Environmental Impacts of Seaweed Farming in the Tropics

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Executive summary

Seaweeds are multicellular algae that occur in marine and brackish-water and that, at some stage in their lives, are attached to a substrate. World-wide there are approximately 10,000 species of seaweeds and at least 221 species of seaweed are utilised by humans. 145 species are used for food while 101 species are used for phycocolloid production (i.e. alginates, agar and carrageenan). Each year around 2 million tonnes dry weight (approximately 13 million tonnes fresh weight) of seaweed is collected at a value of in excess of US$6.2 billion. 50% of this seaweed (by volume) is cultured and approximately 10% of cultured seaweed comes originates in the tropics.

In the tropics the vast majority of seaweed farmed is of the genera *Eucheuma* or *Kappaphycus*. Approximately 120,000 tonnes dry weight (t dw) of *Eucheuma*/*Kappaphycus* are produced annually compared with approximately 15,500 t dw of *Gracilaria* and 800 t dw of *Caulerpa* (Zemke-White and Ohno 1999). Most of the *Eucheuma*/*Kappaphucus* is farmed in the Philippines (~95,000 t dw), followed by Indonesia (22,000 t dw), Zanzibar (4,000 t dw), Malaysia (800 t dw), Kiribati and Madagascar (both around 400 t dw). Most of the *Gracilaria* is farmed in Indonesia (~13,500 t dw) and almost all of the *Caulerpa* is farmed in the Philippines.

Uses

Eucheuma and *Kappaphycus* are both used to produce carrageenan, a gel-forming polysaccharide that forms part of the seaweed cell walls and which has a variety of applications, primarily in the food industry. Carrageenans bind with proteins which makes them ideal for stabilising milk products and suspending fat globules and flavour particles. When added to hot milk and cooled, bonds form between carrageenan and the proteins in the milk to give a creamy thick texture. As it is resistant to high temperatures, carrageenan is used extensively in ultra-high temperature (UHT) processed goods.

Carrageenan is a sulphated galactan consisting of alternating units of β-1,3 and α-1,4 linked D-galactopyranose. There are three forms commercially available: lambda, iota and kappa. Lambda carrageenan does not form a gel and is used for viscosity control: thickening, bodying and suspending applications such as milkshakes, flavoured milk, syrups and sauces. Iota and kappa types form thermoreversible gels and are used in both water and milk gelling systems. *Eucheuma* contains only iota carrageenan while *Kappaphycus* contains only kappa carrageenan and as there are applications for which only one form of carrageenan is required, these two genera are in demand as they require no extra stage of separating the carrageenans after extraction.

There is a growing demand for carrageenan, which means an increasing demand for carrageenan producing seaweeds. To meet this demand, seaweed farming will have to expand, both within the countries where it is currently farmed, and also into new locations in the tropics.

Farming techniques

The main method used for culturing *Eucheuma* and *Kappaphycus* is the monoline method (Trono 1997) in which cuttings of seaweed are tied at to lines at 25-30 cm intervals and the lines are suspended around 0.5 m off the bottom between two stakes. Additional rows are added about 1 m apart. In areas where there is little water movement or problems with benthic grazers, the monolines can be kept floating on the surface with “rafts”. In this case the monolines are stretched between two floating poles (usually bamboo), which are in turn anchored to the bottom. Plants are grown to approximately 1 kg wet weight before harvesting, which involves complete removal of the plants. The fixed type monoline farms are generally located inshore of coral reefs over sandy substrates and can cover extensive areas of these reef flats. The raft monoline farms need not be placed over sand and are sometimes located over coral heads.

Net bags are also used to farm *Eucheuma*/*Kappaphycus* in the Philippines. A piece of fish net with a mesh size of approximately 1 cm is cut to measure 90 cm by 75 cm. This is folded in half and the 75 cm sides are sewn together to form a tube. One end of this tube is bundled and tied to form the bottom of the bag. The top is also tied, but in a manner which allows for repeated opening and closing for loading and harvesting. One kg of seaweed is loaded into the net bag and the bag is then either suspended from staked out monolines (in which case floats are added to the bags to keep them off of the substrate), or the bags are tied to floating longlines.

This method of farming has been found to be more productive and require less capital input per kilogram of seaweed produced than monoline methods. It is also effective against typhoons; in certain areas of the Philippines whole monoline seaweed farms can be lost to typhoons and nets bags eliminate losses during these weather conditions. Net bags can also significantly decrease losses resulting from both epiphytes and herbivores. However, net bag farming is more labour intensive as the bags must be shaken every day or two to disturb any epiphytes or sediment which has collected on the outside of the bag. For this reason, net bag farming is not popular with farmers and is so far limited to areas which experience typhoons.

Environmental Impacts

Impacts of species introductions

While the adverse impacts of accidental algal introductions are quite well documented, there have been few studies on the intentional introduction of seaweeds for culture. This is surprising as *Kappaphycus* has been introduced to 19 countries and *Eucheuma* has been introduced to 13. While quarantine procedures have been researched, they have been implemented in only one case before introducing *Kappaphycus* to a new location. Research indicates that introduced *Kappaphycus* eventually "escapes" from farms and sets up free living populations. The impacts of these populations upon the local flora and fauna may differ between locations, but there is evidence from Hawaii that *Kappaphycus* is overgrowing and killing endemic corals.

Impacts of farming practices

Seaweed farming changes the environment in and around farms. It seems that there are three main causes of this alteration: 1) The farmers remove the macro benthic organisms and cut or remove seagrasses; this alters the community structure, the lower number of herbivores allows more non farmed seaweeds to grow and the lower density of seagrasses seems to encourage tubeworms. 2) The seaweed abrades the surface of the substrate, altering the sediment structure and eliminating the microalgal mats that are prevalent coral reef lagoons; this effects the community structure of the mieobenthic organisms under the farms. 3) The farm provides an increase in habitat for invertebrates and juvenile fishes. There is actually a higher diversity index on the seaweed in farms compared with surrounding areas, but as many of these organisms are harvested along with the seaweed, this may have no net positive effects on the wider community. The increase in juvenile fishes may also contribute to the change in community structure of the mieobenthic organisms under the farms by eating particular species. It is not clear whether these changes in community structure as a result of farms can be categorised as positive or negative as some organisms increase in abundance while others decrease. More research is needed to fully understand the effect of these changes on the whole community.

There are farming practices that definitely have negative impacts on the local environment; a) refuse from farms left to litter the beach and sea floor and b) tying raft anchoring lines to live corals, both fall into this category. In addition to what is known about the impacts of seaweed farming, there are a number of impacts (both positive and negative) which have been suggested but which, as yet, have no research to support them.

Possible negative impacts include: 1) shading of both underlying coral and the microalgae growing in the top layer of the sediment, 2) drying structures and other buildings associated with farming being built on coral reefs, 3) changes in sedimentation, and 4) improper treatment of waste water from carrageenan production facilities.

Possible positive impacts could include: 1) increases in fish numbers, 2) destructive activities replaced by farming, and 3) farmers gaining sense of "stewardship" over the coastal area.

Impacts which could have either positive or negative effects are: 1) changes in primary production caused by farms, and 2) farms acting as nitrogen sinks, changing the nitrogen regime of the reef community. Whether these are positive or negative would depend on a) the normal primary production from the area covered by the farm and how much of the seaweed was lost to herbivores and/or breakage and b) whether the water was characterised by pollution or nitrogen limitation.

Recommendations

- Seaweed farming will increase in the tropics, not only within current locations but also to new areas and countries. There is enough evidence of negative environmental impacts, as well as the tenets of the Precautionary Principle, to argue strongly for undertaking a comprehensive impact study of the farming of *Eucheuma* and *Kappaphycus*. These two species are farmed in the tropics where highly biodiverse and threatened coastal marine ecosystems - such as coral reefs - occur. As shown above, the impact of farming operations can be direct or indirect, and needs to be studied to ensure an environmental catastrophe such as the invasion of the Mediterranean by *Caulerpa taxifolia*, is avoided. To this end, if CI is to promote seaweed farming it should also make a commitment to initiating and/or supporting comprehensive, ongoing research into the environmental impacts of seaweed farming

- Criteria for project entry and participation should include target beneficiaries' involvement in sound coastal management activities. An agency seeking to begin or support development of seaweed farming should make a commitment to educating the seaweed farmers about the possible environmental impacts of farming activities. Specifically, prospective farmers should be encouraged to take into account the following guidelines to mitigate the impact of farming activities.
    - Farms should be located over sandy area and not over live coral
    - Anchor lines should not be tied to live coral
    - Seagrasses should not be removed from the area to be farmed as they will actually provide nutrients to the farms
    - If herbivores are to be removed, they should not be killed, but simply shifted outside the farm boundaries
    - Plastic waste from the farms should be disposed of in an appropriate manner

- If CI is to support seaweed farming in a location which requires the introduction of seaweed to a new location they should ensure that the appropriate quarantine measures are undertaken and should ensure that funding is available for rigorous ongoing monitoring of the immediate environment to look for independent populations of the seaweed and the effects these populations might have on local flora and/or fauna.

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1. Global Seaweed Farming

Seaweeds can be described as multicellular algae that occur in marine and brackish-water and that, at some stage in their lives, are attached to a substrate. There are approximately 10,000 species of seaweeds and they come in three colours: red (rhodophytes), brown (phaeophytes) and green (chlorophytes). They are found on rocky shores in the band between the highest reach of tidal waters to the deepest depth that light can penetrate. In some areas of the world, the sea is so murky that seaweeds can only grow a few meters below low water, in others places they can be found to depths of 250 meters.

The first cultivation of seaweed began in the 17th century concurrently in Japan, Korea and China. As the story goes, a fisherman noticed that *Porphrya* attached itself to, and grew on floating twigs and consequently he began his own seaweed farm by planting bamboo sticks along the seashore (Sohn, 1998).

A recent review of world seaweed utilisation (Zemke-White and Ohno 1999) found that at least 221 species of seaweed are utilised world wide. 145 species are used for food while 101 species are used for phycocolloid production (i.e. alginates, agar and carrageenan). In 1995 a total of 2 million tonnes dry weight (approximately 13 million tonnes fresh weight) of seaweed was collected at a value of in excess of US$6.2 billion. 50% of this seaweed (by volume) was cultured with 90% of the cultured seaweed was produced in China, Korea and Japan. Just four genera made up 93% of the cultured seaweed: *Laminaria*, *Porphyra*, *Undaria* and *Gracilaria*. Approximately 10% of all seaweed cultured is done so in the tropics. Since 1984 the utilisation of seaweeds worldwide has grown by 119%.

1.1 What species are cultured and where?

Figure 1 gives a graphical account of the countries in which seaweed is farmed as well as countries where research has been undertaken into seaweed farming, but has not yet led to commercial ventures. Some 39 species from 15 genera are cultured in 22 countries. Table 1 shows the farming locations within each country for each species (where this information was available) and the references used to compile the information in both Figure 1 and Table 1. In Table 1, the countries are divided into tropical and non tropical categories. Parts of both China and Chile lie inside the tropics, but they have been categorised as temperate as the majority of the seaweed grown in them is in the temperate regions).

Figure 1. Global chart of seaweed farming and experimental ventures

In the tropics the vast majority of seaweed farmed is of the genera *Eucheuma* and *Kappaphycus*. Approximately 120,000 tonnes dry weight of *Eucheuma*/*Kappaphycus* are produced annually compared with approximately 15,500 tonnes dry weight of *Gracilaria* and 5,600 tonnes fresh weight of *Caulerpa* (Zemke-White and Ohno 1999).

Table 1. Location within each country where seaweed is farmed.

Countries	Algal Species	Location	Reference
Tropical			
Antigua	*Eucheuma isiforme*		Allan Smith pers. comm.
Barbados	*E. isiforme*		Allan Smith pers. comm.
Cuba	*Kappaphycus alvarezii* *K appaphycus striatum*		Smith 1998 Smith 1998
Hawaii	*Gracilaria* spp.		
Indonesia	*Eucheuma denticulatum*	Focused in east Indonesia, particularly in Bali and Lombok	Luxton 1993
	Gracilaria lichenoides *K. alvarezii*	East Indonesia, but also in Java, Seribu Is., Cilicap, and Sumatra, Banka Is.	Luxton 1993
Israel	*Gracilaria* spp.		Lipkin and Friedlander 1998
Jamaica	*E. isiforme*		Allan Smith pers. comm.
Kiribati	*K. alvarezii*	Kiritimati and Tabaeuran	Luxton and Luxton 1999
Malaysia	*Gracilaria changii*	Ban Merbok, Perak, on the west coast of Penninsular Malaysia	Moi 1998
	K. alvarezii	Semporna, east coast of Sabah	
Mozambique	*E. denticulatum*		Salomao Bandeira pers. comm.
	K. alvarezii		Salomao Bandeira pers. comm.
Namibia	*Gracilaria gracilis*	Luderitz Lagoon	Molloy 1998
Philippines	*Caulerpa lentillifera*	Centered around Mactan, Cebu	Trono 1998
	E. denticulatum and *K. alvarezii*	Centered on SW Mindanao, Sulu and Tawi-Tawi archipeligoes and southern Palawan. Minor farming areas are found in Cuyo Is. Group in the northern part of the Sulu sea, Batangas and Sorsogon in Luzon and Bohol and Leyte in Visayas	Trono 1998
St. Lucia	*E. isiforme*	Savannes Bay, Laborie and Praslin	Allan Smith pers. comm.
Tanzania	*E. denticulatum*	Zanzibar, Pemba, Tanga	Mshigeni 1998
Thailand	*Gracilaria fisheri*	Southern provinces of Songkhla and Pattani	Lewmanomont 1998
	Gracilaria tenuistipitata	Southern provinces of Songkhla and Pattani	Lewmanomont 1998

Table 1. Cont.

