Exotic Seaweeds: Friends or Foes?

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Abstract

Introductions of exotic species are strongly associated with human mobility and with globalization; it has become a hotly-debated issue in the last decades. Although the marine environment forms a continuum over all the planet, there seems to be more concern with the introduction of marine organisms rather than terrestrial ones. On the other hand, there is a trend to consider organisms brought in from remote places as exotic, which is misleading from an ecosystems point of view. Although a few serious ecological problems have been reported for introduced seaweeds, experience has shown that serious effects arise mostly from accidental or involuntary introduction such as in ships' ballast waters, or associated with transplanted animals for aquacultural purposes. On the other hand, no dramatic problems have been clearly documented from planned introductions of commercial species, such as *Porphyra*, *Kappaphycus*, *Eucheuma*, *Gracilaria* and *Gracilariopsis* species. Nevertheless, each introduction should be treated as a unique case concerning the selected organism and the particular environment. We selected the recent introduction of *Kappaphycus alvarezii* in Brazil as a case study. We argue that if species are introduced following specific criteria and with the necessary safeguards, socioeconomic benefits can be achieved without provoking ecological catastrophes. In the framework of this polemic issue, this paper will address the question: Should we introduce exotic seaweeds in the Western Atlantic and the Caribbean?

Introduction

Distributions of many species are strongly affected by human interference with nature and intrinsically related to the mobility of human populations. However, a genuine concern about the consequence of human interference with the natural distribution of organisms is much more recent. The concern about introduced species in the marine environment has reached non-scientific journals and television broadcasts all over the world, and is much greater than the concern with the introduction of terrestrial organisms. This is somewhat surprising considering that most of the marine environment is spatially interconnected compared to the many apparent barriers that interfere with the natural distribution of terrestrial species. Barriers in the seas are represented mostly by temperature and salinity changes, which vary seasonally, rather than by physical discontinuities. The greater concern with the introduction of marine organisms is probably due to the fact that terrestrial species were introduced long ago, before the appreciation of their intrinsic ecological risk, and because marinomy, is a relatively recent activity. Introduction of marine organisms, in general, has been dealt with exhaustively (eg DeVoe, 1992; Carlton & Geller, 1993), including seaweeds (Neushul *et al.*, 1992; Ribera & Boudouresque, 1995).

Here, we discuss some guidelines of this polemic issue and argue that, under certain favourable circumstances, introductions of seaweeds can bring socioeconomic benefits without seriously damaging the environment. We focus our analysis on seaweed introductions in Western Atlantic and the Caribbean, using the introduction of *Kappaphycus alvarezii* (Doty) Doty in Brazil as a case study. This analysis is timely because a lively debate exists in Brazil, Cuba and Venezuela attempting to define polices and legal constraints regarding the introduction of seaweeds.

The concept of exotic species

There is a general trend to consider only species that originated from another sea or remote places as exotic. Nevertheless, from an ecosystem point of view, an exotic is a species that is found outside its range of natural distribution as a consequence of a process of dispersal by non-natural means. This means that a species can be considered exotic if it came from a nearby environment within the same country, perhaps just a few kilometres away (A Bellorin & E Oliveira, unpublished). As organism's distribution does not respect political boundaries, introduction polices should be determined not only by the authorities of the interested county and country, but also by neighboring countries or even macro-geographic regions.

Main routes of introduction of exotic organisms in the sea

Introductions can broadly be divided into two categories: voluntary and involuntary (Fig. 1). In most cases, introduced organisms do not adapt to the new environment, and disappear. A gross estimation of the chance an alien species has to become a problem is known as the 'tens rule'. It states that only 10 % of the feral invaders become established, of which only 10 % become pests (Williamson, 1996). In the case of an involuntary introduction, the success or failure of the introduction process usually goes unnoticed, unless it becomes a notorious nuisance or welcomed resource. An example is the accidental introduction of *Laminaria japonica* Aresch. on the north coast of China, which lead to its domestication and the most successful programme of mariculture in the world (Tseng, 1981, Neushul et al., 1992). On the other hand, successful voluntary introductions can result in the establishment of longstanding populations whose exploitation may bring economic benefits if there is a market for the introduced organism. This was the case for the introduction of *Porphyra* spp in China and Korea, which resulted in commercial success

