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# Red algal farming in Chile: a review

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## Abstract

Production of seaweeds in Chile has fluctuated between 74,000 and 322,000 wet metric tons/year during the last 14 years, involving different species of Phaeophyta and Rhodophyta. Among Rhodophyta, the most important harvested species include the carrageenophytes *Sarcothalia crispata*, *Mazzaella laminarioides*, *Gigartina skottsbergii*, *Chondracanthus chamissoi*, and the agarophytes *Gracilaria chilensis* and *Gelidium lingulatum*. Other less important taxa are *Gel. rex*, *M. membranacea*, *Ahnfeltia plicata*, *Ahnfeltiopsis furcellata*, *Porphyra columbina*, *Callophyllis variegata*, *Mastocarpus papillatus* and *Chondrus canaliculatus*.

Chilean production comes mainly from wild stocks, as at present, cultivation on a commercial scale is restricted to *Gra. chilensis*. Total landings of *Gracilaria* currently stand at 120,000 wet tons. Large-scale cultivated biomass of this species, on the other hand, has been the result of a sharp increase in the number of farms, from less than 10 in 1982 to almost 322 in 1996. A basic understanding of key biological and ecophysiological aspects, as well as the availability of propagation methods, permitted the development of large-scale *Gracilaria* farming operations. However, during the cultivation process, new problems arose for the farmers, such as abrupt production decline, pests and pathogens.

Similar key knowledge is lacking for other Chilean Rhodophyta, which creates a bottleneck that prevents the development of seaweed farming activities other than *Gracilaria*. This situation prevails in spite of the growing pressure on wild stocks triggered by an increase in the demand for raw material by the industry, with the obvious danger of over-exploitation and the resulting collapse of fisheries. Taking the above into consideration, an effort has been made in recent years

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to provide the basic knowledge necessary for the management and cultivation of some of the most valuable seaweed resources in Chile. Thus, the main objective of this contribution is to summarize the present situation of red seaweed cultivation in the country. We will address this issue by reviewing the landing statistics of these resources, followed by a summary of recent information that favours cultivation. These include propagation methods, culture conditions and techniques, product quality, pest management, strain selection and the diversification of seaweeds currently exploited in Chile. 

*Keywords:* Agarophytes; Carrageenophytes; Chile; Edible seaweeds; Research advances; Seaweed cultivation

## 1. Introduction

Over the last 15 years, seaweed research and utilization in Chile has entered a phase characterized by the development of: (a) an industrial capacity to produce and process algae; (b) a scientific capacity to study seaweeds, and (c) a closer, although still weak, relationship between scientists and industry (Santelices, 1996). In this scenario, seaweed production in Chile reached a maximum (322,000 wet metric tons/year) during 1996, involving various species of Phaeophyta and Rhodophyta. Among Rhodophyta, the most important harvested species are the carrageenophytes *Sarcothalia crispata*, *Mazzaella laminarioides*, *Gigartina skottsbergii*, *Chondracanthus chamissoi*, and the agarophytes *Gracilaria chilensis* and *Gelidium lingulatum* (Norambuena, 1996). Other taxa which also contribute to the harvested biomass, although to a lesser extent, are *Gel. rex*, *M. membranacea*, *Ahnfeltia plicata*, *Ahnfeltiopsis furcellata*, *Porphyra columbina*, *Callophyllis variegata*, *Mastocarpus papillatus* and *Chondrus canaliculatus* (Norambuena, 1996). Algal production in Chile is mainly based upon the exploitation of wild stocks; cultivation on a commercial scale remains restricted to *Gra. chilensis* (Buschmann et al., 1995; Norambuena, 1996).

The main objective of this contribution is to summarize the present state of knowledge on red seaweed cultivation in the country. We address this issue by reviewing both landing statistics and advances in biological knowledge made in recent years. These advances include propagation methods, culture conditions and techniques, product quality, pest management and strain selection, all of which are foreseen as the basis for diversifying red seaweed farming in Chile. Statistics on seaweed exploitation have been repeatedly reviewed (e.g. Avila and Seguel, 1993; Norambuena, 1996; Santelices, 1996). Therefore, our study will be restricted to recent seaweed landings. Exploitation and processing of brown algae in Chile was the subject of a recent review (Vásquez and Vega, 1999).

## 2. Seaweed landings

In 1996, total seaweed landings reached over 322,000 wet tons, but decreased after 1997 because of the Asian economic crisis, and ca. 50% of the landings are red algae (Fig. 1A). Red species are predominantly harvested in the south (Fig. 1B and C), and are either used directly as food, or as raw material for extracting agar and carrageenan. The

