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Seaweeds and their Role in Globally Changing Environments



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A REVIEW OF *KAPPAPHYCUS* FARMING: PROSPECTS AND CONSTRAINTS

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1. Introduction

Global warming is of increasing concern worldwide. The question of how to mitigate the CO_2 released into the atmosphere is the most topical issue, and sustainable solutions are constantly being sought. Aquaculture has been proposed as one method for the sequestration or immobilization of CO_2 through filtration or mechanical/chemical processes for long-term storage (Carlsson et al., 2007). However, the development of new sustainable technologies are but in their infancy, as the aquaculture sector moves to becoming more efficient and sustainable.

In the above context, Chopin (2008) suggested that if limitations to nutrient emission are to be put in place, extractive species such as seaweeds could be considered as suitable for nutrient credits (e.g. for the extraction of nitrogen, phosphorus, etc.), in a similar system to that of carbon credits, which are becoming increasingly acceptable to be traded in the global economy.

Kappaphycus alvarezii, commercially recognized as "cottoni," is considered the main source of *kappa* carrageenan, while *Eucheuma denticulatum*, known as "spinosum," is the main source of *iota* carrageenan. Both species are responsible for approximately 88% of raw material processed for carrageenan production, yielding about 120,000 dry tons year^{-1} mainly from the Philippines, Indonesia, and Tanzania (Zanzibar) (McHugh, 2003). Considered as two of the most commercially successful species, they could be potential candidates for carbon and nutrient credits, if research and technology are developed, since the farms have the potential to

increase the area occupied for seaweed cultivation, thus improving the carbon dioxide sequestration and acting as a nutrient sink when cocultivated with other organisms, thereby improving water quality to some extent.

A review of *Kappaphycus* (broadly including *Eucheuma*) farming is presented, including the current possibilities and challenges with the goal of contributing to sustainable mariculture management practices.

2. Worldwide Trends of *Kappaphycus* Production

The world's geographical area for the *Kappaphycus* farming lies within ±10° latitude (Fig. 1), notably from the Southeast Asian countries extending to East Africa and Brazil. However, the Southeast Asian region, primarily the Brunei–Indonesia–Malaysia–Philippines (East Association of Southeast Asian Nations (ASEAN) Growth Area – BIMP-EAGA – integrated countries) has by far the greatest potential for expanded tropical seaweed cultivation, consisting 60% of the sites in the world. In particular, Indonesia, Malaysia, and the Philippines provide sheltered areas that are favorable for cultivation (IFC, 2003).

The current and estimated increase in *Kappaphycus* production in the BIMP-EAGA region is shown in Fig. 2. Although the production of the southern Philippines and Sabah combined is about 100,000 t dry weight year^{-1}, with the potential to increase by approximately 50%, the shared projected capacity of West, Central, and East Indonesia is huge (approximately 450,000 t) (IFC, 2003). The high potential of Indonesia can be attributed to its extensive coastline, which fits 100% within the tenth parallel latitude, where tropical seaweeds grow abundantly and robustly and, most importantly, where typhoons seldom occur. On the other hand, the single largest area of *Kappaphycus* production in the Philippines (Sitangkai, Tawi-Tawi) offers considerable potential for expansion since it has 60,000 ha available for mariculture purposes, even though only an estimated 10,000 ha are presently used for cultivating *Kappaphycus* (PDAP, 2007). Sabah (Malaysia) had a total production of 50,000 t fresh weight (around 6,250 t dry weight), which was grown on 1,000 ha (= 50 t ha^{-1} year^{-1}) in 2005 (Neish, 2008). Projection for this area aims an expansion to 12,000 ha in 2010, with a target production of 250,000 t fresh weight.

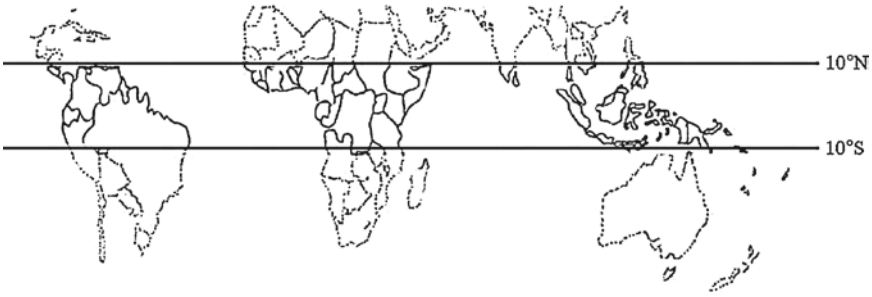


Figure 1. The world's potential geographical area for the *Kappaphycus* farming.

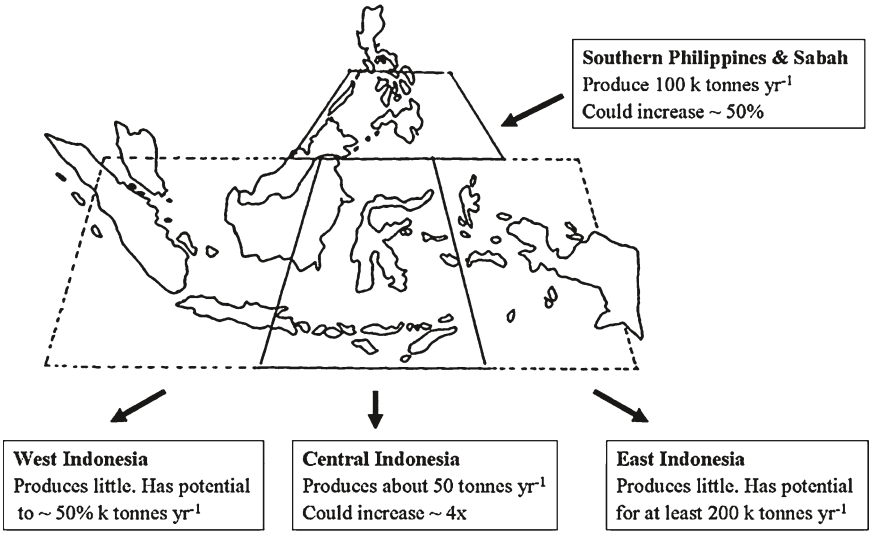


Figure 2. Major areas of *Kappaphycus* cultivation and potential dry weight production in the BIMP-EAGA region (IFC, 2003).

Table 1. World production of *Kappaphycus* (cottonii) in 2006 (Hurtado, 2007).

Country	Volume (ton dry weight)	Total (%)
Philippines	89,000	55.5
Indonesia	61,000	38.0
Malaysia	4,000	2.5
Cambodia/Vietnam	2,200	1.4
China	800	0.5
Kiribati	1,100	0.7
India	400	0.2
Tanzania/Madagascar	1,500	0.9
Brazil	500	0.3
Total	160,500	100

The *Kappaphycus* (cottonii) world production for commercial extraction of *kappa* carrageenan shows that the BIMP-EAGA region produces 96.5% of the total production, of which 55% comes from the Philippines, followed by Indonesia (38%) and Malaysia (2.5%). The rest of the producing areas contribute relatively very small volumes (Table 1).

3. Cultivation Techniques and Post-harvest Management

Since the first successful farming of *Kappaphycus* in the Philippines in 1970, the cultivation technique has undergone many modifications. The main commercial

varieties are presented in Fig. 3 (Hurtado et al., 2008a). The most traditional type of farming is the fixed off-bottom method usually practiced in shallow reef areas. Innovations in the deeper water cultivation areas include using the hanging long line (fixed and swing) and the multiple-raft long line. The fixed hanging long line technique has both ends tied to an anchor bar or block, while in the swing hanging

