# Three decades of *Kappaphycus alvarezii* (Rhodophyta) introduction to non-endemic locations

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## Abstract

Given the increase in demand for sustainable livelihoods for coastal villagers in developing countries and for the commercial eucheumoid *Kappaphycus alvarezii* (Doty) Doty, for the carrageenan industry, there is a trend towards introducing *K. alvarezii* to more countries in the tropical world for the purpose of cultivation. However, there is also increasing concern over the impact exotic species have on endemic ecosystems and biodiversity. Quarantine and introduction procedures were tested in northern Madagascar and are proposed for all future introductions of commercial eucheumoids (*K. alvarezii, K. striatum* and *Eucheuma denticulatum*). In addition, the impact and extent of introduction of *K. alvarezii* was measured on an isolated lagoon in the southern Lau group of Fiji.

It is suggested that, in areas with high human population density, the overwhelming benefits to coastal ecosystems by commercial eucheumoid cultivation far outweigh potential negative impacts. However, quarantine and introduction procedures should be followed. In addition, introduction should only take place if a thorough survey has been conducted and indicates the site is appropriate. Subsequently, the project requires that a well designed and funded cultivation development programme, with a management plan and an assured market, is in place in order to make certain cultivation, and subsequently the introduced algae, will not be abandoned at a later date.

## Introduction

Commercial cultivation of *Kappaphycus alvarezii* (Doty) Doty was developed jointly by Marine Colloids Corporation (purchased by FMC Corporation in 1977 and now part of FMC BioPolymer) and by Dr Maxwell Doty of the University of Hawaii Botany Department (Parker, 1974). This occurred during the latter half of the 1960s in the Philippines using local varieties selected from the wild (Doty, 1973; Parker, 1974). Subsequently, these selected and cultivated varieties, as well as varieties of *K. striatum* and *Eucheuma denticulatum* (the commercial eucheumoids) were introduced to numerous parts of the world for the purpose of research or the development of a commercial cultivation industry, though only a fraction of these countries are commercial producers today. These introductions of cultivated varieties, primarily from the Philippines or originating in the Philippines, have occurred both inside and outside the native range of the commercial eucheumoids. That range is from east Africa to the Federated States of Micronesia (Doty, 1988). It should be noted that some phycologists consider *K. alvarezii* and *K. striatum* to be conspecific (Semesi, 1996).

In spite of three decades of *K. alvarezii* introductions (by far the most widely cultivated commercial eucheumoid), there are very few studies

that address its ecological impact (Russell, 1983; Woo *et al.*, 2000) and practically none from where it has been introduced for cultivation purposes.

This trend of introduction will probably continue for two reasons. First, the market for carrageenan continues to grow and current sources of cultivated eucheumoids seem incapable of meeting demand, at least within quality, price and volume flow requirements of the processing industry. Secondly, numerous tropical countries with coastlines are searching for sustainable alternative livelihoods for coastal villagers, particularly as part of coastal management programs. Commercial eucheumoid cultivation is a very attractive livelihood to promote. Given its numerous environmental, social, economic and political benefits (Ask, 1999; Zertuche-González, 1998) to date, it appears to be one of only a few successful aquaculture industries for coastal villagers. Today, over 100,000 t are produced annually by about 40,000 to 50,000 families worldwide.

Nevertheless, there has been increasing concern over the introduction of exotic species to coastal systems given the potential impact on native ecosystems and biodiversity (de Fontaubert *et al.*, 1996; Ribera & Boudouresque, 1995), as has occurred with *Caulerpa taxifolia* (Vahl) C. Ag. in the Mediterranean (Boudouresque *et al.*, 1995). In light of these events, a summary of all available records of euchemoid introductions and their impact is here reported. A case study of one lagoon in Fiji eight years after introduction and subsequent abandonment by villagers is included. Finally, the protocol for quarantine and introduction procedures for *K. alvarezii* applied in Madagascar is proposed.

## Materials & Methods

### *Eucheumoid introduction cases*

A review of all records available in the literature (or verified by the authors) is reported chronologically indicating its purpose (commercial or laboratory use), whether quarantine procedures were followed and whether introduction resulted in successful commercial farming.