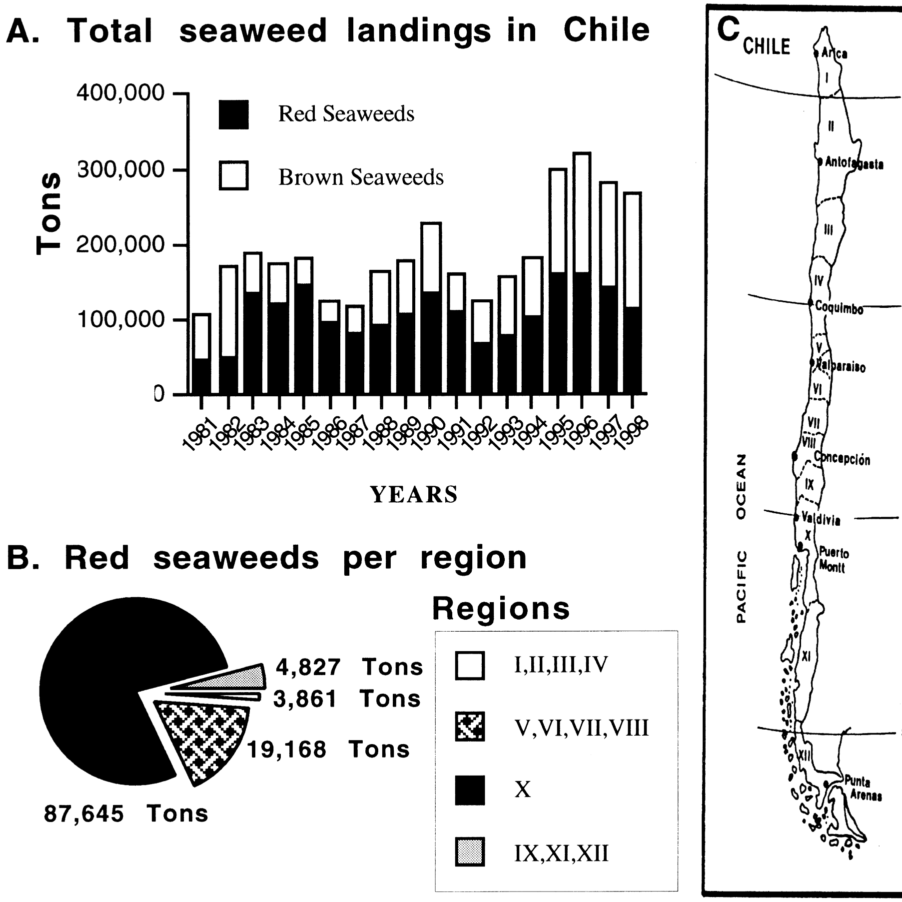


Fig. 1. (A) Total landings (wet tons) of brown (white bars) and red (black bars) seaweeds in Chile; (B) red seaweed landings per administrative region during 1998; (C) map showing the distribution of the administrative regions in Chile.

most commonly exploited agarophytes are *Gra. chilensis, A. plicata,* and *Gel. lingulatum*. Exploitation of natural *Gra. chilensis* beds reached a peak in 1985, and was followed by a gradual but steady decrease during the next few years due to over-harvesting, and unfavourable market conditions (Norambuena, 1996). However, during 1995 and 1996, production was as high as in 1985, with over 120,000 wet tons, and was sustained mainly by the development of management strategies (Poblete and Inostroza, 1987; Poblete et al., 1991), and more importantly, by the establishment of over 500 farming operations (Fig. 2A and B). Farming of *Gra. chilensis* was possible because of the existence of a basic understanding of key biological aspects, such as propagation methods and ecophysiological responses under cultivation conditions, which allowed the development of large-scale planting methodologies (Pizarro, 1986; Santelices and Ugarte,