Countries	Algal Species	Location	Reference
Tropical cont.			
Venezuela	*K. alvarezii*	Araya Peninsula	Raul Rincones pers. comm.
	E. denticulatum		
Vietnam	*Gracilaria asiatica*	Throughout	Huynh and Nguyen 1998
	G. heteroclada	Phu Yen (central Vietnam) and Ba-Vung Tau (southern Vietnam)	Huynh and Nguyen 1998
	G. tenuistipitata	Throughout	Huynh and Nguyen 1998
	K. alvarezii	Central and southern	Huynh and Nguyen 1998
Temperate			
Japan	*Caulerpa lentillifera*	Okinawa	Trono and Toma 1997
	Cladosiphon okamuranus	Okinawa and Kagoshima	Toma 1997
	Enteromorpha compressa		Ohno and Largo 1998
	E. prolifera		Ohno and Largo 1998
	E. intestinalis		Ohno and Largo 1998
	Laminaria japonica	Japan – Hokkaido (Oshima Prov. 55% of all), Aomori, Iwate, Miyagi, also Tokyo Bay, the Inland Sea, Ariake Bay, Tosa Bay	Ohno and Largo 1998
	Monostroma latissimum	Mie, Aichi, Ehime, Kochi, Kagoshima, Okinawa	Ohno and Largo 1998
	Nemacystus decipiens	Okinawa and Kagoshima	Ohno and Largo 1998
	Porphyra tenera		Ohno and Largo 1998
	P. yezoensis		Ohno and Largo 1998
	Ulva spp.	Inner bays and estuaries, recently expanded to the south	Ohno and Largo 1998
	Undaria pinnatifida	Iwate in the north and Tokushima in the south (Sanriko and Naruto)	Yamanaka and Akiyama 1993
South Korea	*Enteromorpha spp.*	Wando and Pusan	Sohn 1998
	Hizikia fusiformis	Wando (south west coast)	Sohn 1998
	Laminaria japonica	Southern coast	Sohn 1998
	Porphyra yezoensis	Central western to south eastern coast	Sohn 1998
	U. pinnatifida	Wando and Pusan	Yamanaka and Akiyama 1993
Chile	*G. chilensis*	Entire coast	Alveal 1998
US	*P. yezoensis*	Maine	Merrill and Waaland 1998
Canada	*Chondrus crispus*	Nova Scotia	Chopin 1998
	Laminaria groenlandica	Barkley Sound, SW of Vancouver Is.	Lindstrom 1998
	L. saccharina	Barkley Sound, SW of Vancouver Is.	Lindstrom 1998
	Macrocystus integrifolia	Barkley Sound, SW of Vancouver Is.	Lindstrom 1998
Taiwan	*Gracilaria verrucosa*		Chiang 1981
	G. gigas		Chiang 1981
	G. lichenoides		Chiang 1981
	Eucheuma gelatinae		Chaoyuan 1998
China	*E. gelatinae*	Hainan Island	Chaoyuan 1998
	G. asiatica	Hainan Is. and Guangxi Province	Chaoyuan 1998
	G. articulata	Hainan Is.	Chaoyuan 1998

Table 1. Cont.

Countries	Algal Species	Location	Reference
Temperate cont.			
China cont.	*G. eucheumoides*	Hainan Is.	Chaoyuan 1998
	G. hainanensis	Hainan Is. and Guangxi Province	Chaoyuan 1998
	G. verrucosa	Shandong and Fujian	Chaoyuan 1998
	Laminaria japonica	from Dialan in the north to Fujian in the south.	Chaoyuan 1998
	Porphyra yezoensis	primarily in the north	Chaoyuan 1998
	P. haitanensis	Hainan	Chaoyuan 1998
	Undaria pinnatifida	Concentrated on Liaoning and Shandong in the north	Chaoyuan and Jianxin 1997
Locations where intiial introduciton and/or research has taken place, but as yet no continued commercial harvesting			
Argentina	*Gracilaria verrucosa*	Golfo Nuevo	Boraso de Zaixso et al.1997
Fiji	*K. alvarezii*		Luxton et al.1987
Djibouti	*E. denticulatum*		Braud and Perez 1974
Brazil	*Gracilaria spp.*	Rio Grande do Norte	Oliveira 1998
	Hypnea musciformis	São Paulo, Rio Grande do Norte	Berchez et al.1993
	Agardhiella subulata		Oliveira 1998
	Pterocladia capillacea		Yokoya and Oliveira 1992
	K. alvarezii	São Paulo	Oliveira 1998
	Laminaria abyssalis	Sao Paulo	Yoneshigue and de Oliveira 1987
	L. brasiliensis	Sao Paulo	Yoneshigue and de Oliveira 1987
	Monostroma spp.		Oliveira 1998
India	*Sargassum swartzii*	Mandapam and Okha	Marih et al.1998
	Cystoseira indica	Mandapam and Okha	Marih et al.1998
	Enteromorpha flexuosa	Okha	Marih et al.1998
	Ulva fasciata	Okha	Marih et al.1998
	Gracilaria edulis	Gulf of Mannar	Marih et al.1998
	Gelidiella acerosa	Krusadi Island	Marih et al.1998
	K. alvarezii	Okha	Marih et al.1998
Mexico	*Eucheuma uncinatum*	Gulf of California	Robledo 1998
	E. isiforme	Yucatan	Robledo 1998
	Gracilaria pacifica	Baja California	Robledo 1998
	G. cornea	Yucatan	Robledo 1998
South Africa	*G. gracilis*	Saldanha Bay	Critchley et al.1998
Madagascar	*E. denticulatum*	Tulear	Mollion 1998
	E. striatum	Tulear	
Italy	*Gracilaria verrucosa*	Lagoon of Grado, Gulf of Trieste, Lagoon of Orbetello, Sacca of Scardovari, Mar Piccola of Taranto, Saline of Trapani	Cecere 1998
Spain	*Undaria pinnitifida*	Galicia	Juanes and Sosa 1998
New Zealand	*U. pinnitifida*	Nelson	Zemke-White et al.1999

1.2 Farming techniques

There are 8 main methods of farming seaweed.

1.2.1 Tanks

Growing seaweed in tanks is undertaken on dry land. Although several species have been grown experimentally in this manner, the only seaweed currently cultured in tanks is *Chondrus crispus*, in Nova Scotia, Canada (Chopin 1998). Of all the methods for growing seaweeds, tank culture is the most productive (per unit area) (Critchley 1997) as it allows control over the biotic and abiotic parameters that regulate productivity (de Oliveira et al. 1989). However, it is also the most expensive technique and is therefore usually restricted to high value end products or polyculture (de Oliveira et al. 1989). In New Zealand attempts have been made to grow *Gracilaria* spp. in tanks as food for abalone, which are cultured in the same tanks.

1.2.2 Pond farming

Gracilaria is grown in specially constructed ponds in China, Israel and Indonesia. It is also polycultured in ponds with shrimp in Malaysia (Moi 1998), and fish in Taiwan (Friedlander and Levy 1995). *Caulerpa lentillifera* is grown in ponds in the Philippines (Trono and Toma 1997).

For *C. lentillifera* the pond water is kept at a depth of 0.5-0.8 m and sub-divided into 0.5-1.0 hectare areas. This type of culture requires constant water , and complete water replacement at least every two days. Seed stock is planted uniformly on the bottom of the pond by burying one end of handful of seedstock at approximately 1 m intervals. The seaweed is harvested after two or more months (Trono 1998).

Both *Gracilaria* and *Caulerpa* can be cultured either by planting the cuttings directly into the substrate of the pond, or by broadcasting, in which the seedstock is not anchored to the bottom. Planting the algae into the substrate is generally preferable, as the seed stock, when broadcast, can concentrate in one part of the pond, resulting in patchy growth.

1.2.3 Bottom stocking

Bottom stocking is an attempt to duplicate the natural field conditions of the algae. In Chile, *Gracilaria chilensis* plants may be pushed into the sediments with a forked instrument, tied to rocks with rubber bands or kept in place with nylon laced over rocks (Santelices and Doty 1989). Alternatively, it can be kept in place with tube-shaped plastic bags filled with sand . Bags are laid out in parallel rows 1 m apart. The bags are manufactured to disintegrate, by which time the plants have developed underground anchors (Critchley 1997). In Hainan Island, China, cuttings of *Eucheuma gelatinae* are tied with rubber bands to small pieces of dead coral, which are then distributed by divers in the subtidal regions of coral reefs (Chaoyuan 1998). In sheltered lagoons in the Philippines, bottom stocking is used to culture *Caulerpa lentillifera*. Using this method the seaweed thallus is pushed into the substrate in much the same way as in pond culture. (Trono and Toma 1997).

1.2.4 Cage culture

In Okinawa *Caulerpa lentillifera* is cultured in multi-layered, cylindrical cages (Trono and Toma 1997). Small bundles of seed stock are tied to the center of each level of the cage, and the cage is suspended under water. *C. lentillifera* is harvested about once per month by cutting the seaweed that protrude from the cage.

1.2.5 Monoline

This the main method used for culturing *Eucheuma* and *Kappaphycus* (Trono 1997). In the fixed type monoline farm, stakes are driven into the substratum approximately 10 m apart and a thin line (up to 5 mm diameter) is stretched between them approximately 0.5 m above the bottom. Additional rows are added about 1 m apart and cuttings are tied to the monoline at 25-30 cm intervals using a soft plastic material. In areas where there is little water movement or problems with grazers, the monolines can be kept floating on the surface with “rafts”. In this case the monolines are stretched between two floating poles (usually bamboo), which are in turn anchored to the bottom. In the floating raft monoline farms, more intensive seeding is applied, with monolines being only 30 cm apart and cuttings arranged on the monolines at 15 cm intervals. Plants are grown to approximately 1 kg wet weight before harvesting, which involves complete removal of the plants. This allows for selection of fast growing plants as subsequent seedlings.

1.2.6 Longlines

Longlines are used for the culture of *Hizikia* (Sohn 1998), *Undaria* (Ohno and Matsuoka 1997), *Laminaria* (Kawashima 1997), *Macrocystis* (Lindstrom 1998), *Gracilaria* (Santelices and Doty 1989) and *Eucheuma* (pers. obs.). The longline is a thick rope which is kept at a particular depth or at the water’s surface with buoys, and anchored to the bottom to keep it place. Drop lines to which seaweed is attached are strung off of the long line at a range of intervals depending on the species being cultured.

For *Eucheuma*, cuttings are either threaded directly through the long line, or inserted into tube shaped mesh bags which are tied to or wound around the longlines. For *Gracilaria*, either cuttings or spore seeded rope (Alveal et al.1997) are wound around or through long lines. The lines are either staked out, or stretched between buoys, or rafts of bamboo.

For the rest of the algae farmed in this way, spores are first collected on a thin line (usually around 1 mm diameter) which is then cultured separately until the plants are large enough to be transplanted to the drop lines. The spore collector line is then cut into small pieces and threaded through the drop lines. The drop lines can be arranged on the longline in a number of ways. They can be weighted to hang straight down, tied parallel along the long line or hung parallel but below the longline. If they are hung straight down, they may be inverted mid-season to ensure even growth.

1.2.6.1. *Laminaria japonica*

Two-year-old plants are used for seeding. Maintaining the seaweed in the dark for a proscribed period of time causes the release of zoospores. Seeding string (3mm diameter), wound onto triangular frames, is placed in the zoospore solution for approximately 24 hours. After 45 days in culture, they are ready for provisional out-planting where they are hung from longlines for 7-10 days. The seeding strings are then cut into approximately 5 cm lengths and inserted at 30 cm intervals into the main cultivation ropes (approximately 5 m in length). The cultivation ropes are either hung vertically from the main line at 2m intervals (vertical hanging method) or the ropes are stretched parallel to the long line (long line method). The main line is suspended approximately 2m below the surface. After six months the lower ends in the vertical hanging method are tied up level with the main line. *Laminaria* is harvested in mid-summer

1.2.6.2 *Undaria pinnitifida*

Zoospores are collected on absorbent synthetic fiber wound on rectangular frames (spore collector). Zoospores attach themselves to the fibre and develop into male and female gametophytes and sexual reproduction takes place after maturation. The spore collector can be outplanted after about three weeks. The seed ropes can then be cut into sections and attached to the main cultivation rope (1-3 cm diameter). In rough seas the cultivation rope can be suspended below and parallel to the main rope , attached every few meters. In a variation on the long line method, the cultivation ropes can be suspended vertically from individual bamboo poles which are separated by ropes. *U. pinnitifida* is harvested around three months after outplanting (February/April)

1.2.7 Nets

Nets are used to culture *Monostroma* and *Enteromorpha* (Ohno 1997), *Porphyra* (Oohusa 1997), *Cladosiphon* and *Nemacystus* (Toma 1997). Spores are settled onto the nets by one of two methods. The nets are either placed in collection grounds where and when the particular species is about to sporulate, or spores are collected in the laboratory and the nets are immersed n the spore solution.

1.2.7.1 *Cladosiphon okamuanus*

The nets are seeded from either mature sporophytes or from apotheca which have been stored over summer. The nets are placed in the spore solution for 2-10 days. In October seeded nets are transferred and placed in layers (up to 12 in a stack) to an intermediate nursery, in seagrass beds at less than 1m depth with moderate currents. These nets are then staked out loosely about 40 cm from the bottom in single layers. Plants are harvested at about 30cm length (80-90 days cultivation).

