Mariculture of Seaweeds

Introduction
Macroscopic marine algae form an important living resource of the oceans. Seaweeds are food important for humans and animals, as well as fertilizers for plants and a source of various chemicals. Seaweeds have been gaining momentum as a new experimental system for biological research and as an integral part of integrated aquaculture systems. We all use seaweed products in our day-to-day life in some way or other.
For example, some seaweed polysaccharides are used in toothpaste, soap, shampoo, cosmetics, milk, ice cream, meat, processed food, air freshener, and many other items. In many oriental countries such as Japan, China, Korea, and others, seaweeds are diet staples.

Need for Mariculture
Traditionally, seaweeds were collected from natural stocks or wild populations. However, these resources were being depleted by overharvesting, so cultivation techniques have been developed. Today, seaweed cultivation techniques are standardized, routine, and economical. Several factors, such as morphology and regeneration capacity of the thallus, as well as complex interaction of irradiance, temperature, nutrients, and water movement, are responsible for the success of large-scale seaweed cultivation.

Cultivation methods
During the last 50 years, approximately 100 seaweed taxa have been tested in field farms, but only a dozen are being commercially cultivated today. Table 1 provides production data for the top taxa.

TABLE 1 Top cultivated seaweed genera in the world during 2000 (FAO 2003).

Taxon	*Value (10^6 U.S.$)*	*Raw material (metric tons)*	*U.S.$ per metric ton*
Laminaria	2,811	4,580,000	613
Porphyra	1,118	1,011,000	1,105
Undaria	149	311,105	480
Eucheuma and *Kappaphycus*	46	628,576	73
Gracilaria	11	12,510	879
Total	4,632	5,972,737	

Different taxa require different farming methods. Although some seaweeds need **one-step farming** through **vegetative propagation**, others need **two-step or multistep farming**. The latter must be propagated from **spores** and cannot survive if propagated vegetatively.
IN VEGETATIVE CULTIVATION, small pieces of seaweed are taken and placed in an environment that will sustain their growth. When they have grown to a suitable size they are harvested, either by removing the entire plant or by removing most of it but

leaving a small piece that will grow again. When the whole plant is removed, small pieces are cut from it and used as seedstock for further cultivation.

The seaweed can be **held in its environment in several ways** (Fig. 1): pieces of seaweed may be tied to long ropes suspended in the water between wooden stakes, or tied to ropes on a floating wooden framework (a raft); sometimes netting is used instead of ropes; in some cases the seaweed is simply placed on the bottom of a pond and not fixed in any way; in other cases, the seaweed is either forced into the soft sediment on the sea bottom with a fork-like tool, or held in place on a sandy bottom by attaching it to sand-filled plastic tubes.