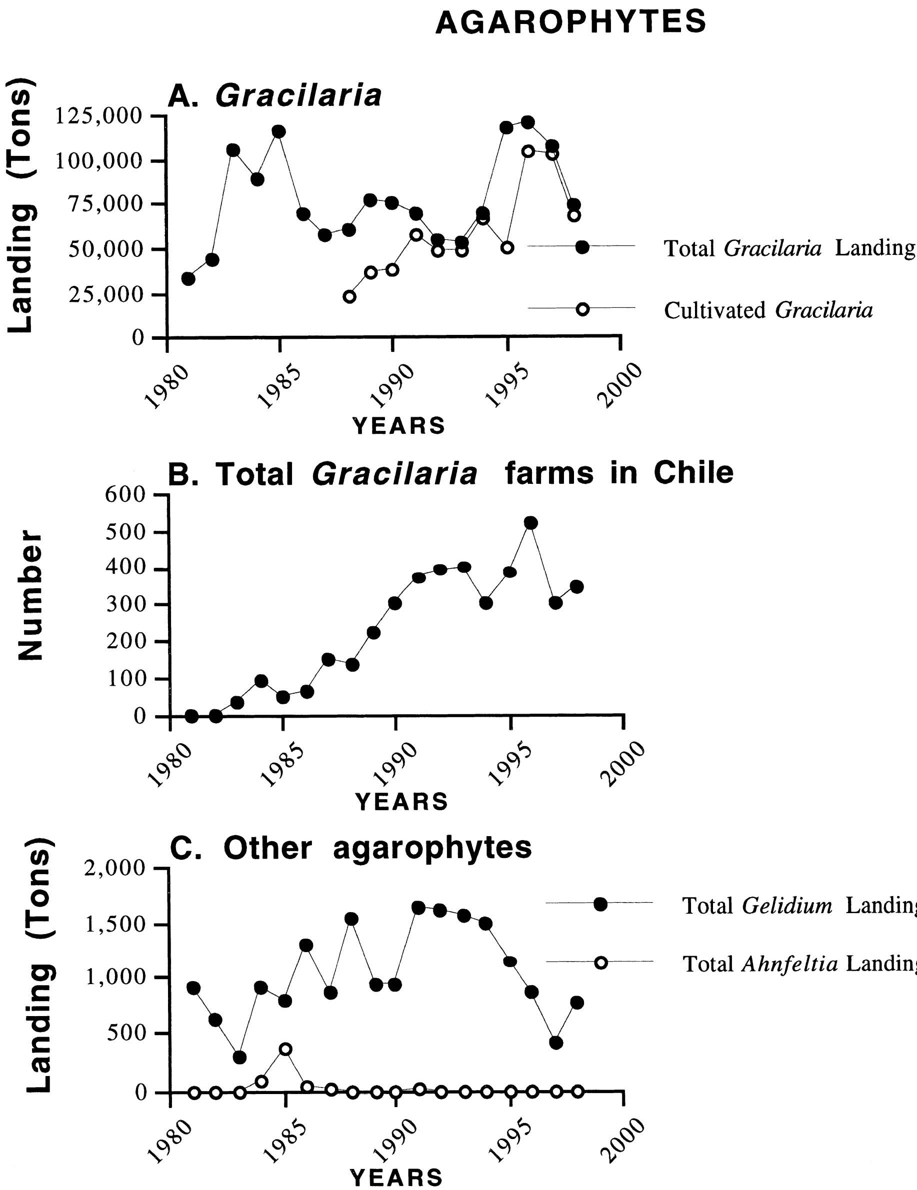


Fig. 2. Agarophytic seaweed production (wet tons) in Chile. (A) Total *Gracilaria* landings and cultivated *Gracilaria* production; (B) number of farms licensed in Chile and (C) landings of *A. plicata* and *Gelidium* production.

1987; Buschmann et al., 1995). Exploitation of *Gel. lingulatum* fluctuated between 800 and 1600 wet tons during the last 10 years, whereas *Ahnfeltia* has been exploited erratically and only in small amounts (Fig. 2C).

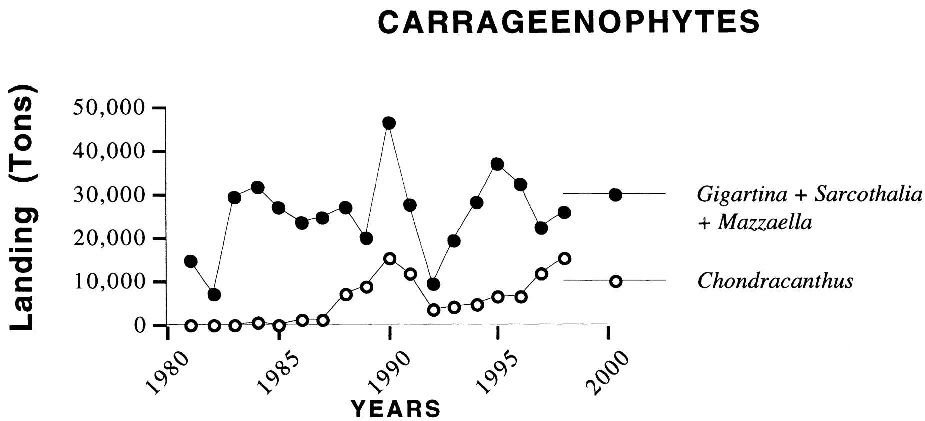


Fig. 3. Carrageenophytic seaweed production (wet tons) in Chile.

The carrageenophytic algal genera mostly exploited in Chile include *Gigartina*, *Chondracanthus*, *Sarcothalia* and *Mazzaella*. Although landings of these species have not increased during the last 10 years, they show a high degree of variation (Fig. 3). *Chondracanthus* is also harvested to be processed as an edible species and exported to Japan. It is not possible to establish the proportion used as raw material by the carrageenan industry and that exported as an edible seaweed. Significantly lower biomass has been obtained from *Gymnogongrus furcellatus* stands (Buschmann et al., 1999a).

Edible seaweeds have also been traditionally exploited in Chile. Landings of the red alga *Porphyra columbina* vary from a few tons to more than 180 wet tons/year (Fig. 4). Another exploited Rhodophyta is *Callophyllis variegata*, (Fig. 4), which has a promising future due to its high commercial value, currently at almost US$ 30/dry kg.

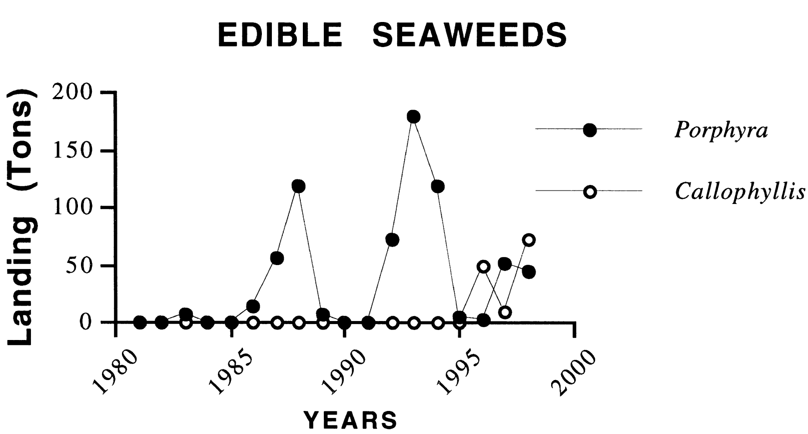


Fig. 4. Edible seaweed landings (wet tons) in Chile.