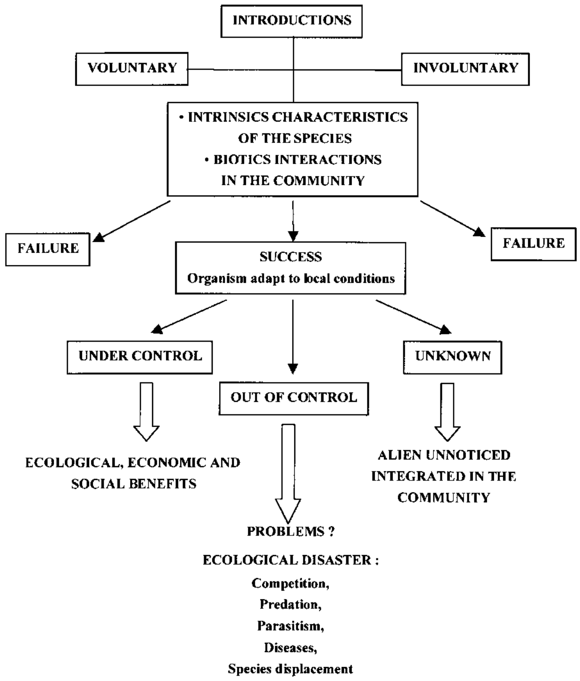

Figure 1. Possible fate of introduced organisms (modified from A. Bellorin & E. C. Oliveira, unpublished).

(Tseng, 1981, Neushul et al., 1992). However, voluntary introductions of marketable species can result in ecological problems. This happens when the introducing agent loses control of the introduced organism that becomes an invasive pest. The concept 'pest' is relative in time and space, but usually refers to an organism outside its natural distribution, which brings about economic or environmental negative impacts.

Introductions initially cause a diversity increase. This is a situation that sometimes becomes reversed due to species interaction, particularly if introduced species overcome local ones. At one extreme, species introductions could lead to the most severe problem in biological conservation, the extinction of one or more local species. This scenario can result directly from competition among similar species (eg Ribera & Boudouresque, 1995) or indirectly from the involuntary co-introduction of a contaminant such as a predator or pathogen (eg Grosholz *et al.*, 2000). Russell (1982) reports that the introduction of *K. alvarezii* (as *K. striatum*) and *E. denticulatum* (Burman) Collins & Hervey to

Kiribati, from Hawaii for mariculture purposes, resulted in the introduction of *Acanthophora spicifera* (Vahl) Børgesen, *Dictyota acutiloba* J. Ag., *Hypnea musciformis* (Wulfen) Lamour. and *Ulva reticulata* Forsskål. All were involuntarily brought in as epiphytes.

The issue of intentional versus accidental introduction is important. Most of the serious problems related to introduced organisms are the consequence of unplanned introductions. This is usually associated with poorly planned introductions lacking a careful quarantine programme. The repetitive introduction of the Japanese oyster *Crassostrea gigas* to many places in the world has been considered a remarkable success (Stickney, 1992). However, the introduction of this oyster was also considered to be a vector for the introduction of undesired organisms (Ribera & Boudouresque, 1995; Verlac, 1996).

An important source of indirect introduction of marine organisms is related to the global circulation of ships, via sessile organisms attached to the hulls and within ballast waters (Carlton & Geller, 1993). The latter is a dispersal mechanism that has no analog in terrestrial systems. These great volumes of water transport various diaspores thousands of kilometres away, resulting in phyletic and non-selective introductions. A survey of organisms brought within ballast water by Japanese vessels in Oregon found 367 species including sixteen animal, three protist and three plant phyla (Carlton & Geller, 1993). In San Francisco bay, California, a survey detected 255 species of exotic invertebrates attributed to involuntary introduction (Hedgepeth, 1993). A few dozen seaweeds species have been involuntarily introduced in the Mediterranean this century (Verlac, 1996). All those species have become integrated in the local ecosystems, increasing the biodiversity without causing much concern.

