

Phenology of *Gigartina skottsbergii* (Gigartinaceae, Rhodophyta) in Ancud Bay, southern Chile

Jaime Zamorano P.¹ & Renato Westermeier H.²

¹Extractos Naturales Gelymar S.A., Casilla 997, Puerto Montt, Chile; Fax: 56-65-259300

²Instituto de Pesquerías y Ocenografía, Facultad de Pesquerías, Universidad Austral de Chile, Casilla 1327, Puerto Montt, Chile; Fax: 56-65-255583

Key words: *Gigartina skottsbergii*, management, seasonal variation, seaweed

Abstract

This study reports the variations in biomass and reproductive phenology in a natural bed of *Gigartina skottsbergii* over a period of a year and correlates these variations with the abiotic factors solar radiation, number of daylight hours, water temperature and salinity. The results obtained show an annual production cycle with maximum biomass values in spring–summer, correlated with high solar radiation and to a lesser extent with salinity. Sexual reproduction was maximum in autumn–winter, correlated with low temperature and short-day conditions. The population showed a large gametophytic dominance according to size and biomass, which suggests that there is not ecological equivalence between the life history phases of the species. Finally, based on the results, a restriction of harvesting to spring–summer is suggested.

Introduction

Gigartina skottsbergii Setchell et Gardner is confined to southern South America and Antarctic (Pujals, 1963; Kühnemann, 1972; Westermeier & Ramirez, 1981; Ramirez & Santelices, 1991). It grows on solid substrata in subtidal habitats, being abundant in wave protected environments (Alveal et al., 1973; Santelices, 1988).

Recently the species of Gigartinaceae have acquired great importance in Chile as raw materials for the production of carrageenan, increasing from six metric tons extracted in 1981 to more than 4 000 metric tons in 1993 (Sernap, 1994). Most of the material comes from Chiloé Island and consists of *G. skottsbergii*.

In spite of the economic importance of *G. skottsbergii*, available literature only includes data on its taxonomy, morphology (Kim, 1976) and chemical composition (Palermo et al., 1984; Cerezo, 1986; Noseda, 1989; Matulewicz et al., 1990; Piriz & Cerezo, 1991; Schnettler et al., 1995). Almost nothing is known of its production ecology.

The vegetative morphology of *G. skottsbergii* corresponds to a flat leathery thallus, generally circular to ellipsoidal, unbranched and attached to the substratum by a short, strong stipe and several haptera of secondary origin located on its inferior face.

Gigartina skottsbergii has a triphasic life cycle, with an alternation of isomorphic generations. Cystocarpic fronds bear papillae containing cystocarps whereas tetrasporic fronds develop tetrasporangia in the middle of the medulla (Kim, 1976).

This study is a first attempt at determining how temporal variation in biomass of a natural bed of *G. skottsbergii* in Ancud Bay (Chiloé Island) is correlated with temporal variation in environmental factors such as solar radiation, daylength, temperature and salinity. Since the relative abundance of life history phases of the species is ecologically and economically important, effort was also devoted to measuring seasonal variations in biomass and phenology.

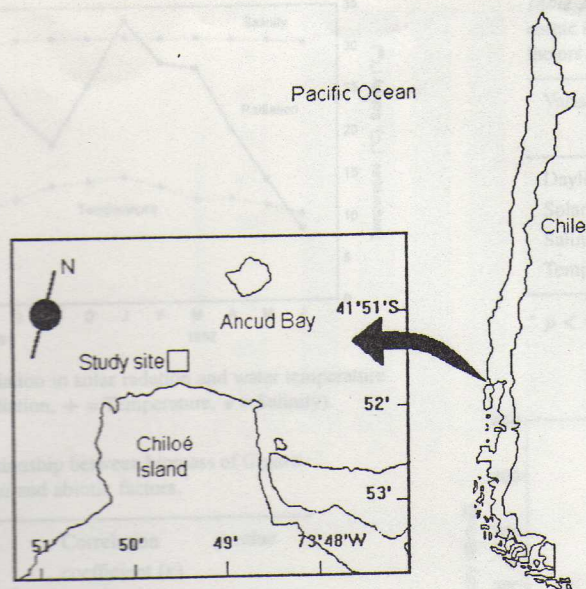


Figure 1. Geographic location of the study site.

Materials and methods

The study site (Figure 1) was Ancud Bay, Chiloé Island (41°51' S, 73°49' W). Chiloé Island has a rainy climate that is dominated most of the year by strong winds from the west (Viviani, 1979). A representative population of *Gigartina skottsbergii*, protected from wave action, was selected at approximately 9 ± 1 m depth (below MLW) living on large metamorphic rocks along an eroded part of the coast.