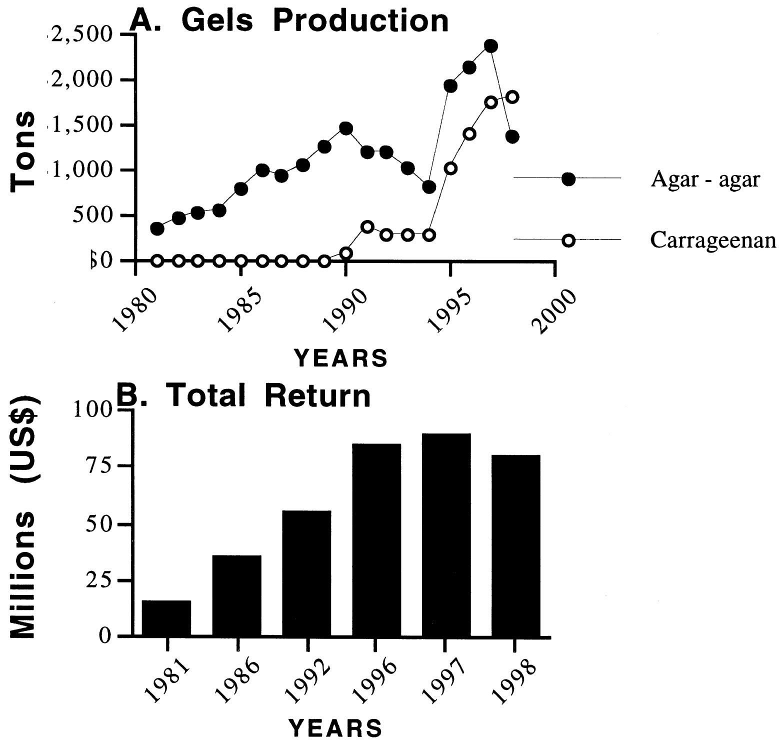


Fig. 5. (A) Gels production (tons) (agar and carrageenan) and (B) total returns (US$) of seaweed products in Chile.

As indicated above, *Chondacanthus chamissoi* is another species presently exploited and processed for this purpose.

Seaweed processing in Chile has increased substantially in recent years. Agar production reached a total of 2,394 tons after 1990, experiencing a decline during 1998 (Fig. 5A). On the other hand, carrageenan production, which began in 1990, has increased steadily, reaching values of 1,834 tons in 1998 (Fig. 5A). Exports of these polysaccharides generated returns of more than US$61 million in 1996. Thus, in 1997 the seaweed industry as a whole represented a revenue of ca. US$90 million to the country. Due to the oriental economic crisis, returns to Chile have declined (Fig. 5B), but information on algal exports and processing indicates that during 1999 demands were on the rise again.

## 3. *Gracilaria* cultivation

It has been indicated that in spite of the morphological variation, Chilean *Gracilaria* correspond to only one species (González et al., 1996; Meneses, 1996; Candia et al., 1999). Cost-benefit analyses indicate that, in Chile, *Gra. chilensis* farming is economically profitable (Pizarro, 1986; Martínez et al., 1990; Buschmann et al., 1995), which has stimulated the activity in recent years. The agar from *Gra. chilensis* has a greater resistance to hydrolysis during storage and a high 'sugar reactivity' (Arminsen, 1995), characteristics which determine the high demand for Chilean *Gracilaria* by the food industry. As prices have been highly variable over the past 10 years (Buschmann et al., 1995), it seems important to optimize production by lowering the costs and increasing productivity through the establishment of better management strategies. In this context, it is our view that the development of basic and applied research is crucial to improve the sustainability of this activity in the country. In the following sections, we describe the cultivation techniques commonly used, the potential problems faced by farmers, and, when available, the possible solutions to those problems.

### *3.1. Cultivation techniques*

Several planting techniques have been developed to fasten *Gracilaria* to the substratum (see Alveal, 1986; Pizarro, 1986 for an extensive review of planting techniques), and two of them have been the most commonly used by commercial farms in Chile. The first of these methods (Direct Method) consists of a direct burial of the thalli into the sandy bottom using different types of tools (see Fig. 4A in Buschmann et al., 1995). The second method (Plastic Tube Method) consists of fastening bundles of thalli to plastic tubes filled with sand, which anchor the algae to the sea bottom (see Fig. 4B in Buschmann et al., 1995). All planting techniques rely upon the capacity of *Gracilaria* to develop an underground thallus system (Santelices and Fonck, 1979; Santelices et al., 1984) which anchors the algae to the soft bottom. After the planting process, beds are maintained by vegetative growth from the underground thallus system which is able to survive burial for several months (Santelices et al., 1984). As the topography of the sandy substratum changes with water currents, buried thalli become exposed to light and growth begins. In general, commercial subtidal farms use the method of plastic tubes (Pizarro and Barrales, 1986; Westermeier et al., 1988a), whereas intertidal farms are planted using the direct technique during low tides, which expose extensive mudflats characteristic of the southern part of the country (Buschmann et al., 1995). This intertidal planting system results in dense seaweed stands in only a few months. Artificially planted areas show the same seasonal pattern of biomass fluctuation characteristic of wild stocks of *Gracilaria* (Pizarro, 1986; Santelices and Doty, 1989). This seasonal pattern is characterized by high growth rates during spring, followed by a decline toward summer and the lowest growth in winter. Storms that naturally remove biomass, or human harvesting, are the main factors modifying the seasonal pattern of growth in *Gracilaria* (Pizarro, 1986).