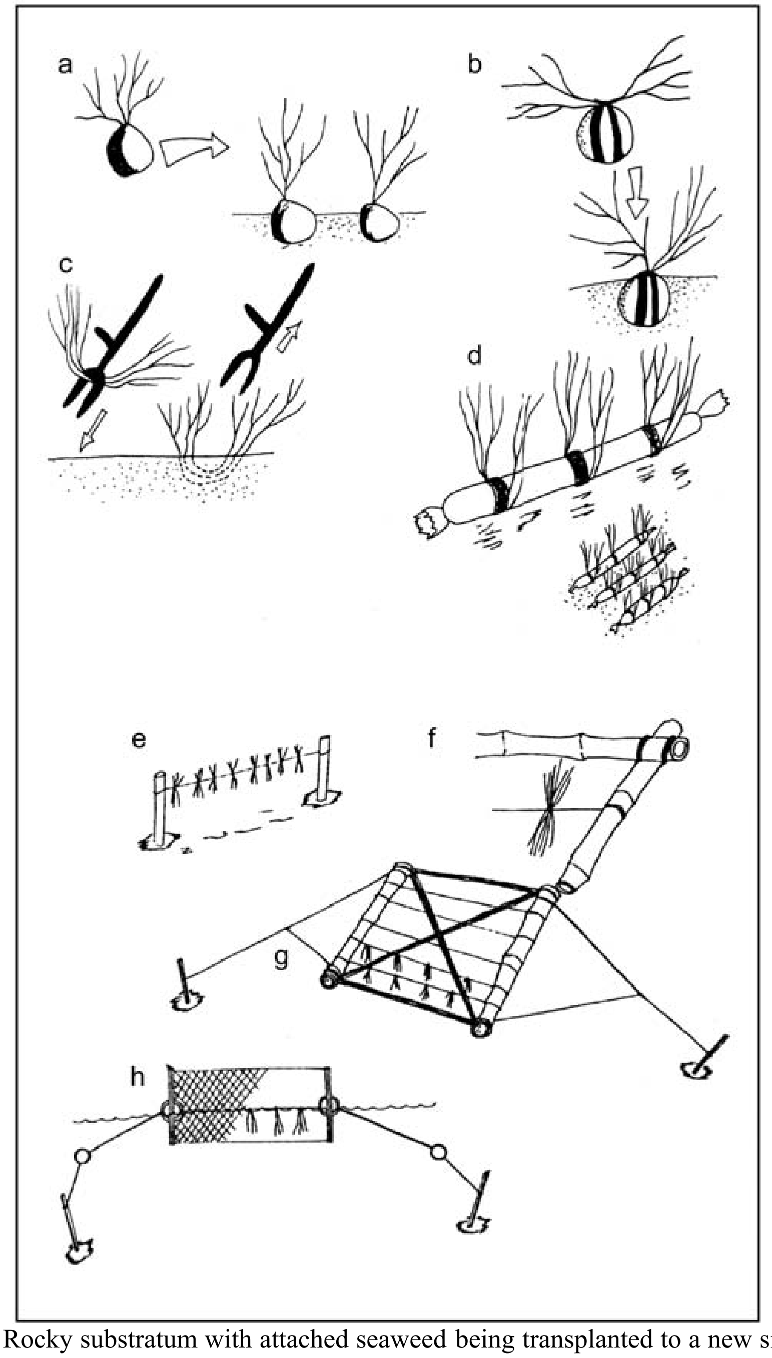

FIGURE 1. **(a)** Rocky substratum with attached seaweed being transplanted to a new site. **(b)** seaweed attached to rocks with rubber bands; method used for anchoring transplants in soft sediments. **(c)** Plants inserted with a fork directly into soft sediments. **(d)** Plants attached to sand-filled plastic tubes. **(e)** seaweed attached to a rope, which is stretched between two poles pushed into the sediments. **(f)** Attachment of plants for rope culture. **(g)** Bamboo floating frame with seaweed attached to ropes spanning the frame. **(h)** A floating net with seaweed attached to the meshes.

The **suitable environment** varies among species, but must meet requirements for salinity of the water, nutrients, water movement, water temperature and light.

CULTIVATION INVOLVING A REPRODUCTIVE CYCLE, with alternation of generations, is necessary for many seaweeds; for these, new plants **cannot** be grown by taking cuttings from mature ones. This is typical for many of the seaweeds.

LAND-BASED CULTIVATION SYSTEMS

TANKS These systems generally use seaweeds growing in tanks receiving a steady stream of aeration and seawater. The aeration provides vigorous water movement in the tanks, sending the algal thalli up and down in the water column in a circular pattern. This vigorous aeration permits rapid uptake of dissolved carbon dioxide, and bringing the biomass to the surface into the light. The use of tanks may provide the greatest productivity per unit area per day and is more efficient than any other type of farming.
Efficiency of these systems is very much **dependent** on the input of various types of energy (compressed air for bubbling, CO_2, and pumping water) and nutrients. Carbon supply can be improved by either pumping more seawater or by adding CO_2. The temperature and salinity also can be manipulated by pumping more seawater. The pH of the tanks should be managed in the range of 7.9 to 8.3, and the nutrient status of the medium must be monitored. Tanks should be cleaned regularly and epiphytes must be controlled.
Tank systems also may hold promise for the processing of polluted water for specific products, the removal of extra nutrients from wastewater, or for energy production.