Sampling was carried out monthly from July 1991 to June 1992. The sampling used was destructive and haphazard and was performed using semi-autonomous diving (hookah). Sampling was done by manually harvesting all organisms present in each of ten 0.25 m² quadrats. Optimum sample size was found following the method described by DeWreede (1985), whereas optimum quadrat size was determined following Pringle (1984). After harvesting, each sample was placed separately in a plastic bag containing sea water, carried to the laboratory and frozen in containers for later sorting (12–24 hours after). Seaweeds were washed with sterilized sea water and weighed wt on a Sartorius balance (0.1 g precision).

Incident solar radiation was measured at the study site using a LI-COR (Li-189) light sensor. Temperature and salinity were measured using a digital thermo-conductivimeter (Orion 140) at three different depths

(0.5, 4.5 and 8.5 m). The number of hours of daylight by month was obtained from Stuvén (1968).

The phase of the life-cycle (gametophyte or tetrasporophyte) of each frond was determined using resorcinol (Garbary & DeWreede, 1988). Each time a resorcinol test was done, a control of known reproductive phase was used. Afterward, gametophytic blades were sorted into fertile and vegetative.

Once the phases were separated, maximum length and width (in cm) of each frond was measured. The area of the blade (in cm²) was determined by the formula:

$$\text{Area} = \Pi \frac{(\text{length} + \text{width})^2}{8}$$

This equation assumes a circular or ellipsoidal shape of the blades, which is exhibited by most blades. Values recorded were used to obtain the frequency distribution of 8 size classes (areas) established in an arbitrary manner. These size classes correspond to <1000, <2000, <3000, <4000, <5000, <6000, ≤7000 and >7000 cm².

In order to establish if there was a statistically significant relationship between changes in biomass and values of salinity, temperature, number of daylight hours and amount of solar radiation, a multiple regression step-by-step was done (Sokal & Rohlf, 1981). This was done using the four variables, removing them into the predictors set if their *p* value was larger than 0.10. The same procedure was used to establish the effect of abiotic factors on the variation in biomass of cystocarpic fronds.

In order to establish if the gametophyte: tetrasporophyte ratio differed from the expected 1:1 value, a G-test was used (Sokal & Rohlf, 1981).

Results

Brief description of the benthic community

Gigartina skottsbergii was the dominant species in regard to biomass in this community. *Sarcothalia crispata* (Bory) Leister, *Myriogramme crozieri* (Hooker et Harvey) Kylin, *Myriogramme multinervis* (Hooker et Harvey) Kylin and *Callophyllis variegata* (Bory) Kuetsing, among the erect algae, and the snail *Tegula atra* (Lesson) were other important components of this community.

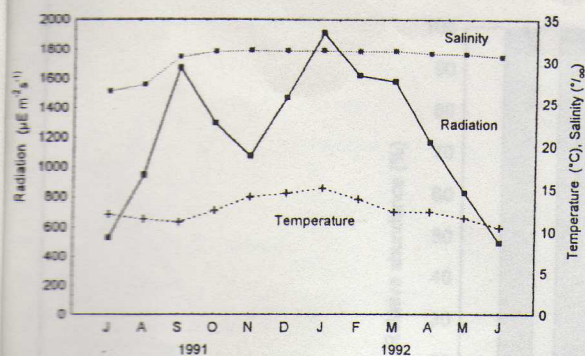


Figure 2. Monthly variation in solar radiation and water temperature and salinity. (■ = Radiation, + = Temperature, * = Salinity).

Table 1. Relationship between biomass of *Gigartina skottsbergii* and abiotic factors.

Variable	Correlation coefficient (<i>r</i>)	<i>p</i> value
Daylight	0.433	0.183 NS
Solar radiation	0.749	0.008 **
Salinity	0.610	0.046 *
Temperature	0.256	0.448 NS

* $p < 0.05$; ** $p < 0.01$.

Table 2. Relationship between biomass of cystocarpic fronds of *Gigartina skottsbergii* and abiotic factors.

Variable	Correlation coefficient (<i>r</i>)	<i>p</i> value
Daylight	-0.596	0.048 *
Solar radiation	-0.172	0.614 NS
Salinity	-0.380	0.250 NS
Temperature	-0.585	0.049 *

* $p < 0.05$.