For subtidal areas in southern Chile, it has been established that *Gracilaria* production can reach 91–149 tons $ha^{-1}$ $year^{-1}$ (Westermeier et al., 1991). In contrast, intertidal systems established at the same latitude are less productive, with biomass levels never exceeding 72 tons $ha^{-1}$ $year^{-1}$ (Buschmann et al., 1995). In northern Chile, on the other hand, production can be higher than in the south of the country (Pizarro, 1986), a phenomenon apparently related to higher temperatures and longer light regimes. Oceanographic conditions also have a major influence on production (Pizarro and Santelices, 1993). Harvesting frequency, planting biomass (see review in

Buschmann et al., 1995), and spatial arrangement of the inoculum (Santelices et al., 1993), are other important factors determining the production capacity of a farming area.

Different tools for harvesting *Gracilaria* in subtidal systems have been tested, either from boats or by divers (Santelices et al., 1984; Westermeier et al., 1988b). The experience obtained from subtidal farms indicates that tools should not be used for cutting the thalli; better production is obtained by hand-pulling of the plants (Westermeier et al., 1991). In intertidal systems, the same manual method has proved to be successful. Regardless of the harvesting method, it is of vital importance that some biomass is left undisturbed and used as stocking (Santelices et al., 1984). If the stocking is excessively reduced, patches depleted of algae develop and production drops rapidly. In such cases, it has been shown that production can be quickly normalized by re-planting the disturbed areas (Buschmann et al., 1995).

### *3.2. Problems and future challenges*

One of the common problems detected in farms is an abrupt drop in productivity, which is always preceded by 2–3 years of high yields. It is believed that this situation is the result of thallus aging, and seems to be influenced by the harvesting method. *Gracilaria* has apical meristems which are continuously removed during each harvesting period, leaving only the older parts of the thalli behind. To overcome the problem of decreased productivity, some farmers have tried to renew the stockings by using ropes seeded with carpospores (Alveal et al., 1997). As an alternative hypothesis, it has been suggested that lower productivity is, in many cases, a consequence of repeated harvesting causing the loss of stocking algae (Buschmann et al., 1995). Recent results with *Gra. ferox* indicate that the growth potential of a specific strain can be maintained over extensive periods of intensive cultivation (Capo et al., 1999). Similar results have been obtained in tank cultures using *Gra. chilensis* (Retamales et al., 1994), suggesting that aging is unlikely to occur. This means that the issue of agronomic diligence (sensu Santelices, 1999) is highly relevant to maintain a stable production of a *Gracilaria* farm.

A further challenge in *Gracilaria* cultivation is strain selection. The over-exploitation of several wild *Gracilaria* stands could be a limiting factor for further development of farming activities, because some of the larger genetic reserves for the species have been destroyed (Vásquez and Westermeier, 1993). To obtain plants with desirable characteristics, *Gracilaria* has been propagated by green-house sporulation and subsequent seeding of nylon ropes (Alveal et al., 1997), by using field-collected spores (Buschmann and Kuschel, 1988), or via tissue culture (Collantes et al., 1990). Research has also been undertaken, screening *Gracilaria* populations, looking for better responses to some environmental factors (Santelices and Ugarte, 1990). Unfortunately, information available indicates that various commercially desirable characteristics of *Gracilaria* do not respond in the same way to abiotic and biotic factors, and therefore, when a specific trait is selected, another can be unintentionally selected as well, even though it might be negative from a production point of view (Buschmann et al., 1992).

Several types of genetic changes can modify the phenotypic expression of selected strains. It has been reported that *Gracilaria tikvahiae* shows an important degree of intraspecific variation, which appears related to mitotic recombinations (van der Meer and Todd, 1977) and transposable genetic elements (van der Meer and Zhang, 1988). These sources of variability may explain the great variation in morphological and growth responses of *Gracilaria* in the field and in the laboratory (Santelices and Varela, 1993a; Santelices et al., 1995, 1996). It seems that genetic changes in vegetative clones of *Gra. chilensis* are quickly and strongly affected by environmental conditions (Meneses and Santelices, 1999). Thus, clonal selection of *Gracilaria* should involve not only isolation of clones with superior characteristics, but also ensure the persistence of the selected characteristics (Santelices, 1992). The use of these new conceptual aspects in strain selection programs should help to improve the production of *Gracilaria* in the future.

Other studies have shown that the persistent use of the same culture area triggers the development of pests that affect the production of *Gracilaria* (Buschmann et al., 1995, 1999a). Herbivorous fish, gastropods and polychaetes have been mentioned as detrimental to *Gracilaria* production (Pizarro, 1986; Jara, 1990). Although polychaetes can be controlled by some pesticides (Briganti, 1992), high mortalities among high-level predators have been reported associated with the use of such chemicals, which indicates negative environmental consequences (Buschmann et al., 1996a). In some areas, the appearance of mussel infestations of the thalli has affected the growth of the host and facilitated dislodgment of the plants due to overweight (Retamales and Buschmann, 1996). So far, experimental evidence supporting methods to control invertebrates in *Gracilaria* farms is scarce. However, it has been suggested that rotation of the farming areas could be a useful strategy to overcome this problem (Retamales and Buschmann, 1996).