PONDS Macroalgae can also be grown in ponds. An advantage of this approach is the low-operating costs. Generally, water exchange in the ponds is accomplished by use of tide gates. Seaweed yields are low because of the lack of water movement in the ponds and the low exchanges of water.

Tank systems are usually in smaller modules that allow a predictable maintenance schedule, several steps however, can be precisely controlled and managed to reduce the labor input, although this type of system has high operational costs. Ponds are larger, and a significant outbreak of epiphytes or other weedy species may be much harder to bring under control.

SEAWEED CULTIVATION IN THE SEA

Aquaculturists grow most macroalgae in the sea as opposed to land. Cultivation occurs along coastal areas. To hold the seaweeds in place, a variety of farm structures are used. These include long lines to which ropes with seaweeds are attached, nets stretched out on frames, and ropes supported by poles. Details of these different systems are provided in the following sections. The capital costs associated with these systems vary depending on locale, water depth, and local economies. The operating costs for these kinds of macroalgal culture systems vary as a function of harvest frequency and lifetime of materials in a site-specific environment.

1. Long-Line Cultivation Systems

In the 1950s, China developed a highly successful method for cultivating *Laminaria*. In this method, sporelings ("seedlings") are produced in cooled water in greenhouses and later planted out in the ocean

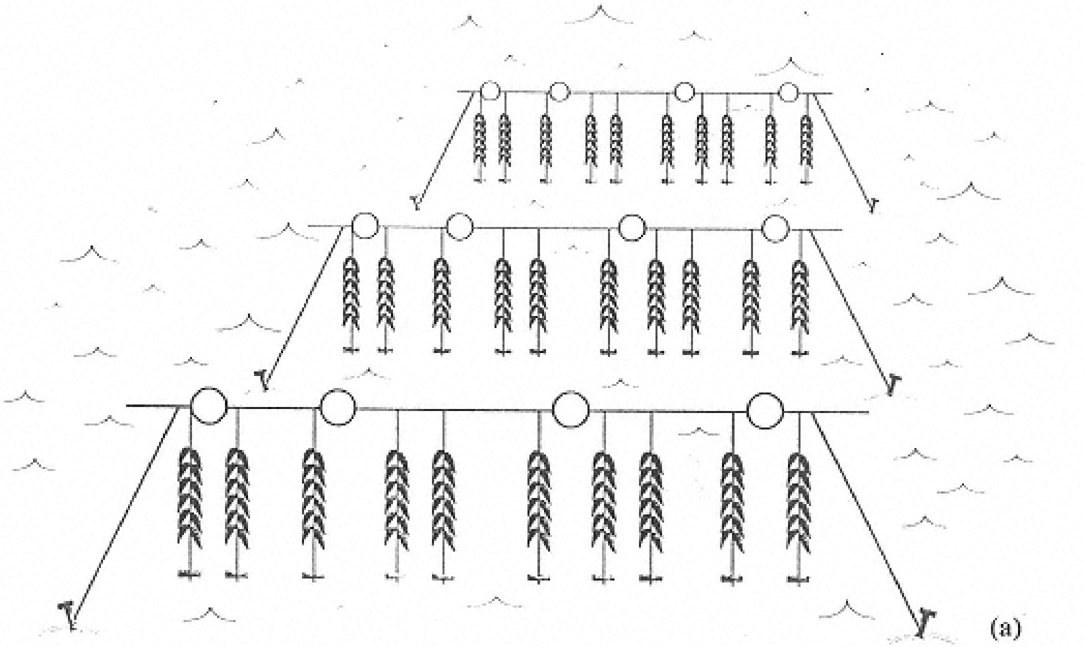

Fig. 2 A Chinese long-line farm for cultivation of Laminaria: The long line is anchored by a rope at each end and held afloat by buoys. Culture lines with attached *Laminaria* include a spacing segment at the top and bottom of the 2- to 5-m-long rope and weighed. The anchor ropes are held by stakes or concrete weights.