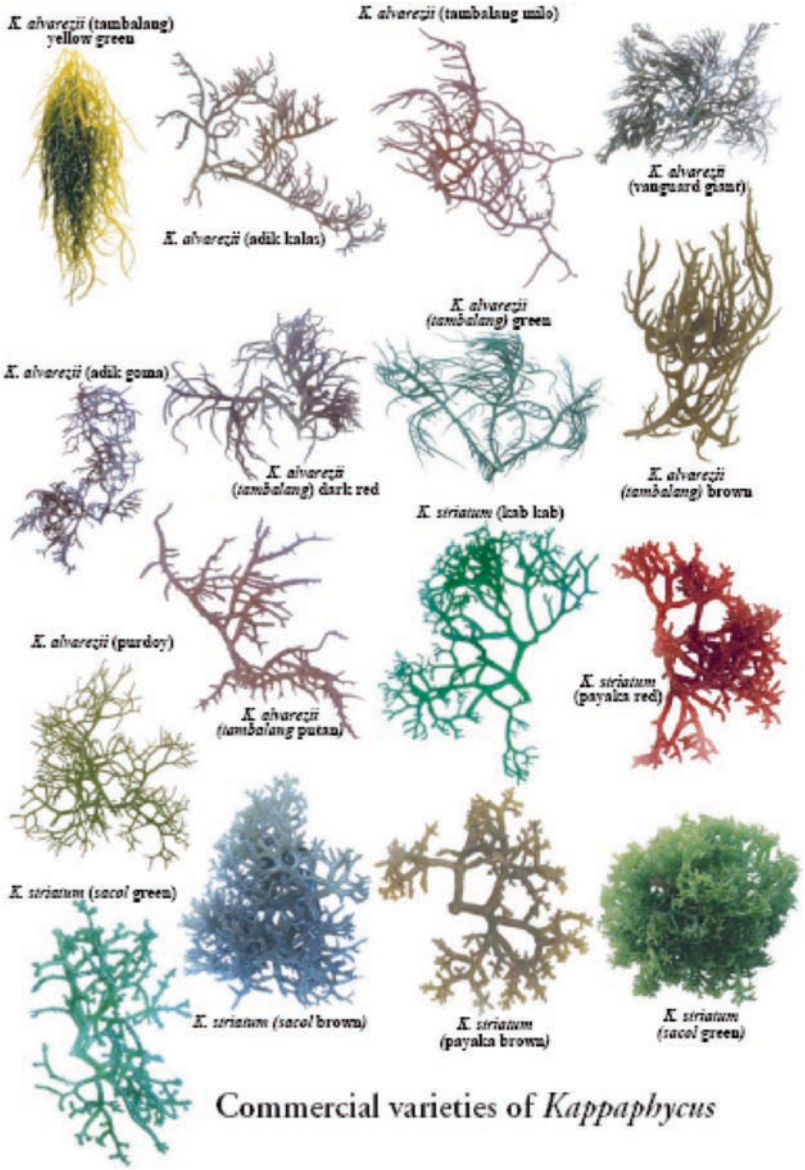


Figure 3. The main commercial varieties of *Kappaphycus* spp. cultivated worldwide (Photos retrieved from Hurtado et al., 2008a).

long line, only one end is tied to an anchor bar or block, and the other end is allowed to swing freely with the current. Figure 4a–d shows examples of the different farming methods commonly used.

Table 2 shows the summary of growth rates of *Kappaphycus* grown by different methods and in different areas. The growth rates varied widely depending on the cultivation system adopted but, in general, plants cultivated in the usual fixed off-bottom system or in rafts showed high values (between 0.2% and 5.3% day^{-1} in the first case and between 0.5% and 10.7% day^{-1} in the last case). When plants were co-cultivated with other organisms in tanks, acting as biofilters, the growth rates were notably lower (0.7–2.7% day^{-1}).

Both the quantity and quality of carrageenan is influenced by the maturity of the thallus. The work of Mendonza et al. (2006) suggested that young (apical) segments of *K. striatum* var. *sacol* yielded higher gel strength, cohesiveness, viscosity properties, and lower average molecular weight than old (basal) segments. However, the latter yielded greater amounts of carrageenan in total. Furthermore, they emphasized that as the thalli aged, the content of *iota* (and precursor) carrageeenan decreased, which may be related to certain physiological and structural functions during the growth and structural maturation of the alga.

The work of Hurtado et al. (2008b) on *Kappaphycus striatum* var. sacol showed that a lower stocking density (e.g. 500 g m^{-1}) and a shorter period of culture (30 days) yielded a higher growth rate than a higher stocking density (1,000 g m^{-1}) and longer period of culture (45 and 60 days) when grown vertically on rafts. Furthermore, the results revealed a higher yield in carrageenan at a lower stocking density (500 g m^{-1} $line^{-1}$) than at 1,000 g m^{-1} $line^{-1}$; and the molecular weight was greater in plants growing at 50–100 cm depth both for 30 and 45 days of cultivation, when compared with those that grow at 150–200 cm depth and 60-day cultivation period. These results simply indicate that "sacol" prefers a shorter period of culture and at a lower depth to synthesize more carrageenan. It is surprising how little such relatively simple studies have been employed given the value of the seaweed biomass to national economies and the carrageenan yield and quality to the extraction/processors.

With regard to *Kappaphycus alvarezii* cultivated in Ubatuba, Brazil, Hayashi et al. (2007) observed that plants cultivated at high density (24 plants of 40 g each in 1 m^2), in PVC pipe multiple raft, showed higher productivity when cultivated at surface for 44 and 59 days. Higher carrageenan yields were obtained from plants cultivated for 28 days; in fact, in this study, the *iota* carrageenan content was highest at 59 days of cultivation; and unlike the observations for *K. striatum*, the older tissues of *K. alvarezii* showed the higher molecular weight and gel strength. Clearly, there is a need for much greater site-specific studies on methods of cultivation and duration of the commonly practiced farming period.

The molecular weight has become an important criterion for the food regulatory authorities since the Scientific Committee on Food (SCF) of the European Commission endorsed in 2003 a molecular weight distribution limit on carrageenan as precautionary approach. This regulation was created based on some suspects that high consumption of low molecular weight carrageenan could

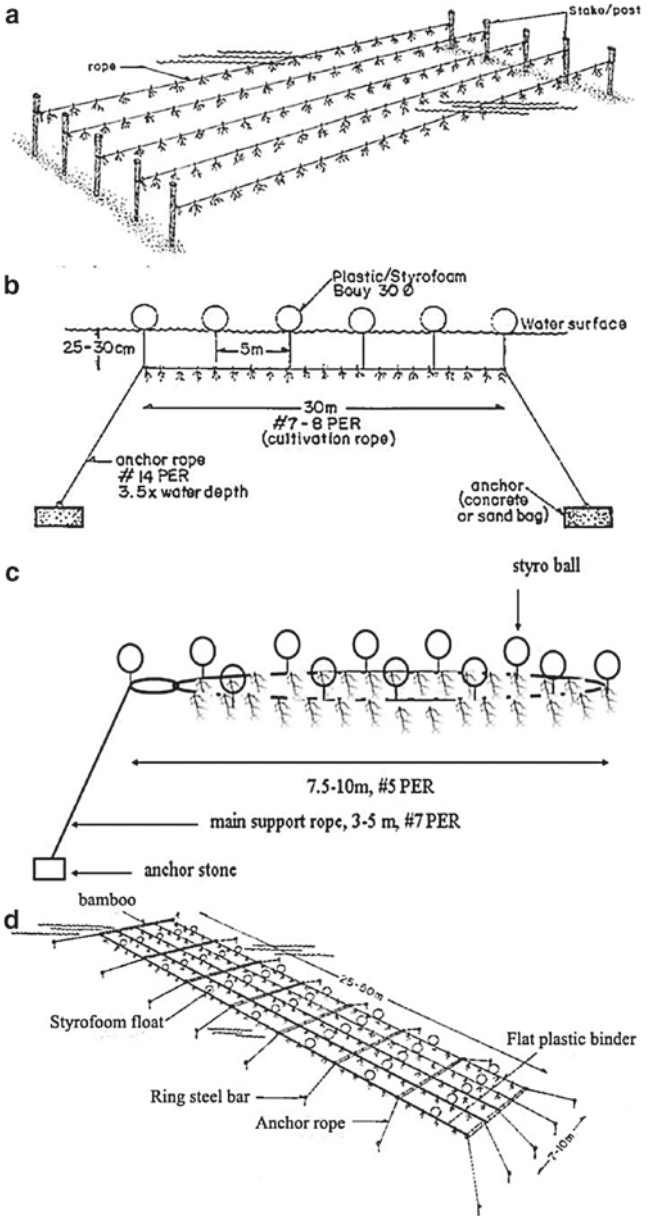


Figure 4. Culture techniques commonly used (**a**) fixed-type (Hurtado et al., 2008a); (**b**) hanging long line (fixed-type) (Hurtado et al., 2008a); (**c**) hanging long line (swing type) (Hurtado et al., 2008c); (**d**) multiple-raft long line (Hurtado and Agbayani, 2002).

Table 2. Reported daily growth of *Kappaphycus alvarezii* using different culture techniques and sites.

