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Seaweed cultivation, product development and integrated aquaculture studies in Chile

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Over the past 10 years, seaweed utilization in Chile reached a volume of over 400,000 tons (wet weight) per year. Fifty percent of that production involved various species of Phaeophyta. The other 50 percent resulted from the harvest of Rhodophyta. Chile has, thus, become one of the most important countries for exploitation, cultivation and uses of algae. Algal production in Chile is mainly based upon the exploitation of wild stocks and cultivation on a commercial scale remains restricted to *Gracilaria chilensis* (Buschmann *et al.* 2001a).

This contribution presents a brief summary of the available information in the country on brown and red seaweed cultivation. Second, we discuss an interest in developing novel seaweed products to increase the profitability of algal markets and third, we provide evidence gathered along the Chilean coast for the use of seaweeds as biofilters. This paper covers only the most important species exploited at the present time in Chile. Therefore, our discussion is restricted to important advances in the development of a diversified seaweed aquaculture industry in Chile.

Seaweed Exportations and Cultivation

Several red algae are being exploited in Chile at the present time, leading to a total landing of 182,056 t in 2001. However, *Gracilaria chilensis* (Figure 1A) is still the only species cultivated on a commercial scale and cost-benefit analyses indicate that, in Chile, *Gracilaria chilensis* farming is profitable, which has stimulated the activity in recent years (Buschmann *et al.* 1995). However, inasmuch as prices have been highly variable over the past 10 years, it seems important to optimize production by lowering costs and increasing productivity.

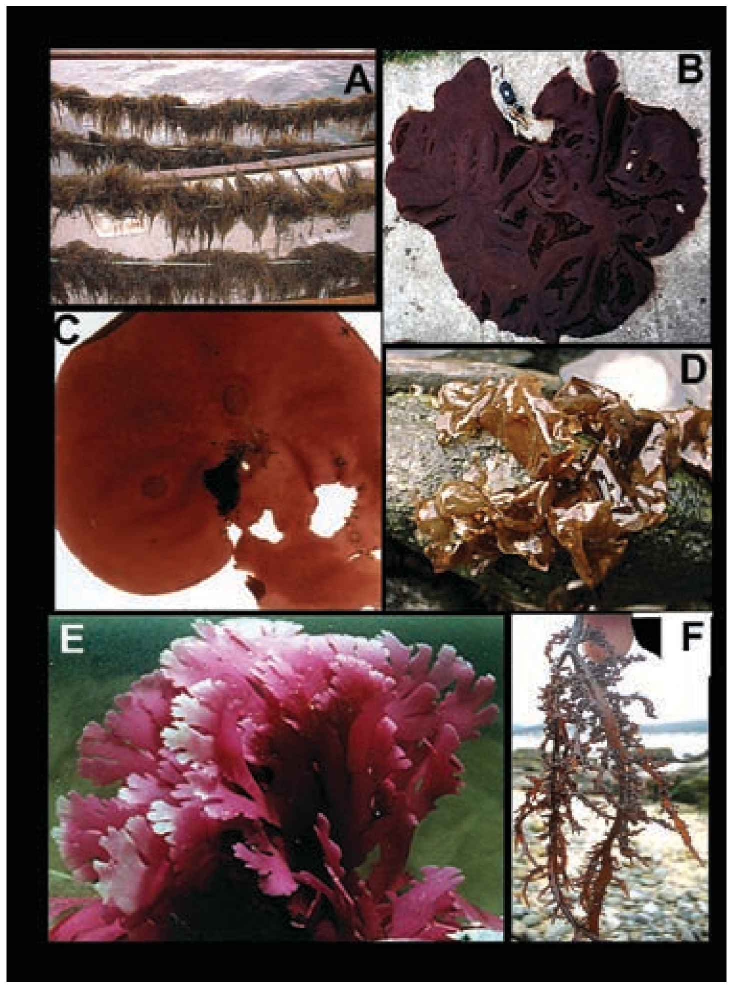

Fig. 1. Economically important red algae from Chile. A. Gracilaria chilensius*; B.* Sarcothalia crispate*; C.* Gigartina skottsbergii*; D.* Porphyra columbina*; E.* Callophyllis variegata *and F.* Chondracanthus chamisoii.

Several planting techniques have been developed to fasten *Gracilaria* to the substratum, and two that have been the most commonly used by commercial farms in Chile were described fully by Buschmann *et al.* (1995, 2001a).

The 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. The supply of these species relies on the harvesting of wild stocks of *Sarcothalia crispata* (Figure 1B) as well as *Mazzaella laminarioides* and *Gigartina skottsbergii* (Figure 1C). Several research groups are currently working to develop mariculture strategies and techniques for those species. To date, no report exists of hatchery-produced *Gi-*

Fig. 2. Organic fertilizers produced from Chilean Ulva *and* Macrocystis*. This product is already in a commercial production phase.*

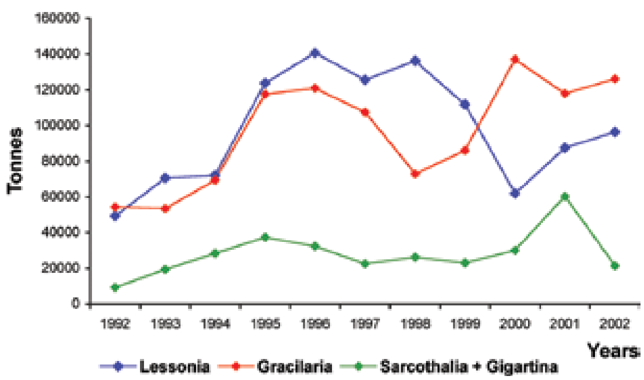

Fig. 3. Seaweed landings (wet tons) in Chile of the brown alga Lessonia*, the agarophyte* Gracilaria *and the carrageenophytes* Sarcothalia + Gigartina*.*

gartina germlings that have then been cultivated in open systems.