For cultivation, *Laminaria* must go through its life cycle, and this involves an alternation of generations between a large sporophyte - the sporophyte is what is harvested as seaweed- and a microscopic gametophyte. The mature sporophytes form sori -surface organs where sporangia are produced- from which motile zoospores are released. To stimulate zoospore release, a selected parent *Laminaria* plants are dried for a few hours and placed in the seeding container which is filled with cool seawater. The seed string (a synthetic twine of 2 to 6 mm in diameter or palm line 6 mm in diameter) is placed on the bottom of the same container. Released zoospores are attached to the strings and germinate into male and female gametophytes.

As the gametophytes become fertile, they release sperm and eggs that join to form zygotes which attach themselves to the collectors – i.e. the same substrate materials - and develop into seedlings or sporelings. The seedlings are reared into young sporophyte plants.

The strings are then cut into small pieces that are transferred to the sea and inserted into the warp of large diameter, 60 m long culture rope. The ropes with the young sporophytes are kept floating by buoys fixed every 2–3 m. Each end of the rope is anchored to a wooden peg driven into the sea bottom. The ropes with the young sporophytes attached hang down from this rope at 50 cm intervals (Fig. 2). These slowly develop into the large sporophytes that we harvest.

The principal difficulties in this kind of cultivation lie in the management of the transitions from spore to gametophyte to embryonic sporophyte; these transitions are usually carried out in land-based facilities with careful control of water temperature, nutrients and light. The Japanese use a **forced cultivation** technique to produce plants with 2-year-old characteristics in a single growing season by controlling the water temperature and light.

By the same method, the Japanese also farm a similar kelp, *Undaria*, which is sold as the food wakame.