Monostroma, *Enteromorpha* and *Porphyra* are cultured by either “pole” or “floating” methods. In the former, the nets are placed in the intertidal zone at a height which ensures an optimal time out of the water at low tide. The latter method is used in locations where there is not adequate areas for pole farms (e.g in deep water). Nets are suspended at a particular depth with floats and anchor ropes.

1.2.7.2 *Monostroma* and *Enteromorpha*

Two types of seeding are used, either the nets are spread in sets of about five in spore-collection grounds (in the open ocean), or the maturation of zygotes is promoted during September and culture nets are submersed overnight in large tanks containing the collected zoospores. *Monostroma* is harvested 3-4 times during growing period, *Enteromorpha* 2-3 times.

1.2.7.3 *Porphyra* spp.

Between January and March oyster shells are spread in a carpospore solution, the carpospores germinate and penetrate the oyster shells. The resulting conchospores are then seeded onto nets. The nets are usually 1.5 m by 18 m, and are suspended by either the pole system or floating system. As *Porphyra* growth is inhibited by high water temperatures in dark conditions (high temperatures at night) and these conditions are prevalent in Japan in mid-late November, the nets can be removed from the water, partially dried and stored frozen. The nets can be reintroduced to the water at any time.

This technique has aided the stabilisation of Japanese Nori production.

The pole system provides a higher quality product as the *Porphyra* is periodically out of the water. In Korea buoys are attached to floating nets at intervals of ~2m which allows the nets to be inverted to allow air contact. This has provided increases of up to 150% in *Porphyra* production (and a 400% increase in income for farmers).

1.2.8 Net bags

Net bags have recently been employed in the farming of *Eucheuma*/*Kappaphycus* in the Philippines. A piece of fish net with a mesh size of approximately 1 cm is cut to measure 90 cm by 75 cm. This is folded in half and the 75 cm sides are sewn together to form a tube. One end of this tube is bundled and tied to form the bottom of the bag. The top is also tied, but in a manner which allows for repeated opening and closing for loading and harvesting. One kg of seaweed is loaded into the net bag and the bag is then either suspended from staked out monolines (in which case floats are added to the bags to keep them off of the substrate), or the bags are tied to floating longlines.

This method of farming has been found to be more productive and require less capital input per kilogram of seaweed produced than monoline methods. It is also effective against typhoons; in certain areas of the Philippines whole monoline seaweed farms can be lost to typhoons and nets bags eliminate losses during these weather conditions. Net bags can also significantly decrease losses resulting from both epiphytes and herbivores. However, net bag farming is more labour intensive as the bags must be shaken every day or two to disturb any epiphytes or sediment which has collected on the outside of the bag. For this reason, net bag farming is not popular with farmers and is so far limited to areas which experience typhoons.

2. Tropical Seaweed Farming

This section will focus specifically on the seaweed farmed in the tropics, i.e. the genera *Eucheuma* and *Kappaphycus* and to a lesser extent *Caulerpa* and *Gracilaria*. First is a description of the biological features of these seaweeds which is followed by an outline of their uses, focusing on a description of phycocolloids (the major product of seaweeds farmed in the tropics) and phycocolloid manufacturing.

It is difficult to find data on the amount of area covered by seaweed farms in the tropics, however, extrapolation from production projections may provide a rough guide. In the Philippines, a one hectare farm can be expected to generate 35-38 tonnes of dried seaweed per year (Barraca 1999). With the Philippine production of dried seaweed at around 93,000 tonnes per year, this equates to around 2,500 hectares of farms. However, Trono (1996) estimated that up to 7,000 hectares was being used in the Philippines (the equivalent of 13 tonnes per hectare per year). This may be the case, as the 35-38 tonnes per hectare estimate is based on a well maintained farm, probably in optimal growing conditions. It also does not take into account the areas between farm plots which are not actually farmed, but are likely to be as effected by farming as the actual farm sites. Allowing for poorly maintained farms and farms in less than optimal growing conditions, and based on a worldwide production of 120,000 tonnes of *Euchuema* and *Kappaphycus*, some 9,000 hectares of shallow coastal areas, which are closely associated with coral reefs, are being used for the cultivation of seaweed in the tropics.

Carrageenan demand has been predicted to grow by 5 - 7 % annually over the next ten years (Mojica et al 1997). If the supply is to meet the demand this would effectively double the area farmed over a ten year period.

2.1 Biology of seaweed species farmed in the tropics

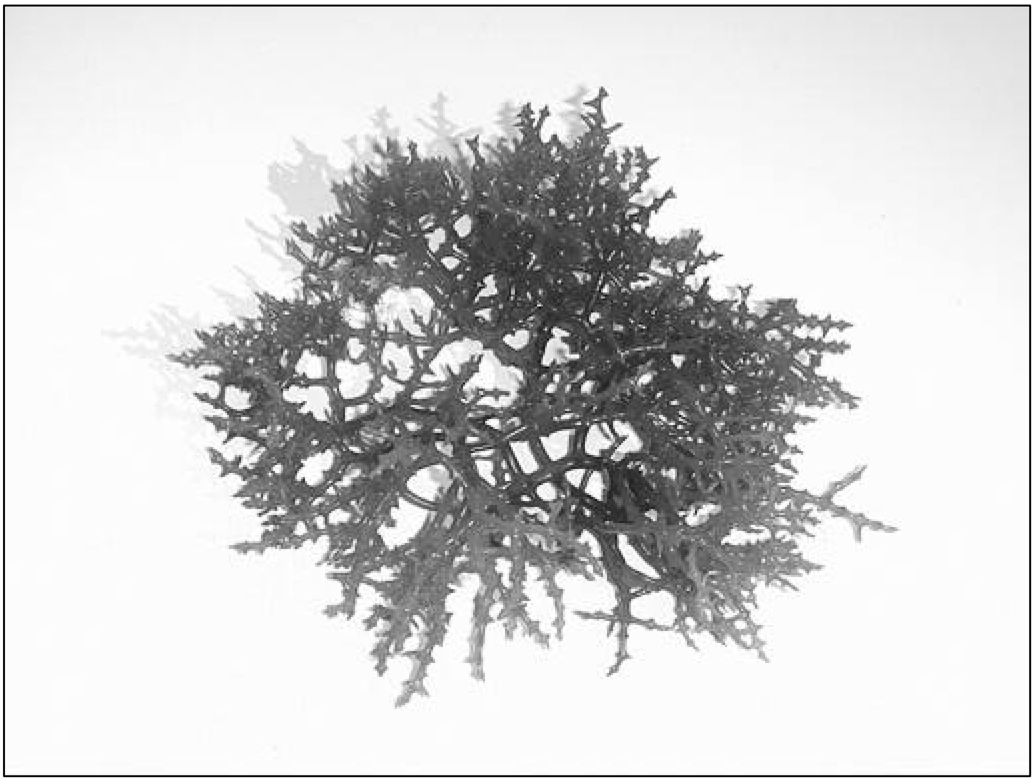
2.1.1 *Caulerpa lentillifera*

2.1.1.1 Native distribution

Caulerpa lentillifera (Figure 2) is found from the Indian to the Western Pacific Ocean.

Figure 2. *Caulerpa lentillifera*, Mactan Is. Philippines.

Figure 3. *Eucheuma isiforme*, Savannes Bay, St. Lucia



2.1.1.2 Habit

Found on sandy to muddy substrates in protected areas of shallow reef flats and bays, it also can be found on coarse sandy-coral substrata on seaward parts of reef flats. It forms either thick beds or patchy growth.

2.1.1.3 Life cycle

A diplontic alga, sexual reproduction takes place in warmer months (spring to summer). The protoptasts of the ramuli transform into flagellated gametes of both sexes. The gametes are released and conjugate to form the gametes. These settle to the bottom to germinate and then grow into the adult form (Trono and Tomo 1997)

2.1.2 *Eucheuma* spp. *and Kappaphycus* spp.

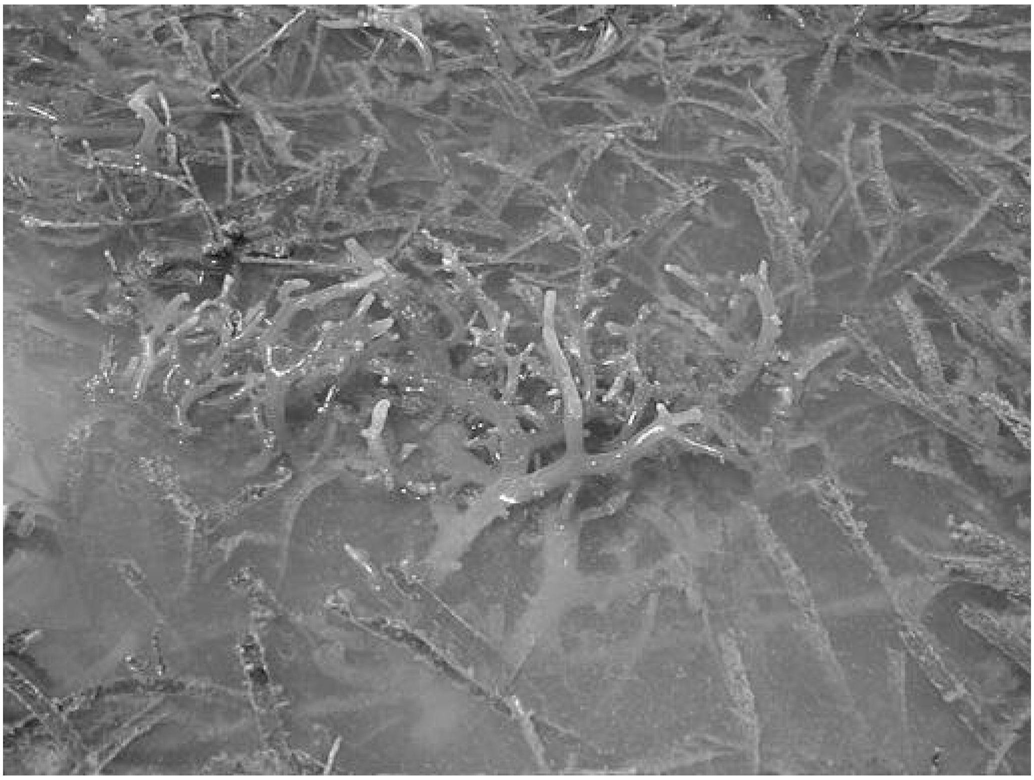
2.1.2.1 Native Distribution

These genera have recently been revised. What was historically the genus *Eucheuma* has been split into *Eucheuma*, *Kappaphycus* and *Betaphycus* on the basis of the type of carrageenan found in the algae (see section 2.2.1). This makes it difficult to determine the native range of these algae as they have been called different names over the years. Doty (1987) reported that the two major commercial forms of *Eucheuma*, *E. spinosum* and *E. cottonii*, are native to the Old World tropics and westward to the eastern coast of Africa. Since that publication *E. spinosum* has become *E. denticulatum*, while *E. cottonii* has become *Kappaphycus cottonii*. Even armed with this knowledge it is difficult to ascertain the native distribution of these two genera as the terms "spinosum" and "cottonii" has been used in the industry to describe many species of both *Eucheuma* and *Kappaphycus*.

Currently there are only four species of these genera commercially cultivated: *Eucheuma isiforme*, *E. denticulatum*, *Kappaphycis alvarezii* and (to a lesser extent) *K. striatum*. *Eucheuma isiforme* (Figure 3) is native to the entire Carribean and is farmed in St. Lucia, Barbados, Antigua and Jamaica. However, the strain being farmed in these locations was transferred from Belize in 1997 (Allan Smith pers comm.) *E. denticulatum* (Figure 4), known in the industry as "spinosum" and *Kappaphycus alvarezii* (Figure 5) and, *K. striatum*, both known in the industry as "cottonii" are native to the Indian and the Western Pacific Oceans. They are native at many of the tropical locations where they are being farmed, but the strains being farmed were almost all imported from original stocks in the Philippines. See Table 3 for details of these introductions. There is still common confusion between *K. striatum* and *K. alvarezii* both in the literature and in the farming industry, consequently these two species are virtually interchangable in this report.

Figure 4. Eucheuma denticulatum, Paje, Zanzibar

Figure 5. *Kappaphycus alvarezii*, Unguju Ukuu, Zanzibar.



2.1.2.2 Habitat

Eucheuma denticulatum thrives on coarse, sandy to rocky substrata in areas with moderate to strong water currents. *Kappaphycus alvarezii* and *K. striatum* grow from just below the low tide mark on sandy to rocky substrata, in slow water currents (Trono 1997).

2.1.2.2 Life cycle

Eucheuma and *Kappaphycus* exhibit the triphasic “polysiphionia” life history (outlined by Doty 1987). The first two phases are isomorphic (they look identical). Phase 1 is the tetrasporophyte, which is diploid; phase 2 is the gametophyte, which is haploid and dioecious (male and female reproductive organs are on different individuals). Stage 3 is the microscopic carposporophyte, which lives parasitically on the female gametophyte. The tetrasporophyte produces structures called tetrasporangia which undergo meiotic division and release tetraspores. These develop into the mature male and female gametophytes. The male gametophyte produces gametes (spermatia), and the female forms carpogonial branches, within which are formed the carpogonium (female gametangium). The male gametes are passively transmitted to the female carpogoium, resulting in fertilisation within the tissue of the female gametophyte, creating the carposporophyte. The carposporophyte produces carpospores which, when released, develop into the mature tetrasporophyte.

2.1.3 *Gracilaria* spp.

2.1.3.1 Native Distribution

Gracilaria is widely distributed throughout the world (Santelices and Doty 1989) and more than 16 species of this genus are cultured. It occupies a variety of habitats in both the tropical and temperate waters and can form either monospecific stands or multispecific assemblages. *Gracilaria* is generally farmed in its native location and there is little indication in the literature that species of this genera have been introduced to, or transferred between, countries in the tropics for the purposes of aquaculture.

