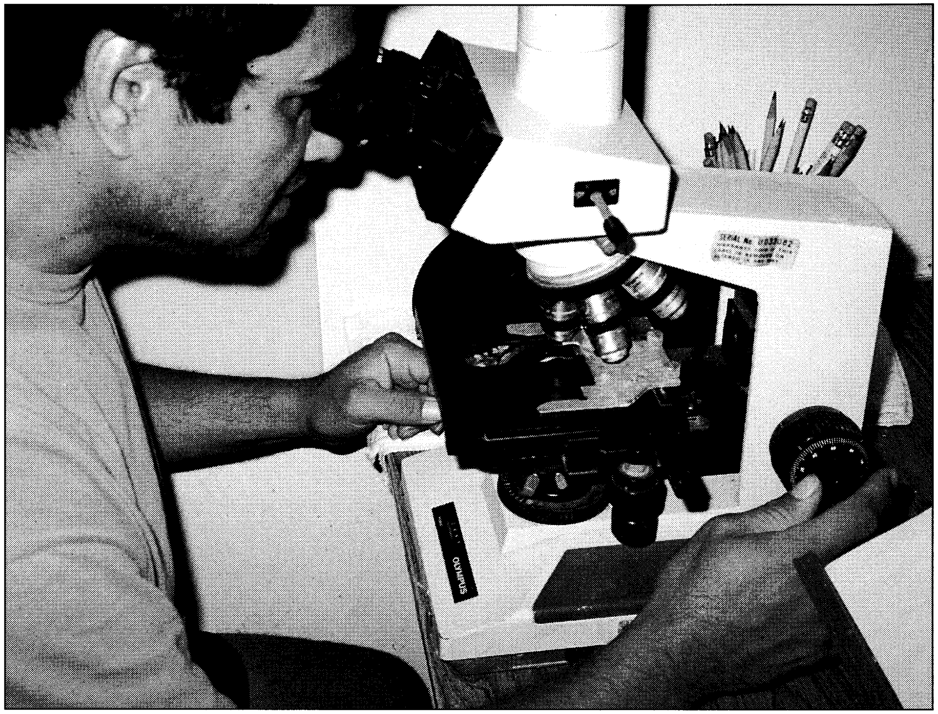
DATA COLLECTION & RECORD KEEPING

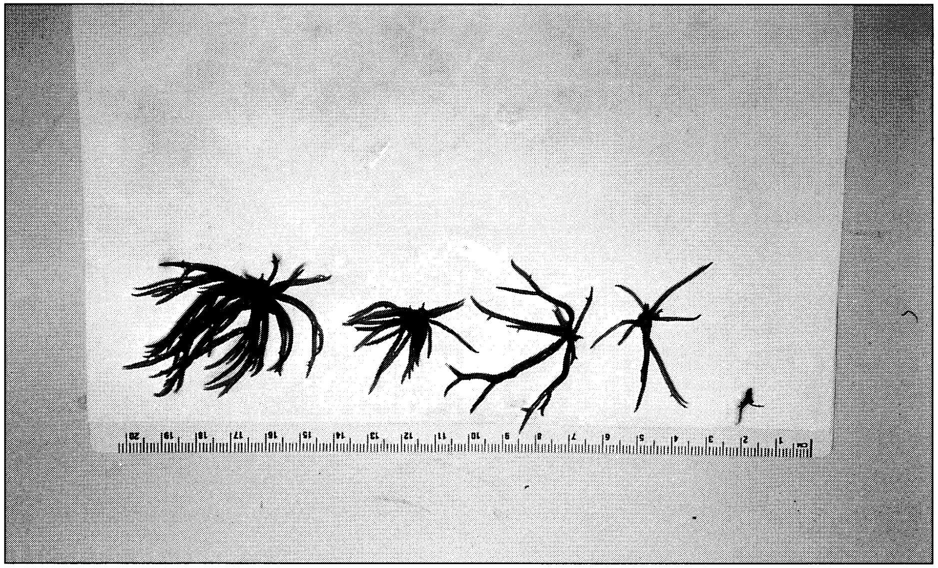


Crop logging is an important part of running a successful farm. Each individual hatch should be documented in permanent notebooks. These logs should note: the source of cystocarpic material, the handling of the hatch if there were modifications in procedure, the number of spores recorded on test slides, and the exact location the substrates were planted out, so they can be relocated to determine the success rate from that hatch. A planting map is helpful in keeping track of the crops.