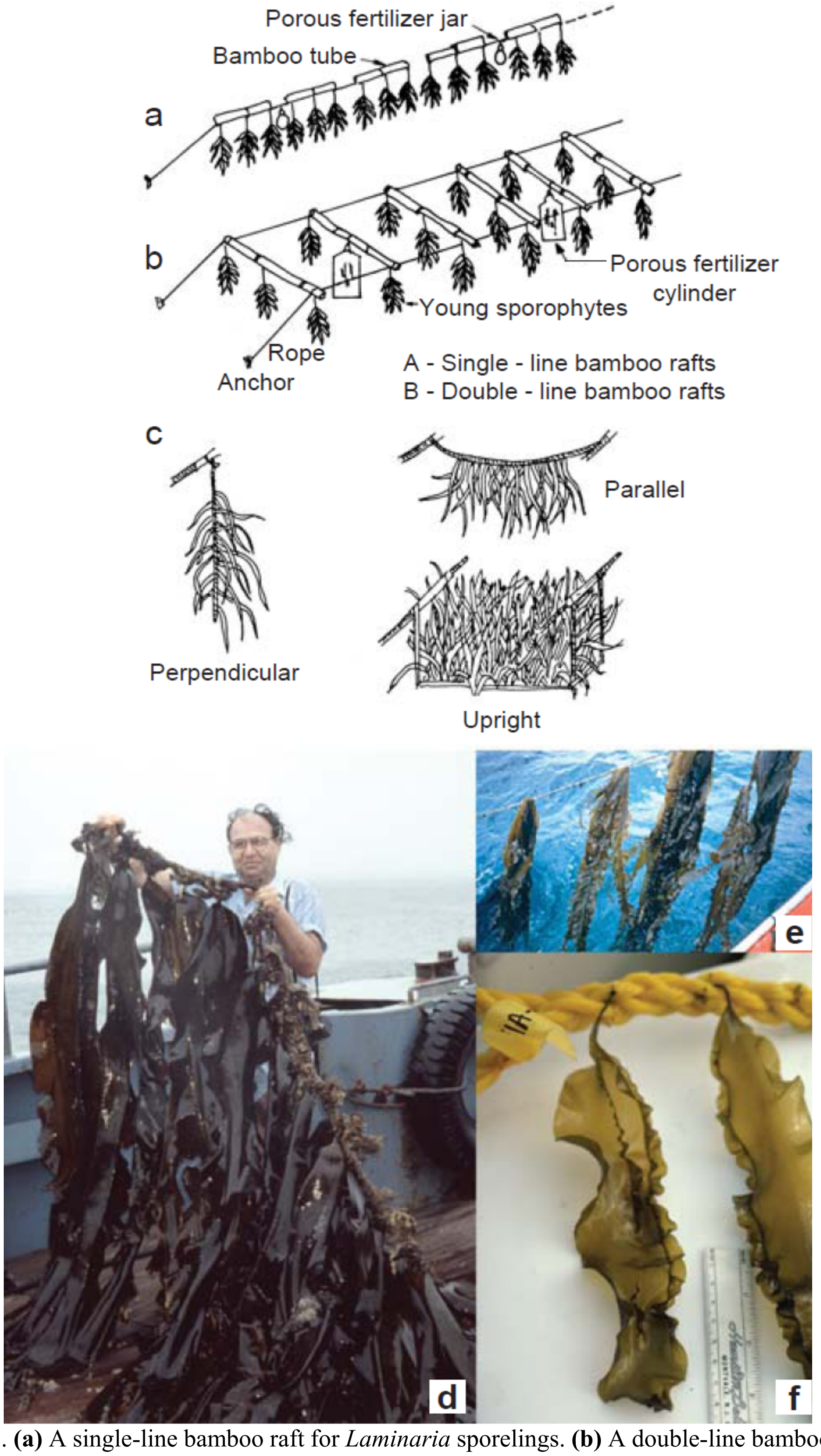

FIGURE 3. **(a)** A single-line bamboo raft for *Laminaria* sporelings. **(b)** A double-line bamboo raft used in Japan. **(c)** Perpendicular, parallel, and upright culture methods. **(d)** Long line with *Laminaria* after 8 months of growth (Yellow Sea, China). **(e)** Long line showing attached *Laminaria* plants (South Korea). **(f)** Young sporophytes growing on long line.

2. Net-Style Farm Systems

Porphyra, or nori, is the world's most valuable marine crop. The crop is valued at more than 1 billion dollars worldwide and is used mainly for human food. These plants grow mainly in cooler waters. The algal spores are seeded onto nets that are then put in place on fixed support systems (see Fig 4). The fixed support system exposes the nets to the atmosphere at low tides. This periodic exposure and drying act to improve the growth of nori and to inhibit fouling organisms (e.g., other seaweed species or diatoms). Nori grows as a flat sheet and has a high surface area/volume ratio, a feature that aids nutrient uptake. *Porphyra* are allowed to grow to 15–30 cm in about 40–50 days before they are harvested (Fig. 5 c,d). The remaining thalli are allowed to grow and may be ready for a second harvest after another 15 to 20 days. Several harvests may be made from the same nets in one growing season. The harvested crop is washed and transferred to an automatic nori-processing machine, which cuts the blades into small pieces. The nori is then processed by the cultivator into dried rectangular sheets or processed by the manufacturer per market requirements.