### *Impact of introduction and abandonment of* K. alvarezii

On Ono-i-Lau Island, Fiji, a villager introduced *K. alvarezii* in 1990 with the intent to begin cultivation. However, no cultivation took place and the initial plants were left in the reef flat near the village (Sam Mario, *pers. comm.*). The cultivation industry in Fiji ended in 1993. In 1998, it was resumed and in mid-1999, Fiji's Ministry of Agriculture, Fisheries and Forestry's Fisheries Division targeted Ono-i-Lau for development. A survey of the area was done to determine how far afield the plants had spread and at what density (as % cover). Transects, following the techniques presented in English *et al.* (1997), were placed perpendicular to the beach where the introduction took place (20°40' S and 178°43.3' W). In addition, two sites, 500 m and 1 km to the north, were studied to gauge the spread of *K. alvarezii.* Five replicate transects were placed randomly at each location.

### *Introduction and Quarantine Practice*

Forty kilograms of *K. alvarezii* were collected from a farm 10 km from the airport of Unguja Island, Zanzibar, Tanzania. Only visibly clean and healthy thalli (without necrotic tissue, sediment, loose macroalgae, epiphytic algae and animals) were accepted. These plants were placed in insulated plastic containers and flown by private plane to Nosy Be, Madagascar and immediately taken to the Centre National de Recherches Océanographiques (CNRO) where a quarantine facility had been constructed. Government protocols for exportation from Tanzania and importation to Madagascar were followed, including the procurement of proper documents from respective government agencies.

Besides establishing a quarantine protocol, the introduction procedure created for the cultivated variety of *K. alvarezii* was designed by considering the guidelines proposed by the FAO-Code of Conduct for Responsible Fisheries (1995) and FAO-Technical Guidelines for Responsible

Fisheries (1996). Specifically, the following actions were taken:

- An economic analysis for the area was conducted in order to determine the economic feasibility of *K. alvarezii* cultivation.
- A market for the potential production was assured (FMC BioPolymer was an integral part of the project).
- A precautionary plan was established to reduce the risk if negative effects of introduction were realized.

*The precautionary plan included:*

1) A prior identification of the natural conditions where the plants were to be introduced and a programme to monitor the area after the seaweed introduction.
2) A quarantine facility design that considered Mexican Official Code NOM-011-PESC-1993 (1994) to regulate the application of quarantines. Specifically:
   - The unit was isolated from other aquaculture facilities.
   - It included structures that did not permit the entrance of other aquatic organisms.
   - It had an independent water supply of good quality.
   - It had a discharge system, also independent, which would allow the treatment of the water and would not allow the organisms to escape.

The quarantine facility at the CNRO on the island of Nosy Be consisted of four 1,000 l fibreglass containers as the holding facilities. Seawater from coastal water was filtered in series at 5 and 1 µm levels and placed in the tanks using an independent hose and pump system. Aeration was provided by battery powered aquarium aerators (six per container) that provided a minimal but adequate level of water flow.

The plants were maintained in the tanks for two weeks. A visual inspection, using a magnifying glass (5X), was performed on the thalli twice a week to monitor for the growth of macroalgae and animals. Water was changed twice per week with the discharged water treated with chlorine bleach (5.25 %) for 24 h at a dose of 125 ml $m^{-3}$ before being poured onto the ground 500 m from the coastline.

Plants were outplanted on June 21, 1998, to a long-line type test farm (Trono, 1993), located 2 km west of Helleville, Nosy-Be. Transect and manta tow surveys were conducted prior to and every three months after introduction for one year as part of a precautionary plan, following the techniques described by English *et al.* (1997). As a precaution against environmental problems, the test plot was small, observed daily and the entire system could have been removed in 15 min if needed. Soon after introduction, a farm site was created at 13°26.2' S and 48°22' E in 2–3 m of water at low tide. Twelve months later, a survey using transects was conducted at the introduction site and at sites 0.5 km north and south (up and down the beach) of the introduction site (Fig. 2) following the techniques described by English *et al.* (1997). This was done to assess changes in substrate and submarine biota between the farm site and the reference sites, which were deemed similar. Transects were placed perpendicular to the beach at random intervals and five replicates were conducted.