The status of each hatch should be checked every 2-4 weeks and recorded to determine which ones are producing crops and which ones are not. An unsuccessful crop can be overplanted with new substrates. The yield of harvestable *Gracilaria* and of cystocarpic material from each hatch should be recorded at first harvest and for subsequent harvests. When yields decline, it is time to overplant the substrates with new material.

Finally, the farmer must keep track of the amount sold and the price obtained. Careful record keeping will reveal seasonal and spatial production patterns that the farmer can use to maximize yield and profits. Summer is peak production time in Hawai'i, for example, but the time period from Thanksgiving to Super Bowl Sunday is when prices are highest. A farmer may discover that a late summer crop can be left for harvest in fall and winter to maximize returns.

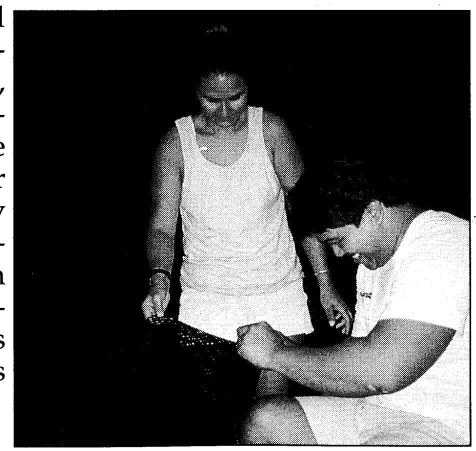




Community Involvement

Gracilaria farming is often a community activity. Large areas of ponds, reef flats or bays are needed to grow crops. In Chile, whole villages may be involved in growing and harvesting *Gracilaria* at favored locations. Farmers frequently pool their crops for sale to buyers. Spore culture is especially suited for this type of diffused activity, since a central hatchery can supply many farmers with spore-coated substrates. The hatchery can form the nucleus of a cooperative activity which may also involve extension services, assistance in acquiring leases to ponds or other growout areas, pooling crops for sale and other supports.

On Moloka'i, the culture of long ogo is being developed as a minibusiness for the coastal residents, many of whom are native Hawaiians. The motivation is to find an economic use for the traditional Hawaiian fishponds on the island's south reef, which enclose several hundred hectares of water. A nascent network of ogo growers is developing around the central hatchery, which also provides cleaning facilities, cold storage, shipping and preparation of value-added ogo products, such as "Limu Salsa", which multiplies the returns from each pound of ogo. Spore culture is a sustainable form of *Gracilaria* culture, which is needed to replace the current harvest practices which are depleting the natural beds faster than they can replenish. It can play a role in fostering community cohesion and economic resilience in rural coastal regions that are challenged to develop cash economies without destroying the resources that make these areas unique.



Business Plan and Marketing

Gracilaria culture is not new. It is already practiced in several parts of the world using pond, tank and ocean culture and business plans specific to those sites and culture methods are available. What is new is the addition of a hatchery stage of culture to produce sporlings. For simplicity, we will analyze this component as a free-standing enterprise, which would produce spore-coated substrates and sell them to growers for planting out, similar to other aquaculture hatchery enterprises. However, hatcheries can also be integrated into growout enterprises.