Culture technique	Growth rate (% day^{-1})	Reported by	Country
Fixed off-bottom	5.7	Lim and Porse, 1981	Bohol, Philippines
	3–4	Adnan and Porse, 1987	Indonesia
	3.5–3.7	Luxton et al., 1987	Fiji
	2.04	Samonte et al., 1993	Western Visayas, Philippines
	0.2–3.2	Hurtado et al., 2001	Antique, Philippines
	2.0–8.1	Muñoz et al., 2004	Yucatan, Mexico
	4.2–4.3	Wakibia et al., 2006	Southern Kenya
	1.6–4.6	Hung et al., 2009	Camranh Bay, Vietnam
Bamboo raft (single)	1.24	Samonte et al., 1993	Western Visayas, Philippines
	0.5–5.6 (Unfertilized)	Msuya and Kyewalyanga, 2006	Zanzibar, Tanzania
	0.5–7.6 (Fertilized)	Msuya and Kyewalyanga, 2006	
	4.4–8.9	Dawes et al., 1994	Zanzibar, Tanzania
	6.5–10.7	Paula et al., 2002	
	4.5	Gerung and Ohno, 1997	Philippines
	4–5	Bulboa and Paula, 2005	São Paulo, Brazil Southern Japan
	5.2–7.2	Hayashi et al., 2007	São Paulo, Brazil
PVC pipe raft (multiple)	0.8–1.3	Lombardi et al., 2006	São Paulo, Brazil
	3.7–7.1	Hurtado-Ponce, 1992	São Paulo, Brazil
Cages	0.9–3.8	Hurtado-Ponce, 1995	Guimaras, Philippines
	3.7	Hurtado-Ponce, 1994	Guimaras, Philippines
Cages: polyculture	3.8		
vertical lines	5.3		
cluster			
horizontal	0.2–4.2	Hurtado et al., 2001	Antique, Philippines
Hanging long line (fixed)	2.8–3.0	Hurtado et al., 2008b	Tawi-Tawi, Philippines
Hanging long line (swing)	1.8–10.86	Wu et al., 1989	China
Vertical lines	1.9–6.3	Glenn and Doty, 1990	Hawaii
Pens (loose thalli)	9–11	Ohno et al., 1996	Vietnam
Lagoon	7–9	Ohno et al., 1996	Vietnam
Inlet	5–6	Ohno et al., 1996	Vietnam
Pond	2–2.7	Rodrigueza and Montaño, 2007	Philippines
Biofilter in tanks	0.7–0.8	Hayashi et al., 2008	São Paulo, Brazil
Polyculture with oyster	1.9–6.1	Qian et al., 1996	China
Polyculture with grouper	3.7–5.3	Hurtado-Ponce, 1994	Antique, Philippines

provoke peptic ulcer. However, until nowadays, several animal studies have been made and supported the safety of carrageenan for use in foods; thus, regulatory authorities saw no reason to question the safety of carrageenan as long as the average molecular weight was 100,000 Da or higher (Watson, 2008).

4. Moisture Content of Raw Dried Seaweed

Moisture content (MC) of the harvested seaweed biomass plays a major role in its market acceptance and commercial value. The more water content the seaweed has, the lower the farm gate price. Frequently, seaweed farmers have no capacity to determine the MC properly, so most of the time they are dependent on decisions of the traders. In turn, these traders rely on the final measurement by the processors, often after some considerable time of transportation. It would be prudent if one small testing laboratory could be installed at major producing areas in order to accurately determine MC of the seaweed, so that the farmers could be paid accordingly. MC is a critical factor along the value chain.

Generally, fresh seaweeds from far-flung islands of the Philippines are sun-dried for 1–2 days only due to very limited availability of space for drying. These are sold immediately to collectors (first trader) with an estimated MC of 45–50% (given the local conditions and humidity; obtaining lower levels without mechanical drying are not practical). The collector will in turn sell to a larger trader (second trader) who will sell either to local processors or to exporters of Raw Dried Seaweed (RDS) (Fig. 5). In other areas, e.g. Tanzania, MC varies from 15% to 20% after 2–3 days of sun drying.

There are advantages when the farmers are organized. The bargaining power of a farmers' association is much stronger. The possibility of selling directly either to a local or off-shore processor is increased and bypasses two to three layers of traders, thus providing a higher profit margin to the association.

5. Social and Economic Aspects of *Kappaphycus* Cultivation

Seaweed farming is an industry that can contribute significantly to the economy of the producing countries, bringing a foreign income and improving the socio-economic situation of the coastal people involved. Apart from the governments of the respective countries taking a key role in helping their communities through seaweed farming, other institutions have also taken actions on such activities. In Tanzania, NGOs like the USAID-funded Agricultural Cooperative Development International and Volunteers in Overseas Cooperative Assistance (ACDI-VOCA) have implemented different programs on seaweed farming for the benefit of coastal communities. The successful cultivation practices have increased the economic purchasing power and social empowerment of women seaweed farmers (Pettersson-Löfquist, 1995; Bryceson, 2002; Msuya, 2006a). In this country,

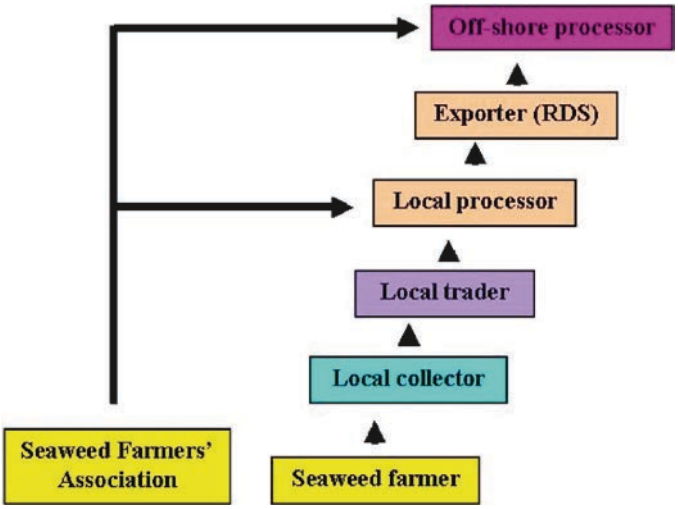


Figure 5. Trade chain of *Kappaphycus alvarezii* crop.

the significance of the industry as a foreign income was documented in 2006 when it had contributed 14.7% and 27.3% of the Zanzibar's marine resources exports between 1993 and 1994 (Msuya, 2006a). In Indonesia, it has been shown that 7,350 families source their livelihood from seaweed farming (Watson, 2000), while in the Philippines it was shown that seaweed farming became the main source of income to village communities where seaweed was farmed (Quiñonez, 2000).

6. Current Trends

While seaweed farming has contributed significantly to the economies of many countries, there have been recent changes that have significantly affected the industry and consequently farmers and countries at large. First of all, is the preference by the world market for one species *Kappaphycus alvarezii* over *Eucheuma denticulatum* because of its stronger gel (*kappa* carrageenan) compared with the latter's *iota* carrageenan, which is a weaker gel? As a result, the price of *K. alvarezii* is higher than that of *E. denticulatum.* Examples are in Tanzania where the price of the former in 2008 was US$0.2 kg^{-1} of dry weight, almost double that of the latter, which is US$0.1. In 2002, the price was US$0.09 (Bryceson, 2002). In the Philippines, the current farm gate price (as of 30 March 2009) is US$0.67–0.73. This picture directly reflects the farmers payment, which can vary among the countries, e.g. US$49–91 $month^{-1}$ in Pacific Islands (Bergschmidt, 1997), and US$2,000 in the Philippines (Murphy, 2002).

Seaweed sales can also be influenced by the distance from the farming sites to the export point and the farmer's efforts. In Tanzania, for example, farmers are

currently receiving US$50–500 month^{-1}. Other aspects coupled with the market change is the proliferation of "diseases," as ice-ice, and die-offs of the higher-priced *K. alvarezii*, experienced in a number of countries.

A recent study showed that while seaweed farming in Songosongo Island in the South of Tanzania had proved to be an alternative livelihood to the people, the farming is failing in many cultivation sites in the shallow intertidal areas where it used to grow. The main cause observed during a short survey by Msuya (2009) was the water temperature, which was higher than had been observed previously in seaweed farms in other areas and other years in Tanzania. Water temperatures had been less or equal to 33°C. In Msuya (2009), surface seawater temperature values taken between 11:00 and 13:00 h along the seaweed farming area showed values ranging from 33°C to 38°C. The seaweed showed signs of being burnt with bleached thalli; sometimes, the whole thallus was bleached. Farmers have abandoned these sites to concentrate in a smaller area. The number of farmers decreased by 60% between 2003 (seaweed production peak) and 2008. Production decreased by 94% during the same period (Msuya, 2009).