There are two bottlenecks for the future development of *Gigartina* mariculture. Seasonal availability of spores and their low germination and growth potential are slowing large-scale cultivation in Chile. For this reason, efforts have been made to propagate vegetatively through the fragmentation and regeneration of the thalli of this species. Laboratory experiments showed that *Gigartina* has a high healing and regeneration capacity (Buschmann *et al.* 2001b). Those 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 increment increases of 90-250 percent over a 6 month period during summer.

At least one study has demonstrated that the cultivation of the Chilean nori (*Porphyra columbina*; Figure 1D) is biologically feasible (Seguel and Santelices 1988). Nevertheless, a recent study recorded nine species of *Porphyra* in central Chile that appear to be important candidates for the development of nori cultivation (González and Santelices 2003). Also, during the last three years, a market has opened in Chile for *Callophyllis variegata* (Figure 1E) and *Chondracanthus chamissoi* (Figure 1F). Knowledge related to these species was restricted to distribution data, although some information regarding phenology and spore handling in the laboratory is now available for *C. chamissoi*. For *C. variegata,* carpospores are available during winter, whereas tetraspores are available during spring. Furthermore, natural populations of *C. 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 population to recover.

In Chile, *Lessonia trabeculata* and *L. nigrescens* are collected for alginate, *Macrocystis pyrifera*, has been harvested over the last few years for abalone feed and the bull kelp, *Durvillaea antarctica*, is used for human consumption in local markets. The total landings of brown algae reached 117,735 t during 2001, showing *Lessonia nigrescens* to be in the greatest demand. Experimental cultivation of *Lessonia trabeculata* has been carried out in northern Chile. As a result of the expanding abalone industry in Chile, there is also great interest in the culture of *Macrocystis pyrifera* in the open sea. Pilot production of this kelp is currently being carried out in southern Chile. Furthermore, the cultivation of *Macrocystis pyrifera* has been studied to obtain different products for human consumption and the development of organic fertilizers (Figure 2).

The high production level allows for the exportation of brown and red algae as dry material, with *Lessonia* being the most important species with 21,096 t (Figure 3). The species that contributse the most to the revenues of Chile is *Gracilaria* with US$35,244,300 from the production of 126,184 t in 2002 (Figure 3). However, we must indicate that the importance of *Gigartina* and *Sarcothalia* have increased steadily during the past 10 years (Figure 3). Also, Chile no longer exports raw material and, in 2002 for the first time the revenues of the exports of agar and carrageenan (US $57,597,200 together) were higher than for the export of dry material. In this context, it is necessary to indicate that intensive research is underway to develop food products, fertilizers and animal feed to increase algal value and to stimulate seaweed commercial activity.

Integrated cultivation

The use of seaweed as nutrient extracting organisms have been demonstrated to be biologically, technically and economically feasible (Chopin *et al.* 2001, Troell *et al.* 2003, Neori *et al.* 2004). Salmon tank cultivation effluent recycling with *Gracilaria chilensis* has been undertaken in Chile.

This system (Figure 4) was highly productive, and did not involve additional pumping, nutrient input and CO_2 costs. If *Gracilaria* tank culture is integrated into 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 makes the whole system profitable and ecologically friendly (Chopin *et al.* 2001). A further advantage is that algae cultivated with fish wastewaters have a higher agar quality.

Similar to tank cultivation, floating culture of *Gracilaria* can also be integrated with salmon rafts, helping to reduce nutrient load in the surrounding water (Troell *et al.* 1997). This system increased the biomass productivity and nitrogen content by 30 percent in comparison to *Gracilaria* monoculture. At the present time there is a good chance that integrated open culture systems will develop on the southern coast of Chile, increasing the economic and social benefits. The environmental associated with salmon farms benefits, because the massive macroalgal cultures scrub nutrients from the water. Industry and universities research groups are joining in an effort to establish demonstration farms at the present time.

Fig. 4. A general view of the pilot integrated tank culture system of the Universidad de Los Lagos in Metri.

Summary

In Chile, the seaweed industry has diversified significantly over the past 10 years. The number of species being commercialized and processed has increased. The development of the carrageenan industry, the addition of highly valuable species, such as the edible seaweed *Callophyllis variegata* and *Chondracanthus chamissoi* to the Chilean exports and the production of organic fertilizers are the most remarkable. In spite of the above achievements, *Gracilaria chilensis* remains the only commercially cultivated species, a situation that is expected to change in the near future especially due to the high demand of brown algae to feed abalone. Tank culture of algal species has not been developed on a commercial scale, although efforts are being made to develop integrated land-based fish, mollusc and seaweed farming systems as well as in open cultivation systems. The increasing development of salmon cultivation in southern Chile opens the door for an integrated seaweed industry, especially if added value for the seaweeds has been developed.

Notes

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