*Hydrobiologia* **398/399:** 435–442, 1999.
*J.M. Kain (Jones), M.T. Brown & M. Lahaye (eds), Sixteenth International Seaweed Symposium,*



# Economic feasibility of *Sarcothalia* (Gigartinales, Rhodophyta) cultivation

Marcela Avila[1], Erick Ask[2], Brian Rudolph[3], Mario Nuñez[1] & Ricardo Norambuena[4]
[1]*División de Fomento a la Acuicultura, Instituto de Fomento Pesquero, Casilla 665, Puerto Montt, Chile*
[2]*Marine Colloids Phil. Inc. Ouano Compound, Looc, Mandaue City, Cebu Philippines*
[3]*Copenhagen Pectin A/S Division of Hercules Incorporated. DK- 4623 Lille Skensved, Denmark*
[4]*Subsecretaría de Pesca Chile, Casilla 100V, Valparaíso, Chile*
*E-mail: mavila@ifop.cl*

*Key words: Sarcothalia*, cultivation, Gigartinales

**Abstract**

Studies to develop a technology for *Sarcothalia* cultivation were carried out based on results of a pilot scale farm. Mature cystocarpic and tetrasporic fronds of *Sarcothalia crispata* were collected in Chiloé island (41° S), southern Chile and sporulated in semi controlled conditions. Frames with nylon and polyfilament of different diameters were seeded and incubated in tanks of 400 l. Small gametophytes attached to ropes were maintained in the hatchery for 3 months before out-planting to the sea. Small fronds were grown in a floating system in the open sea. Plants attained 1.5 cm after 3 months cultivation in tanks in semi-controlled conditions. After out-planting to the sea, frond growth took place mainly during spring and summer. The annual timing of the cultivation and production process is described.

## Introduction

In Chile, seaweeds belonging to the genus *Sarcothalia, Gigartina* and *Mazzaella* have been harvested from wild beds for more than three decades and used commercially for extraction of carrageenan (Avila & Seguel, 1993; Norambuena, 1996). These resources have become especially important during the last five years due to the construction of carrageenan processing plants in Chile, which provide about 20% of the world carrageenan production capacity (Bixler, 1996). These seaweeds are mainly being harvested in central Chile, from Valparaiso (36° S) to southern Chile in Chiloé Island (41° S). In 1997, around 8000 t of dry seaweed (US$ 9 200, 000) was exported as raw material and a quantity not specified was utilized together with imported seaweed by the domestic carrageenan industry (4 companies), which produced 2079 t of carrageenan, representing an income of US$ 16 400, 000. Substantial price increases during the past 5 years suggest an increase in demand of the raw material in the future (Bixler, 1996).

*Sarcothalia crispata* (Bory) Leister (formally *Iridaea ciliata*) is found from the intertidal to subtidal, down to 10 m and its distribution is antiboreal (Hommersand et al., 1993) from Valparaíso (33° S) to the Magellan Strait (53° S).

The thallus is foliose, with one or two oval fronds, with numerous proliferations on the blade of the gametophytes but not on the tetrasporophytes (Hommersand et al., 1993). Fronds are attached to the substratum through a disc-like holdfast, with cilia-like proliferations on the margins of the frond. This is characteristic of the species in the juvenile and adult stages. The thallus varies in length reaching up to 2 m. Its life cycle is isomorphic.

Field and laboratory studies have been conducted for cultivation of small thalli of *Iridaea cordata* and *Gigartina exasperata* (Waaland, 1973, 1976; Mumford 1977, 1979; Mumford & Waaland, 1980). Field experiments determined that the maximum growth rate was obtained at 3–5 m depth. The laboratory experiments showed that the optimum temperature for growth was between 10 and 14 °C. In semi-closed systems yield from tank cultures was determined also using different sizes of thalli. Hansen (1983), likewise, attempted to farm *Iridaea*. One methodology used to farm seaweeds commercially is the use of

spores. This method has been used successfully in the commercial farms of brown seaweeds such as *Laminaria* (Kawashima, 1984), *Undaria* (Ohno & Matsuoko, 1993), red seaweeds such us *Porphyra* (Okazaki, 1971; Tseng, 1981; Oohusa, 1993) and recently in *Gracilaria* (Alveal et al., 1997) and *Eucheuma* (Azanza et al., 1996). Navarro (1991) induced sporulation of *S. crispata* and recorded the settling of viable spores on various substrata. Avila et al. (1996) inoculated artificial substrata with spores in controlled and in semi-controlled conditions and obtained fronds, but during the out-plant of the ropes to the sea, mortality rates were high (94%) and the density of discs low (5 discs/cm$^2$). The present study has been encouraged by the carrageenan industry to develop a technology for *Sarcothalia* cultivation, and to produce an economic model to estimate the costs of production based on results of a pilot scale farm.