In Zanzibar, in an area where *K. alvarezii* used to be purchased for seed during experimental studies, farmers have stopped cultivating the species due to die-offs. Seed is now taken from either South or North of the study site that has been used since 2005. In a continuing study in the area, highest temperatures in January–February 2008 were 36–37°C (Msuya, 2009). Further studies are required to ascertain if the area in general is suitable for *Kappaphycus* and or *Eucheuma* spp.

In an effort to farm the higher-priced seaweed, farmers spend the growing seasons (up to 6 months) only to end up losing the seedlings during bad seasons. This has frustrated them who have been wasting their time, energy, and resources with no returns. In so doing, the production of even lower value *Eucheuma* species has decreased. Equally affected by the situation are the middlemen who buy and export the seaweeds as they cannot get enough materials for their business. Such events cause dismay and farmers stop the cultivation activity. Pollnac et al. (1997) observed several examples of other communities in North Sulawesi that had taken up and then abandoned seaweed farming in the past. A drop in seaweed prices in 2001 led to a reduction in seaweed farming in the Bentenan–Tumbak area of North Sulawesi (Unsrat, 2001).

7. *Kappaphycus alvarezii* Diseases and Epiphytes

"Ice-ice disease" and epiphyte infection are two factors occurring as "outbreaks" that can be frequently observed in high-density commercial farming (Vairappan et al., 2008). "Ice-ice" is a symptom that *Kappaphycus alvarezii* presents after suffering stresses such as abrupt changes in temperature and/or salinity. The term "ice-ice" was coined by Philippine farmers using the English term "ice" to describe the senescent tissue devoid of pigments that causes healthy branches to break off

(Doty, 1987). The "ice-ice" problem was first reported in 1974 during the start of commercial seaweed farming in Tawi-Tawi, the Philippines (Barraca and Neish, 1978, Uyengco et al., 1981) and severe instances have reportedly wiped out entire farms (Largo et al., 1995). According to Doty (1987), the onset is a sharp loss of thallus pigmentation until it becomes white; the segment may remain for a day or two before it dissolves away, separating the two adjacent parts of the thallus, which seem to be otherwise unaffected (Fig. 6).

Although most of the publications consider "ice-ice" as a disease, Doty (1987) and Ask (2006) affirmed that it is not a disease since there was little evidence that it was caused by pathogenic bacteria. However, Largo et al. (1995) presented convincing evidence that bacterial groups from the complex *Cytophaga-Flavobacterium* and the *Vibrio-Aeromonas* could be the causative agents in the development of the symptom. The numbers of bacteria on and in "ice-ice"-infected branches were 10–100 times greater than from normal, healthy plants. In other work, Largo et al. (1999) noted that the combined effect of stress and biotic agents, such as opportunistic pathogenic bacteria, were primary factors in the development of "ice-ice," and that the different bacterial groups have different strategies of infection. Mendonza et al. (2002) observed de-polymerization of carrageenan from "ice-ice"-infected portions of the *K. striatum* thallus as well as lowered levels of *iota* carrageenan and methyl-constituents, which consequently lowered the average molecular weight (30 kDa) of the colloid, which could be extracted. Appreciable decreases in carrageenan yield, gel strength, and viscosity, with a combined increase in the syneresis index were also noted. The authors recommended complete removal of the infected portions of thallus prior to sun drying to prevent contamination of yields by low molecular weight carrageenan.

Another problem more recently described is the occurrence of epiphyte outbreaks in *Kappaphycus alvarezii* farms. Epiphytic and endophytic filamentous algae (EFA) are a serious threat to the health of the seaweeds and to overall farm productivity (Ask, 2006) (Fig. 7).

The development of problems caused by epiphytic algae has been described in the Philippines, Malaysia, Tanzania, and India (Hurtado et al., 2006, Msuya and Kyewalyanga, 2006; Muñoz and Sahoo, 2007, Vairappan, 2006). Hurtado



Figure 6. "Ice-ice" symptoms in some commercial *Kappaphycus alvarezii* samples (Photos retrieved from Hurtado et al., 2008a).

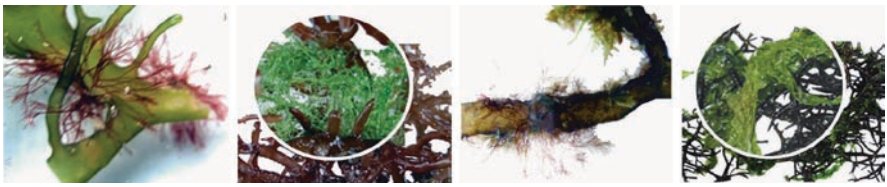


Figure 7. Examples of epiphytic and endophytic filamentous algae (EFA). From *left* to *right*, *Ceramium*, *Boodlea composite*, *Neosiphonia,* and *Ulva* (Photos retrieved from Hurtado and Critchley (2006) and courtesy of A. Hurtado).



Figure 8. *Neosiphonia* infection on *Kappaphycus alvarezii* thallus (Courtesy of C. Vairappan).

and Critchley (2006) used the terminology of Kloareg, who studied epiphytes of *Gracilaria*, in which he classified epiphytes into five types: Type I – epiphytes weakly attached to the surface of the host and with no evidence of host tissue damage; Type II – epiphytes strongly attached to the surface of the host but host tissue damage still absent; Type III – epiphytes that penetrate the outer layer of host cell wall without damaging the cortical cells; Type IV – epiphytes that penetrate the outer layer of the host cell wall, associated with host's cortical disorganization and Type V – epiphytes that invade the tissues of the host, growing intercellularly, and associate with destruction of cortical and (in some cases) medullary cells (i.e. forming a parasitic relationship). Among these types, the most harmful is certainly the last one: the red filamentous alga first attributed to the genus *Polysiphonia* and subsequently described as *Neosiphonia*, which causes great losses in the crops (Fig. 8).

According to Hurtado and Critchley (2006), *Neosiphonia* (= *Polysiphonia*) infestations were first observed in a dense population by an American Peace Corp Volunteer, Jesse Shubert, in Calaguas Island, the Philippines, in 2000. He observed that there was widespread infestation of this epiphyte in this specific locality and this was brought to the attention of the international seaweed community through the internet. This epiphyte caused a distortion of the *K. alvarezii* thallus in the site of penetration, from the cortical to the medullary layers, and was named "goose bumps" by D. Largo (Hurtado et al., 2006) (Fig. 9).

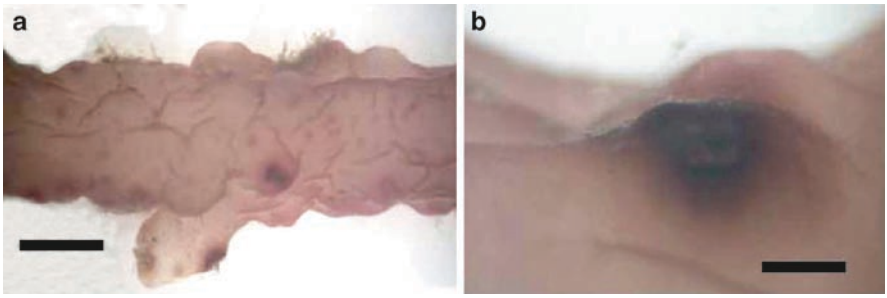


Figure 9. "Goose bump" formation caused by *Neosiphonia* infections on *Kappaphycus* thalli: (**a**) at the end of epiphyte infection phase and (**b**) epiphyte infected "mounts" with the onset of secondary bacterial infection. Scale bar = 300 µm (Courtesy of C. Vairappan).

Hurtado et al. (2006) affirmed that the occurrence of *Neosiphonia* (= *Polysiphonia*) epiphytes in Calaguas Is. resulted in tremendously reduced biomass production of *Kappaphycus* in the formerly productive cultivation area. Even now, only a few people continue to farm the species in the area since the *Neosiphonia* (= *Polysiphonia*) outbreak. The infestation is persistent rather than periodic, unlike the observations of Msuya and Kyewalyanga (2006) in Jambiani, Zanzibar, where seasonal presence of reddish filaments on the thalli of almost all seaweed cultivated after 6 weeks was noted, besides some additional signs of "ice-ice."

In Malaysia, Vairappan (2006) isolated a total of five epiphytic species from outbreaks: *Neosiphonia savatieri*, *N. apiculata*, *Ceramium* sp., *Acanthophora* sp., and *Centroceras* sp. The author observed the first emergence in late February 2006, with the appearance of tiny black spots on surface epidermal layer, which then became rough and the vegetative epiphyte surfaced after 3–4 weeks. Epiphytes were observed as solitary plants growing on the algal surface with rhizoids penetrating into the tissue of the cortical cell layers.