## Results

### *Eucheumoid introduction cases*

On most occasions, introductions have occurred without regard to internationally held protocols on quarantine and introduction such as those proposed by the FAO (FAO, 1996). Examples of uncontrolled introductions are Indonesia (Adnan & Porse, 1987), Tanzania (Lirasan & Twide, 1993) and Guadeloupe, French Antilles (Barbaroux *et al.*, 1984). On only two occasions were quarantine procedures followed for the introduction of *K. alvarezii* and on no occasion for *E. denticulatum*; in the Solomon Islands (Smith, 1990) and in Brazil (De Paula *et al.*, 1998), respectively. The former author gave no details of the procedure. The latter author cultivated 1 g in a closed system tank for

*Table 1.* (Updated from Ask & Azanza, 2001). Countries where commercial Eucheumoids have been introduced for cultivation or experimental purposes and where commercial quantities (1,000 m t $y^{-1}$) are currently being produced for the carrageenan industry.

| Country | Year Introduced or Experiments begun | Commercial? (1,000+ t $y^{-1}$) | Reference |
|---|---|---|---|
| Philippines | 1971 | Yes | Doty & Alvarez, 1973; Doty, 1973; Parker, 1974 |
| Indonesia | 1985 | Yes | Soerjodinoto, 1969, Adnan & Porse, 1987 |
| Hawaii, USA | 1971 | | Doty, 1985 |
| Djibouti | 1973 | | Braud *et al.*, 1974; Braud & Perez, 1978; Perez & Braud, 1978. |
| Fiji | mid-1970s, 1984 | | Prakash, 1990; Luxton, *et al.*, 1987; Doty, 1985 |
| Christmas Island, Kiribati | 1977 | Yes | Russell, 1982; Tanaka, 1990; Luxton & Luxton, 1999; Robertson, 1990 |
| Tuvalu | 1977 | | Gentle, 1990 |
| Samoa | previous to 1978 | | Doty, 1978 |
| Malaysia | 1978 | Yes | Doty, 1980 |
| French Antilles | 1978 | | Barbaroux *et al.*, 1984 |
| Tarawa Island, Kiribati | 1981 | | Tanaka, 1990 |
| Tonga | 1982 | | Doty, 1985; Tanaka, 1990; Fa'anunu, 1990 |
| Japan | 1983 | | Mairh *et al.*, 1986 |
| California, USA | previous to 1985 | Lab use only | Doty, 1985 |
| Ponape, Federated States of Micronesia | previous to 1985 | | Doty, 1985 |
| French Polynesia | previous to 1985 | | Doty, 1985; Tanaka, 1990 |
| Guam | previous to 1985 | | Doty, 1985 |
| China | 1985 | ? | Wu *et al.*, 1988 |
| Cook Islands | 1886 | | David Luxton *pers. comm.* |
| Maldives | 1986 | | de Reviers, 1989 |
| Solomon Islands | 1987 | | Tanaka, 1990; Smith, 1990 |
| Tanzania | 1989 | Yes | Lirasan & Twide, 1993 |
| India | 1989 | | Mairh *et al.*, 1995 |
| Florida, USA | 1988 | Lab use only | Dawes, 1989 |
| Cuba | 1991 | | Serpa-Madrigal *et al.*, 1997 |
| Vietnam | 1993 | ? | Ohno *et al.*, 1995; Ohno *et al.*, 1996 |
| Brazil | 1995 | | de Paula *et al.*, 1998; de Paula *et al.*, 1999 |
| Venezuela | 1996 | | Rincones & Rubio, 1999 |
| Kenya | 1996 | | Joseph Wakibia, *pers. comm.* |
| Madagascar | 1991, 1998 | | Mollion & Braud, 1993; Ask, *pers. comm.* |
| Cambodia | late 90s | | Daily Express, 2000 |

nine months.

Of the countries indicated in Table 1, however, only five cultivate and sell commercial eucheumoids today in quantities of 1,000 t or more (Philippines, Indonesia, Tanzania, Malaysia and Kiribati). Information about the fate of introduced plants is poorly documented.

## *Impact of Introduction and abandonment of* **K. alvarezii**

Coverage of *K. alvarezii* decreased markedly from the initial point of introduction at 5 % and 0 % at, respectively, 500 and 1,000 m from the introduction site (Fig. 1). In addition, most of the macroalgae represented at 1,000 m also exist at the introduction point, indicating that no species were out-

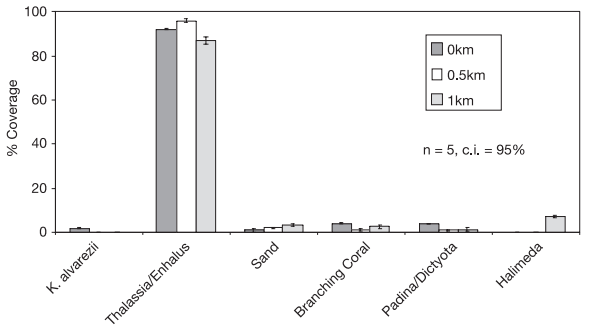


*Figure 1.* Percent bottom coverage results from transects (n=5) conducted at 0, 0.5 and 1 km from initial introduction of *K. alvarezii* to Ono-I-Lau Island lagoon in the Fiji Islands. Confidence intervals are 95 %.