## Materials and methods

Mature tetrasporic fronds of *Sarcothalia crispata* were collected from Ancud (41° 52′ S; 73° 51′ W) and transported to the hatchery in insulated styrofoam boxes. Plants with mature tetrasporangia were sorted immediately upon arrival at the hatchery and kept overnight at 10 °C to increase spore production. Collections were made during autumn and winter (between March and August, 1996).

Selected fronds were rinsed in a series of four baths in filtered seawater before sporulation, blotted dry and left to dry further for 10–15 min. Mature fronds were kept in sporulation containers (3 kg seaweed/20 l capacity), and filled with filtered seawater. Sporulation containers were covered to reduce contaminants and kept still for 2 h. After this, fronds were removed and the remaining spore solution was stirred, filtered and poured into tanks (400 l capacity) where the string had been already wrapped on frames which were lying horizontally one on top of the other (Figure 1). Spore settlement and density was checked on coverslips placed on the frames.

Both sides of the frames were inoculated on two different days and on the third day filtered seawater was changed and enriched Provasoli solution (300 ml) at half strength was added to the tanks. Bubbling was started one week after seeding. Nylon and polyfilament of different diameters were used as substrata.

During winter, light was increased with fluorescent light placed 70 cm above the tanks with a long photoperiod of 18 h light and 6 h darkness to increase growth of the discs. The temperature of the tanks fluctuated as indicated in Figure 2. After the first three weeks of incubation in the tanks, effluents from a nearby scallop hatchery were added twice a week to increase nutrient availability and reduce costs. Once a week, frames were cleaned with seawater to reduce diatoms and other contaminants.

After three months in the hatchery plants reached 5–15 mm in length and 1.170 m of substrata with little fronds were transplanted to the sea. Nylon was out-planted to the sea in April, 1996 and distributed over 92 lines of 10 m in a horizontal floating system located about 2 m below the sea surface. Material of 3 mm was also out-planted and distributed in 5 lines and 50 m length and growth was evaluated. The length of about 40 plants was measured from nylon and polyfilament weekly.

For the second out-plant, lines were controlled and cleaned of epiphytes every 2 weeks in the sea but not measured. Experimental harvesting was done after 3 months in the sea, 60 individual fronds were measured in length and width. Two harvests were carried out on the pilot farm during the growth season (September–April), one in January 30, 1997 and the other in March 13, 1997. The area of the fronds was estimated using the following formula:

$$\text{Area} = a \times b \times \pi/4.$$

The design of the farm in the sea (Figure 3) was a rectangular module of 20 × 100 m with a 50 × 50 cm styrofoam float in each corner and held in place by four concrete anchors. Small anchors were placed on the sides to provide tension on the lines. A 12 mm rope was used for the anchor lines.

## Results

### *Inoculation of substrata and incubation in tanks*

The best germination and survivorship were achieved with nylon of 1 mm and polyfilament of 3 mm. Tetraspores germinated on both types of substrata but the gametophytes developed and grew at a slower rate on the polyfilament of 3 mm.

Germination of spores occurred in the 5 days following inoculation. Spores settled and became attached firmly to the substratum, starting development. Densities of discs attached on the ropes fluctuated between 56 and 80 spores mm$^{-2}$ after inoculation and