Less obvious sources of involuntary introductions have gone unnoticed. Likely candidates are imported microalgae, used in aquaculture to fed animal larvae and frozen marine food products that may be contaminated with microorganisms capable of invading local environment.

The main problem is that we can only guess about pristine biogeography, and many floristic and faunistic surveys were made on already disturbed communities.

Examples of ecological problems caused by exotic seaweeds

Sargassum muticum (Yendo) Fensholt, and *Caulerpa taxifolia* (Vahl) C. Ag. are the most notorious villains among introduced seaweeds (eg Ribera & Boudouresque, 1995). Neither has commercial value and both were introduced accidentally. *Sargassum muticum*, a brown algal species originating in Japan, spread to several places where *Crassostrea gigas* was introduced for mariculture (Lüning, 1990). The green algae *Caulerpa taxifolia*, has caused great concern in the Mediterranean and seems to have spread to California (algae-l@listserv.heanet.ie). *Caulerpa taxifolia* was introduced to the Mediterranean by aquarists (Jousson *et al.*, 1998), and is possibly a clone from an Australian population (Jousson *et al.*, 2000). In addition to these two 'classic' examples are reports of other seaweeds causing ecological disturbance. These cases are on a smaller scale and less thoroughly documented.

Should we introduce exotic seaweeds in the Western Atlantic?

Regarding putative seaweed candidates for introduction in Latin America, we should consider only species with great commercial potential.

Among the agarophytes, the candidates are the temperate water species *Gracilaria chilensis* Bird, McLachlan and Oliveira, *G. gracilis* (Stack.) Steentoft, Irvine and Farnham and the warm water species *Gracilariopsis tenuifrons* (Bird & Oliveira) Fredericq & Hommersand. The two temperate species of *Gracilaria* are the most promising since they have been partially domesticated, there is a known technology for cultivation and, above all, a growing market. Laboratory experiments have shown that both species can adapt well to subtropical waters (Macchiavello *et al.*, 1998). In the tropical Atlantic and Caribbean, there are more than a dozen species of *Gracilaria* (Oliveira & Plastino, 1994). However, most of them do not produce quality agar, have a small thallus or do not adapt to an economically feasible cultivation technology. Similar problems exist for warm water carrageenophytes. *Hypnea musciformis*, for example, has a market, but the cultivation technology is not available. To produce carrageenan in the warm waters of the Caribbean and the Western Atlantic, the best candidates are the aliens species of *Kappaphycus* and *Eucheuma*. Rodgers & Cox (1999) reported that *Kappaphycus* had spread in Hawaii beyond the areas of introduction in the early 1970s, but gave no evidence that the species became an ecological problem.

With the large market for nori, especially in Brazil, *Porphyra tenera* Kjellm. and *P. yezoensis* Ueda are strong candidates for introduction to warm temperate waters (*sensu* Lüning, 1990). Other popular algae utilized as food, such as *Laminaria japonica* Aresch. and *Undaria pinnatifida* (Harvey) Suringar, are not recommended for introduction since they have a small market and are difficult to control. The involuntary (?) introduction of *U. pinnatifida* in Argentina is currently causing concern (Casas & Piriz, 2000, at http://www.ib.usp.br/apf). In addition, evidence exists that species of *Porphyra* and *Undaria* had been introduced in southern Brazil (Oliveira, 1984), but died out.

The case of Kappaphycus alvarezii introduction in Brazil

Introductions of *Kappaphycus* and *Eucheuma* spp. have been attempted in many places (Table 1). There is anecdotal evidence that a species of *Eucheuma* (probably *Kappaphycus alvarezii*), was introduced many years ago in northeast Brazil, without the support of scientific personnel or observation of minimum protocols of quarantine, but soon disappeared (Oliveira, 1984).