Red, green and brown epiphytic algae can cause severe damage in Chilean *Gracilaria* farms (Pizarro, 1986; González et al., 1993; Buschmann et al., 1995). It has been demonstrated that epiphytism implies lower algal growth rates, increased loss of stocking biomass, and that production of a raw material with lower economic value is due to the presence of the nuisance algae (Kuschel and Buschmann, 1991; Buschmann and Gómez, 1993; Buschmann et al., 1994a). The epiphytic loads results in an increased water drag that causes the lower production rates. Several methods have been suggested to control epiphytes, such as physical removal from the host, reducing light intensity with netting or changing light quality, drying of culture systems, changing water circulation, preventive chemical methods (e.g. use of hypochlorite solutions) such as copper based paints, manipulation of pH and nutrient regimes, and biological methods (Fletcher, 1995). Most of these methods are only suitable for tank cultures and are difficult to apply successfully in open culture areas, as is the case of *Gracilaria* farming in Chile. Recent information indicates that an understanding of recruitment patterns and mechanisms of host infection is useful when selecting management strategies for minimizing epiphyte loads in *Gracilaria* farms (Buschmann et al., 1997a, 1998). An alternative approach includes the use of the snail *Tegula atra* as a biological control due to its selective consumption of ceramialean epiphytes (Buschmann et al., 1994a). This approach, however, has not been tested at a commercial scale. *Gracilaria* susceptibility to epiphytes varies among populations (Santelices and Ugarte, 1990; Buschmann et al., 1992), and according to the production of sulfated polysaccharide exudates (Santelices and Varela, 1993b).

*Gracilaria* thalli can also be infected by an endophytic amoeba (Correa and Flores, 1995). When cultured in the laboratory, *Gracilaria* developed whitish spots that rapidly spread throughout the thallus and ultrastructural evidence indicated that the amoebae perforate the host cell wall and digest the protoplast. Nevertheless, this disease has not been recorded in wild populations or commercial farms in Chile.

Sedimentation has been cited as an important problem in subtidal cultivation systems. Although *Gracilaria* needs to be covered by sand for a proper anchoring to the bottom, an excess of sediment is detrimental as it diminishes light needed for growth (Westermeier et al., 1988b, 1991). The natural process of sand accumulation induced by *Gracilaria* plants is enhanced by the extended use of wooden fences to delimit the planted areas and to capture drifting algae, a practice that also alters the sedimentation process. Sedimentation dynamics do not appear to have the same influence on production in intertidal farms, but the selection of adequate areas for planting *Gracilaria* can improve production and maintain low loads of herbivore polychaetes (Buschmann et al., 1997b).

### 3.3. Alternative production approaches

According to current Chilean legislation, the use of protected areas for aquaculture purposes is under state regulation. Expansion of salmon, mollusc and *Gracilaria* farming during the past 10 years has severely limited suitable cultivation areas in southern Chile (Buschmann et al., 1996a). For this reason, efforts are being made to look for alternative technologies. Bravo et al. (1992) suggested that intertidal enclosures could be installed high in the intertidal zone where the tidal regime exchanges seawater twice a day, obtaining 30% higher biomass production than the traditional intertidal farming. This alternative provides, in addition, an improved agar yield and tolerable epiphytism levels. As water replacement occurs during high tide, the cost of water pumping and fertilization normally involved in similar cultivation systems became irrelevant. However, scaling up this system still represents a challenge for the future. Research aimed to integrate filter feeders into the ponds is currently underway in southern Chile, in order to increase economic returns.

Tank cultivation of *Gra. chilensis* has also been undertaken (Edding et al., 1987; Ugarte and Santelices, 1992). Nevertheless, this type of culture has not attracted private investors because it is not profitable. To improve profitability, tank cultivation using salmon effluents has been developed (Buschmann et al., 1994b). This system was highly productive (biomass production over 48 wet kg $m^{-2}$ $year^{-1}$), and did not involve additional pumping, nutrient and $CO_2$ costs. If the *Gracilaria* tank cultures are integrated to a salmon farm, it is possible to reduce the negative impact of fish waste, and most of the costs for cultivating the algae are covered by the operational costs of the salmon farm, which turns the whole system both economically profitable and ecologically friendly (Buschmann et al., 1996b). A further advantage is that algae cultivated with fish waste waters have a higher agar quality (Martínez and Buschmann, 1996). Floating culture systems like those used in Africa and Venezuela (Dawes, 1995) were also experimentally tested in Chile (Pizarro, 1986; Westermeier et al., 1993). Similar to tank cultivation, floating cultures of *Gracilaria* can also be integrated with salmon rafts, helping to reduce nutrient load in the surrounding water (Troell et al., 1997).

## 4. Cultivation of other red seaweeds

### *4.1. Agarophytes*

Algae belonging to the genus *Gelidium* are the main agarophytes currently exploited commercially in Chile. Species of *Gelidium* typically occur on rocky substratum, from low in the intertidal zone down to a depth of 25 m, often on coralline crusts, and associated with rapid water movement (Santelices, 1991). Several of these species have been studied to assess their potential for cultivation in free-floating or net culture systems (Santelices, 1987). *Gel. lingulatum*, for which demand is highest, showed that net cultures installed in intertidal gullies and rapids can reach daily growth rates as high as 3%, at intertidal levels of 0.4–0.8 m above MLW. More recently, Rojas et al. (1996) successfully induced the reattachment of *Gel. rex* to scallop shells, producing 1.5 cm plantlets in 40 days. Nevertheless, the market conditions do not favour a higher demand for other agarophytes.