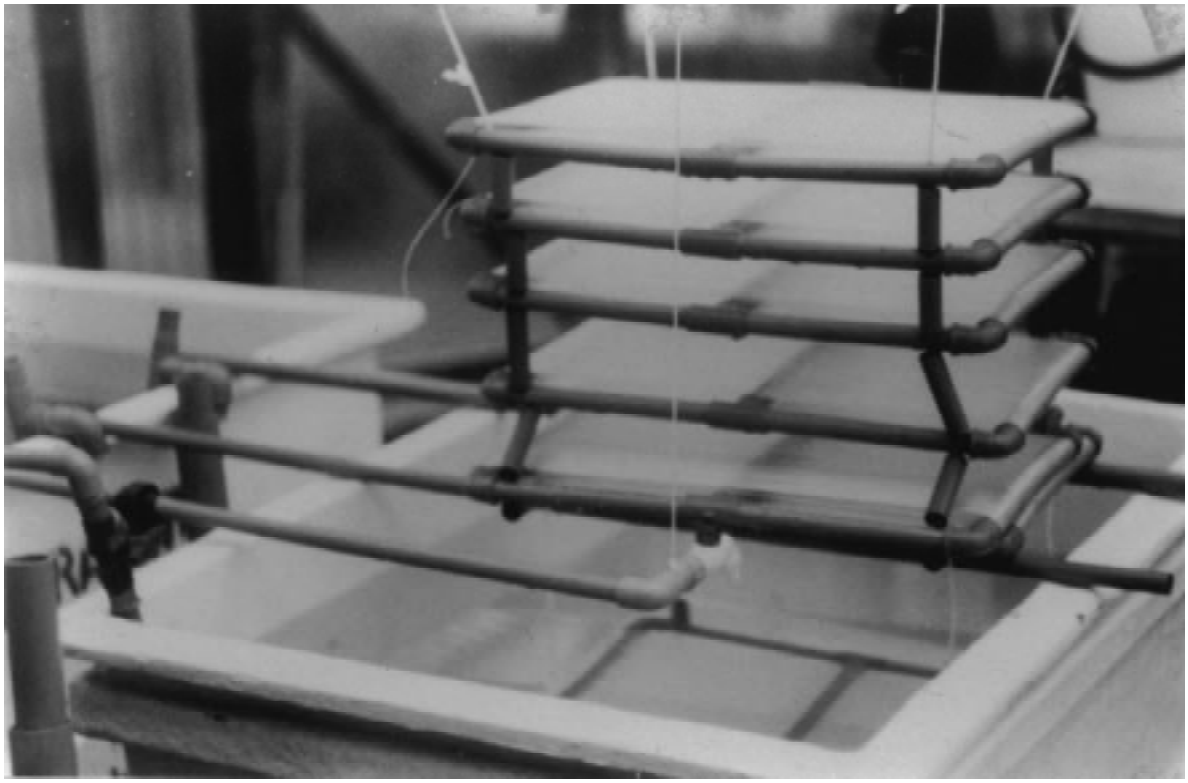

*Figure 1*. Frames used to settle spores in tanks of 400 l.

after three months of incubation in tanks density decreased to an average of 10.3 ± 4.4 plants mm$^{-2}$. Fouling organisms such as diatoms, *Enteromorpha*, and *Ulva* were evident after two to three weeks after inoculation. After three months, plants growing on nylon attained an average length of 15 ± 6.6 mm in length while on polyfilament of 3 mm, length was 5.3 ± 5.2 mm.

*Growth in the field*

The first out-plant showed that fronds of less than 1 cm length were not able to grow in the sea because they became covered with epiphytes. Frond enlargement corresponding to the first out-plant during winter is shown in Figure 4. The algae *Ectocarpus*, *Giffordia* and *Polysiphonia* became abundant on the lines during spring (September–December). During spring and summer, *Ulva* was the major weed present. On the second out-plant, placed in October 1996, *Ectocarpus* and *Giffordia* were not observed but *Ulva* was present on the lines.

*Production level*

After three months in sea, the fronds of the second out-plant reached harvestable size >10 cm (Figure 5). In Table 1 data from the harvests are shown. In the laboratory the harvested biomass was dried in the oven to constant weight to obtain the dry weight. The first harvest was done by cutting or breaking fronds of harvestable size about 2 cm above the holdfast. After the harvest the discs remained on the line with new uprights which grew into new fronds. An average of 33 harvestable fronds were found in a linear metre of line. The mean size of the fronds of the first harvest expressed as area was 170 ± 193 cm$^2$. In the second harvest it decreased to 118 ± 91 cm$^2$.