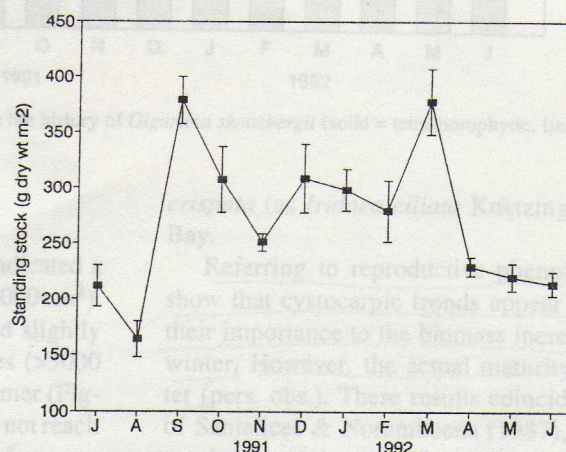


Figure 3. Monthly variation in biomass of *Gigartina skottsbergii*. The error bars correspond to standard deviation.

Seasonal changes in environmental factors

Photon flux densities measured over a year at the study site exhibited a clear seasonal trend, with a minimum of 400–500 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$ in winter and a maximum of 1600–1900 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$ in summer (Figure 2). Temperature (average of three depths) closely followed the same seasonal pattern, with a winter minimum of 10.5–12 °C and a summer maximum of 15 °C. Salinity (average) also exhibited temporal variation, but the trend is not strictly seasonal. Salinity was 26–27‰ during the rainy winter months, but then it flattened out at about 31‰ during the rest of the year.

Standing stock variations

Figure 3 shows that the maximum biomass (dry weight) occurred in spring (September 1991) and late summer – early fall (March 1992). The minimum values occurred in fall and winter (April–August). Values for salinity, temperature, number of daylight hours and amount of solar radiation together explained 56% of the biomass variation of *G. skottsbergii*. The step-by-step procedure indicated solar radiation was the most important single predictor for biomass (Table 1).

Reproductive phenology

Control tests for resorcinol were definitive. Results indicated that the population at this study site was dominated by the haploid phase (Figure 4). The departure from the expected 1:1 ratio is statistically significant ($\alpha = 0.01$).

Fertile tetrasporophytic fronds were present throughout the year (Figure 5). Even though there was a slight increase in fertile fronds during some months (e.g. September) the presence of tetrasporic thalli do not confirm a typical seasonal cycle. By contrast, the abundance of fertile cystocarpic thalli exhibits a very clear bimodal cycle, with a maximum in late winter – early spring and a second maximum in late summer – early fall. The statistical analysis shows that temperature and number of daylight hours were the environmental factors correlated with the variation in biomass of cystocarpic fronds (Table 2).

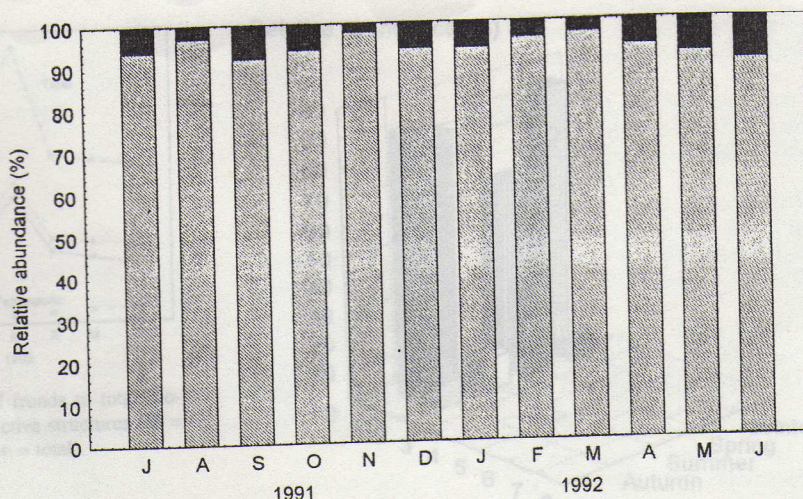


Figure 4. Percentages in biomass corresponding to the life history of *Gigartina skottsbergii* (solid = tetrasporophytic, lined = gametophytic).

Size structure

The size structure of gametophytic fronds indicated a predominance of size classes 1 and 2 (area $<2000 \text{ cm}^2$). The relative importance of class 1 decreased slightly during summer months, whereas bigger sizes ($>3000 \text{ cm}^2$) appeared principally in spring and summer (Figure 6). Tetrasporophytic fronds (Figure 7) did not reach sizes over 2000 cm^2 ; therefore the patterns of appearance of recruits and disappearance of large fronds was impossible to observe in this phase.