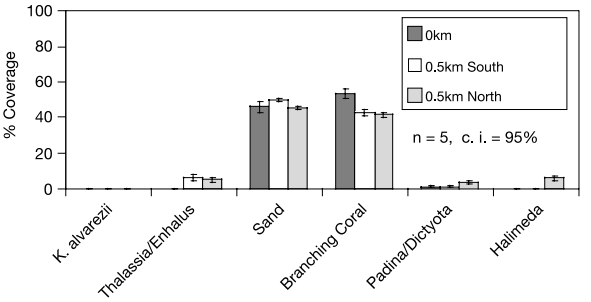


*Figure 2.* Results from transects at the introduction site and 0.5 km north and south of the farm site one year after introduction. There is no significant difference in bottom coverage between the farm site and the reference sites 0.5 km north and south of the site. Not one *K. alvarezii* propagule was found on the bottom at any of the sites. A confidence interval of 95 % and five replicates were used. In Northern Madagascar, the floating long line system is utilized and the depth of the water at these sites was 2 metres at low tide.

competed by 'wild' populations of *K. alvarezii*. *Kappaphycus alvarezii*, in addition, seemed only to survive in sandy hollows amongst eelgrass and wedged in between stones or coral heads. At the time of the survey, the plants were heavily grazed, probably by juvenile siganid fish. Only tip portions protected by outer thalli were growing well

Shortly after the survey, commercial harvesting began. Within two months, six dry t were harvested in Ono-I-Lau (Esaroma Ledua, *pers. comm.*) and a follow up visit indicated that very little wild *K. alvarezii* was left in the area. This indicates the power of 'gleaners' once a price is put on the seaweed. Currently cultivation is ongoing in Ono-I-Lau.

### *Introduction of* K. alvarezii *in Madagascar*

Upon arrival, 20 kg of material were selected. The rest that was stressed or damaged during transportation was sun dried. No macroalgae or animals were observed growing on the thalli during and after the quarantine treatment.

The transects sampled at the point of introduction and the similar sites 0.5 km north and south of the introduction site showed a similar bottom type and biota as well as no sign of free living *K. alvarezii* (Fig. 2). This indicates two things, first, there were no wild populations of *K. alvarezii* originating from the test-farm and second, the farm did not change the substrate and bottom biota.

## Discussion

The importance of quarantine procedures was highlighted by the introduction of *K. striatum* and *E. denticulatum* to Christmas Island, Kiribati (Russell, 1982). In this case, *Acanthophora spicifera* (Vahl) Boerg., *Dictyota acutiloba* J. Ag., *Hypnea musciformis* (Wulfen) Lamour and *Ulva reticulata* Forsskal were introduced with the commercial eucheumoids, probably as spores. Though they were apparently eradicated from the site, a quarantine system could have prevented the problem from arising in the first place.

Quarantine rules for many marine animals (molluscs, crustaceans and fish) describe two groups of disease: 'Certifiable' and 'Notifiable'. The former group consists of diseases that are difficult to control and may cause high mortality rates. The latter, 'Notifiable' diseases, are those that can be treated and subsequently have low mortality rates. When a species indicates a 'Certifiable' disease during quarantine, the organisms should be discarded in a way that precludes spreading the disease. When a 'Notifiable' disease appears, a treatment may be applied. In both cases, the disease has been previously described and a list of potential diseases is included. For the commercial eucheumoids (*Kappaphycus alvarezii*, *K. striatum* and *Eucheuma denticulatum*) diseases, as such, are

unknown. 'Ice-ice' is the only malady that has been noted among the commercial eucheumoids.

'Ice-ice' is a descriptive name for a malady that besets the commercial eucheumoids during stress (Largo *et al.*, 1995a). Though it has been associated with high levels of certain bacteria (Largo *et al.*, 1995b), it appears this is probably secondary to the condition. Stress induces the production of toxic volatile halocarbons by the plant itself, which in turn brings about necrosis of tissue in the stressed area of the plant (Pedersen *et al.*, 1996).