## Discussion

Preliminary surveys have shown that *Sarcothalia crispata* occurs in populations along the Chilean coast (Santelices, 1989; Westermeier et al., 1996). Natural populations in central Chile have seasonal variations in biomass (Hannach & Santelices, 1985; Poblete et

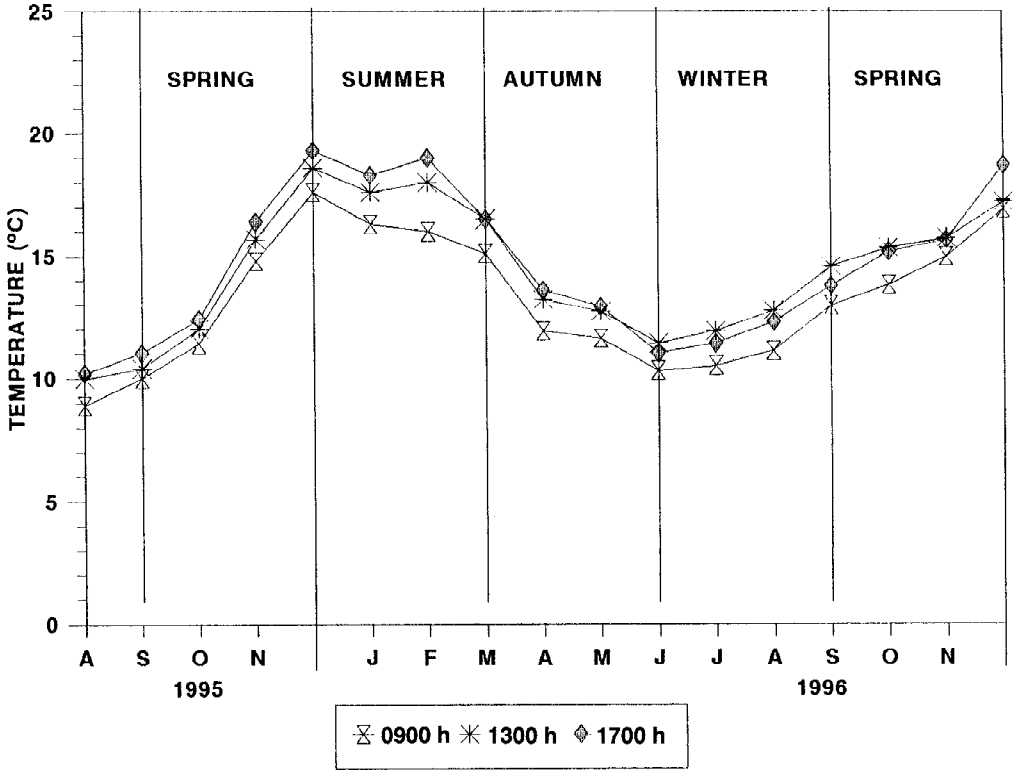


*Figure 2.* Fluctuations of seawater temperature in the tanks between spring of 1995 and spring of 1996, at different times of day.

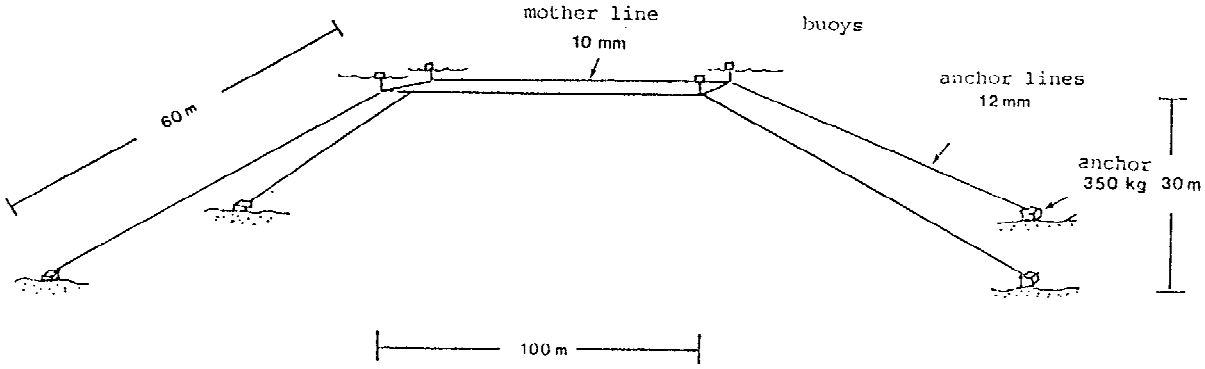


*Figure 3.* Design of the pilot module in the sea.

