Reproductive biology of *Gigartina skottsbergii* (Gigartinaceae, Rhodophyta) from Chile

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**Abstract**

Reproductive phenology and spore viability were studied in a natural bed of *Gigartina skottsbergii* at the locality of Ancud, Chile. Monthly sampling of biomass and density disclosed a decrease of both parameters in time, from 40 g m⁻² in June 1996 to 1 g m⁻² December 1997 and from almost 4 thalli m⁻² to 1 thallus m⁻² in the same period, respectively. Mature reproductive structures, cystocarps and tetrasporangial sori, were observed over the whole study period. Greatest cystocarp densities occurred in October through February (16 to 29 cystocarps cm⁻²) and of tetrasporangial sori between July and October (66 to 88 sori cm⁻²). In both types of reproductive structures, sporulation is more frequent in winter and early spring. High mortality of carpospores and tetraspores was observed in laboratory experiments performed between June and September.

**Introduction**

*Gigartina skottsbergii* Setchell & Gardner is a subtidal carrageenophyte of commercial importance in Chile (Avila & Seguel, 1993; Norambuena, 1996; Bixler, 1996). Its distribution is from Niebla (39° 53' S) to Cape Horn (54° 56' S) and it is endemic to the southernmost part of South America (Ramírez & Santelices, 1991). It is also found on the southern coasts of Argentina and the sub-antarctic islands (Piriz, 1988; 1996). In Chile this species has been exploited since the late 1980s reaching up to 8000 dry tons in 1996 (Avila et al., 1997), and the annual quantity of carrageenan extracted has gradually increased, up to 1700 t in 1996.

The landing zone of this resource extends from Faro Corona (41° 47' S; 73° 53' W) to Puerto Aguirre (45° 10' S; 73° 32' W) (Schnettler, pers. com.).

The information available on this species refers mostly to its geographical distribution (Ramírez & Santelices, 1991; Santelices, 1989), vegetative frond morphology (Santelices, 1989; Alveal et al., 1990), reproductive structures (Kim, 1976) and chemical composition (Schnettler, pers. com). Other recent studies deal with the fluctuation of biomass and density in natural populations (Piriz, 1988; 1996; Zamorano, pers. com.) as well as with the species phenology (Zamorano & Westermeier, 1996; Avila et al., 1997; Candia, pers. com.).

The reproductive biology of this species is little documented, although sexual reproduction is known to occur seasonally (Zamorano & Westermeier, 1996; Westermeier & Sigel, 1997); an alternation in the dominance of the reproductive phases, as described for other species of the Gigartinales (e.g. *Iridaea splendens*, Ang et al., 1990) also occurs seasonally. Kim (1976) indicated that the species has a triphasic life cycle with alternation of isomorphic generations.

In contrast to other Gigartinales where the population is maintained by perennial holdfasts which produce or regenerate new blades (May, 1986; Santelices & Norambuena, 1987; Gómez & Westermeier, 1991), *G. skottsbergii* adheres to the substratum by means of secondary haptera which develop in juvenile stages (Piriz, 1996). Studies conducted at the Island of Chiloé showed that natural recruitment occurs in winter time between June and August, being...
strongly associated to the period of greatest abundance of mature reproductive phases (Avila et al., 1997).

The relative importance between the abundance of cystocarpic and tetrasporic phases, spore production (carpospores and tetraspores) and recruitment has not been established for G. skottsbergii. The aim of this work was to determine plant fecundity and spore viability in order to establish the importance of the reproduction through spores in the maintenance of G. skottsbergii natural beds.

Materials and methods

To determine the abundance of the tetrasporophyte, gametophyte and carposporophyte phases in G. skottsbergii, a subtidal population was sampled at the locality of San Antonio, Ancud (41° 52’ S; 73° 51’ W), Chiloe Island, Chile. The depth in the sampling area was between 6 and 10 m below mean tide level, the subtidal algal community was dominated by G. skottsbergii and covered approximately an area of 12 ha. Monthly samplings were done from June 1996 to February 1998 by hooka diving. On each occasion two non-permanent transects of 100 m each were established, perpendicular to the coastline. A 1 × 1 m quadrat was sampled every 10 m along the transect, making a total of 20 samples in each month. Fronds were collected with the substrate and placed in polyethylene bags and labelled, subsequently analyzed in the laboratory, reproductive phases and sizes were separated, and wet biomass (g m⁻²) and frond density (fronds m⁻²) were determined. Plants below 1 cm were directly counted on the substratum under a stereomicroscope.

Since mature fronds were scarce in the San Antonio locality, reproductive thalli of the tetrasporophyte and carposporophyte phases to study plant fecundity were sampled in a nearby natural bed. Two kg of each mature tetrasporophyte and cystocarpic were sampled for 21 months from June 1996 until February 1998, at Bahía de Ancud, Chiloe (41° 55’ S; 73° 51’ W). Of these, 10 fronds bearing cystocarps and 10 thalli with tetrasporangial sori were separated in the laboratory. Wet biomass was determined for each frond. Subsequently, the density of reproductive structures (cystocarps or tetrasporangial sori) was determined in the 10 thalli and from each phase, by counting under the microscope the structures present in ten 1 cm² random locations on each frond. In tetrasporophytic thalli, the number of mature, immature and empty tetrasporangial sori present in each sampled area was determined. Maturity in sori was determined by colour scale (Santelices & Martínez, 1997), as follows: mature sori, brown to black; immature sori, orange to light brown, and empty sori, white (Figure 1).

Gigartina skottsbergii cystocarps originate in papillae which jut out from the surface of the female gametophytic thallus. Due to this arrangement, we first counted the number of papillae cm⁻², then the number of cystocarps per papilla and finally the total number of cystocarps cm⁻². With these data, we estimated the density and abundance of reproductive structures in an area of 1 cm² of the tetrasporophytic and carposporophytic phases.

Carpospore and tetraspore cultures were started to determine their viability during June, July and September, when mature tetrasporophyte and carposporophyte are abundant. Sections of 2 × 2 cm were cut from gametophytic thalli with cystocarps and from tetrasporophytic thalli with tetrasporangial sori. Three pieces of each phase were placed into Petri dishes (20 × 100 mm) with filtered seawater enriched with Provasoli solution (Provasoli, 1968). After the liberation of carpospores and tetraspores, 1 ml aliquots of each spore type were drawn separately. They were put in dishes with culture medium to obtain germination and development of carpospores and tetraspores.

These cultures were kept at 10 °C and 16:8 h light: dark cycle, with a 10 μmol m⁻² s⁻¹ and observed after 5 days. Two Petri dishes with carpospores and tetraspores were sampled under an inverted microscope, with 10 ocular fields (10 × 10 ×) corresponding to an approximate area of 2.443 mm². Live and dead spores were counted in each field. The percentage of mortality and of survival was estimated for each spore type.

Data of density of reproductive structures and biomass were tested using a correlation analysis. Mortality rates were tested using a two-way ANOVAs with a posteriori Tukey HSD for multiple comparisons (Sokal & Rohlf, 1981).

Results

During the study period (June 1996 to February 1998), a decrease was observed in the total and reproductive biomass (reproductive phases) in the bed studied at San Antonio. This biomass fell from about 40 g m⁻² in winter (June, 1996) to under 1 g m⁻² the subsequent