The fact that gametophytic fronds reached bigger sizes than sporophytic fronds should be noted.

Discussion

Gigartina skottsbergii is the dominant seaweed in the community studied. The semi-horizontal blades overshadow the understory, which here is almost exclusively represented by calcareous crusts and small thalli of *G. skottsbergii*. As soon as the large, overshadowing fronds are removed, the small fronds start growing (pers. obs.).

The production cycle observed for *G. skottsbergii* at the site is clearly seasonal, showing a good correlation between biomass and solar radiation. It is important to note the poor correlation found between biomass and water temperature. However, Hansen (1977) got similar results for *Mazzaella splendens* Setchell et Gardner (Fredericq) (as *Iridaea cordata* (Turner) Bory) in California as did Poblete et al. (1985) for *Sarcothalia*

crispata (as *Iridaea ciliata* Kuetszing) in Concepción Bay.

Referring to reproductive phenology, the results show that cystocarpic fronds appear in summer, and their importance to the biomass increases in autumn-winter. However, the actual maturity occurs in winter (pers. obs.). These results coincide with the those of Santelices & Norambuena (1987), referring to the maximum production of cystocarps on *Mazzaella laminarioides* (Bory) Fredericq (as *Iridaea laminarioides* Bory), as well as those of Piriz (pers. comm.), who observed the spontaneous liberation of tetraspores and carpospores in winter from *G. skottsbergii* in Argentina. Biomass of cystocarpic fronds was inversely correlated with temperature and number of daylight hours. This fact shows a clear asynchrony between the time of maximum biomass and the time of maximum sexual reproduction. These results suggest that biomass production and sexual reproduction are associated with different environmental factors, with solar radiation being the most important for production, and temperature and photoperiod for reproduction.

Tetrasporic fronds do not show much variation through the year, with a small peak in biomass at the beginning of spring (September). These results agree very well with those reported for the same species in Argentina, where cystocarpic thalli had a higher density in autumn, and a minimum in springtime, whereas tetrasporic thalli did not show any maximum or minimum values throughout the year (Piriz, 1988).

The abundance values for the different life history phases of the species at the study site, which favor the

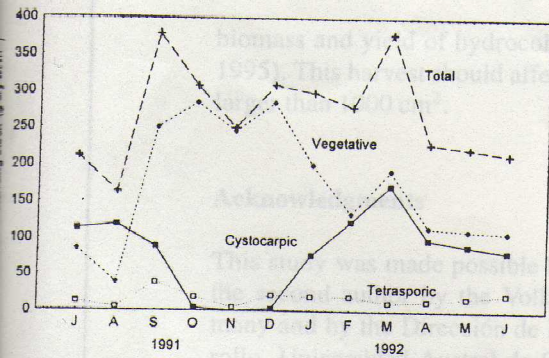


Figure 5. Contributions by different types of fronds to total biomass, according to ploidy and type of reproductive structures (■ = cystocarpic, ♦ = vegetative, □ = tetrasporic, + = total).

relative abundance (%)

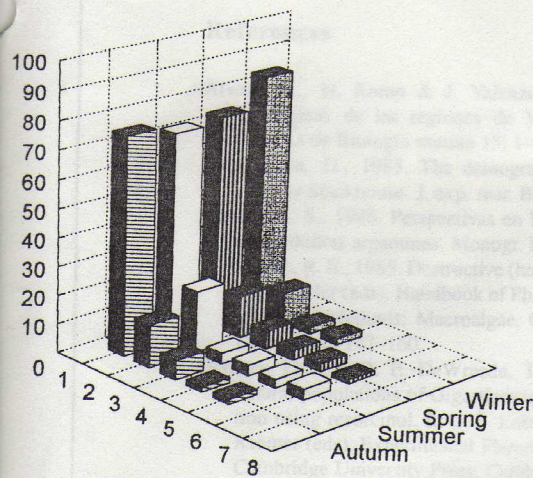
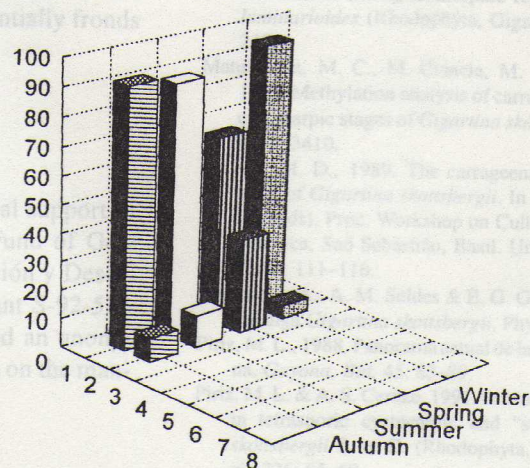