2.1.3.2 Habitat

Large commercial crops of *Gracilaria* are generally found in intertidal or shallow sub-tidal, wave sheltered, horizontal or only slightly inclined surfaces. The substrate is generally sandy to muddy, unconsolidated and non-carbonate in composition. *Gracilaria* often withstands frequent fresh-water dilutions, high fertilizer yields, low water motion, high temperatures and burial by sediments. *Gracilaria* beds in Chile have been found to contain surviving fragments of *Gracilaria* even after being buried in sediment for up to 6 months (Santelices et al. 1984). *Gracilaria* can also exist as large free-floating populations.

2.1.3.3 Life history

Triphasic lifestyle identical to that of *Eucheuma*.

2.2 Uses of tropical seaweeds

Seaweeds are used in a variety of ways: for food, medicines and agricultural products (Chapman and Chapman 1980), paper (Cecere 1998), production of biogases (Beavis and Charlier 1987), as biofilters (Bushmann 1996; Jimenez del Rio et al. 1996), in polyculture with other species (Petrell and Alie 1996; Troell et al.1997) and for the phycocolloids found in their cell walls. Of the four genera farmed in the tropics *Caulerpa lentillifera* is farmed exclusively for food. Similarly, *Gracilaria*, *Eucheuma* and *Kappaphycus* are also used for food but they are primarily farmed for phycocolloid extraction. The following section reviews the origin and uses of these important seaweed components.

2.2.1 Phycocolloids – an introduction

Generally, the cell walls of marine seaweeds are composites of at least two main components, microfibrills and "matrix" polysaccharides (Mackie and Preston 1974). The microfibrils encircle the cell in varying patterns (spirals, helices, etc.) and are the most inert and resistant part of the cell wall. In various algal species this "skeletal" component can be: cellulose, a 1,4 linked β-D-glucose polymer; mannan a polymer of a 1,4, linked β-D-mannose (Mackie and Preston 1968); or xylan, a polymer of 1,3 linked β-D-xylose (Preston 1974). The matrix is generally a gel-forming (mucilagenous) polysaccharide in which the microfibrillar phase is embedded. In some cases the microfibrills and these gels occur in alternating layers like a sandwich (Hanic and Craigie 1969). It is these mucilagenous polysaccharides that are called phycocolloids, and which have commercial value, especially agar and carrageenan from the red algae (Rhodophyta) and alginic acid from the brown algae (Phaeophyta).

Only seaweeds containing agar (*Gracilaria*) and carrageenan (*Eucheuma* and *Kappaphycus*) are farmed in the tropics.

2.2.1.1 Agar

This sulphated galactan is commercially extracted from algae of the genera *Gelidium*, *Gracilaria* and *Pterocladia* (Glicksman 1987). It is composed of 1,3 linked β-D-galactose and 1,4 linked anhydro-α-L-galactose (Margulis et al. 1993). Agarose, the portion of agar which forms a gel, has a double helical structure. The double helices join together and form a three dimensional structure which holds water molecules, thus forming thermoreversible gels (Arnott et al. 1974). Agar is soluble in boiling water and sets to a firm gel on cooling to about 35^0C. This gel will not melt at temperatures less than about 85^0C.

Agar is mostly used in foods and as a microbiological culture media. Its unique properties make it useful for a variety of food applications (Glicksman 1987). As it can hold large amounts of soluble solids (e.g. sugar) without losing its adhesive qualities or crystallising, it is widely used in bakery glazes, icings etc. Its resistance to high temperatures without breaking down make it ideal in the canning industry, where products are autoclaved during the canning process.

2.2.1.2 Carrageenan

Carrageenan is commercially extracted from the genera *Chondrus*, *Gigartina*, *Eucheuma*, *Kappaphycus*, *Hypnea*, *Iridaea*, *Gymnogongrus*, *Ahnfeltia* and *Furcellaria* (Glicksman 1987). Like agar, it is a sulphated galactan but consists of alternating units of β-1,3 and α-1,4 linked D-galactopyranose (Margulis et al. 1993). There are three forms available commercially (Mackie and Preston 1974):

- kappa - alternating 1,3 linked β-D-galactose 4-sulphate and 1,4 linked 3,6-anhydro α-D-galactose
- lambda - alternating 1,3 linked β-D-galactose and 1,4 linked α-D-galactose 2,6 disulphate
- iota - alternating 1,3 linked β-D-galactose 4-sulphate and 1,4 linked 3,6-anhydro α-D-galactose 2-sulphate.

Carrageenans bind with proteins which makes them ideal for stabilising milk products and suspending fat globules and flavour particles. When added to hot milk and cooled, bonds form between carrageenan and the proteins in the milk to give a creamy thick texture. As it is resistant to high temperatures, carrageenan is used extensively in ultra-high temperature (UHT) processed goods. Lambda carrageenan does not form a gel and is used for viscosity control: thickening, bodying and suspending applications such as milkshakes, flavoured milk, syrups and sauces (Glicksman 1987). Iota and kappa types form thermoreversible gels and are used in both water and milk gelling systems (Nussinovitch 1997).

Eucheuma contains only iota carrageenan while *Kappaphycus* contains only kappa carrageenan (Chapman and Chapman 1980). As there are applications for which only one form of carrageenan is required, these two genera are useful as they require no extra stage of separating the carrageenans after extraction.

The market for iota carrageenan is static while the market for kappa carrageenan continues to increase (Eric Ask pers. comm.). One of the persons interviewed from the processing industry stated that while there is currently around 100,000 tonnes of *Eucheuma* and *Kappaphycus* produced annually, if another 30,000 tonnes was available it would be purchased immediately. There is high demand for this phycocolloid.

2.2.1.3 Alginic acid and its salts (alginates)

Alginic acid is commercially extracted from the genera *Macrocystis*, *Laminaria*, *Ascophyllum*, *Ecklonia*, *Eisenia*, and *Sargassum* (Glicksman 1987). It is made up of 1,4 linked β-D-mannuronic acid and 1,4 linked α-L-guluronic acids in varying ratios (Margulis et al.1993).

Alginates are used in many food applications: their water-holding capacity make them ideal for maintaining the texture of frozen foods during the freeze-thaw cycle, their stabilising and emulsifying capabilities are used in salad dressings, beer, fruit juices, sauces and gravies (Nussinovitch 1997). One of the useful properties of alginates are their reactivity with calcium to form a rigid skin. This enables the construction of “fabricated foods”. Food pulp is mixed with the alginate and dropped into a soluble-calcium-salt solution where a skin is formed around the surface of the droplet. This method has been used to create of imitation cherries, apples and berries, and to fabricate pimento strips and onion rings (Glicksman 1987).

Table 2. Functional properties of phycocolloids used in foods (from Glicksman 1982)

Function	**Example**
Binding agent	pet foods
Bodying agent	diabetic drinks
Crystalisation inhibitor	ice cream, frozen foods
Clarifying agent	beer and wine
Clouding agent	fruit drinks
Coating agent	Fabricated onion rings
Dietary fibre	Cereals, breads
Emulsifier	salad dressing
Encapsulating agent	Powdered flavours
Film-former	Sausage casings
Flocculating agent	Wine
Foam stabiliser	Beer
Gelling agent	Deserts, confectionery
Molding agent	jelly candies
Protective colloid	Flavour emulsions
Stabiliser	salad dressing, ice cream
Suspending agent	Chocolate milk
Swelling agent	Processed meat products
Syneresis inhibitor	Cheese, frozen foods
Thickening agent	jams, pie fillings
Whipping agent	Marshmallows

2.2.2 Carrageenan production

There are two main grades of carrageenan, refined and semi-refined. Semi-refined carrageenan (SRC) is produced without the carrageenan ever going into solution. There at two types of SRC, pet food and (human) food grades. While semi-refined carrageenan is usually abbreviated as SRC it may also be called (from McHugh 1996):

- Alkali treated cottonii – ATC
- Alternatively refined carrageenan – ARC
- Natural washed carrageenan – NWC
- Philippines natural grade – PNG
- Processed *Eucheuma* seaweed – PES
- Seaweed flour – SF

To produce SRC the seaweed is sorted, washed in fresh water (to remove sand and other debris) then treated in a hot alkali solution of potassium hydroxide. This removes water soluble carbohydrates, protein and salts. The residue (carrageenan and cellulose), which still resembles the seaweed in morphology, is then washed in fresh water, bleached (food grade only), dried and milled. The product is then sterilised (food grade only) and blended with SRC product of known qualities (gel strength, carrageenan %) to give the desired finished product.

There are two main types of refined carrageenan, KCL precipitated and Alcohol precipitated.They have different applications, but the processing is similar for both. The initial product is SRC; the carrageenan is solubilised in alkali, filtered to remove the cellulose and then precipitated in KCL or alcohol. The precipitated carrageenan is then pressed to remove much of the water, pelletised, dried and sterilised, dried further, and blended to yield the end product with the desired gel strength.

The manufacturing of carrageenan produces waste water with high pH, chemical oxygen demand (COD) and biochemical oxygen demand (BOD). The proper treatment of this waste water is an important factor in relation to the effects of seaweed farming on the environment and are discussed below in section 3.4.3.

3. Biodiversity Impacts of seaweed farming

3.1 Introduction

To assess the environmental impacts of seaweed farming in the tropics a literature review was carried out and experts were interviewed from the seaweed industry, Government departments and agencies, non-governmental organisations, and academia (see appendix 5.2 for a list of contacts). In addition, three locations were visited to view farm sites first-hand: St. Lucia in the Caribbean, Zanzibar in the Indian Ocean, and the Philippines in the Pacific Ocean. These three locations were chosen as they represent different biogeographic areas and because each has existing seaweed farming operations.

The results of the literature search revealed only four studies on the impacts of seaweed farming. Unfortunately all of these studies employed sub-optimal designs (Green 1979) as farming was already established before the studies were carried out. In this type of study reference sites are used for comparison, rather than true controls.

Johnstone and Olafsson (1995) compared benthic microbial processes between both farmed and reference sites.They measured benthic and water column primary production, bacterial production in the sediment and water column, nutrient flux, and sediment total organic carbon and total nitrogen. Olafsson et al. (1995) compared farm sites with two types of reference site, “close” (5 m from farm) and “away” (50 m from farm). They sampled the sediment for major mieofaunal taxa as well as measuring sediment grain size, chlorophyll a, salinity and temperature. Msuya et al. (1997) examined differences between farmed and reference sites in terms of sediment composition and macro benthic organisms. Hindely (1999) examined fish and macrobenthic invertebrate numbers at farm and reference sites and surveyed farmers to determine diversity of fishes found in farms. These studies are discussed in detail below.

When experts interviewed for this study were asked why there is a paucity of literature on the impacts of seaweed farming, two answers were the most often given: 1) that there were not the funds available for what would need to be an extensive study (see section 4.0 below), and 2) that, from an environmental impact perspective, seaweed farming has generally been thought to be a relatively benign or even positive form of marine agronomy. This second point is typified by Ask (1999) which lists the ways *Eucheuma*/*Kappaphycus* can play a “positive role” in coastal management:

1. Farms act as nutrient sinks
2. As farms are a site of both primary production and herbivory, they can act to enhance fish stocks.
3. Farms can increase the available habitat for certain fish and invertebrates
4. Farming can provide a sustainable livelihood which may take people away from more destructive activities (e.g. dynamite or cyanide fishing).
5. As farms require a certain standard of water quality, the farmers will develop a sense of stewardship toward the coastal area and will influence people whose activities are a threat to water quality.

These factors are both intuitively appealing and are widely cited by proponents of seaweed farming. The first three of these points are discussed in section 3.3. Unfortunately there has been no empirical examination of the last two points at all. Farming is very seldom a full time activity for any single farmer. This is evidenced by the lack of interest shown for using the net bag farming method for *Kappaphycus* (Barracca pers. comm.), which provides greater productivity but which requires daily attention. With either the monoline or longline type of farm, farmers need not spend every day engaged in farming and so it would not be necessary for a farmer to abandon other more destructive activities (except within the farm site itself). Without empirical evidence, one could just as easily conclude that seaweed farming is one of several economic activities that occupies a farmer's time, who may supplement this income by a number of environmentally destructive and non-destructive activities. If seaweed farmers persist in destructive activites in addition to tending there farms, this would also belie the 5th point of Ask et al. Farmers can hardly be said to be developing a "sense of stewardship" over the coastal area if they are willing to dynamite or cyanide fish in locations on the basis that they are not near their own farms.

This section begins with an introduction to the seaweed farming activities in each of the three locations visited for this report and is then followed by a discussion of what is currently known about the environmental impacts of seaweed farming in the tropics. This discussion utilises the ideas and comments of the experts interviewed for this report, the literature on the impacts of farming and also incorporates an examination of the possibly positive impacts listed above. This discussion has been broken into the impacts of introduced species for aquaculture, farming activities and associated human activities.

3.1.1 St. Lucia

Until the 1980s all of the seaweeds used in the Caribbean were harvested from wild stocks. In 1981 the Government of St. Lucia began a research program to develop methods for farming seaweeds. By 1985 a small group of farmers had begun farming *Gracilaria* spp. in St. Lucia (Smith 1997). The methods learned in St. Lucia were transferred to Grenada, St. Vincent, Dominica, Barbados, Antigua, Jamaica and Haiti. However, there is currently only commercial farming of seaweed in St. Lucia, Barbados, Antigua, and Jamaica (Allan Smith pers. comm.) and Venezuela (Rail Rincones pers. comm.).