### *4.2. Carrageenophytes*

Compared to agarophytes, demand for carrageenophytic seaweeds along the Chilean coast has increased in recent years, mainly related to the establishment of processing plants to extract the colloid. However, the supply of these species relies on the harvesting of wild stocks. Following the experience gained with *Gracilaria*, several studies have reported the results of research on basic biological and ecological aspects of several carrageenophytes exploited in Chile. For example, studies on population ecology and reproduction (Martínez and Santelices, 1992; Santelices and Martínez, 1997), biotic interactions (Jara and Moreno, 1984; Hannach and Santelices, 1985; Buschmann and Santelices, 1987; Buschmann and Vergara, 1993), diseases (Correa et al., 1997; Buschmann et al., 1997c) and recommendations for population management of wild stocks (Santelices and Norambuena, 1987; Westermeier et al., 1987; Gómez and Westermeier, 1991), are available for *M. laminarioides*. However, studies directly related to mariculture are lacking.

Other algae, like *Sarcothalia crispata* and *Gigartina skottsbergii*, are much less studied, but several research groups are currently working to develop mariculture strategies and techniques for these species. *S. crispata* is, today, one of the red algae most demanded for carrageenan extraction in Chile. Population studies of this species show a marked variation in abundance, with maximum densities around 2,000 fronds $m^{-2}$ in late spring and maximum biomass of 1.2 wet kg $m^{-2}$ in summer (Avila et al., 1996). Information available suggests that the abundance of this alga does not depend on the regeneration capacity of the holdfast, but is controlled by recruitment from spores (Mora, 1992). Laboratory experiments with *S. crispata* determined a suitable combination of environmental factors (temperature, salinity, light intensity, photoperiod and macronutrients) to optimize seeding of artificial substrata (different types of ropes and rocks). Transplanting these laboratory-produced sporelings has had limited success with survival rates below 40% after 2 months in the field (Avila et al., 1995). Very recently, Avila et al. (1999a) presented results of studies where frames with nylon and polyfilament of different diameters were seeded in the laboratory and out-planted to the sea. These authors indicate that a total output of 140 g (dry weight) $m^{-1}$ can be obtained over the growth period (November–May).

*Gigartina skottsbergii* is another species subject to intensive research, in particular due to the quantity and quality of its carrageen content (Buschmann et al., 1999a). A population study of *G. skottsbergii* demonstrated that in Chile this species shows a higher gametophytic abundance during autumn–winter, associated with low temperatures and short-day conditions (Zamorano and Westermeier, 1996; Westermeier et al., 1999). This abundance pattern is similar to that found in southern Argentina (Piriz, 1996), where it has also been shown that the most abundant standing stocks develop from spring to late summer, with values around 300 g (dry weight) $m^{-2}$. The reproduction effort is concentrated in winter and early spring, where high carpospore and tetraspore abundance was observed in laboratory experiments (Avila et al., 1999b). However, other laboratory experiments with *G. skottsbergii* presented a clear seasonal pattern of successful germination, with the highest value of 50% recorded for winter spores (July and August) (Buschmann et al., 1999b). Better germination results were obtained at 5°C than at 10°C or 15°C (Buschmann et al., 1999b). Germlings smaller than 500 μm have been transplanted from a nursery to outdoor tanks, where their survival was higher than 80% with growth of up to 1–2 mm in 30–45 days. To date, no report exists of hatchery-produced *Gigartina* germlings, which have then been cultivated in open systems. This evidence emphasizes two bottlenecks for the future development of *Gigartina* mariculture. First, the seasonal availability of spores, and second, their low germination rates and growth potential. For this reason, efforts have been made to propagate vegetatively this species, and laboratory experiments showed that *Gigartina* has a high healing and regeneration capacity (Correa et al., 1999). These results encouraged further experiments in nursery facilities, which have shown that fragmentation of the fronds is technically feasible and that healing and regeneration responses can be optimized by experimental manipulation of temperature, light and nutrient concentrations. Explants of *Gigartina* fronds have also been cultivated in floating ropes in southern Chile, demonstrating that they can regenerate and have surface increments of 90–250% over a 6-month period during summer (Buschmann et al., 1999b). Other forms of vegetative propagation are also being explored. The use of rhizoids attached to rocks and transplanted to the sea could be an interesting possibility that requires further research.

The main restriction to furthering development of *Gigartina* is its low growth potential. It is important to assess the plant growth potential to enhance production when developing a strain selection program. In this context, growth rate and production potential in *Gigartina* require further attention and it seems that the development of a strain selection program is unavoidable. Vegetative propagation of this species is feasible, a feature which should contribute greatly to the establishment of such a program. As part of this strategy, research is underway to obtain strains with higher growth rates (Buschmann et al., 1999b).

### 4.3. Edible algae

Population studies on *Porphyra columbina* show that maximum abundance occurs in spring. This pattern is modified in the lower intertidal zone by competition with *Mazzaella laminarioides* and by grazing (Santelices and Avila, 1986). At least one study has demonstrated that cultivation of this species is biologically feasible (Seguel and Santelices, 1988). Nevertheless, the limited local market is not sufficiently attractive to stimulate the investment required to cultivate this species at a commercial scale.