In the peak season, the dominant epiphytes, *N. savatieri*, were seen to grow close to each other at a maximum density of 40–48 epiphytes cm^{-2} (Vairappan, 2006). The emergence of epiphytes coincided with drastic changes in salinity and temperature; the author (op. cit.) suggests that there could be a possible correlation between the fluctuations in the abiotic factors and the emergence of epiphytes. In fact, Hurtado et al. (2006) found a strong correlation between the percentage cover of "goose bumps"- *Neosiphonia* (= *Polysiphonia*), light intensity, and water movement. According to these last authors, if these factors were limiting (leading to crop stress), then problems with epiphyte infestations increased. It seems that infestation by EFA in *Kappaphycus alvarezii* has a direct implication for careful selection of appropriate farm sites and selection of noninfected seedlings.

Other species of epiphytes had been identified by Hurtado et al. (2008a), e.g., red macro-epiphytes (*Actinotrichia fragilis*, *Acanthophora spicifera*, *A. muscoides*, *Amphiroa foliacea*, *A. dimorpha*, *A. fragilissima*, *Ceramium* sp., *Gracilaria arcuata*,

Hydropuntia edulis, *Hypnea musciformis*, *H. spinella*, *H. valentiae*, *H. pannosa*, *Champia* sp., *Chondrophycus papillosus*), brown macro-epiphytes (*Hydroclathrus clathratus*, *Dictyota divaricata*, *D. cervicornis*, *Padina australis*, *P. santae-crucis*), and green macro-epiphytes (*Boodlea composita*, *Chaetomorpha crassa*, *Ulva clathrata*, *U. compressa*, *U. fasciata*, *U. media*, *U. pertusa*, *U. reticulata*).

Vairappan et al. (2008) in a collaborative study including Filipino, Indonesian, Malaysian, and Tanzanian researchers identified the causative organism of epiphyte infestation in these countries, analyzed the infection density, the stages of infection, and observed the occurrence of secondary bacterial infection after the epiphytes dropped off. In all countries, the causative organism was identified as *Neosiphonia apiculata*, which presented on the host seaweed as follows: the Philippines (88.5 epiphytes cm^{-2}), Tanzania (69.0 epiphytes cm^{-2}), Indonesia (56.5 epiphytes cm^{-2}), and Malaysia (42.0 epiphytes cm^{-2}). According to these authors (op. cit.), the "goose-bump" is a characteristic feature of the epiphyte infection, with a formation of a pit in the middle where the epiphyte's basal primary rhizoid was loosely attached (Fig. 10a). After the drop off of the secondary rhizoids and their upper main thalli, tissue degradation began with the formation of tiny pores on the "goose-bumps" (Fig. 10b), followed by their disintegration and the establishment of secondary bacterial infection, mainly *Alteromonas* sp., *Flavobacterium* sp., and *Vibrio* sp. (Fig. 10c). C. Vairappan (2008, personal communication) observed in *N. apiculata* infected plants 25.6% lower carrageenan yield, 74.5% lower viscosity, 54.2% lower gel strength, 22.4% higher syneresis than healthy plants from commercial farms of *K. alvarezii* in Sabah, Malaysia, and a reduction of carrageenan size from 800 kDa in healthy specimens to 80 kDa in infected plants.

To try to minimize the occurrence of epiphytes, the use of uninfected, clean, and healthy "seedlings" of *Kappaphycus* is strongly recommended besides the careful selection of a farming site with clean and moderate to fast water movement, which has less siltation (Hurtado and Critchley, 2006). However, if a proliferation of *Neosiphonia* (= *Polysiphonia*) is noted, the cultivated seaweed must be totally harvested; attempts to select young branches of the infected plant for "seedling" purposes should not be made to prevent the transfer of epiphytes from one crop

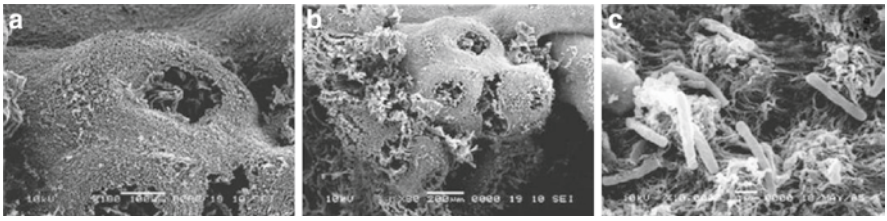


Figure 10. Scanning electron microscopy (SEM) micrographs showing phases of cellular decomposition of the epiphyte-infected site. (**a**) Epiphytes rhizoids drop off from the "goose-bump"; (**b**) tissue degradation of the "goose-bumps"; and (**c**) secondary bacterial infection (Photos retrieved from Vairappan et al., 2008).

to another. If possible, it is recommended not to use the same farming site for the next cropping season (for other details, consult Hurtado and Critchley, 2006).

The impact of increasing surface seawater temperatures and the noted stress on cultivated seaweeds remains largely unknown. However, it could be speculated that the cultivated seaweeds are stressed and their vigor compromised, which then leaves them susceptible to colonization by epiphytes.

Other contamination, still not identified, was observed in Brazil, in *Kappaphycus alvarezii* cultivated in vitro. Despite the "optimum" conditions of the laboratory, some strains developed black spots on the thallus (within the cortical tissue) where after some days signs of "ice-ice" began (Fig. 11) (L. Hayashi, 2008, personal communication). An unsubstantiated report also exists of a graying of cortical tissue of plants from the Philippines, which resulted in even the normally white, finished, refined carrageenan powder having a gray discoloration (A.T. Critchley, 2008, personal communication). It would not be surprising if these signs are caused by fungal attack, especially given the history of the pathology of terrestrial crops. It is not "rocket science" to expect that carrageenophyte cultivars, asexually selected, and grown as monocrops will become increasingly the target of marine pathogens. The outcome needs to be seen, but much closer attention is required to the pathology of seaweed crops.

Considering all these problems that are possibly correlated with environmental change, and to avoid future problems with "ice-ice," epiphytes and even the presence of undesirable pathogenic organisms (such as fungal infestation), it is essential, now more than ever, to choose the best cultivation areas. Moreover, only the very best management practices available should be employed since *K. alvarezii* is a crop with limited genetic variability, i.e., cultivated plants are propagated only vegetatively and have no sexual reproduction, so that the species is very vulnerable to pathogenic agents. Vairappan et al. (2008) suggest that the outbreak of *N. apiculata* in Malaysian farms was caused by the negligent introduction of already "infected" *K. alvarezii* seedlings from the Philippines, without sufficient monitoring

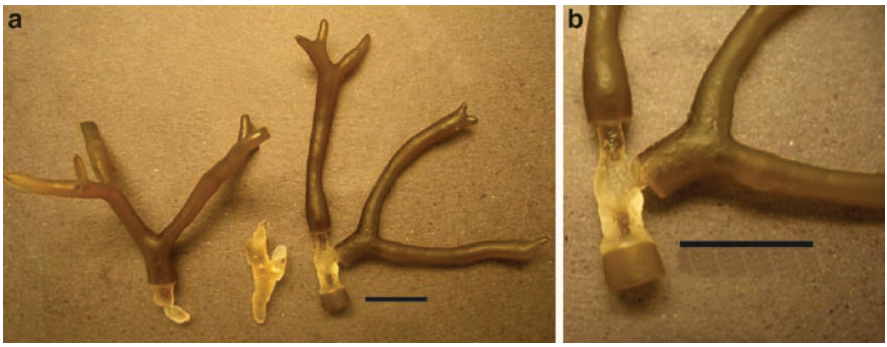


Figure 11. Unknown infection observed in *Kappaphycus alvarezii* in vitro cultivation in Brazil. (**a**) Three infected thalli. (**b**) Details of one infected part. Scale bar = 1 cm (Photos by L. Hayashi).

and quarantine procedures, after the farms were badly infected by "ice-ice disease" and epiphytes.

Adequate quarantine protocols and strict adherence are very important to minimize the risk of importing associated species or any diseased plants (Sulu et al., 2006). According to Ask et al. (2003), among all of the worldwide introductions of *K. alvarezii*, appreciative quarantine procedures were made only in the Solomon Islands and Brazil. In the first case (Solomon Islands), the seaweed was placed in raceways for 14 days, with the initial aim to remove invertebrates rather than to prevent the spread of infectious disease (and/or superficial algal epiphytes). In Brazil, a branch of 2.5 g was isolated and propagated in unialgal conditions in the laboratory, with seawater sterilized for 10 months (Paula et al., 1999). These procedures are quite different from each other, the first too imprecise and other (perhaps) too stringent. Sulu et al. (2006) recommend washing the seaweeds with filtered seawater to remove macro- and microbiota and to reduce the incidence of organisms on the transplanted fragments over a 2-week quarantine period. In Brazil, successive washes with distilled water and sterilized seawater, and then drying with tissue towel has been effective; in addition, the *K. alvarezii* branches were kept in quarantine for at least 2 months (L. Hayashi, 2008, personal communication).