Thus, after 30 years of cultivation, no pathogenic agents for the commercial eucheumoids have been noted. To ensure that introductions of commercial eucheumoids are free of 'ice-ice', stress must be kept to an absolute minimum. If it does appear during introduction however, it apparently does not harm native plants. During the introduction of *Eucheuma denticulatum* in Guadeloupe, French Antilles, 'ice-ice' was rampant but did not spread to neighbouring endemic populations (Barbaroux *et al.*, 1984).

Based on the primary author's experience visiting farming sites around the world for 12 years, and the findings of Zertuche-González (1998), no serious and blatant impacts, such as decreased fish stocks, out-competing native species and destruction of habitat, have occurred. This study was done upon introduction, when no commercial farming was taking place. In a commercial operation, plants are not allowed to lie loose on the bottom because they have value. Either a farmer will pick up the plant and tie it to the farm, or 'gleaners', people who do not have farms but make a living by collecting 'drop-offs' from farms, will pick up the loose plants. In addition, the impact of introduction and farming must be weighed against the impact of not introducing *K. alvarezii* and cultivating it. The latter can have far more severe repercussions for the coastal ecosystem and biodiversity as villagers pursue alternative livelihoods such as dynamite fishing, cyanide fishing, overfishing with legal and conventional methods, coral harvesting, reef gleaning and unsustainable slash and burn farming on coastal hills causing sedimentation of coastal waters (Zertuche-González, 1998).

On most occasions, introduction and abandonment in other parts of Fiji and the world have resulted in the plants dying out. This was the case in Kiuva village, villages of the Rakiraki area and Lakeba village, Fiji, where farming produced 277 t in 1987 (Prakash, 1990) but was abandoned in 1993. It was also the case in the entire Solomon Islands where a recent search for seedstock in areas farmed 10 years ago revealed no *K. alvarezii* (Ask, *pers. comm.*) and in Samoa where farming trials were conducted over 20 years ago.

Of course, there are other situations like Ono-I-Lau, where introduced and abandoned *K. alvarezii* have survived and grown wild. This has been the case in a few other areas of Fiji, Tonga (Ask, *pers. comm.*) and in Kane'ohe Bay, Oahu, Hawaii, USA (Doty, 1978; Russell, 1983; Woo *et al.*, 1999; Rodgers & Cox, 1999). It should be noted that the introduction in Hawaii was for research purposes, hence there was never any economic force present that might deter the spread of wild plants by harvesting them. Therefore, it is not an example of the dangers that face introduction for commercial purposes in other countries. However, the Kane'ohe Bay case has been highly publicised and is often cited when discussions of introduction of *K. alvarezii* for commercial purposes occur, so it is important to understand that this situation is not representative of a commercial introduction. In addition, Kane'ohe Bay is by no means a pristine area. The entire ecosystem has changed dramatically over the last 100 years due to human impact (Gulko, 1998). The primary author has discussed the Kane'ohe Bay situation with a representative of the State of Hawaii's Department of Natural Resources' Aquatic Resource Division, suggesting that a volunteer cleanup be organized annually to 'mow the lawn' as it were. The production could be sold to a carrageenan company and money used to support a scholarship, for example. Nevertheless, it is important to recall that numerous foreign algae have been introduced to the islands of Hawaii and most, unlike the commercial eucheumoids, are spore bearing and have spread over a far larger area and have a greater biomass.

## Conclusion

It should be noted that nowhere in the world where *K. alvarezii* has been introduced for cultivation over the last 30 years have any blatant negative impacts occurred. It appears that one of three scenarios unfold upon introduction:

1. Farming is abandoned and commercial eucheumoids disappear completely from the environment.
2. Farming is abandoned and the commercial eucheumoids survive. This was the case in parts of Fiji (Ono-I-Lau, Taveuni and Lakeba) as well as Tongatapu, Tonga. In Kane'ohe Bay, Oahu Island, Hawaii, introduction was for research purposes only.
3. Farming is successful. In this case plants have value and those that drop off the farm are retrieved either by farmers or by 'gleaners', people who elect not to farm, but pick up and dry farm-loss plants.

Given this, the authors suggest that quarantine procedures should be followed and details of the introduction published for future reference. In addition, the introduction should be monitored for at least one year and contingency plans should be in place in case problems arise. The importance of an initial survey, adequate funding and experienced project management should also be recognized as important to establishing a cultivation industry. By following these criteria, it is believed that future introductions will result in a successful cultivation industry for all concerned, thereby justifying the introduction and allowing villagers to enjoy the benefits that a cultivation industry has to provide.

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