The present programme of introduction of *K. alvarezii* in Brazil has followed a series of steps:

1. Literature review of the biological, ecological and maricultural attributes of the species, including reports of previous introductions related to disease, dispersal, reproduction and

Table 1. Examples of experimental introductions of *Eucheuma* and *Kappaphycus* spp. aiming at mariculture.

Locality	Year	Species	Biomass	Reference
Hawaii	1971	*K. alvarezii*	—	Doty, 1985
	1974	*K. alvarezii*	—	Russell, 1983
Djibouti	1975	*E. spinosum*	—	Pérez & Braud, 1979
Fiji	1976	*K. alvarezii*	—	Luxton *et al.*, 1987
	1984	*K. alvarezii*	—	Luxton *et al.*, 1987
Kiribati	1977	*E. denticulatum*	10 kg	Russell, 1982
	1977	*K. alvarezii*	10 kg	Russell, 1982
French Antilles	1978	*E. denticulatum*	—	Barbaroux *et al*., 1984
Japan	1983	*K. striatum*	15 g	Mairh *et al*., 1986
	1991	*K. alvarezii*	4 g	Ohno *et al.*, 1994
Indonesia	1984	*K. alvarezii*	—	Adnan & Porse, 1987
Maldives	1986	*Eucheuma* sp.	85 kg	De Reviers, 1989
Zanzibar	1989	*K. alvarezii*	3 kg	Lirasan & Twide, 1993
	1989	*E. spinosum*	2 kg	Lirasan & Twide, 1993
Cuba	1991	*E. denticulatum*	—	Areces, 1995
	1991	*K. alvarezii*	—	Areces, 1995
	1991	*K. striatum*	—	Areces, 1995
Vietnam	1993	*K. alvarezii*	0.5 kg	Ohno *et al.*, 1996
Brazil (RN)	—	*Eucheuma* sp.	—	Oliveira, 1984
Brazil (SP)	1995	*K. alvarezii*	2.5 kg	Paula *et al*., 1998
Venezuela	1996	*K. alvarezii*	4.5 kg	Rincones & Rubio, 1999
	1996	*E. denticulatum*	2.0 kg	Rincones & Rubio, 1999

consequences to the environment (Paula *et al*., 1998).

2. Selection of a vigorous and sterile strain from plants propagated in Uranouchi Inlet in Tosa Bay, Japan. This strain was introduced to Japan from Northern Bohol, Philippines (M. Ohno, *pers. comm*.).
3. The project began with a unialgal culture started from a single branch of 2.5 g grown under standard conditions (Oliveira *et al*., 1995) in our laboratory located 60 km from the coast. This branch was propagated *in vitro* for ten months to ensure that we were dealing with a unialgal culture (Paula *et al*., 2001).
4. Twenty branches produced *in vitro* to mean fresh weights of 3.0 g were transplanted monthly to a protected bay in Ubatuba, SP, Brazil (23°S).

The introduction site was located close to a rocky shore dominated by belts of *Sargassum vulgare* C. Ag. and *Pterocladiella capillacea* (Gmelin) Santelices et Hommersand. Sixty five species of seaweeds have been identified in the region (Horta & Berchez, *unpubl*.). The site is located within the marine premises of a state owned mariculture research centre that hosts several ecological and experimental mariculture studies, including the local mussel *Perna perna* and the red alga *Hypnea musciformis*.

Factors that could be considered unfavourable for *K. alvarezii* growth at this site are: i) low water temperature (annual mean of 20°C); ii) high turbidity and rainfall (100–500 mm per month); iii) high rates of epiphytism and herbivory (Berchez *et al*., 1989) and iv) eutrophication by urban sewage. In light of these disadvantages, we hypothesized that a floating culture method would reduce most of the limiting factors and allow reasonable growth of *K. alvarezii* during some periods of the year.