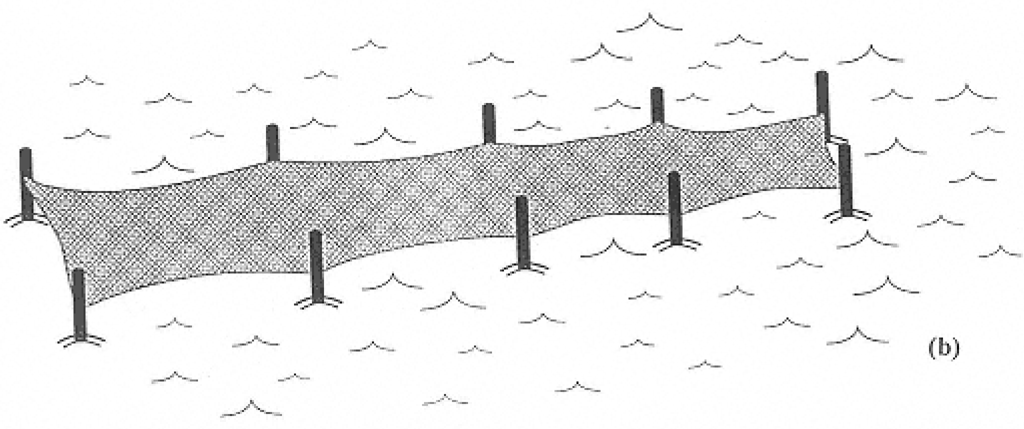

Fig. 4 A Japanese *Porphyra* culture net system: Poles hold the net in place so that it is exposed at low tides. The Porphyra grows attached to the nets.

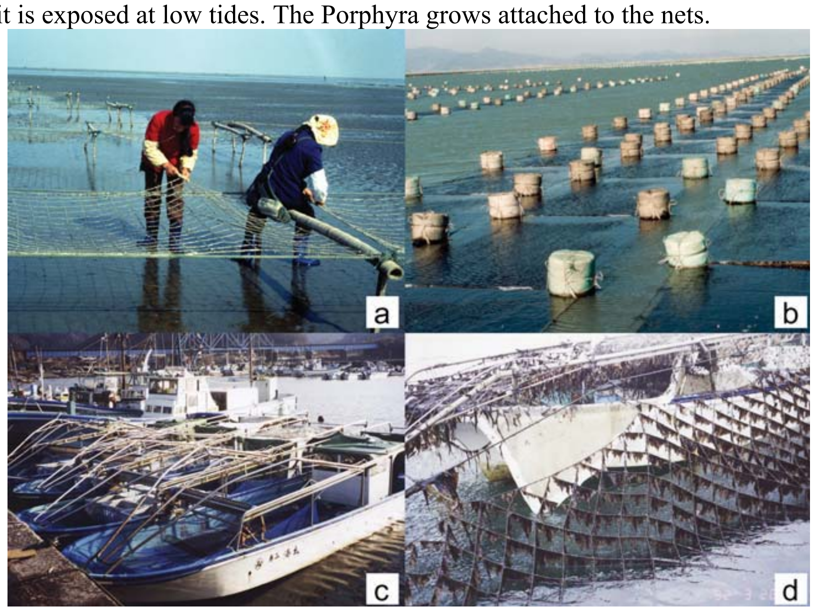

FIGURE 5. **(a)** Attachment of *Porphyra* nets to a semifloating raft. **(b)** Korean-style all-floating rafts. **(c)** Fleet of *Porphyra* harvesting boats. Note the tubular frames that lift the nets (see **d**). **(d)** Harvesting boat with *Porphyra* net lifted from the sea.

3. Line and Rope Farm Systems

Fishermen in the Philippines use rope and lines to grow tropical seaweeds. These seaweeds comprise species of genera *Eucheuma* and *Kappaphycus*. The seaweeds are tied to the lines, and the lines are then staked over the bottom. The water level should be 0.5 to 1.0 meter during low tide and not more than 2.0 to 3.0 m during high tide. The lines are constructed to form plots or units of a standard size (Fig. 6c). Seedlings weighing between 50 and 100 g are tied to the monolines at 25- to 30-cm intervals using soft plastic tying material called *tie-tie.* Usually the plants are harvested after 45 days when each seedling weighs up to 1 kg (Fig. 6e). The best looking healthy plants are selected to serve as seedlings for the next crop. The remaining plants are sun dried or sold fresh in the market. *Eucheuma* and *Kappaphycus* are important carrageenophytes (80% of world's carrageenan production).