In the Caribbean there are approximately ten species of seaweed that have historically been harvested locally for food, especially in the preparation of drinks and desserts (Smith 1997). The most popular of these are species from the genera *Gracilaria* and *Eucheuma*. The agar and carrageenan, from *Gracilaria* and *Eucheuma* respectively, is extracted by boiling the seaweed in water and straining the mixture to separate the extracted phycocolloid from the seaweed. This extracted carrageenan is then added to a variety of desserts and drinks, or bottled and sold in a liquid form for home use.

All of the seaweed currently being farmed in the West Indies was intentionally transferred from Beize. While *Gracilaria* was originally used in farming ventures in the West Indies, there were problems with epiphytism on this genus. In 1997 *Eucheuma isiforme* was transferred from Belize to St. Lucia, Barbados, Antigua and Jamaica and it is this species currently being farmed in these locations (Allan Smith pers. comm.). The implications of species introductions are discussed in section 3.2.

The seaweed is farmed using a longline type method. Seaweed cuttings are either threaded through the weave of the longline or placed into long mesh bags which are then attached to the longlines. The lines are anchored at each end and floats (generally discarded drink and oil containers) are attached at approximately 1 m intervals to maintain the lines just below the surface of the water (see Figure 6).

By world standards, there is little seaweed produced on St. Lucia. While they have mastered the farming techniques in St. Lucia, the main limitation to the industry is the lack of a market. The seaweed produced in St. Lucia is used within the West Indies in various food and drink applications and as the farmers can locally receive up to US$3.50 per kg of dry seaweed, they are not interested in selling their product to FMC or Copenhagen Pectin for a much lower price (Marie-Louise Felix pers. comm.).

3.1.2 Tanzania

In 1989, following extensive field trials, commercial scale farming of *Kappaphycus alvarezii* and *Eucheuma denticulatum* began in villages on mainland Tanzania as well as on Unguja and Pemba Islands, Zanzibar. Since that time, the farming of these two species has spread to involve over 30,000 villagers generating in excess of US$10 million in foreign exchange annually (Mshigeni 1998) and comprises approximately 3.3 % of the world production of carrageenan producing seaweeds.

Although both *K. alvarezii* and *E. denticulatum* are native to Tanzania, all of the farmed seaweed orginated from cuttings introduced from the Philippines. In Zanzibar the majority of the seaweed farmed is *E. denticulatum*, which has been shown in many villages to grow faster and with less problems of epiphytism than *K. alvarezii*. As mentioned above the world market for *E. denticulatum* is currently quite small and there are efforts being made by at least one carrageenan manufacturer which sources seaweeds from Zanzibar to encourage seaweed farmers to change to *K. alvarezii*.

The industry in Tanzania is well regulated. A small number of locally owned seaweed purchasing companies obtain permission from the government to develop seaweed farming in a specified area. These companies supply the villagers in that area with the education and materials necessary to undertake seaweed farming, provide storage for the dried seaweed (Figure 7), and press the seaweed into 100 kg bales for export (Figures 8 and 9). These companies also commit to buying the seaweed from the farmers at least twice per week. In return for the services offered by these companies, the farmers agree to only sell the resulting seaweed to the company doing the development in a given area. In this way the success of farming in a given area rests not only on the existing biophysical conditions but on the quality of the ongoing technical input provided by the seaweed purchasing company.

The off-bottom farming technique is the only method currently used in Tanzania (Figures 10, 11 and 12). However, in order facilitate a shift to growing *K. alvarezii* in locations where it does not grow well with the off-bottom technique, experiments are being carried out with a floating longline type method (Figure 13).

On Zanzibar's Unguja Island the distance between the shore and the reef is generally quite large (1-2 kms). Every second week there is a week of very low tides and it is during this time that the seaweed farms are tended. The farms are planted in areas of the lagoon in which there is a water depth of between 30-60 cm at the lowest tide. In this way the seaweed remains submerged but the farmers are able to sit in the water to tend to the farms at low tide (Figures 14 and 15). In Zanzibar the part of the lagoon which conforms to these water levels at low tide is generally a strip lying parallel to the beach some 100-400m wide, and in villages where seaweed is farmed, this strip is almost entirely covered by seaweed farms along the beach for several kilometers either side of the village (pers. obs.).

Figure 6. Monoline farming of *Eucheuma isiforme*, Savannes Bay, St. Lucia.

Figure 7. Dried seaweed, ready for baling, Paje, Zanzibar

Figure 8. Baling equipment, Zanzibar Agro Seaweed Company Ltd., Zanzibar

Figure 9. Baled seaweed, ready for shipment, Zanzibar Agro Seaweed Company Ltd., Zanzibar.

Figure 10. Monoline farming of *Eucheuma denticulatum*, Paje, Zanzibar.

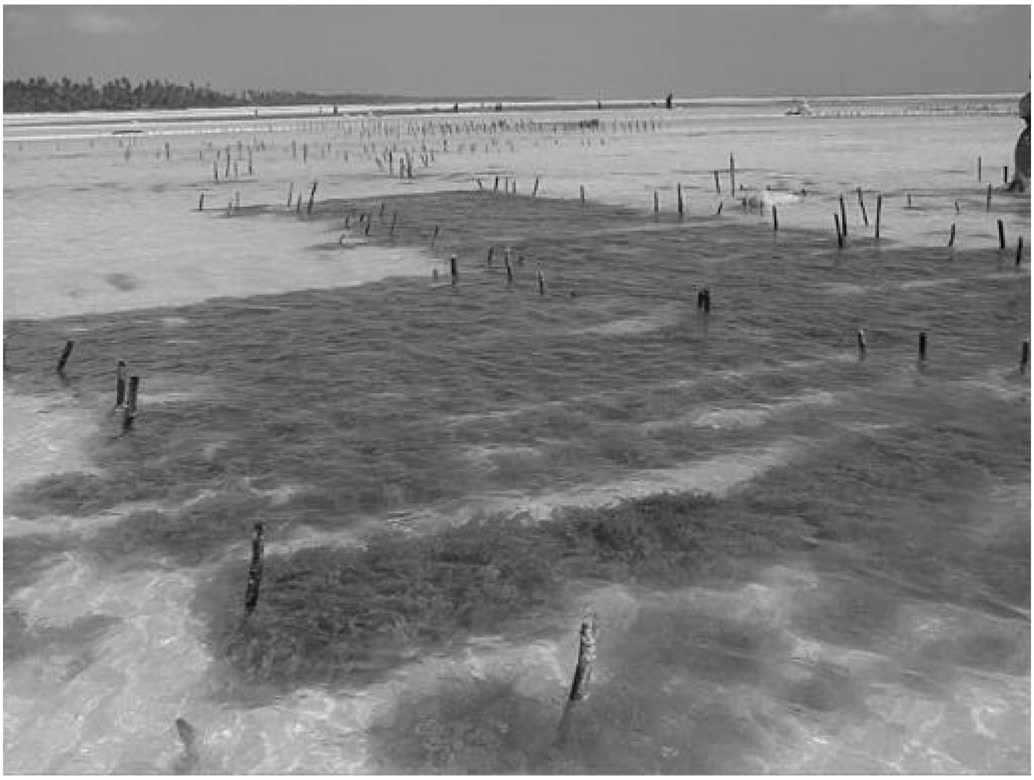


Figure 11. Monoline farming of *Eucheuma denticulatum*, Paje, Zanzibar.

Figure 12. Monoline farming of *Eucheuma denticulatum*, Paje, Zanzibar.

Figure 13. Monolines farming of *Kappaphycus alvarezii* with floats, Uguju Ukuu, Zanzibar.

Figure 14. Tying *Kappaphycus alvarezii* seedlings to monolines, Unguju Ukuu, Zanzibar.

Figure 15. Tying *Eucheuma denticulatum* seedlings to monolines, Paje, Zanzibar.

3.1.3 Philippines

In the Philippines *Caulerpa lentillifera*, *Eucheuma denticulatum*, *Kappaphycus alvarezii* and *K. striatum* are farmed. *C. lentillifera* farming is on quite a small scale compared to the other species. Approximately 5,600 tonnes fresh weight of *C. lentillifera* is cultivated each year compared with over 100,000 tonnes dry weight (in excess of 300,000 fresh weight) of the other algae.

C. lentillifera has been farmed since the 1950s in ponds created out of mangroves on Mactan Island (Figure 16 –page 54) and currently involves approximately 400 hectares in total (Trono 1998). The seaweed is harvested and sent fresh to Japan for food. There are currently no plans to expand this sector of farming.

The vast majority of the seaweed farmed in the Philippines is *Eucheuma denticulatum Kappaphycus alvarezii* and *K. striatum*. Farming of *Eucheuma*/*Kappaphycus* was pioneered in the late 1960's in a collaborative effort between researchers at the University of Hawaii and Marine Colloids Inc, a subsidiary of FMC Corporation, USA. Since the early 1970's the industry has grown considerably; more than 7000 hectares of shallow coastal waters are now devoted to farming these species (Trono 1996). The largest concentrations are in Sulu, Tawi Tawi, Palawan, Zamboanga el Norte and Bohol and it is estimated that up to 100,000 families are involved in farming these seaweeds (Mojica et al. 1997). The Philippines cultivates approximately 78 % of the worlds carrageenan producing seaweeds.

Unlike the situation in Tanzania, various methods are employed to cultivate *Eucheuma/Kappaphycus* in the Philippines. While most of it is farmed with the off bottom monoline method, net bags, longlines and rafts are also used (Rueben Barracca pers. comm.).

3.2 Impacts of species introductions

Anthropogenic introduction of species, whether by accident or design, is having a homogenising effect on the world's biota (Lodge 1993; Walker and Kendrick 1998), and marine algal species are no exception. Over 150 species of marine algae have been introduced or transferred throughout the world (Eldredge 1994). While many of these were transported by ships, nearly half have been transplanted with aquaculture experiments, some have been carried along with other introduced aquaculture species (e.g. oysters), and some transferred through canals or by un-known mechanisms (Russell 1987).

Many cultured seaweed species have been introduced around the globe in the hopes of creating more farming sites. Unfortunately, there is no evidence that any studies were undertaken prior to introduction. There is also little literature on the effects these introductions have had after the fact, on either community structure or function.

3.2.1 Accidental introductions of seaweeds

It may be difficult or impossible to predict the impact of a given species introduction, but sometimes aspects of a species biology which enable it to spread widely and (sometimes) adversely effect new habitat can be identified. While there have been few studies on the impact of algal species introduced for the purposes of aquaculture, these are numerous examples of the adverse effects of accidental introductions of seaweeds. This section 1) outlines the accidental introductions of *Sargassum muticum*, *Caulerpa taxifolia* and *Undaria pinnitifida*; 2) discusses the effects of these introductions, and 3) suggests some of the possible reasons underlying their success in spreading and colonising new locations.

3.2.1.1 *Sargassum muticum*

Originally just a minor component of the Japanese marine flora, *Sargassum muticum* is now a well established member of the marine community on the Atlantic coast of north America and the south-western coast of Europe.

Introduced to British Columbia with *Crassostrea gigas* (oysters) in the early 1940's, it subsequently spread along the Pacific coast of North America. By 1971 it was as far south as Baja California. Critchely et al. (1983) give a chronology of the spread of *S. muticum* to European waters. While it was first recorded in 1973 at Bembridge, Isle of Wight on the south coast of England, the site of infestation was most likely the French oyster beds at Normandy. Populations around the Isle of Wight continued to grow despite an attempted clearance program (Critchley et al. 1983). By 1981 it had spread north along both coasts of the English Channel, to Belgium and the Netherlands, and had established a population on the Mediterranean coast of France. By 1989 *S. muticum* had spread as far north as Sweden, Denmark and Norway (Rueness 1989), and south to the Atlantic coast of Spain and Portugal (Critchley et al. 1990).

Andrew and Viejo (1998) found that invasion of *S. muticum* in northern Spain was inhibited by the density of local species, observing the greatest recruitment in cleared patches. They concluded that lack of free space and differences in wave exposure played important roles in limiting the invasion of *S. muticum*. While this is a hopeful sign, there is evidence that once *S. muticum* does gain a foothold, it can effect recruitment of local species. This was the case in southern California, where, following a natural disappearance of the giant kelp *Macrocystis pyrifera* populations, *S. muticum* was found to inhibit the recruitment of *M. pyrifera* such that this species did not reinvade disturbed locations (Ambrose and Nelson 1982). The means of inhibition was most likely shading. There is intense competition between *S. muticum* and *M. pyrifera*, as they utilise the same resource and both form canopies. As kelp forests are regularly exposed to both natural and human-made disturbances (North and Pearse 1970; North 1971; Rosenthal et al. 1974), *S. muticum* may continue to have an impact on the distribution of *M. pyrifera* (Ambrose and Nelson 1982), and possibly on populations of other kelp species.

There are many features of *S. muticum* biology which make it an effective “weed” (Paula and Eston 1987, Andrew and Viejo 1998).

- It is monoecious
- It is highly fecund (produces massive numbers of gametes)
- It has a perennial holdfast which may regenerate shoots
- The fronds detach from the holdfast towards the end of its growth cycle and can float for long distances (unlike most seaweeds which would sink) due to air filled vesicles on the fronds. This floating material can not reattach but is fertile, so can inoculate new areas
- It has rapid growth - up to 4 cm/day (Nicholson et al. 1981)
- It is tolerant of a wide range of temperatures and salinities.

These features, with the added ability to quickly infect disturbed areas, make *S. muticum* an ideal weed and has ensured the spread of this species.