*Table 1.* Results of the first and second harvest in the pilot system that was installed in the sea (size is expressed as area ± S.D.)

| | Wet weight, g $m^{-1}$ | Dry weight, g $m^{-1}$ | Number of plants $m^{-1}$ | Size of the harvested fronds ($cm^2$) |
|---|---|---|---|---|
| First harvest | 184 ± 77 | 37 | 34 ± 16 | 170 ± 193 |
| Second harvest | 281 ± 132 | 56 | 41 ± 23 | 118 ± 91 |
| Total | 465 | 93 | | |

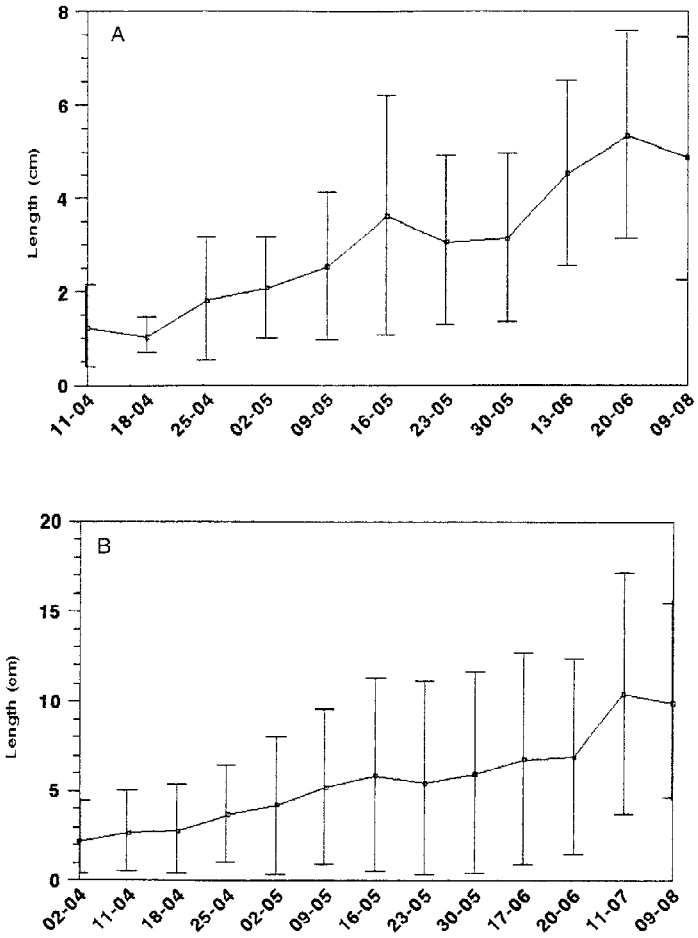


*Figure 4.* Frond enlargement in winter. (A) Material of 3 mm (polyfilament), (B) Monofilament. Vertical bars indicate standard error.

al., 1985) and predominance of the gametophyte over the tetrasporophyte has also been described (Otaíza, 1996). Biomass in natural beds is mostly regulated by two mechanisms: holdfast regeneration and settlement of spores (Santelices, 1989). Avila et al. (1996) showed that natural beds in southern Chile present marked seasonality both in reproduction and growth. Maximum biomass of non reproductive plants occurs in late summer. Phenological studies indicate that in late summer and early autumn (March) tetrasporic blades begin to show reproductive structures and, in the following months, appear to be the dominant reproductive phase, while cystocarpic blades reach their maximum density in winter (August) when tetrasporic fronds have already declined. Considering these phenologic data, sporulation of tetrasporic fronds was induced in winter time.

The results of this work show the technical feasibility of culturing *Sarcothalia* in the field. However, the cost of investments has to be optimized, and the productive process must be further developed in some biological aspects such as the yield per metre. *Sarcothalia* culture by spores requires, as in other red and green algae, two important phases, one in the greenhouse and the second in the sea. In the greenhouse phase, it takes about three months to obtain fronds of 1.5–2 cm. Smaller fronds are covered with epiphytes in the sea, reaching almost 100% mortality. According to our results, this size is adequate for transport to the field with low mortality; the final mean density achieved was 33 fronds $m^{-1}$ in the sea. There is evidence that the density of the fronds can affect growth and production (Flores-Moya & Fernández, 1996). Thus it is advisable to test the effect of density on productivity.

*Figure 5.* Line with fronds ready to be harvested.