8. The Issue of *Kappaphycus alvarezii* as an Invasive Organism

According to Zemke-White and Smith (2006), the genus *Kappaphycus* was introduced in 19 tropical countries versus *Eucheuma* into at least 13 tropical countries. Despite the polemics of the exotic species introduction, after more than 30 years from the beginning of *Kappaphycus* commercial cultivation in the Philippines, it is only in recent years that cases of bioinvasion have been reported. In the 19 tropical countries, two presented effective cases of invasion, causing serious environmental damage, mainly in coral reefs. Another good example of the edict is that just because a species will grow in a new environment is not a sufficient case for its introduction. Several people involved in seaweed cultivation (including Ask, 2008, personal communication) have stated that *Kappaphycus* and *Eucheuma* (while eminently suitable for cultivation) should not be relocated outside their natural range of distribution.

The most studied case of the impacts of *K. alvarezii* cultivation in the tropics is from Hawaii. The first study conducted by Russell (1983) 2 years after the introduction of the species (which he refers as *Eucheuma striatum*) in Kaneohe Bay, attested that *Eucheuma* did not establish over deep water or out of depressions, hollows, or channels, and was unable to colonize neighboring reefs without human help. He observed that the greatest accumulation of *Eucheuma* (23 t) occurred on the reef edge, but this was not a permanent or established population.

In 1996, Rodgers and Cox went back to the same bay and observed that *Kappaphycus* spp. (mentioned as *K. alvarezii* and *K. striatum*) had spread 6 km away from the initial site of introduction, at an average rate of 250 m year^{-1} (Rodgers and Cox, 1999).

After a further 5 years, Smith et al. (2002) concluded that *Kappaphycus* spp. had still not spread outside of Kaneohe Bay but had continued to spread northward in the bay since the Rodgers and Cox (1999) study.

Conklin and Smith (2005) found that in just 2 years, the alga had increased from less than 10% to over 50% cover on some patch and fringing reefs. According to this work and their account to Zemke-White and Smith (2006), in many cases the alga occupied over 80% cover of the benthos and generally grew in large three-dimensional mats in Kaneohe Bay, eventually overgrowing or interacting with reef-building coral (Fig. 12a and b). The removal of these plants has been made using a new weapon specially developed to this case, named "Super Sucker": an underwater vacuum that sucks the algae right off the reef (for more details, please consult: www.nature.org/wherewework/northamerica/states/hawaii/projectprofiles/art22268.html).

Bioinvasion is just one of the major problems in places where *Kappaphycus* is introduced. However, a fundamental issue involves the identification of the problem genus: *Kappaphycus* or *Eucheuma*? Recently, the problem seems to receive a highlight. Molecular analyses indicated that plants introduced to Hawaii, presumably from the Philippines, are distinct from all other *Kappaphycus* worldwide cultivated samples and their unique genotypes, as expressed in their unique haplotypes, may explain their invasive nature in Hawaii (Zuccarello et al., 2006). The work of Conklin et al. (2009) confirms that the species is *Kappaphycus alvarezii*, but the Hawaiian strain forms a separated grouping of the strains from Venezuela, Tanzania, and Madagascar.

Between 2007 and 2008, *Kappaphycus* bioinvasion problems received yet further, serious media attention. This time in India and as such received much attention even in journals as *Nature and Science*. Chandrasekaran et al. (2008) observed that *K. alvarezii* had successfully invaded and established on both dead and live corals in Kurusadai Island, India. The species had specifically invaded

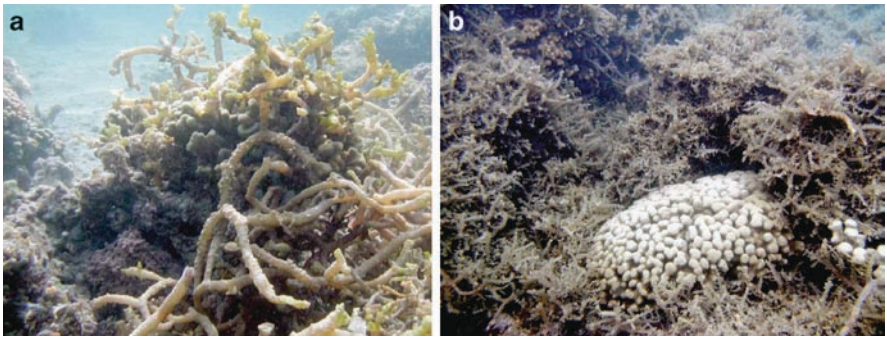


Figure 12. *Kappaphycus alvarezii* (**a**) and *Eucheuma denticulatum* (**b**) overgrowing coral reefs in Kaneohe Bay, Hawaii (Photos from Zemke-White and Smith, 2006).



Figure 13. *Kappaphycus alvarezii* overgrowing corals in Kurusadai Island, India (Photos from Chandrasekaran et al., 2008).

the *Acropora* sp. and destroyed them by shadowing and smothering effects. The authors (op. cit.) noted an extraordinary phenotypic plasticity in terms of distinct variations in color and shape of the thallus, thickness of its major axis, morphological features, and frequency of primary and secondary branching (Fig. 13). The shadowing was due to smothering effect in which the major axis extends like an elastic rubber sheet and covers the maximum surface area of the corals. The invaded corals lost their skeletal integrity, stability, and rigidity and could be easily detached from the reef matrix.

The seaweed colonies could have been established from vegetative fragments of past and present trials of *Kappaphycus* cultivation. Many fragments can be generated and if not recollected, can be dispersed through wave action and settle on coral substrata. According to Chandrasekaran et al. (2008), other factors could include the relatively long duration (1 year) of cultivation experiments conducted in 1997 at different depths, as well as ongoing cultivation and ideal environmental conditions such as water temperature and availability of nutrients. Detachment of the thalli from the open and raft cultures during rough weather conditions, especially during the southwest and northeast monsoon seasons and their dispersal to other areas, cannot be ruled out.

In a public response to the publications concerning the invasion in India, scientists of Central Salt and Marine Chemical Research Institute (CSMCRI) contested the fact, arguing that they surveyed the region from 2005 to 2008 and had not observed the occurrence of nonfarmed populations of *Kappaphycus*. Furthermore, they stated that there was little possibility of the original germplasm in Kurusadai be the source of the reported outcome. The activities were discontinued in November 2003 due to inferior growth and heavy grazing (in this document however, they refer the plants as *Eucheuma* and not *Kappaphycus* – a common misrepresentation which has to be borne in mind when each genus is referred to, particularly in popular literature).

According to a review by Pickering et al. (2007), many Pacific Island countries attempted to cultivate *Kappaphycus* with no success. In some places, abandoned *K. alvarezii* aquaculture trials resulted in the thalli dying out, while in other places there were small residual populations. Zemke-White and Smith (2006), in their review, related the spread of *Kappaphycus alvarezii* and *Eucheuma denticulatum* from farms to neighboring reefs in Zanzibar, Fiji, and Venezuela, which had

proceeded without bioinvasion into their coral reef environments. According to Pickering et al. (op. cit.) in this oligotrophic reef environments, *K. alvarezii* may be said to "persist" but it is not "proliferating."

It is clear that the invasive potential of the *Kappaphycus* or *Eucheuma* in environments is a prevailing danger but remains unpredictable. Zemke-White and Smith (2006) presupposed that given enough time, *Kappaphycus* and *Eucheuma* used in commercial cultivation could have the ability to spread from farm sites and establish independent populations. However, both the extent of this spread and the effects on local species may differ between locations and species. The introduction of *Eucheuma*/*Kappaphycus* from the Phillipines into Hawaii, and later into the Pacific Islands, demonstrates the complexity of this subject. Confusion in identifications between the genera is also a point of contention; the original report of *K. alvarezii* is regarded as a serious pest at one location in Hawaii. However, the cultivar *K. alvarezii* has in fact failed to establish in many localities in the Pacific Ocean where it was deliberately introduced for commercial cultivation (Pickering et al., 2007). Eucheumatoids are normally cultivated in relatively oligotrophic conditions, and the impacts of anthropogenic eutrophication of the bays in Hawaii have not been fully investigated, given sufficient association to changes in environmental conditions that may have tipped the balance in favor of successful development of eucheumatoids as invasive species.