Markets for *Gracilaria*

In Hawai'i, Asia and the Pacific *Gracilaria* is a food. It is usually eaten fresh as a crunchy addition to seafood poke (marinated, raw fish), kim chee (spicy Korean vegetable preserves), or other Hawaiian, Filipino, Chinese and Japanese dishes. It is increasingly used as an element in gourmet cooking in Hawai'i, and it is being used in new retail products such as "Limu Salsa". As a food, *Gracilaria* brings anywhere from $5 per kilogram at wholesale to seafood dealers, to $10 or more when sold to restaurants or used in value-added products. The market for food *Gracilaria* is limited in size; in Hawai'i it is worth approximately $1 million per year. A much larger market is for *Gracilaria* as a source of agar, the most-used thickening agent in Japanese cooking. *Gracilaria* for agar extraction is sold dried (sun-drying reduces the weight to about 25% of the wet weight) in 60 kg bales to extraction factories in Japan. The price the farmer gets is much lower than for *Gracilaria* sold as a food. Dry seaweed brings $500-1000 per ton depending upon the species, the agar content, quality and the cleanliness of the product. United States farmers, with high labor costs are so far not competitive in this market. Most of the farmed *Gracilaria* for agar extraction comes from Asia or Chile. Spore culture methods could have a major impact on the production systems, by allowing mass cultures to be initiated at much reduced labor costs for planting, and by allowing expansion into coastal areas that do not have wild populations to serve as seed sources for vegetative propagation. The market for *Gracilaria* for agar extraction is greater than $200 million per year.

Markets for Sporlings

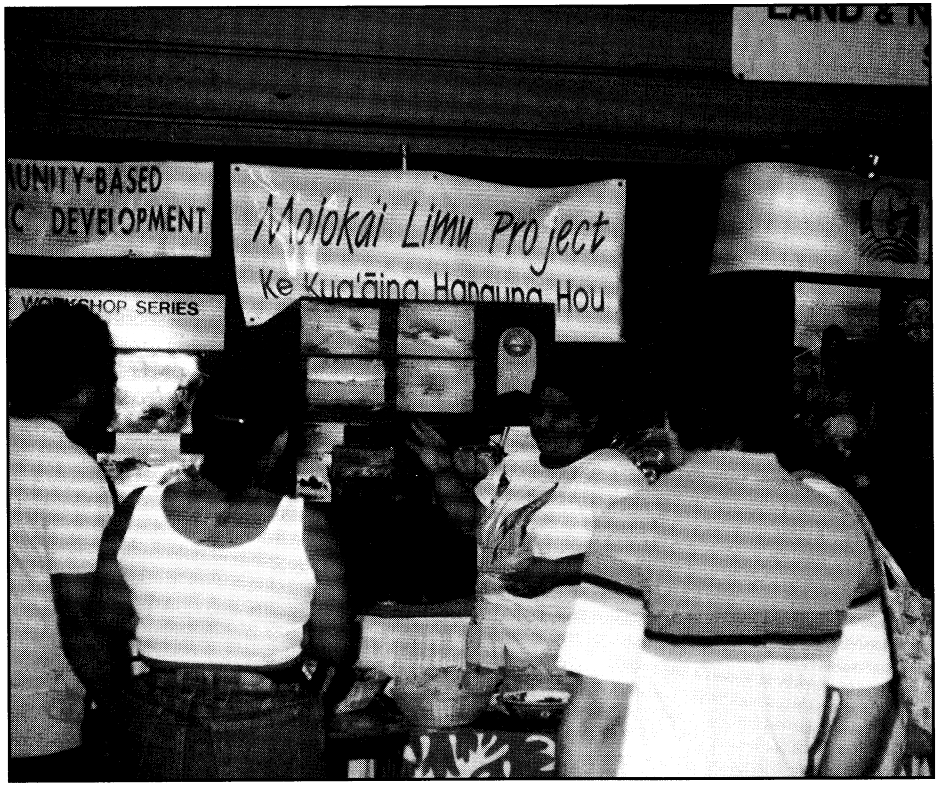
The market for sporlings from a new hatchery is likely to develop from two sources. Existing *Gracilaria* farmers purchase hatchery-reared sporlings to supplement or replace their current stocking procedure. This depends upon collecting plants in the wild and bringing them into their farms for vegetative growth, especially as wild stocks become depleted. The second market which may develop is remedial stocking of the wild to compensate for the heavy demand on plants from commercial and family-use pickers. A state or industry supported program of restocking may be needed if the heavy pressure from commercial and auto-consumers continues.

