Vegetative propagation and spore-based recruitment in the carrageenophyte *Chondracanthus chamissoi* (Gigartinales, Rhodophyta) in northern Chile

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SUMMARY

In the present study we compared vegetative and spore-based propagation for *Chondracanthus chamissoi* (C. Agardh) Kützing. Monthly field observations were made over a 1-year period at Puerto Aldea, Tongoy Bay, Chile. Data were collected both outside and within a bed of *C. chamissoi*. Vegetative propagation was assessed via attachment of drifting fronds to shell-encrusted concrete blocks at both sites. Germination of spores was recorded on the same shell substrates. Substrate re-adhesion varied seasonally between sectors. Highest averages occurred within the algal bed between January 1997 and March 1997. The number of sporelings showed two peaks of maximal recruitment in spring and summer months (January–March 1997 and September 1997–January 1998). Spore-based propagation is an important mechanism of seasonal regeneration of biomass in the *C. chamissoi* bed; however, re-attachment of fronds may have been important in maintaining production of the bed during the period of maximum biomass accumulation.

Key words: Chile, *Chondracanthus chamissoi*, frond re-attachment, recruitment, reproduction, spores.

INTRODUCTION

Chondracanthus chamissoi (C. Agardh) Kützing is an economically important carrageenophyte harvested along the Chilean coast (Santelices 1989). It provides an important source of income for coastal settlements in northern Chile (González and Meneses 1996). *C. chamissoi* grows to a maximum depth of 15 m between the lower intertidal and subtidal zones. It is commonly found in calm bays protected from wave action (Hoffmann and Santelices 1997).

Dispersion and maintenance of marine benthic algae populations occur by reproductive structures, including spores and zygotes, and by vegetative means, such as thallus fragmentation (Hoffmann 1987; Santelices 1990; Serrão 1998). Thallus fragmentation can be caused by the action of herbivores and water movement (Fletcher and Callow 1992; Serrão 1998). Recent studies on *C. chamissoi* in Herradura Bay (29°28′S) have demonstrated the importance of sexual reproduction in maintaining biomass of this alga. This species produces spores throughout the year, with a greater number of sori and spores per sorus in spring and summer months (Vásquez and Vega 2001). González *et al*. (1997) suggested that the permanence of the adhesive disks and re-adhesion of drifting fronds might also be important mechanisms for the regeneration of biomass and establishment of new *C. chamissoi* plants in the beds at Puerto Aldea, Tongoy Bay, Chile (30°15′S). However, no data have been provided regarding the relative importance of these two mechanisms.

The objective of the present study is to determine the importance of two mechanisms of population maintenance in *C. chamissoi* in Puerto Aldea. This project is part of a continuing study of this species (González *et al*. 1997; Macchiavello *et al*. 1999; Bulboa and Macchiavello 2001; Vásquez and Vega 2001), which aims to establish a management program for the sustainable exploitation of this important algal resource.

MATERIALS AND METHODS

The study site

The study was carried out on a subtidal bed of *C. chamissoi* located at Puerto Aldea in Tongoy Bay, Chile (30°15′S; 71°35′W) at a depth of 4–5 m. The population is attached to small boulders and shelly sand, and is divided into four irregularly shaped patches or sub-beds. One of these sub-beds, with an area of approximately 1 hectare during the summer, was chosen as the experimental plot. The study area was restricted to a 15 × 15 m plot in the center of the bed to avoid edge effects and changes in size during the remaining seasons. An area of the same dimensions and devoid of *C. chamissoi* approximately 200 m away from the bed was selected as a control sector (Fig. 1).