3.2.1.2 *Caulerpa taxifolia*

Caulerpa taxifolia, a species native to the Pacific (Garrigue 1995) was first found in 1984 in Mediterranean waters on the shore at Monaco, outside the Oceanographic Museum where it had been on display (Meinesz et al. 1993). Once established, it spread very rapidly, with an estimated cover of 30 ha in 1991, 430 ha in 1992 and 1300 ha by late 1993 (de Villele and Verlaque 1995). Since its introduction in Monaco it has spread along the Mediterranean coasts of Italy, France and Spain (Ferrer et al. 1997).

C. taxifolia represents a biological pollution which threatens the biodiversity of the marine ecosystem as it is altering the appearance of benthic communities in the western Mediterranean sea. Much research had been carried out on the adverse effects of *C. taxifolia* upon local species. It has been shown to have an apoptotic effect in the marine sponge *Geodia cydonium* (Schroeder et al. 1998), and cause regression in the seagrasses *Cystoseira barbata* (Ferrer et al. 1997), *Posidonia oceanica* (de Villele and Verlaque 1995) and *Cymodocea nodosa* (Ceccherelli and Cinelli 1998). It lowers productivity in the macroalgae *Gracilaria bursa-pastoris* (Ferrer et al.1997) and it has been shown to inhibit or delay the proliferation of several phytoplankton strains (Lemee et al. 1997). In addition, when compared to native conditions, there are lower fish densities on stands of *C. taxifolia* (Relini et al. 1998).

There are several biological factors which may be contributing to *C. taxifolia*'s successful invasion of the Mediterranean.

- It grows much larger and is more tolerant to changes in temperature and turbidity than in its native tropical seas (de Villele and Verlaque 1995)
- It is able to invade all kinds of substrata including mud, sand and rock (Ceccherelli and Cinelli 1998)
- Once established it persists throughout the year (Hill et al. 1998)
- It possesses a high capacity for vegetative spreading (de Villele and Verlaque 1995),
- There is weak pressure from grazers which is at least partially attributed to the presence of repulsive secondary metabolites (Lemee et al. 1997)
- Like other Caulerpales it is possibly able to uptake nutrients directly from the sediment through its rhizomes (Williams 1984)
- It is favored by high nutrient loads in the water (Ceccherelli and Cinelli 1997), assisting its grow in eutrophic waters.

3.2.1.3 *Undaria pinnatifida*

Native to Japan and Korea *Undaria pinnatifida* is farmed extensively in these countries and northern China. Found in the subtidal zone from 2-12 m in depth, *U. pinnatifida* is an annual seaweed with maximum growth in spring and early summer. In late summer the sporophylls, located on the stipe of the sporophyte, release spores and the sporophyte dies back. Between 100,000 and 1,000,000 spores are produced per gram of sporophyll per day (Sanderson and Barret 1989). The microscopic gameteophytes develop from the spores and lay dormant over winter. In spring, sexual reproduction takes place between gametes produced by the gametophyte, and the macroscopic stage begins again.

In 1971 *U. pinnatifida* was accidentally introduced to the Mediterranean coast of France (Perez et al. 1981), probably with imported oyster spat. In 1983 the French Research Institute for Exploitation of the Sea (IFREMER) transplanted *U. pinnatifida* to the Atlantic coast of France at Brittany. It has since spread to Spain and Italy (Floc'h et al.1996) and the south coast of England (Fletcher and Manfredi 1995). *U. pinnatifida* has also been introduced to New Zealand (Hay and Luckens 1987), Tasmania (Sanderson 1990), mainland Australia (Campbell and Burridge 1998) and Argentina (Casa and Piriz 1996).

In Europe, New Zealand and Argentina *U. pinnatifida* mainly occurs on artificial structures and Castric-Fey et al. (1993) claim that this alga is typified by its non-aggressive behaviour against other flora. This is borne out by the interaction of *U. pinnatifida* with the native *Saccorhiza polyschides*, another opportunistic kelp and *U. pinnatifida*'s main competition in Brittany. Floc'h et al. (1996) found that *U. pinnatifida* preferred to settle on artificial structures and that *S. polyschides* was dominant at the sites experimentally denuded.

Hay (1990) identified three features of *U. pinnatifida* that make it an effective weed.

- As with *S. muticum*, it quickly colonises disturbed substrates, or new substrates such as wharf piles and retaining walls
- There are *U. pinnatifida* propagules in the water column for most of the year (March to December in NZ) and in some locations (unlike in its native habitat) it may have two generations per year
- It has a propensity for colonising artificial structures, a trait selected for by Asian aquaculturists. In fact *U. pinnatifida* is readily spread from one harbour to another on the hulls of ships. In New Zealand sporophytes were shown to survive a four week oceanic voyage in this manner.

3.2.2 Species introduced for culture in the tropics

3.2.2.1 *Kappaphycus alvarezii*

There have been many cases where seaweed has been introduced to new locations for the purpose of farming and none more extensively than *Kappaphycus* and *Eucheuma*. Table 3 lists introductions made in the tropics and shows that algae of the genera *Kappaphycus* were introduced to 19 tropical countries versus *Eucheuma* to at least 13 tropical countries. Despite the rapid and widespread introduction of these algae there have only been a few studies that have investigated the effects of these introductions. The introductions to Hawaii have been the most studied and a number of adverse effects have been reported.

The results of these studies are far from conclusive. Lodge's (1993) conclusion that different locations will react differently to the same invader appears to be true. To date five studies have been carried out on the impacts of *Kappaphycus* introductions: Three in Hawaii, one in Fiji and one in Venezuela.

Russell (1983) investigated the ecology of *K. striatum* (previously *Eucheuma striatum*) two years after it was introduced to Coconut Is. (Moko o Loe Is.), Kanehoe Bay, Oahu, Hawaii in 1974. Russell found that from the reef flat (where it was first introduced) the algae drifted across to the reef edge where it established a small, non-self sustaining population that was maintained by the influx of more seaweed fragments. He concluded that the reef edge was merely acting as a sieve before the alga would move into deeper water where it could not survive. *K. striatum* in Hawaii does not produce spores, therefore reproduction was purely by fragmentation. Small fragments were capable of disseminating short distances and regenerating into full sized plants but Russell found that fragments did not cross deep channels. He found large numbers of fish (mostly juvenile scarids and acanthurids) grazing on the algae, and an increased invertebrate diversity (the section of the reef with algae had a higher index of diversity than the control site).He concluded that *K. striatum* did not compete with native algae, as it inhabited barren sand-covered grooves on the reef edge not inhabited by native algae. He did find one negative effect; when the algae was allowed to drift onto the reef edge, it covered a few small *Porites compresa* coral heads. After 74 days the corals were dead, which Russell attributed to shading. This was an isolated incident and Russell found it more common to find damaged algae than coral when the two came into contact.

While Russell found that the *K. striatum* had not spread to neighboring reefs in two years, after 22 years it was a different story. Rodgers and Cox (1999) determined that it had spread 5.7 km (throughout Kanehoe Bay) from 1974 to 1996. Abundances of this species were highest at sites with shallow depth and moderate water motion. They predicted that *Kappaphycus* will continue to expand its range at 260 m/yr. While Russell (1983) had predicted that physical barriers would stop the effective spread of *Kappaphycus*, Rodgers and Cox (1999) found that this has not been the case; in fact they suggest that this introduced alga has the ability to spread throughout Hawaii.

Woo (1999) further investigated the spread of *K. striatum* in Kanehoe Bay, examining the effects of herbivory upon its spread, seasonal patterns of growth, the effects upon local coral, and the minimum fragment size which could regenerate whole plants. She found that the ability of *K. striatum* to spread was enhanced by its capability to regenerate whole plants from fragments weighing as little as 0.05 g, and its ability to alter morphologically in response to environmental conditions, such as high wave energy and grazing pressure. While Russell (1983) only found one case of *K. striatum* overgrowing and killing coral, Woo (1999) found this to be a common ocurrence. Woo also found that grazing plays an important role in determining its distribution and limiting its spread. This last point is significant as a) Hawaii does not have rabbitfish (siganids), which have been cited as one of the main problem herbivores on *Kappaphycus* farms elsewhere, and b) there are few herbiovrous urchins in Kanehoe Bay (David Gulko pers. comm.). So over a 25 year period *Kappaphycus* has spread throughout Kanehoe Bay, and there may be nothing stopping it from spreading further in the Hawaiian islands, where it may slowy but steadily overgrow and kill live coral.

In Zanzibar there is anecdotal evidence that fragments of both *Kappaphycus alvarezii* and *Eucheuma denticulatum* are washed from farms to neighboring reefs, where free living populations seem to subsequently flourish. While there has been no attempt to assess the extent or impacts of these populations, locals assert that they are kept in check by fishermen who collect the seaweed to sell (Haruna Juma pers. comm.).

Two other studies have examined the spread of *K. alvarezii* from farms sites. Ask et al. (in press) monitored the movement of *K. alvarezii* for one year from test-farm sites in Ono-I-Lau Island, Fiji. In Venezuela Rincones (in press) monitored the movement of *K. alvarezii* from farms sites over 3 years. In Fiji no independent populations of *K. alvarezii* were found outside the farms while in Venezuela small populations were found but Rincones concluded that these could only be maintained by the influx of thallus fragments from the farms. Russell (1983) came to a similar conclusion two years after the introduction of *K. alvarezii* to Kanehoe Bay, Hawaii, but the later, longer term studies identified adverse effects and determined that independant populations did eventuate, so Russell’s conclusion is questionable.

It seems that, given enough time *Kappaphycus* used in commercial cultivation has the ability to spread from farm sites and establish independent populations. Both the extent of this spread and the effects upon local species may differ between locations, but following introduction, these effects should be determined before large scale farming is undertaken.

3.2.2.2 Quarantine procedures

As was evidenced by the accidental introduction of *Sargassum muticum* to the Pacific north west with oyster spat, one of the byproducts of species introductions can be the accidental introduction of non-target species; an introduced alga may have spores of other species attached to its thallus. This highlights the importance of using adequate quarantine procedures when introducing a new species.

Ask et al. (in press) report that of all the introductions of *Eucheuma*/*Kappaphycus* seaweed throughout the tropics, in only two cases were quarantine procedures undertaken. To combat this problem, Ask et al. (in press) outline quarantine procedures for the introduction of *K. alvarezii*. These procedures were created by taking into consideration the guidelines proposed by the FAO-Code of Conduct for Responsible Fisheries (1995) and the FAO-Technical Guidelines for Responsible Fisheries (1996).

The quarantine facility should:

- Be isolated from other aquaculture facilities
- Include structures that stop the entrance of other aquatic organisms
- Have an independant supply of good quality water
- Have a discharge system that allows for the treatment of the discharged water, not allowing organisms to escape

Plants should be maintained in this facility for at least two weeks. During that time the plants should be visually examined several times each week to check for the growth of microalgae or animals on the thalli. The water should be changed twice per week and the changed water treated or poured on the ground at least 500 m from the coastline to ensure that no aquatic organisms escape into the local waterways. There should also be a program in place to monitor the area after introduction.

Table 3 Introduction of algal species for the purposes of aquaculture.

Country	**Location**	**Species**	**Date of introduction**	**Source**	**Commercial farming**	**Reference**
Antigua		*Eucheuma isiforme*	1997	Belize	Just beginning	Allan Smith pers comm.
Barbados		*E. isiforme*	1997	Belize	Just beginning	Allan Smith pers comm.
Brazil		*Kappaphycus alvarezii*	1995	Philippines	No	De Paula et al. 1998
Cook Islands	Aitutaki	*K. alvarezii*	late 1980s	Fiji	No	Eldredge 1994
Cuba		*K. striatum* *K. alvarezii*	1991	Philippines	Unknown	Smith 1998
Djibouti		*Eucheuma denticulatum*	1973	Singapore	No	Braud and Perez 1978
Fiji	Suva and Mana Island	*K. striatum*	1976	Philippines	No	Eldredge 1994
	Telau Island, Bau, east of Suva	*K. striatum*	1976	Hawaii	No	Eldredge 1994
	four sites north of Rakiraki	*K. alvarezii*	1984	Tonga	No	Eldredge 1994
Hawaii	Honolulu Harbor, Kaneohe Bay, etc.	*E. denticulatum*	1970 - 1976	Philippines	No	Eldredge 1994
	Kaneohe Bay	*Gracilaria eucheumoides*	rnid-1970s	Philippines	No	Eldredge 1994
	Kaneohe Bay and Kahuku	*G. tikvahiae*	rnid-1970s	Florida	No	Eldredge 1994
	Honolulu Harbor, Kaneohe Bay, etc	*K. striatum*	1970 – 1976	Pohnpei and Philippines	No	Eldredge 1994
	Waikiki and Kaneohe Bay	*Gracilaria epihippisora* *G. salicornia*	1971 and 1978	Hilo, Hawaii	No	Eldredge 1994
	Honolulu Harbor	*Gracilaria sp.*	1971	Philippines	No	Eldredge 1994
	Makapuu and Keahole Point	*Macrocystis pyrifera*	1972 and 1980s	California	No	Eldredge 1994
	Kaneohe Bay	*Hypnea musciformis*	1974	Florida	No	Eldredge 1994
	Oahu	*Porphyra sp*	???	Japan	No	Eldredge 1994
India	Saurashtra region (west coast)	*K. alvarezii*	1989	Japan	No	Mairh et al. 1995
Indonesia		*E. denticulatum* *K. cottonii*	1984	Philppines	Yes	Adnan and Porse 1987
Jamaica		*E. isiforme*	1997	Belize	Just beginning	Allan Smith pers comm.

Table 3 Cont..