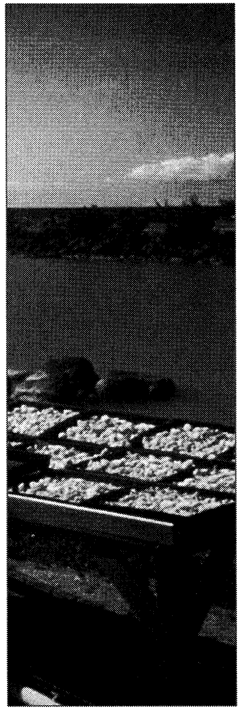
The Supply

The barriers to entry for potential hatchery operators are significant but not overwhelming. The technology is being disseminated to the public. The equipment is widely available and requires little training to operate. The start-up costs are not excessive. The primary barrier is likely to be access to shoreline sites and high quality water.

Existing seaweed farmers and producers of other marine organisms with facilities for microalgae or larval invertebrates and fish are likely to consider *Gracilaria* limu hatchery techniques as a method of diversification. Their barriers to entry will be marginal once they examine the technology documents produced by the present project. They are likely to have the land site, access to water, needed equipment and knowledgeable staff.

We have scaled the model to reflect the existing hatchery on Moloka'i, Hawai'i, described in the atlas, supplying sporlings to Hawai'i growers supplying the market for fresh *Gracilaria* for the Honolulu wholesale market. Labor, electricity and land costs were based on Moloka'i values (among the highest costs in the world). Equipment costs were from mainland United States suppliers and include delivery costs to Moloka'i. A hatchery to supply sporlings for growout for the agar market would need an entirely different economic structure than this model, because fresh *Gracilaria* in Hawai'i commands a much higher price than dried *Gracilaria* grown overseas for the agar market. However, many of the components of the system model below would be similar.





Elements of a Limu Hatchery

Installation:

4, 1000 liter capacity fiberglass tanks (@ $500 each, delivered)	$2000
Diatomaceous sand filter	400
Centrifugal Pump,	449
Air Blower, (1/2 hp)	427
Work table	500
Plumbing	250
Site preparation (100 m2)	2000
Pump & tank installation	1000
Microscopes, other equipment	1500
Subtotal	$8526

Depreciation schedule: tanks, 5 years, blower & pump, 2 yrs, microscopes, 10 yrs

Operating Costs Monthly:

Land lease (rental of shoreline space)[1]	$ 500
Electricity	130
Expendable supplies (trays, slides, chips, etc.)	200
Personnel:	
1 Hatchery manager (50%-FTE)[2]	1783
1 50%-FTE worker	500
Monthly Operating Costs[3]	$3113

Returns Monthly:

Four hatches per month producing 7200 coated pebbles or chips, sold at gate for $0.15 each[4]	$4320

1) This example pro forma is based on the Moloka'i operation and will vary with each individual farming enterprise.

2) Land rental can vary widely - present hatchery does not pay lease fee as it is on trust land assigned to Ke Kua'aina. Also assumes office space available within Limu Coop office for microscope, data logging on computer, at no additional expense to hatchery.

3) The hatchery manager would also be the general manager for Limu Coop (see original business plan), requiring the other 50% of his time, recovered from market sales of harvested ogo.

4) Monthly operating expenses must be paid for first two months before limu sporling sales begin to cover operating expenses.

5) The return to the farmer from each chip would be approximately $1.00 at harvest based on 250 g plant material over 2 years, 40% success rate of chips and $5.00 per kg wholesale price (see Final Report).