Figure 6. Seasonal variation in the size structure of gametophytic fronds (winter = Jun.-Aug., spring = Sep.-Nov., summer = Dec.-Feb., autumn = Mar.-May).

gametophytes at a frequency of approximately 90%, which is too high. However, studies of *Chondrus crispus* showed similar results in Canada (Bhattacharya, 1985). Studies of *G. skottsbergii* in Argentina also showed the presence of a small proportion of tetrasporophytes (Lazo et al., 1988).

The disproportion found in some seaweeds has been explained as the result of selective forces acting in different ways on the two phases (Gómez & Westermeier, 1990), with one phase better prepared than the other, competing more favorably for space and generating an asymmetric structure in the population (Lazo et al., 1990). Even though this idea was initially stated for

Relative abundance (%)



Size class

Figure 7. Seasonal variation in the size structure of tetrasporophytic fronds (seasons include the same months as Figure 6).

species with an alternation of heteromorphic generations (Lubchenco & Cubitt, 1980), it has been postulated also for species with an alternation of isomorphic phases to explain the inequality in the representation of these phases obtained in field studies (Luxoro & Santelices, 1989). Gametophytic and tetrasporophytic fronds show a reduction in the size class 1 during summer months, which reinforces the idea that reproduction and recruitment are centered in autumn-winter (May and June), when the highest percentage of plants with areas less than 10 cm² was registered. On the other hand, the fact that the largest sizes were obtained in spring and summer confirms the idea that the species possesses a cycle with loss of the largest fronds at the end of the growing season.

The fact that gametophytic fronds reach bigger sizes than the tetrasporophytic fronds adds to the dominance in frequency and biomass of the former and puts in doubt the equivalence of the life history phases of the species.

The elaboration of a management plan for this species needs research into the maintenance and natural recovery capability of the population as well as further research at other sites along the Chilean coast for comparison. However, based on this study, a restriction of harvesting to the spring-summer months (September to March) can be suggested, with the dual purpose of protecting the populations during their reproductive period and still obtaining the greatest production in

biomass and yield of hydrocolloids (Schnettler et al., 1995). This harvest should affect preferentially fronds larger than 1000 cm².

Acknowledgments

This study was made possible by financial support to the second author by the Volkswagen Fund of Germany and by the Dirección de Investigación y Desarrollo, Universidad Austral de Chile (Grant S-92-52). We thank B. Santelices, B. Rudolph, and an anonymous reviewer for their critical comments on the manuscript.