Country	Location	Species	Date of introduction	Source	Commercial farming	Reference
Kenya		*K. alvarezii*	1996		No	Ask et al.in press
Kiribati	Fanning Island	*K. alvarezii* *E. denticulatum*	1977	Hawaii	Yes	Eldredge 1994
	Christmas Island (Kiritimati)	*K. cottonii* *E. denticulatum*	1977	Philippines	Yes	Eldredge 1994
Madagascar		*K. alvarezii*	1998	Tanzania	Just beginning	Ask et al.in press
Malaysia		*K. alvarezii*	1978	Philippines	Yes	Doty 1980
Maldives		*Kappaphycus alvarezii*	1986	Philippines	No	de Reviers 1989
Marshall Is.	Majuro lagoon Mili and Lildep	*E. denticulatum* *K. alvarezii*	1990 1990	Pohnpei Majuro	No No	Eldredge 1994 Eldredge 1994
Micronesia	Pohnpei Kosrae	*E. denticulatum* *K. alvarezii*		Hawaii	No	Eldredge 1994
Solomon Islands	Vonavona, Munda, Gizo, and Ontong Java	*K. alvarezii*	1987	Fiji	No	Eldredge 1994
St. Lucia		*E. isiforme*	1997	Belize	Yes	Allan Smith pers comm.
Tanzania		*E. denticulatum* *K. alvarezii*	1989	Philippines	Yes	Mshigeni 1998
Tonga	Vava'u Vava'u (reintroduced)	*K. alvarezii*	1982 1989	Tarawa	No	Eldredge 1994
Tuvalu		*K. alvarezii*	1977	Kiribati	No	Eldredge 1994
Venezuela		*K. alvarezii* *E. denticulatum*	1996	Philippines	Yes	Rincones and Rubio 1999
Vietnam		*K. alvarezii*	1993	Philippines	No	Ohno et al.1996
Western Samoa	Upolo	*K. alvarezii* *E. denticulatum*	1975		No	Eldredge 1994

3.3 Impacts of farming activities

3.3.1 Location choice

The site chosen for seaweed farming can effect the environmental impact of the farm. Generally farmers have been encouraged to place farms over sandy areas with little or no underlying coral and/or seagrasses. For the off bottom farming technique this advice is usually followed as farmers are unlikely to undertake clearance of a site if a location which needs a minimum of clearance is available. In addition, herbivorous fishes are found around coral reefs more than on sandy reef flats and as they can virtually destroy seaweed farms, it makes good sense to farm away from these agents of farm destruction. However, when long lines or rafts of monolines are employed, the farmers have greater freedom in choosing farm sites as they are not limited by the substrate. In these cases the anchoring lines may be tied to live coral resulting in damage or death of the coral (Rueben Barraca pers. comm.) and the seaweed could be located directly above live coral. Shading has been found to have adverse effects on corals (Stimson 1985), but the extent to which shading from farmed seaweed effects underlying corals has not been investigated.

3.3.2 Site clearance

Compared with other forms of marine agronomy such as shrimp farming, seaweed farming requires very little in the way of habitat modification. However, in various guidelines to prospective farmers it has been suggested that other organisms (seaweeds, seagrasses, urchins) be removed from the area before laying out the farm. While this information has been modified over the years and now suggests cutting long seagrasses rather than removing them, there is no doubt that this sort of activity has had an effect on the environment. Hindley (1999) reports that only 8 out of 22 farmers interviewed from various villages in Bohol, Philippines admitted to either cutting or completely removing seagrasses from their farms.

The removal of seagrasses could have adverse effects on the local environment. The importance of seagrasses as sites of nitrogen fixation and as nurseries for juvenile invertebrates has been well established in the literature (Johnson and Johnson 1995) and the effect of removing seagrasses prior to farming upon the productivity of the farmed seaweed has also been examined (Mtolera in press, see section 3.3.4.4 for further discussion).

As well as clearance of urchins and starfish prior to farming there is also ongoing clearance of these organisms after farming has begun. Hindley (1999) reports that out of 29 farmers interviewed from the Bohol region in the Philippines 80% admitted to removing urchins and starfish while tending their farms. They reportedly throw these organisms back into the water outside their farms, but whether the organisms are alive or dead when put back into the water was not investigated.

Gomez et al. (1983) found that the urchins *Diadema setosum* and *Tripneustes gratilla* were the most common herbivores on farms in the Philippines. They experimented with the application of a pesticide in farms and found that quicklime (CaO) applied at slack tide at 0.25 kg/m^2 resulted in death of all urchins in the immediate area. The collateral damage upon other invertebrates was not investigated.

3.3.3 Increases in habitat area and food supply

In the tropics most native seaweeds tend to be more widely dispersed and form stands that are less dense that those in temperate waters (Dawes 1987). Dawes suggests that this dispersal may be as a result of, or and adaptation to, grazing pressure. He also suggests that the abundance of epiphytic life in the tropics indicates substrate limitation. The creation of seaweed farms can thus provide a three dimensional habitat for epiphytic organisms, as well as fishes and invertebrates. In fact, epiphytism is one of the main problems of seaweed farming, and lines and seaweed must be cleared of epiphytes on a regular basis to ensure good growth of the farmed species (Ask 1999; Barracca 1999).

A number of other organisms use seaweed farms either as substrate or shelter. In Kanehoe Bay, Hawaii Russell (1983) recorded a higher biodiversity index on *K. alvarezii* stands than those from surrounding areas. In Coche Island, Venezuela *K. alvarezii* was found to shelter 22 species of (juvenile) fishes and 35 invertebrate species, including larval stages of crustacean, mollusks, solitary and colonial ascidians, sponges, sea urchins and holothurians (Rincones in press). In St. Lucia there are studies underway to investigate the numbers of lobster larvae (generally *Panularus argus*) which have been observed settling onto seaweed in quite high numbers. These larvae measure 2-3 cm by the time the seaweed is harvested at which time the farmers pick them off and release them (Allan Smith pers. comm.). From these examples it is clear that *K. alvarezii* is providing habitat for marine organisms. What is missing from these studies is what happens to these organisms once the seaweed is harvested. While there may be an increase in invertebrate diversity on the farms, if all of these invertebrates are then harvested along with the seaweed, the increase to the local community at large may not eventuate.

In addition to an increase in habitat, it has been suggested that seaweed farms may increase fish stocks, either directly by increasing food supply for herbivorous fishes, or indirectly by adding increased herbivore biomass to the food web. In tropical environments, an increase in algal cover can increase herbivorous fishes numbers (Carpenter 1990b; Robertson 1991). This was clearly demonstrated in the Caribbean when a massive increase in algal cover followed the mass mortalities of the sea urchin *Diadema* (Lessios 1988; Carpenter 1990; Hughes et al. 1987). While it may be assumed that a similar increase in herbivorous fish numbers would result from an increase in algal cover due to farms, no research has yet been carried out to confirm this.

If seaweed farms do increase fish stocks there may be downstream effects upon other species. Many herbivorous fishes have omnivorous juvenile stages, so increased numbers of these species may place increased feeding pressure on invertebrates (see section 3.3.4.2 below). In addition, higher numbers of adult herbivorous fishes could increase bioerosion of coral reefs (Sammarco et al. 1986). However, any negative effects of increased herbivorous fishes are likely to be mitigated by the intense fishing pressure from villagers in the areas where seaweed is farmed.

3.3.4 Benthic environment

3.3.4.1 Sedimentation

Farmed seaweeds in Chile have been shown to alter the bottom composition by acting as sediment traps (Buschman et al. 1996). In Zanzibar it has been noticed that the beach structure in some of the villages where farming takes place has changed since the inception of farming; there has been an increase in the width of intertidal flats as a result of increased sand accretion (Mtolera pers. comm.). Unfortunately, in the absence of empirical research, it is not possible to assign a cause to this change. It could have been caused by the seaweed farms, but could also be either a natural change or caused by factors other than the seaweed farms.

Impact studies on Zanzibar are made difficult by the inability to find appropriate controls. As noted previously, the farms generally form a contiguous strip (100 – 300 m wide) at a particular level along the beach, so reference sites for impact studies must either be at different beaches, or at the same beach but at a different height from the farm site. Msuya et al. (1997) found differences in the sediment composition between farm and reference sites by visually inspecting the substrate and “feeling the substrate between fingers”. They found more sand under farms and more mud in reference sites. However, it is not clear from that study whether this was a result of farming or due to conditions influencing the selection of farming sites. Olafsson et al.

(1995) found a significant difference in medium grain size between “away” reference sites (50 m from farm) and farm sites. There was also a tendency for the samples from the “close” sites (5 m from farm) to exhibit a higher percentage of smaller particles ($< 63\ \mu m$) than the farm sites. This was not statistically significant but the authors suggest this was due to averaging the samples and a low number of replicates. While it is possible that the difference in medium grain size simply reflects a location effect, it does seem that there was a trend away from fine sediments under the farms.

3.3.4.2 Meiofauna

Meiofauna has been found to serve as a better indicator of environmental perturbation than larger macrofauna (Hicks 1991). Olafsson et al. (1995) examined the variation in population density of the major meiofaunal taxa and community composition of free living nematodes in both farm and reference sites. They found that the benthos under *Eucheuma denticulatum* farms in Zanzibar exhibited altered meiofaunal assemblage structures and lower density of meiofauna, but no difference in overall diversity. The authors experimentally ruled out toxic substances from the algae as a causal factor and suggest that the differences could be due to a) increased predation due to juvenile fish sheltering under farms, b) mechanical alteration of the sediment from seaweeds brushing against the substratum, or c) the difference in abundance of two species of nematode (found to be most abundant in the farms sites) could be due to an affinity to the algae.

3.3.4.3 Macro benthic organisms

Msuya et al. (1997) found that farms had a negative effect on several organisms examined examined (seagrasses, urchins, ophiroides, gastropods and bivalves), except for non-farmed seaweeds and tubeworms. Hindely (1999) compared farm and reference sites and found fewer starfish, sea cucumbers and sea urchins in farmed sites, but observed no effect on the height or density of the seagrasses *Thalassia hemprichii*, *Cymodacea rotundata*, *Enhalus acoroides* or *Halophila ovalis*. As mentioned above, there is evidence that farmers remove urchins from their farms. Certainly the removal of these herbivores and the consequent lack of feeding pressure on seaweeds could account for the increase in un-farmed seaweeds within the farm sites. The lower volume of seagrasses in farmed sites found by Msuya et al. (1997) could be a result of: trampling, active removal by farmers, or shading by the farmed seaweeds. Alternatively, there may have been a lack of seagrasses in the first place, influencing farmers to select these sites for seaweed farming.

3.3.4.4 Microbial processes and productivity

Johnstone and Olafsson (1995) found that *Eucheuma denticulatum* farms have a significant effect with lower total nitrogen and bacterial production and higher benthic ammonium fluxes in farm site sediments than in reference site sediments. The authors suggest that these differences could be due to the seaweed brushing the surface of the substrate and thus preventing formation of micro-algal assemblages, which are widespread in sediments outside of farms.

The productivity of the microalgae that live on and in the upper 5 cm of the sediment is substantial (Hatcher 1988). The sediments in sandy reef flat areas could contribute significantly to reef biogeochemistry as carbon sinks, because they are sites of organic matter storage and bacterial activity (Boucher et al. 1998). Therefore disturbances to the sediment and the associated microalgae reduction could have downstream effects on the reef community, and may be at least partially responsible for the observed difference in meiofaunal assemblages as microalgae are a source of food for many meiofaunal taxa (Hatcher 1988).

In addition to seaweed farms possibly lowering primary productivity by inhibiting the growth of microalgal mats, the productivity of the seaweed in farms is removed through harvesting and not cycled through the reef energy web. So while primary productivity per m^2 is probably increased as a result of farmed seaweed, this productivity does not contribute to the reef energy web. Of course there are losses to the seaweed grown on the farms, through both breakage and herbivory. Ruben Barracca (pers. comm.) estimates that between 30-50% of the farmed seaweed is lost before harvest, either by drifting away after breakage, or to herbivores. Any of this “lost” seaweed could be decomposed or digested and add to the nutrient pool of the local environment and so these losses would contribute to the carbon budget of the reef. In this way the decrease in benthic microalgal primary production could be offset by the losses of seaweed from the farms. Unfortunately there is no empirical evidence one way or another.

While it has been suggested that a positive benefit of seaweed farms is as a nutrient sink, this may actually have negative effects in some reef environments. In eutrophic waters this nitrogen removal would have positive repercussions, but coral reef systems, as with most marine environments, are generally nitrogen limited (Carpenter and Capone 1983). Consequently the nitrogen being removed from the area by the seaweed is not available to other organisms on the reef. The effects of this have not been investigated, but it is possible that some species are adversely effected by this nitrogen removal. As noted above, not all of the seaweed is harvested and so some of the nitrogen would make it back into the food web of the reef through losses of seaweed from the farms.

There is anecdotal evidence that seaweed farms deplete nutrients from the surrounding environment. Farmers in various parts of the Philippines have noticed that areas become non productive after being farmed for a period of 4-5 years (Monette Flores pers. comm.). If the area is left in “fallow” for a year or two, it again becomes productive. This is particularly noticable in Tawi Tawi, where farmers were encouraged to remove all seagrasses from sites before commencing farming operations (Monette Flores pers. comm.). As seagrasses fix nitrogen, it is possible that the removal of these plants decreases the available nitrogen of a given area, which could lead to nitrogen depletion following intensive seaweed farming. No research has been conducted to investigate this phenomenon, so the impacts, if any, on other organisms in the “non-productive” area is not known.