Culture in the greenhouse comprises sporulation, germination, adhesion to a substratum and growth up to 2 cm while culture in the sea consists in the growth of fronds until reaching a harvestable size. To induce sporulation in mature fronds we used desiccation, as described by Infante & Candia (1988). However, prior to frond stimulation, the reproductive material was kept at low temperature for at least 12 h. Using a spore suspension for seeding results in a fairly homogeneous distribution of the spores on the substratum. In the greenhouse phase, different artificial substrata were tested for spore settlement. A high settlement and good adhesion was achieved with 3 mm ropes and monofilament. The presence of epiphytic algae such as diatoms and some Chlorophyceae, which are present

*Table 2.* Timing of *Sarcothalia* cultivation

| TIMING OF CULTIVATION | A | M | J | J | A | S | O | N | D | J | F | M | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Collection & selection of mature plants | → | | | | | | | | | | | | |
| Releasing spores | → | | | | | | | | | | | | |
| Inoculation of Figures | → | | | | | | | | | | | | |
| Growth of juveniles | → | | | | | | | | | | | | |
| Farm design | | → | | | | | | | | | | | |
| Farm installation | | | → | | | | | | | | | | |
| Twine deployment | | | | | → | | | | | | | | |
| Growth season | | | | | → | | | | | | | | |
| Harvest season | | | | | | | | | | → | | → | → |

over the whole greenhouse phase, did not preclude the development of *Sarcothalia* plants.

According to the results obtained, we elaborated a calendar for *Sarcothalia* culture (Table 2), where the selection of the reproductive phase to be cultured is to be done between April and August. Sporulation and inoculation of substrata must be carried out immediately. However, the density of the plants should be optimized, since a high density could affect production. Holdfasts firmly adhered will initiate the development of small thalli after 3–4 weeks in the greenhouse, under conditions of filtered, enriched sea water and illumination. The small fronds must be kept in greenhouse culture until reaching the adequate size for their transfer to the field (1.5 cm). It is advisable to transport the ropes with plants in early spring to allow for the growth of *Sarcothalia* fronds before the occurrence of an explosive growth of unwanted species, as it has occurred in the commercial culture of other algae like *Gracilaria* (Kushel & Buschmann, 1991; Westermeier et al., 1991; Buschmann et al., 1995). Fronds longer than 10 cm may be harvested at the end of January, in March, and early May.

The cost of spore production under semi-controlled conditions may be optimized, considering that in other species, such as *Gracilaria chilensis*, this technique has been developed at low cost (Alveal et al., 1997) and implemented at commercial level.

If results obtained in the first harvests at pilot scale are extrapolated to 3 yearly harvests over the growth period (November–May), the total output would be about 700 g of fresh weight or 140 g dry weight per (linear) metre.

## References


Alveal, K., H. Romo, C. Werlinger & E. C. Oliveira, 1997. Mass cultivation of the agar-producing alga *Gracilaria chilensis* (Rhodophyta) from spores. Aquaculture 148: 77–83

Avila, M. & M. Seguel, 1993. An overview of seaweed resources in Chile. J. appl. Phycol. 5: 133–139.

Avila, M., R. Otaíza, R. Norambuena & M. Núñez, 1996. Biological basis for the management of 'luga negra' (*Sarcothalia crispata* Gigartinales, Rhodophyta) in southern Chile. Hydrobiologia 326/327: 245–252.

Azanza, R., T. Aliaza & N. Montaño, 1996. Recruitment of *Eucheuma* and *Kappaphycus* on a farms in Tawi- Tawi, Philippines. Hydrobiologia 326/327: 235–244.

Bixler, H. J., 1996. Recent development in manufacturing and marketing carrageenan. Hydrobiologia 326/327: 35–57.

Buschmann, A., R. Westermeier & C. Retamales, 1995. Cultivation of *Gracilaria* on the sea bottom in southern Chile: a review. J. appl. Phycol. 7: 29–301.

Flores-Moya, A. & J. Fernández, 1996. Growth pattern, reproduction, and self-thinning in seaweeds. J. Phycol. 32: 767–769.

Hannach, G. & B. Santelices, 1985. Ecological differences between the isomorphic reproductive phases of two species of *Iridaea* (Rhodophyta: Gigartinales). Mar. Ecol. Prog. Ser. 22: 291–303.

Hansen, J. E., 1983. A physiological approach to mariculture of red algae. J. World Maricul. Soc. 14: 380–391.

Hommersand, M., M. Guiry, S. Fredericq & G. Leister, 1993. New perspectives in the taxonomy of the Gigartinaceae (Gigartinales, Rhodophyta). Hydrobiologia 260/261: 105–120.