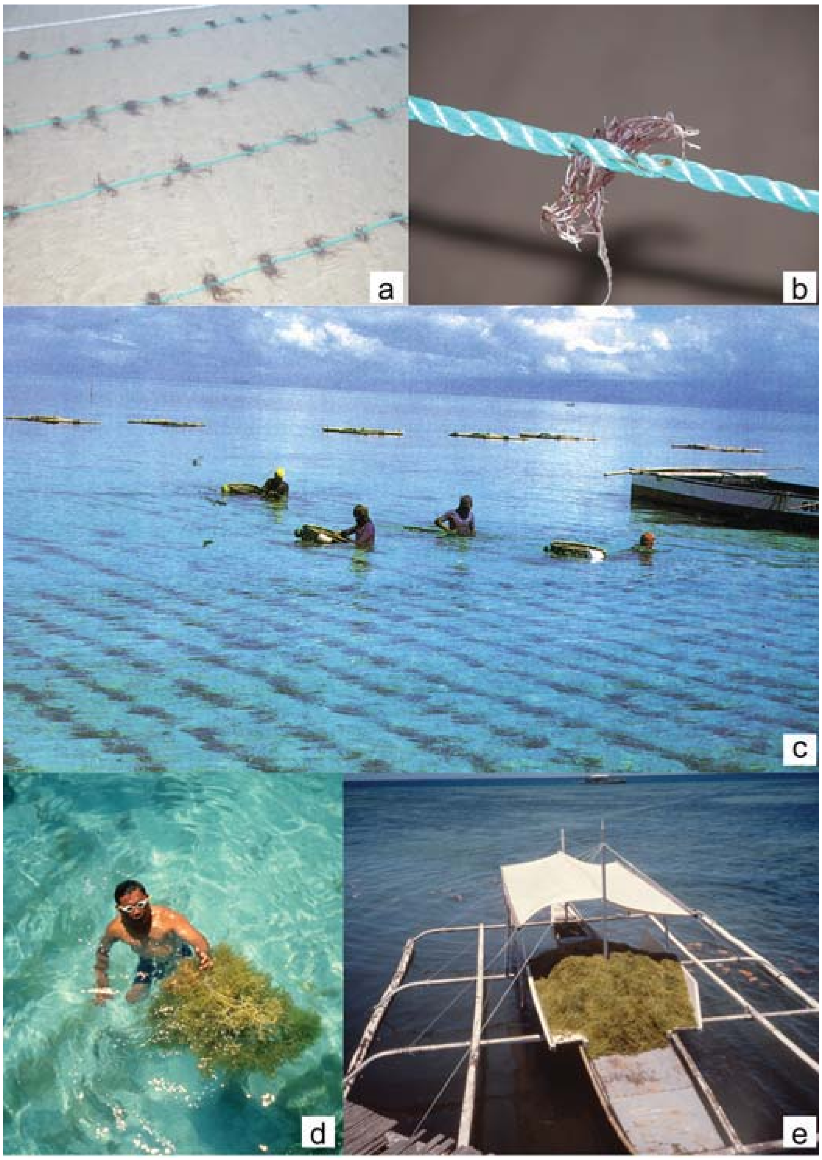

FIGURE 6. **(a)** Rope cultivation of *Gracilaria* using monofilament long lines. **(b)** Enlarged image showing a *Gracilaria* plant held within the twists of the lone line rope. **(c)** *Eucheuma* farmers harvesting plants from submerged long lines. **(d)** Open water cultivation and harvesting of *Kappaphycus*; diver bringing a large plant to the boat. *Eucheuma* and *Kappaphycus* are tied to the lines that are held just above the sediment surface. The depth of the plants are adjusted so that they are not exposed at low tides. **(e)** Typical outrigger boat used for open water harvesting.

4. Offshore or Deep-Water Seaweed Cultivation

Various attempts were made to cultivate the brown alga *Macrocystis pyrifera* on farm structures designed for use in deep water. The nutrients for these seaweeds were to come from cold, deep waters that would be pumped up into the growing kelps. The benefits of this approach is that growth of macroalgae would not be constrained by available shallow nearshore regions.

Despite several trials using different farm designs, operational problems prevented the production of actual kelp crops. However, the experiments did establish that *M. pyrifera* could grow in an open ocean environment, and that deep waters supplied ample nutrients for sustained growth without toxic side effects. It is probable that these research results could be extended to other brown kelps, such as *Laminaria* spp. or *Undaria* spp. However, no reports are available that describe such offshore-farming approaches with green or red algae.