The effects of seagrass removal on seaweed productivity have been investigated in Zanzibar (Mtolera in press). It was found that while seaweed productivity increased immediately following seagrass removal, over a 4 year period seaweed productivity decreased. This evidence certainly seems to suggest that as nutrient sinks seaweed farms may not be having as much of a positive effect as previously assumed. Given that a lot of seaweed is farmed in areas of low population and low industrialisation, there would be less nitrogenous waste in the seawater and consequently the seaweed farm acting as a nutrient sink may have detrimental rather than positive effects on the local environment.

Coral reefs communities have stocks of nutrients (such as nitrogen) which are kept in pools of living biomass, detritus and sediments. As a consequence they do not generally suffer from nutrient limitation, even when flushed with depleted, oligotrophic (nutrient poor) oceanic waters (Sorokin 1993). However, nitrogen taken up by seaweeds which are then removed is not available to “recharge” these pools. Over long periods of time this nitrogen loss may cause negative downstream effects on the reef community.

3.3.5 Refuse from farms

The main refuse resulting from seaweed farms in the tropics is the plastic “straws” or “tie-ties” used to tie the seaweed to the monolines as well as styrofoam pieces and plastic bottles used as floats. This refuse can be found strewn above the high water mark in many of the seaweed farming villages in Zanzibar (pers. obs.). In the Philippines the situation is worse, as some farmers have abandoned reusable monolines in favor of the plastic “straw” material. The plastic straw is used as both monoline and to tie the seaweed seedlings (Barraca pers. comm.). Using this technique both the monoline and the ties are disposed of after each harvest, adding to the tonnes of this material littering the shoreline and seafloor around seaweed farms.

In the Philippines, farming has also been introduced to areas where people were not living. The farmers constructed buildings for farm operations, as well as drying structures on the beach. In these areas, farmers produce both human and farming waste.

3.3.6 Farming structures

In some areas of the Philippines there is a lack of space for structures on land, so the community has built seaweed drying platforms on stilts out on the reef. This is common in northern Bohol and southern Leyte (Monette Flores pers. comm.) and has negative impacts as parts of the reef are destroyed or damaged in the process of building the platforms.

In Zanzibar the seaweed farmers simply lay the harvested seaweed out on the ground to dry (Figures 17 and 18). As this results in sand and other debris collecting in the seaweed as it dries, the carrageenan production companies prefer that seaweed be dried off the ground on specially built structures (Figure 19).

In the Philippines and elsewhere, mangrove stakes are prefered by farmers to stake out the monolines, because they do not rot as quickly as other woods. This has caused serious depletion of mangroves in some areas, and this practice is discouraged by all agencies involved with seaweed farming. In Tanzania, serious fines have been imposed for cutting mangroves. These regulations are actively enforced which has largely stopped the cutting of mangroves for seaweed farming stakes (Haruna Juma pers. comm.).

Figure 16. Ponds for farming *Caulerpa lentillifera*, Mactan Is., Philippines.

Figure 17. Laying out *Eucheuma denticulatum* on the ground to dry, Unguju Ukuu, Zanzibar.

Figure 18. Laying out *Eucheuma denticulatum* on the ground to dry, Unguju Ukuu, Zanzibar

Figure 19. Purpose built structure for drying seaweed, Paje, Zanzibar.

3.4 Impacts of associated activities – carrageenan extraction

The production of carrageenan from *Eucheuma/ Kappaphycus* is carried out in several locations around the world. While the largest carrageenan manufacturers (FMC and Copenhagen Pectin) have plants in the US and Europe respectively, there are also several plants of various sizes in the Philippines and Indonesia (McHugh 1996).

The largest plant outside of the US or Europe is the Shemberg plant in Mandaue City, Cebu, Philippines. This plant creates 2361 m^3 waste water per day with a pH of 12-13 and a biochemical oxygen demand (BOD) load of 1539 kg. Given this high pH and BOD, it is important that the effluent be properly treated before discharge into the local marine environment. In the Philippines the Department of Environment and Natural Resources (DENR) is responsible for enforcing the legislation regarding discharge of industrial effluent. Both the FMC and Shemberg plants were visited in Cebu and both state that they have waste water treatment facilities but admit that they are not operating at levels which ensure that the standards of effluent required by the DENR are met. Other plants in the Philippines do nothing to treat their waste water finding it cheaper to pay the fines imposed by DENR rather than pay for an expensive water treatment plant.

3.5 Summary

Effects of introducted species

Introducing seaweed to a new location can have adverse effects on the local flora and fauna. Many seaweed species have been introduced in the tropics but none more so than *Kappaphycus*, the genus that underpins the world industry for kappa carrageenan. So far the only location to report adverse effects resulting from the introduction of this genera is Hawaii. However, it is significant that Hawaii is the location where the most research on the impacts of introducing *Kappaphycus* has been carried out. It is also significant that it has taken some 25 years for adverse effects to be reported.

In the literature on alien introductions, the species receiving the most attention are the ones that invade and cause problems very quickly. Following introduction, *Sargassum muticum*, *Caulerpa taxifolia* and *Undaria pinnitifida* all invade new areas quickly and as a consequence there has been much research carried out on the effects of these invasions. Slow spreading seaweeds such as *Kappaphycus* do not seem to receive the same amount of research attention as do faster spreading species. There is a danger in this as there is no *a priori* reason to assume that just because a species is slow spreading, it will have no adverse effects on local organisms. Kappaphycus is a case in point; although it has taken 22 years, the species has spread over 5.7 kms of Hawaii and has been shown to have killed an endemic coral.

Some suggest that this introduced seaweed in Hawaii is only a problem because unlike in other countries, individual plants are not rapidly collected and sold the way they would be in seaweed farming countries and areas. However, in Tanzania seaweed escapes from farms and sets up independent populations even where it is harvested. Perhaps no adverse effects have been reported as a result of these populations in Zanzibar simply because nobody has looked yet.

Impact studies are generally carried out over a relatively short period of time (generally just a few years). This means that species introductions that take decades or longer to pose a threat to local species may go unnoticed.

Other Effects of farming activities

The environmental impacts of seaweed farming in the tropics can be placed into three categories.

1) Impacts proven by empirical research (in some but not all areas)

- lower numbers of macro benthic organisms (urchins, starfish, sea cucumbers) under farms
- higher density of non-farmed seaweeds and tubeworms
- changes in the meiofanual assemblages and microbial processes in the benthic sediments under farms
- a higher biodiversity index on farmed seaweed compared to surrounding areas

2) Impacts with no empirical support, but that are self evident

- plastic refuse from farms littering the environment both in and out of the water
- tying anchoring lines for longlines or rafts to coral heads damaging or killing coral

3) Impacts that can be (or have been) assumed, but have no research with which to support or reject them.

- shading
- drying structures
- waste water disposal
- changes in primary production of whole reef area – not likely to be positive
- changes in nitrogen regime
- sedimentation

- increase in fish numbers
- destructive activities replaced by farming
- farmers gaining sense of “stewardship” over the coastal area

Refuse from farms, anchor lines tied to coral, shading of corals, drying structures built on the reefs and improper waste water disposal are all negative impacts. Increases in fish stocks, destructive activities being replaced by farming and farmers gaining a sense of stewardship in coastal areas would all constitute positive impacts. However, for some of the impacts it is not so clear.

The first category of impacts, those shown by research, indicate that seaweed farming changes the environment in and around farms. It seems that there are three main causes of this alteration: 1) The farmers remove the macro benthic organisms and cut or remove seagrasses; this alters the community structure, the lower number of herbivores allows more non farmed seaweeds to grow and the lower density of seagrasses seems to encourage tubeworms. 2) The seaweed abrades the surface of the substrate, altering the sediment structure and eliminating the microalgal mats that are prevalent coral reef lagoons; this effects the community structure of the mieobenthic organisms under the farms. 3) The farm provides an increase in habitat for invertebrates and juvenile fishes. The increase in fishes also contribute to the change in community structure of the mieobenthic organisms under the farms. It is not clear whether this change in community structure as a result of farms can be categorised as either positive or negative as some organisms increase in abundance while others decrease.

The other impacts which could have either positive or negative effects are changes in primary production caused by farms and the farms acting as nitrogen sinks. Whether these are positive or negative would depend on a) the normal primary production from the area covered by the farm and how much of the seaweed was lost to herbivores and/or breakage and b) whether the water was characterised by pollution or nitrogen limitation.

3.6 Recommendations

If Conservation International is to support or initiate seaweed farming projects in the tropics, there three main areas where they can act to minmise the threats to coral reef biodiversity.

3.6.1 Education of farmers

Criteria for project entry and participation should include target beneficiaries' involvement in sound coastal management activities. CI should make a commitment to educating prospective seaweed farmers about the possible environmental impacts of farming activities. Specifically, farmers should be encouraged to take into account the following guidelines to mitigate the impact of farming activities.

- Farms should be located over sandy area and not over live coral
- Anchor lines should not be tied to live coral
- Seagrasses should not be removed from the area to be farmed as they will actually provide nutrients to the farms
- If herbivores are to be removed, they should not be killed, but simply shifted outside the farm boundaries
- Plastic waste from the farms should be disposed of in an appropriate manner

3.6.2 Quarantine measures

As the longterm impacts of *Kappaphycus* introductions are largely unstudied, CI discourage introduction of this seaweed to new locations. If introduction is going to take place anyway, CI should ensure that the appropriate quarantine measures are undertaken and should ensure that funding is available for rigorous ongoing monitoring of the immediate environment to look for independent populations of the seaweed and the effects that these populations might have on local flora and/or fauna. In addition, contingency plans (and funds) should be put into place to deal with problems if they arise as a result of the introductions.

3.6.3 Need for comprehensive impact study

Finally, if CI is to promote seaweed farming it should also make a commitment to initiating and/or supporting comprehensive, ongoing research into the environmental impacts of seaweed farming.

In sharp contrast to the uncertainty regarding the environmental impact of seaweed farming is the certainty that seaweed farming will increase in the tropics, not only within current locations but also to new areas and countries. There is enough evidence of negative environmental impacts, as well as the tenets of the Precautionary Principle, to argue strongly for undertaking a comprehensive impact study of the farming of *Eucheuma* and *Kappaphycus*. These two species are farmed in the tropics where highly biodiverse and threatened coastal marine ecosystems - such as coral reefs - occur. As shown above, the impact of farming operations can be direct or indirect, and needs to be studied to ensure an environmental catastrophe such as the invasion of the Mediterranean by *Caulerpa taxifolia*, is avoided.

This study should be undertaken in more than one location in the tropics to enable generalisation of the results. It should include an ongoing monitoring program of the local flora and fauna associated with farming areas. Historically there have been many international and national agencies that have funded the development of seaweed farming in the tropics. Many of these agencies have a commitment to funding environmentally sustainable activities, and yet there has as yet been no commitment to funding research on the impacts of the seaweed farming that they have helped to develop. While seaweed farming has always been thought of as a fairly benign form of agronomy, the long time taken for adverse effects of *Kappaphycus* introduction into Hawaii and the apparent nutrient depletion in heavily farmed areas may indicate that this is not the case and that monitoring the long term impacts of seaweed farming would be prudent.

3.7 Conclusion

The cultivation of seaweed worldwide is a growing industry. In the tropics the vast majority of farmed seaweeds are either *Eucheuma* and *Kappaphycus* which are both used in the production of carrageenan. The current supply of this carrageenan is not enough to meet the growing demand and so the farming of these genera, in particular *Kappaphycus,* is likely to undergo extensive expansion both within countries where it is currently farmed, as well as into new locations.

Given the extensive scope of existing farming operations, surprising little is known about the impacts of tropical seaweed farming on the environment. From published studies it is clear that there are changes to the organismal community structure in and under farmed sites, but the effects of these changes on the wider coral reef community have not been investigated.

Impacts on biodiversity are ambiguous at best; the seaweed thallus within farms has a higher diversity index when compared with surrounding areas, but many of these organisms are likely to be harvested along with the seaweed, so the net effect of this increased diversity is uncertain. Introduced seaweeds may have a negative impact on biodiversity if they are able overgrow and kill organisms as is the case for some corals in Hawaii.

There are also some assumed or possible effects of farms that are in need of empirical examination (e.g. the effects of nitrogen uptake by farms, or farming replacing destructive activities) before they can be proved as either positive or negative impacts.

It is unfortunate that a comprehensive, controlled study of the impacts of seaweed farming has yet to be carried out and it is hoped that one of the outcomes of this report is to generate interest in undertaking such a study.

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6. Appendices

6.1 Glossary

Carpospores	Alpha spore. Spore of rhodophytes, typically dipliod, released from a carposporangium
Commensalism	Living in close relationship with another organism but not parasitic
Conchocelis	Microscopic, branched, filamentous, endolithic, sporophytic phase of conchospores
Conjugate	Fusion of two one celled organisms for reproduction where fertilisation occurs
Dioecious	Organisms that have male and female reproductive structures on different individual members of the species
Diplontic	A life cycle in which individual cells are diploid throughout their life history
Eutrophic	Waters rich in dissolved nutrients
Gamete	Mature haploid reproductive cell capable of fusion with another gamete, to form a diploid nucleus
Gametophyte	Life cycle stage in many plants and algae, individual plant or alga composed of haploid cells which produce gametes
Germinate	To begin to grow or develop
Monoecious	Referring to organisms that have both male and female reproductive structures on the same individual
Phenotype	A character or individual defined by its appearance and not by its genetic makeup
Phycocolloids	Complex polysaccharides produced by algae (e.g. agar, alginates and carrageenan)
Protoplast	Actively metabolising membrane-bound part of a cell as distinct from the cell wall
Ramuli	Branches
Spore	Type of propagule, small or microscopic agent of reproduction
Sporophyll	Structure which produces reproductive cells
Sporophyte	Life cycle stage in plants and algae, individual plant or alga composed of diploid cells. This generation terminates in meiosis to produce spores

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