Craige (2007) affirmed that properties of the invaded community could determine the success of the invader. Shifts from coral to algal domination on reefs have been found to be associated with the loss of biodiversity, reduction in the numbers of fish, decrease in the intrinsic value of the reef, and ultimately the erosion of the physical structure of the reef (Cocklin and Smith, 2005).

According to Pickering et al. (2007), there are many cases of *K. alvarezii* having been introduced, often without quarantine protocols for aquaculture projects that were underfinanced, or commercially, socio-economically or institutionally unsound, even without guaranteed markets. These ventures were essentially set up to fail from the outset. By so doing, these states expose themselves to the full extent of potential environmental risk, without capturing any of the anticipated socio-economic benefits against which they had balanced this risk.

Whether the bioinvasion is caused by *Kappaphycus* or *Eucheuma* is not the main concern. The main issue is what is the cause and how will the situation be controlled. Effective control options for current cultivations and establishment of quarantine protocols before any new introductions are even envisioned and would prevent similar problems in other reefs around the world.

9. Integrated Multitrophic Aquaculture

Aquaculture is probably the fastest growing food-production sector worldwide, being responsible for almost 50% of the fish for food and with greatest potential for satisfying the growing demand for aquatic food (FAO, 2006). According to

FAO, in the last 50 years, production increased from 20 million tons in the early 1950s to 157 million tons in 2005 (FishStat Plus – version 2.3). However, concerns over the impacts of these growing, intensive aquaculture activities has prompted the development of Integrated Multi-Trophic Aquaculture (IMTA) as one of the most sustainable alternative to minimize these impacts and increase the income of the organisms involved (Chopin et al., 2001).

According to Neori et al. (2007), the sustained expansion of intensive seafood production inescapably requires "trophic diversification" – an ecologically balanced, combined culture of organisms of high trophic levels (carnivores) with "service crops" from lower trophic levels (mainly seaweeds and filter feeders) to perform these tasks while adding income (Figs. 14 and 15). Based on this, the application

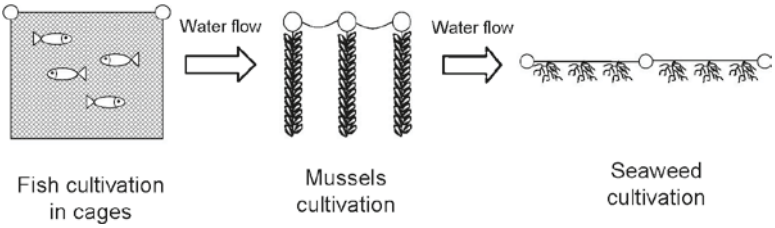


Figure 14. IMTA design in open sea and in Hainan Island cultivation (China) (Photos retrieved from Neori and Shpigel, 2006).

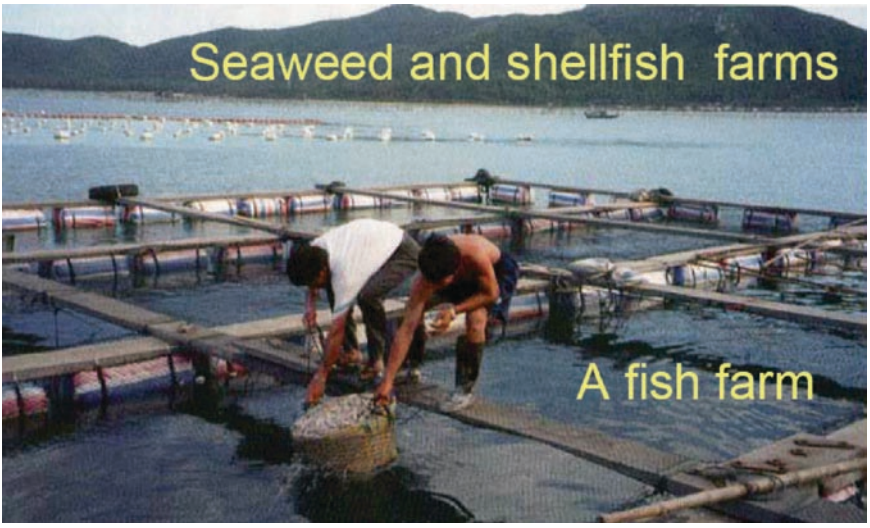


Figure 15. IMTA design in tanks and in Seaor Marine Enterprises in Israel (Photos retrieved from Neori and Shpigel, 2006).

of IMTA principles has been proposed as an eco-technological alternative to the optimization of productivity and utilization of energy, for removal and recycling toxic metabolites with the use of re-circulation systems. Adoption of such principles works towards the minimization and mitigation of the ecological impact of the activity (Folke and Kautsky, 1992; Buschmann et al., 2001; Chopin et al., 2001; Troell et al., 2003).

The best IMTA farms – whether intensive or extensive and whether in coastal waters, ponds, or tanks – are those in which there is a balance of waste production and extraction, thus becoming environmentally benign minibiospheres (Neori et al., 2007).

Seaweeds with commercial value were considered to be more advantageous, since they may offer high bioremediation efficiency and the nutrients absorbed are converted to biomass products (i.e. a nutrient sink), used for their growth. Apart from acting as agents for nutrient removal, seaweeds are promising sources of high-value biochemicals (such as antibiotics, cosmetics, and nutritional additives), phycocolloids (agar, carrageenans, and alginates), and nutritious food for other cultivated marine animals (such as abalone), and serve as popular and healthy foods, particularly in Southeast Asia. Together with shellfish, they are sources of healthy marine omega-3 fatty acids. With further research and development, and strain selection, many new uses could be found for various seaweeds, and they might even replace a significant proportion of the fishmeal employed to supply carnivorous fish diets with balanced proteins and oils (Neori et al., 2007). Ask and Azanza (2002) suggested that polyculture systems with commercial eucheumatoid species might improve the economic potential for cultivation if their production costs decreased and/or the production increased due to benefits derived from co-cultivation.

The potential for *Kappaphycus alvarezii* to remove N-compounds from seawater has been proven. Doty (1987) reported reductions of 24% in nitrate and nitrite concentrations, and a reduction of 6% in phosphate concentration by the commercial cultivation of *Eucheuma* (*Kappaphycus*) in the Philippines. Li et al. (1990) observed that plants fertilized for 1 h in 5–25 mM of ammonium had higher growth rates than plants without fertilization; however, plants fertilized with 35–50 mM of ammonium decreased their growth rates, probably because of the toxic effects of higher concentrations. These authors also observed that plants fertilized and transferred to open sea cultivation resulted in higher growth rates and carrageenan yield and quality than the control. According to them, the coloration of plants changed from yellowish-brown to dark brown, possibly indicating N storage. Mairh et al. (1999) tested other species, i.e., *K. striatum* and observed that cultures supplied with 1–3 mg N L^{-1} from $(NH_4)_2SO_4$ or 3–5 mg N L^{-1} NH_4NO_3 showed a significant increase in wet weight and bioaccumulation of total nitrogen content. The conclusions of this study proposed that the alga could accumulate NH_4^+ ions from low concentrations to maintain its growth. Dy and Yap (2001) observed that a surge uptake of ammonium by *K. alvarezii* usually occurred within the first 30 min of fertilization and ranged from 15 to 35 μmol NH_4^+ g^{-1} dry weight h^{-1}. The authors forecast that surge uptake might be an

important strategy for the alga to survive in areas with low nitrogen concentrations and take advantage of the naturally occurring nitrogen pulses in the field. Msuya and Salum (2007) observed higher carrageenan yield and gel strength in fertilized than unfertilized *K. alvarezii*, with TAN (total ammonia nitrogen) uptake efficiency of 81% after fertilization with 12:10:8 NPK in small natural pools that remained when the tide was out, in Zanzibar, Tanzania. However, in contrast, Msuya and Kyewalyanga (2006) working in a similar setup observed an average of 67 ± 15% TAN removal efficiency of *K. alvarezii* and no significant differences were observed in dry matter ($p = 0.347$), carrageenan yield ($p = 0.059$), *iota* content ($p = 0.767$), and gel viscosity ($p = 0.968$) between fertilized and unfertilized treatments.