Our experiments were made on a floating raft (6.0 x 6.0 m) anchored 30 m from the rocky shoreline at a depth of 3.5 m on a sandy bottom. The system contained nine polypropylene ropes placed horizontally at a depth of 30–40 cm. Each rope supported 20 *K. alvarezii* cuttings. Additional ropes were tied on a mussel culture system located close by. Vertical ropes were also mounted to assess limiting factors for growth, such as light attenuation and herbivory at different depths.

Experimental data

The results summarize observations made monthly from 1996–1999. Daily growth rates varied seasonally from 3.6 to 8.9 % day^{-1} (Table 2). Growth rates were positively correlated with seawater temperature, which had monthly means from 20.3 to 28.5°C, with extremes of 17.0 and 32.0°C. Secondary factors affecting production were occasional grazing and one event of salinity reduction (30–35 to 15 PSU) due to heavy rains. Light attenuation and grazing limited growth to a maximum depth of 60 cm.

This system has yielded a few tons of *K. alvarezii* in the last four years (de Paula & Pereira, *unpubl*). During this period, many specimens were lost, and the putative sterile clone became reproductive and produced tetraspores (Paula *et al*., 1999). Since the beginning of the experiment, we have been looking systematically for the establishment of *K. alvarezii* in the surrounding area. So far, after five years of observations, we could not find any plant attached to rocks or other substrate in the area.

Conclusions

In spite of many successful examples (eg Steirer, 1992), there has been a trend among biologists to point out only the negative aspects of species introduction. This cautious yet pessimistic approach disregards the fact that modern life with all its commodities would not have been possible in many regions without the introduction of various species of plants, animals, fungi, protists and bacteria.

Regarding seaweeds, the reported problems have resulted from non-controlled involuntary introductions illustrated by the invasive *Sargassum muticum* and *Caulerpa taxifolia*. It is clear that the introduction of economically valuable algae is less likely to be a problem because of harvesting. In addition, we know that red algae have very effective reproductive isolating mechanisms and do not

1. Growth rates: 3.6–8.9 % per day	(+)
2. Semi-refined Kappa carrageenan yield: 25–35 % (d.w.)	(+)
3. Absence of epiphytic macroalgae	(+)
4. Epiphytism by ascideans	(–)
5. Absence of noticeable diseases in a period of four years	(+)
6. Moderate herbivory by sea hare, turtles and fish	(–)
7. Atraction of fish juveniles (groupers, triggerfishes, etc.)	(+)
8. Reproduction by spores (tetraspores)	(–)
a) low viability of spores	(+)
b) possibility of strain selection	(+)
9. Biomass loss due to various causes (1.7 %).	(–)
10. Plants did not colonize any substrates	(+)

Table 2. Mean results obtained monthly from 1996–1999 with *Kappaphycus alvarezii* on a floating raft experimental cultivation at Ubatuba, SP, with indication of positive and negative factors in view of commercial cultivation and dispersion (modified from Paula & Pereira, 1998).

hybridize (eg Plastino & Oliveira, 1988).

Environmental risks are implicit to human manipulations, including mariculture. However, one should consider that mariculture is a significant source of employment, food and other products in many regions. Furthermore, seaweed cultivation can potentially ameliorate the serious problem of eutrophication that threatens marine ecosystem biodiversity via blooms of harmful algae.

We agree with Sinderman (1992), that a balance must be achieved between complete laissez-faire and total prohibition regarding marine introduction. With careful planning and selection of species and localities, technology exists to successfully introduce valuable species of seaweeds with a minimum of risks and maximum of benefits. In doing so, we can avoid the 'ecological roulette' (Carlton & Geller, 1993) of badly planed introductions. Above all we should look more seriously to the many instances of involuntary introduction of aliens, and take measurements to effectively restrict them in benefit of well-planned and purposeful introductions.

Finally, the answer to the question in the title is probably: Friends and foes.

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