Infante, R. & A. Candia, 1988. Cultivation of *Gracilaria verrucosa* (Hudson) Papenfuss and *Iridaea ciliata* Kutzing (Rhodophyta, Gigartinaceae), *'in vitro'*. Induced shedding and carpospore colonization on different subtrata. Gayana, Bot. 45: 297–304.

Kawashima, S., 1984. Kombu cultivation in Japan for human foodstuff. Jap. J. Phycol. 32: 379/94.

Kuschel, F. & A. Buschmann, 1991. Abundance, effects and management of epiphytism in intertidal cultures of *Gracilaria* (Rhodophyta) in southern Chile. Aquaculture 92: 7–19.

Mumford, T. F., 1977. Growth of Pacific northwest marine algae on artificial substrates: potential and practice. In Krauss, R.

(ed.), The Marine Plant Biomass of the Pacific Northwest Coast. Oregon State University, Corvallis, 139–161.

Mumford, T. F., 1979. Field and laboratory experiments with *Iridaea cordata* (Floridophyceae) grown on nylon netting. Proc. int. Seaweed Symp. 9: 515–523.

Mumford, T. F. & J. R. Waaland, 1980. Progress and prospects for field cultivation of *Iridaea cordata* and *Gigartina exasperata*. In Abbott, I. A., M. S. Foster & L. F. Eklund (eds), Pacific Seaweed Aquaculture. California Sea Grant College Program, Pacific Grove , California, 92–105 & 192–197.

Navarro, R., 1991. Cultivo de *Iridaea ciliata* Kützing (Rhodophyta, Gigartinales) en el laboratorio y su factibilidad de crecimiento en terreno. Tesis de grado. Universidad Austral de Chile. Facultad de Ciencias Escuela de Biología Marina, 79 pp.

Norambuena, R., 1996. Recent trends in seaweed production in Chile. Hydrobiologia 326/327: 371–379.

Oohusa, T., 1993. The cultivation of *Porphyra* 'Nori'. In Ohno, M. & A. T. Critchley (eds), Seaweed Cultivation and Marine Ranching. Kanagawa International Fisheries Training Center, Yokosuka, 57–73.

Ohno, M. & M. Matsuoko, 1993. *Undaria* cultivation 'wakame'. In Ohno, M. & A. T. Critchley (eds), Seaweed Cultivation and Marine Ranching. Kanagawa International Fisheries Training Center, Yokosuka: 41–49.

Okazaki, A, 1971. Seaweeds and their Uses in Japan. Tokai University Press, Tokyo, 165 pp.

Otaíza, R., 1996. Respuesta a la herbivoría de discos gametofíticos y esporofíticos de *Iridaea ciliata.* VI Symposium de Algas Marinas y IV Encuentro de Microalgólogos. Puerto Montt, Chile: 70.

Poblete, A., A. Candia, I. Inostroza & R. Ugarte, 1985. Crecimiento y fenología reproductiva de *Iridaea ciliata* Kützing (Rhodophyta, Gigartinales) en una pradera submareal. Biol. Pesq. 14: 23–31.

Santelices, B., 1989. Algas Marinas de Chile. Ediciones Universidad Católica de Chile, Santiago. 400 pp.

Tseng, C. K., 1981. Commercial cultivation. In Lobban, C. S. & M. J. Wynne (eds), The Biology of Seaweeds. Blackwell Scientific, Oxford: 680–725.

Waaland, J. R., 1973. Experimental studies on the marine algae *Iridaea* and *Gigartina*. J. exp. mar. Biol. Ecol. 11: 71–80.

Waaland, J. R., 1976. Growth of the red alga *Iridaea cordata* (Turner) Bory in semi-closed culture. J. exp. mar. Biol. Ecol. 23: 45–53.

Westermeier, R., M. Morales, J. & D. Patiño, 1996. Caracterización de poblaciones de algas carragenófitas en el mar interior de la X y XI Región, con especial referencia a *Iridaea ciliata* Kutzing y *Gigartina skottsbergii* Setchell et Gardner (Rhodophyta, Gigartinales). VI Symposium de Algas Marinas y IV Encuentro de Microalgólogos. Puerto Montt, Chile: 91.

Westermeier, R., P. Rivera & I. Gomez, 1991. Cultivo de *Gracilaria chilensis* Bird, McLachlan & Oliveira, en la zona inter y sub mareal del estuario Cariquilda, Maullín Chile. Rev. chil. Hist. nat. 64: 307–321.