During the last 3 years, a market has opened in Chile for *Callophyllis variegata* and *C. chamissoi*. Knowledge about these species was restricted to distribution data (Hoffmann and Santelices, 1997), although some information regarding phenology and spore handling in laboratory is now available for *Chondracanthus chamissoi* (González and Meneses, 1996). In *Callophyllis variegata*, carpospores are available during winter, whereas tetraspores are available during spring (Güttler, 2000). Furthermore, natural populations of *Cal. variegata* are also being studied to develop management recommendations. From this perspective, it has been demonstrated that the holdfast of this species has a high regeneration capacity, which enables the harvested populations to recover.

## 5. Conclusions

In Chile, the seaweed industry diversified significantly its activities over the last 10 years. The number of species being commercialized and processed has increased. Remarkable are: the development of the carrageenan industry; the increased production of agar and the addition of highly valuable species, such as the edible seaweed *Cal. variegata*, to the Chilean exports. In spite of the above achievements, *Gra. chilensis* remains the only commercially cultivated species, a situation which is expected to change in the near future. *Gracilaria* farming in open systems has proved to be technically and economically feasible in southern and northern Chile. Unpredicted fluctuations in prices and the appearance of previously unknown problems such as pest organisms and sedimentation processes have affected production. The establishment of large *Gracilaria* cultivation areas has caused modifications in the environmental (Fig. 6) which has stimulated research aimed at increasing production predictability (Buschmann et al., 1997b). Tank culture of *Gracilaria* has not been developed at a commercial scale, although efforts are being made to develop integrated land-based fish, mollusc and seaweed farming systems.

An analysis of the knowledge accumulated on other exploited red algae in Chile indicates that for species like *S. crispata*, *G. skottsbergii*, *C. chamissoii* and *Cal. variegata*, additional studies are considered essential for the development of mariculture (Table 1). For other species, like *P. columbina* and *M. laminarioides*, basic information is already available. However, these studies have not addressed issues specifically related to scaling up experimental cultures (Table 1). Perhaps a greater collaboration between the scientific community and industry can help in the future (Santelices, 1996).

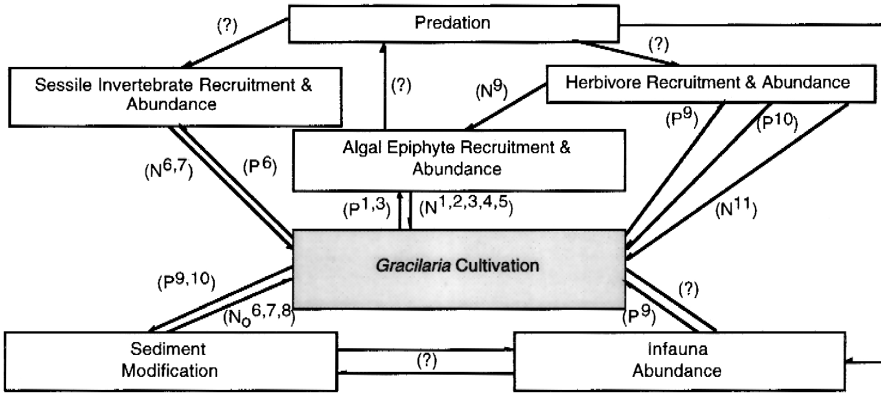


Fig. 6. Model showing important interactions occurring in a *Gra. chilensis* farm in Chile. N = Negative effects; P = positive effects, No = neutral effects and ? = unknown interactions. [1]Kuschel and Buschmann (1991); [2]Buschmann and Gómez, 1993; [3]Buschmann et al., 1995; [4]Buschmann et al., 1997a; [5]Buschmann et al., 1998; [6]Buschmann et al., 1997b; [7]Retamales and Buschmann, 1996; [8]Westermeier et al., 1988b; [9]Westermeier et al., 1991; [10]Buschmann et al., 1994a; [11]Jara, 1990.

In this context, it is important to mention that some research groups are developing different approaches for the management and cultivation of several economically important Chilean seaweeds, and some companies have become involved in these efforts (for example, see Rojas et al., 1996). This should be seen as an important complement to government agencies that currently support basic and applied phycological research in Chile, and will likely result in a greater diversification of species farmed in the coming years.

Table 1
Summary of applied studies (experimental and pilot scale) of commercially important red algal species in Chile

| Species | Population dynamics | Laboratory cultures | Nursery studies | Tank cultivation | Suspended cultivation | Bottom cultivation | Pest control |
|---|---|---|---|---|---|---|---|
| *Gra. chilensis* | ** | ** | ** | ** | ** | ** | * |
| *Gelidium* spp. | ** | * | – | * | * | × | – |
| *M. laminariodes* | ** | ** | – | – | – | × | * |
| *S. crispata* | ** | * | * | * | * | × | * |
| *G. skottsbergii* | ** | * | * | – | * | × | * |
| *C. chamissoi* | * | * | – | – | – | × | – |
| *Gym. furcellatus* | * | * | – | – | – | × | – |
| *P. columbina* | ** | ** | * | × | * | × | – |
| *Cal. variegata* | * | * | * | – | – | × | – |

** = Complete information available; * = incomplete information; – = information not available and × = does not apply.

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