References

- Alveal, K., H. Romo & J. Valenzuela, 1973. Consideraciones ecológicas de las regiones de Valparaíso y de Magallanes. *Revista de Biología marina* 15: 1-29.
- Battacharya, D., 1985. The demography of fronds of *Chondrus crispus* Stackhouse. *J. exp. mar. Biol. Ecol.* 91: 217-231.
- Cerezo, A. S., 1986. Perspectivas en la utilización de ficoloides de Rodofitas argentinas. *Monogr. biol.* 4: 111-127.
- DeWreede, R. E., 1985. Destructive (harvest) sampling. In M. Littler & D. Littler (eds), *Handbook of Phycological Methods. Ecological Field Methods: Macroalgae*. Cambridge University Press, Cambridge: 147-160.
- Garbary, D. J. & R. E. DeWreede, 1988. Life history phases in natural populations of Gigartineae (Rhodophyta): quantification using resorcinol. In C. S. Lobban, D. J. Chapman & B. P. Kremer (eds), *Experimental Phycology, A Laboratory Manual*. Cambridge University Press, Cambridge: 174-178.
- Gómez, I. & R. Westermeier, 1991. Frond regrowth from basal disc in *Iridaea laminarioides* (Rhodophyta, Gigartinales) at Mehuín, southern Chile. *Mar. Ecol. Prog. Ser.* 73: 83-91.
- Hansen, J. E., 1977. Ecology and natural history of *Iridaea cordata* (Gigartinales, Rhodophyta): growth. *J. Phycol.* 13: 395-402.
- Kim, D. H., 1976. A study of the development of cystocarps and tetrasporangial sori in Gigartineae (Rhodophyta, Gigartinales). *Nova Hedwigia* 27: 1-145.
- Kühnemann, O., 1972. Bosquejo fitogeográfico de la vegetación marina del litoral argentino. *Physis* 31(83): 295-325.
- Lazo, M. L., M. Greenwell & J. McLachlan, 1989. Population structure of *Chondrus crispus* Stackhouse (Gigartineae, Rhodophyta) along the coast of Prince Edward Island, Canada. *J. exp. mar. Biol. Ecol.* 126: 45-58.
- Lubchenco, J. & J. Cubit, 1980. Heteromorphic life histories of certain marine algae as adaptations to variations in herbivory. *Ecology* 61: 676-687.
- Luxoro, C. & B. Santelices, 1989. Additional evidence for ecological differences among isomorphic reproductive phases of *Iridaea laminarioides* (Rhodophyta, Gigartinales). *J. Phycol.* 25: 206-212.
- Matulewicz, M. C., M. Ciancia, M. D. Nosedá & A. S. Cerezo, 1990. Methylation analysis of carrageenans from tetrasporic and cystocarpic stages of *Gigartina skottsbergii*. *Phytochemistry* 29: 3407-3410.
- Nosedá, M. D., 1989. The carrageenan system of the tetrasporic stage of *Gigartina skottsbergii*. In E. C. de Oliveira & N. Kautsky (eds), *Proc. Workshop on Cultivation of Seaweeds in Latin America*, São Sebastião, Brasil. Universidad de São Paulo, São Paulo: 111-116.
- Palermo, J. A., A. M. Seldes & E. G. Gros, 1984. Free sterols of the red alga *Gigartina skottsbergii*. *Phytochemistry* 23: 2688-2689.
- Piriz, M. L., 1988. Panorama actual de la ficología marina en Argentina. *Gayana, Bot.* 45: 83-89.
- Piriz, M. L. & A. S. Cerezo, 1991. Seasonal variation of carrageenans in tetrasporic cystocarpic and "sterile" stages of *Gigartina skottsbergii* S. et G. (Rhodophyta, Gigartinales). *Hydrobiologia* 226: 65-69.
- Poblete, A., A. Candia, I. Inostroza & R. Ugarte, 1985. Crecimiento y fenología reproductiva de *Iridaea ciliata* Kützinger (Rhodophyta, Gigartinales) en una pradera submareal. *Biología Pesquera* 14: 23-31.
- Pringle, J. D., 1984. Efficiency estimates for various quadrat sizes used in benthic sampling. *Can. J. Fish. aquat. Sci.* 41: 1485-1489.
- Pujals, C., 1963. Catálogo de Rhodophyta citadas para Argentina. *Revista del Museo Argentino de Ciencias Naturales 'Bernardino Rivadavia'*, Botánica 3(1): 1-139.
- Ramírez, M. E. & B. Santelices, 1991. Catálogo de las algas marinas bentónicas de la costa temperada del Pacífico de Sudamérica. *Monografías Biológicas* 5: 437 pp.
- Santelices, B., 1988. Algas marinas de Chile. Distribución, ecología, utilización y diversidad. Ediciones Universidad Católica de Chile, Santiago: 399 pp.
- Santelices, B. & R. Norambuena, 1987. A harvesting strategy for *Iridaea laminarioides* in central Chile. *Proc. int. Seaweed Symp.* 12: 329-333.
- Sernap (Servicio Nacional de Pesca), 1994. Anuario estadístico de pesca 1993. Valparaíso, Chile, 190 pp.
- Schnettler, P., R. Westermeier, B. Matsuhira & C. Urzúa, 1995. Seasonal variations of carrageenan in the three stages of *Gigartina skottsbergii* S. et G. (Gigartinales, Rhodophyta). XVth International Seaweed Symposium, Abstracts and Program: 101.
- Sokal, R. R. & F. J. Rohlf, 1981. Biometry. The principles and practice of statistics in biological research. Second ed. W. H. Freeman & Company, New York, 859 pp.
- Stuven, H., 1968. 43 Gráficos de trayectoria solar para ciudades de Chile y Argentina. Facultad de Arquitectura y Urbanismo, Universidad de Chile, Santiago, 36 pp.
- Viviani, C. A., 1979. Ecogeografía del litoral chileno. *Studies on Neotropical Fauna and Environment* 14: 65-123.
- Westermeier, R. & C. Ramírez, 1981. Artendiversität und nekromasse der algen im strandanwurf von Niebla (Valdivia, Chile). *Bot. mar.* 22: 241-248.