Long Ago Hatchery — 5 Year Cash Flow Estimates

	Year 1	Year 2	Year 3	Year 4	Year 5
Chips/Yr(thousands)	274	343	343	343	343
Cash Inflow ($):					
Capital Assets	8526	0	0	0	0
Working Capital	6200	0	0	0	0
Capital Req'd	14726	0	0	0	0
Sales Revenue	43200	51408	51408	51408	51408
Total Inflow	57926	51408	51408	51408	51408
Cash Outflow ($):					
Constr. Payments	8526	0	0	0	0
Equipment Replacement	0	0	850	0	850
Tanks Replacement	0	0	0	0	2400
Labor	27396	27396	27396	27396	27396
Energy, Land & Other	9960	9960	9960	9960	9960
Total Cash Out ($):	45882	37356	38206	33960	40606
Period Cash Flow ($):	12044	14052	13202	14052	10802
Accumulated Cash Flow ($):	12044	26096	39298	53350	64152
Cost of product ($/chip)	0.167	0.100	0.102	0.091	0.109
Selling Price	0.150	0.150	0.150	0.150	0.150
Gross Profit on Sales ($/chip)	-0.017	0.050	0.048	0.059	0.041

Payback period of initial investment of $14,726: 15 months

Feasibility and Risk Factors

The analysis, based on actual operation of a long ogo hatchery over 24 months, supports the economic and technical feasibility of this enterprise providing: 1) a sufficient market can be developed for the product; 2) the returns to the growout farmer can support a sale price of approximately $0.15 per unit in Hawai'i. The preliminary analysis suggest that these conditions can be met since there is an identifiable market for long ogo in Hawai'i. The sale price per unit is too high, however, to contemplate growing this species for the agar market (a much larger market than the fresh market). Economies of scale and further technical innovations in the handling of substrates will be needed to approach this market. A risk factor that has not surfaced with *Gracilaria parivspora* but can be anticipated as a possibility is disease. *Gracilaria* is subject to bacterial and other diseases in nature and these can be intensified in culture systems. The Hawai'i tank culture growers, using an imported species of *Gracilaria* from Florida, have experienced disease problems that reduce their stocks. The history of intensive culture of marine organisms such as shrimp suggest that the disease factor should be considered in advance, and steps taken to minimize the spread of disease among farms before it becomes a problem. A seaweed hatchery serving numerous growers would be capable of becoming a disease vector. Procedures to develop pathogen-free stocks should be developed whenever specific disease conditions begin to appear in hatcheries or growout areas.

The single greatest impediment to implementation of long ogo culture on Moloka'i at present is lack of access of potential growers to fish ponds and the reef. In contrast to tank culture, the type of growout system this project has developed is an extensive system, aimed at utilizing the fishponds and the reef, and relatively large areas are required for economic returns (1-2 ha per grower). Institutional reforms recommended by the "Governor's Task Force on Fishponds" would help provide the needed access to the coastal residents to the state-owned ponds. Some privately owned ponds are already available for aquaculture and these may be the first sites to be developed. Hawai'i state law allows the lease of reef space for aquaculture but to date this has not been implemented. The growout of spore-coated coral chips on reef land could be an appropriate form of aquaculture for this resource since it does not involve adding structures, feed, chemicals or other additives to the water, and it propagates a species already desired on the reef. Spore release from cultivated plantings would help repopulate the surrounding reef area to the value of pickers of the wild crop.

Project Benefits

The hatchery would create two half time positions, provide a positive cash flow to someone in the form of rent. In Hawai'i, it would be a benign use of ocean front property, in keeping with the desire of many coastal residents to preserve a rural lifestyle.

It would assure a steady supply of stock to growout farmers. Just as an improperly managed hatchery could spread disease, a properly managed hatchery could be a control point to ensure that disease free stock is available. It could help replenish the wild stocks, either by providing substrates for deliberate stock enhancement or simply by the escape of spores from mass plantings started from hatchery products. Through further innovation, a hatchery/growout system could perhaps become sufficiently cost-efficient to supply sporlings for overseas farmers growing *Gracilaria* for the agar market.

Selected Further Reading on *Gracilaria* Culture

Abbott, I. and Norris, J., 1984. Taxonomy of economic seaweeds with reference to some Pacific and Caribbean species. California Sea Grant Program, University of California, La Jolla, California.

Buschmann, A. and Kuschel, F., 1988. Intertidal culture of Gracilaria sp.: spore colonization and interaction with Ulva lactuca. Biota, 4: 107-113.