Taking all this evidence into account, the efficiency of *K. alvarezii* as a biofilter has been tested in IMTA with oyster, shrimp, and fish. Qian et al. (1996) observed that *K. alvarezii* fertilized for 1 h with pearl oyster (*Pinctada martensi*) wastes grew faster than those without fertilization in sea cultivation. Lombardi et al. (2006) estimated a production of 17.5 kg of fresh *Kappaphycus* m^{-2} $year^{-1}$ co-cultivated with shrimps (*Litopeneaus vannamei*) in floating cages $1 \times 1 \times 1$ m^3. Despite the promising results, unfortunately, not one of the previous authors quantified the nutrients removed by the species. They only verified the effects of nutrient pulses on *K. alvarezii* growth (in the first case) and the productivity of the species cultivated in cages with the shrimps (in the second case).

The first attempts to evaluate the biofilter potential were made by Rodrigueza and Montaño (2007) and Hayashi et al. (2008), with an IMTA project including *K. alvarezii* with fish (*Chanos chanos* and *Trachinotus carolinus*, respectively). Despite the low growth rates obtained in these studies, the removal of ammonium from fish effluents was similar (e.g. 66–70%), in both studies. Rodrigueza and Montaño (op. cit.) observed a considerable increase in carrageenan yield from the plants cultivated in effluents; the rheological properties and colloid quality did not vary. Hayashi et al. (op. cit.) also observed maximal removal efficiency of 18.2% nitrate, 50.8% nitrite, and 26.8% phosphate, but did not distinguish any differences in carrageenan yield between plants cultivated in effluent or in the open sea. They also noted that after the period nutrient preconditioning by tank cultivation (10 days), healthy seedlings transferred to the sea cultivation presented higher growth rates than seedlings without previous tank cultivation, suggesting the possibility of nutrient storage.

As Troell et al. (2003) suggested, for future research it is essential to consider some important points listed below:

- Be familiar with biological/biochemical processes in closed recirculating and open seaweed cultivation systems
- Optimize the production of the extractive organisms as well as the fed organisms
- Try to establish the best water flow and circulation
- Conduct research into technologies at scales relevant to commercial implementation or suitable extrapolation

- Attain a detailed understanding of the temporal variability in seaweed-filtered mariculture systems and study the influences of location-specific parameters, such as latitude, climate, and local seaweed strains/species on seaweed filter performance, among other things

For details, see Troell et al. (2003).

The first published results obtaining by Rodrigueza and Montaño (2007) and Hayashi et al. (2008) are promising and require further study, searching the best site-specific system(s) that optimize the biofilter potential of the species, the seaweed growth, and (importantly) improve the carrageenan yield and quality to increase the economic benefits of the operational efforts.

According to Neori et al. (2007), the introduction of a nutrient emission tax or its exemption through the implementation of biomitigative practices would make the economic validity of the IMTA approach even more obvious. Moreover, by adopting the IMTA approach, the mariculture industry could increase its social acceptability. Although it is very difficult to assign a monetary value to such a sociopolitical variable, gaining public acceptance is imperative for the development of the industry's full potential. Also, reducing environmental and economic risk in the long term should make financing easier to obtain.

10. Efforts Taken to Combat the Problems

Apart from the efforts to combat the "ice-ice" problem, only limited efforts have been made by stakeholders, especially scientists and processing companies, to combat the die-off problem and increase seaweed production. One such effort was the development of the floating methods in contrast to the off-bottom method (Msuya, 2006b Msuya et al., 2007). Whereas the off-bottom method is used during low tides only, the deep-water floating lines technique can be used all the time. However, boats or canoes are required to go into deep waters for the floating lines technique. This may be a challenge to the poor coastal communities, but with more effort, entrepreneurship training, and encouragement, the farmers are able to possess at least one boat/canoe per family or per group.

Another example of efforts applied is the use of natural fertilization with seaweeds extracts to mitigate the proliferation of epiphytes, reduce die-offs, and increase productivity. Experiments utilizing Acadian Marine Plant Extract Powder (AMPEP) have been published; viz. Loureiro et al. (2009) tested apical branches of *Kappaphycus alvarezii* cultivated in vitro in different concentrations of AMPEP normally used in horticultural or agricultural applications for land plants. These authors observed considerable reduction of epiphytes and an increase in *Kappaphycus* growth rates. Other experiments could be made to test the effects of the extracts in open sea farms.

The growth of the three color morphotypes of *Kappaphycus alvarezii* var. *tambalang* was also enhanced using AMPEP. Furthermore, there was no incidence

of *Neosiphonia* infestation during the 3-month culture period and there was a limited occurrence of macro-epiphytes (A. Hurtado, 2008, personal communication). The presence of filamentous green *Ulva* did not hamper the robust and healthy growth of the three color morphotypes of *K. alvarezii* var. *tambalang*. The results of the study indicate the capacity of AMPEP to reduce the incidence of epiphytes. In another study, the use of AMPEP in tissue culture of *K. alvarezii* var. *tambalang* was successful in the micropropagation of plantlets for outplanting purposes (Hurtado et al., 2008).

Buyers of seaweeds who are also the exporters from producing countries have tried to solve the problem of die-off by introducing different varieties (or species) of *Kappaphycus*. In Tanzania, the buyers of the seaweed introduced a species of the seaweed, *Kappaphycus striatum* (locally known as "kikarafuu") about 5 years ago. This was done in collaboration with the government due to import restrictions on introducing new species. The species got its local name from its fronds that look like the clove, which is locally called karafuu in Kiswahili, the local language of Tanzania. The species is now farmed in a number of villages in the Zanzibar Islands. The buyers also introduced a species that is thought to be a variety of *Kappaphycus alvarezii* known locally as "kikorosho," which has not been as successful as the "kikarafuu." The additional species and variety had lower growth rates than the commonly farmed *K. alvarezii* (variety "cottonii"). However, they are not as prone to environmental problems as the cottonii, although *K. striatum* does get black spots (of unknown cause) during bad growth seasons.

Farmers have been practicing what we can call "shift cultivation." When they find that the seaweed is failing, the farmers have moved the cultivation site to a different area within the shallow lagoons. In Tanzania, for example, farmers in the area of Bagamoyo, on the mainland, have been doing this for sometime and it is possible for them to tell which area they can farm at what time of the year, although the weather has been very unpredictable in the most recent 2–3 years. Having found it difficult, due to the unpredictable weather, the farmers are now also using the deepwater floating lines technique following the efforts of scientists in Tanzania (Msuya et al., 2007).

11. Issues To Be Considered for the Future of *Kappaphycus* Farming

It has been shown that the farming of the genus has been failing in many cultivation sites where it used to grow well. It may well be that changes in environmental conditions over the cultivation periods have affected the seaweed negatively. Unfortunately, the actual causes of the die-offs are not studied extensively nor well documented, but possible causes such as abrupt changes in surface seawater temperature, salinity, pH, have been mentioned by several scientists as contributing factors, e.g. Bryceson (2002), Mmochi et al. (2005). Other negative impacts are suggested having anthropogenic causes, e.g. eutrophication from runoff, agrochemicals used in agriculture, etc. Whether these changes are related to global

climate change in surface seawater temperatures or direct anthropogenic causes must remain speculative until the issues are studied in much greater detail.

Floating cages are a good way of producing more *Kappaphycus* whether in polyculture or monoculture (Hurtado-Ponce, 1992). The fact that polyculture of the seaweed with animals such as shrimps (Lombardi et al., 2001, 2006) or fish (Rodrigueza and Montaño, 2007; Hayashi et al., 2008) leads to more production provides a bright future for production of the seaweed when demand for raw materials is high.

There is also need to further study the genetics of eucheumatoids and to cross-breed the *Kappaphycus* varieties currently cultivated to develop more resistant strains that can be farmed in the areas where the current strains have failed. This is a challenge to scientists as well as other stakeholders worldwide. The genetic modification of eucheumatoids should be rejected outright, since there will be significantly reduced demand for the carrageenan products if labeling (as practiced in EU countries) were required.

As seaweed farming has already been taken as a viable economic activity of many communities worldwide and as a tool for economic empowerment of coastal women in developing countries (Pettersson-Löfquist, 1995; Quiñonez, 2000; Bryceson, 2002; van Ingen et al., 2002; Msuya, 2006a), there is need to take more action to sustain the activity. The world preference of *K. alvarezii* as a source of *kappa* carrageenan as opposed to *E. denticulatum* (as the dominant source of *iota* carrageenan) is a challenge that should be taken by all stakeholders to find ways of producing more of the higher-valued, but environmentally challenged, species. Without concentrated, sustained additional efforts, the future of *Kappaphycus* monocrop cultivation could be at stake. All the stakeholders have a challenge of providing ways of solving the problem for the benefit of coastal communities, the producer countries, and the industry dependent on the reliable supply of high-quality, sustainably produced raw materials.

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