Chen, L., 1990. Aquaculture in Taiwan. Blackwell Scientific Publications, Ltd., Oxford.

Doty, M. S. and Fisher, J. R., 1987. Experimental culture of seaweeds (Gracilaria spp.) in Penang, Malaysia. FAO, Rome.

Fortner, H., 1978. The Limu eater: a cookbook of Hawaiian seaweed. University of Hawaii Sea Grant College Program, Honolulu, Hawaii.

Freidlander, M., 1992. Problems of Gracilaria pond cultivation in an Israeli experimental farm. Israeli Journal of Aquaculture - Bamidgeh, 44: 151-152.

Glenn, E., Moore, D., Fitzsimmons, K. and Azevedo, C., 1996 (in press). Spore culture of the edible red seaweed, Gracilaria parvispora. Aquaculture.

Hurtado-Ponce, A., Samonte, G., Luhan, M., and Guanzon, N., 1992. Gracilaria (Rhodophyta) farming in Panay, Western Visayas, Philippines. Aquaculture, 105: 233-240.

LaPointe, B., Williams, L., Goldman, J., and Rhyther, H., 1976. The mass outdoor culture of macroscopic marine algae. Aquaculture, 8: 9-20.

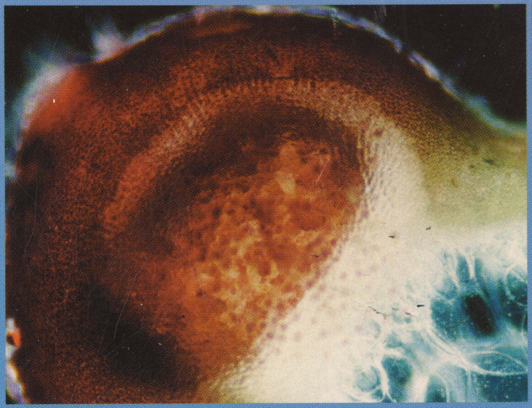
McHugh, D., 1987. Production and utilization of products from commercial seaweeds. FAO Fisheries Technical Paper 288, Rome.

McHugh, D., 1991. Worldwide distribution of commercial resources of seaweeds. Hydrobiologia, 221: 19-29.

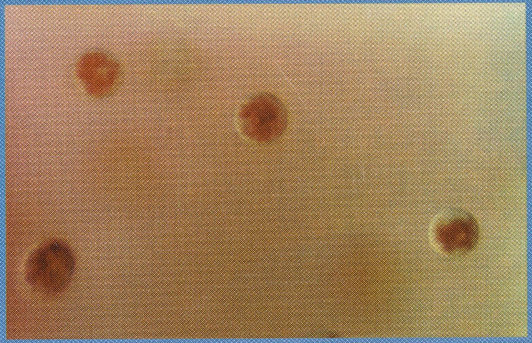
Romo-Donos, H., 1988. Seaweed aquaculture by spore propagation. Investigaciones Pesq. Santiago, 35: 89-98.

Santelices, B., and Doty, M., 1989. A review of Gracilaria farming. Aquaculture, 78: 95-133.

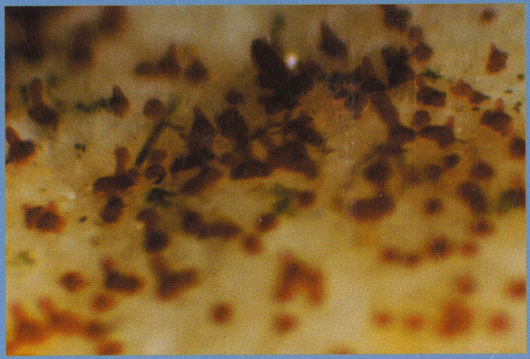
Trono, G., 1990. A review of the production technologies of tropical species of economic seaweeds. In: Regional workshop on the culture and utilization of seaweeds, Vol. II, FAO, Cebu City, Philippines, pp. 3-26.



Cystocarp with Spores



1 Day Old Spores



21 Day Old Sporlings on rock