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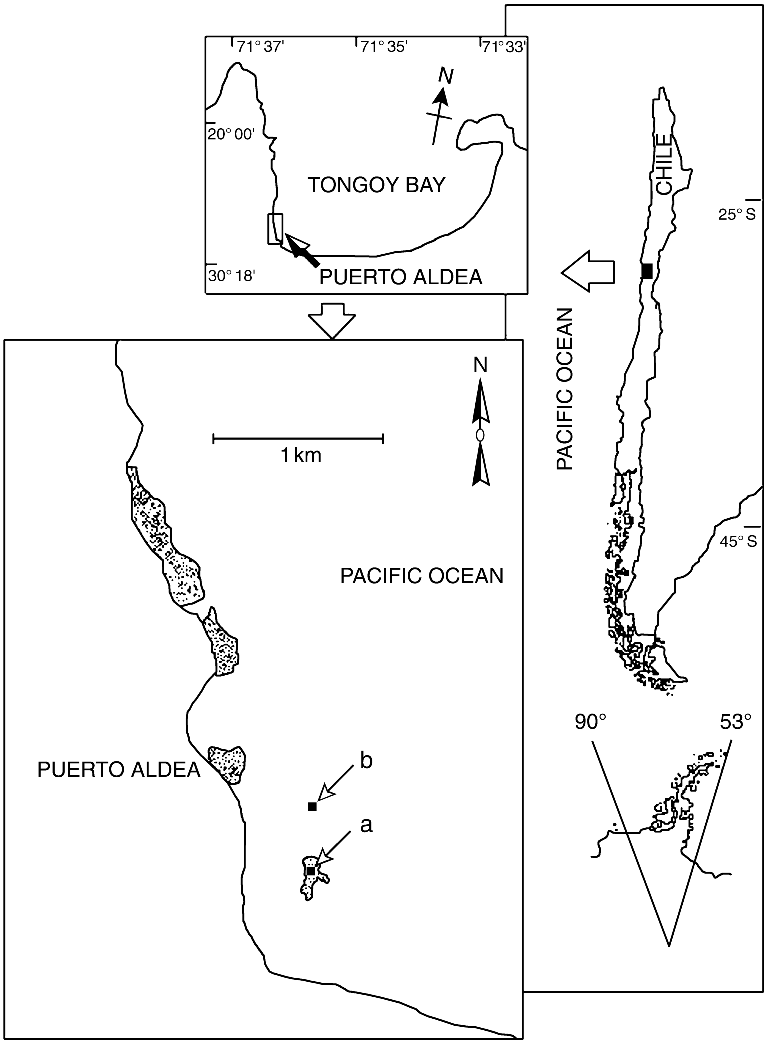

Fig. 1. Geographic location of the study area illustrating the four sub-beds of *Chondracanthus chamissoi*. (a) Sub-bed of the present study. (b) Plot in the 'control sector'.

Vegetative propagation

Drifting fronds

Sampling was carried out every 30 days in both sectors to determine the density of fronds drifting freely across the bottom. All free plant material was collected from within the limits of a 1-m^2 quadrant placed randomly in the study plot. This was repeated five times, and data were expressed as plants m^{-2}.

Re-adhesion of drifting fronds

Five concrete blocks ($27 \times 27 \times 3$ cm) with upper surface covered by bivalve shells *Argopecten purpuratus* (Fig. 2) were distributed randomly within both study plots. All blocks were recovered and replaced with new blocks every month between January 1997 and January 1998. All *C. chamissoi* plants that adhered to the blocks were counted, and recorded as plants m^{-2}.

Propagation from spores

Spores settlement plates (2.5×5.0 cm) made from clean shells of *Tagelus dombeii* were fixed to each cement block (Fig. 2). Settlement plates were recovered and brought to the laboratory in seawater for culture under controlled conditions to determine the number of *C. chamissoi* plantlets produced by spore settlement (sporelings) during the test period. Culture conditions were as follows: (i) 45 μmol photons m^{-2} light intensity; (ii) 12 h light : 12 h dark regimen; (iii) 16°C temperature; (iv) constant aeration with compressed air; and (v) weekly changes of seawater enriched with von Stosch medium (Edwards 1970) diluted to 50%. Cultures were observed for 2–3 months until *C. chamissoi* arising from spores could be clearly identified and counted.

Data on drifting fronds, re-attached fronds, and spore-based recruitment were analyzed separately

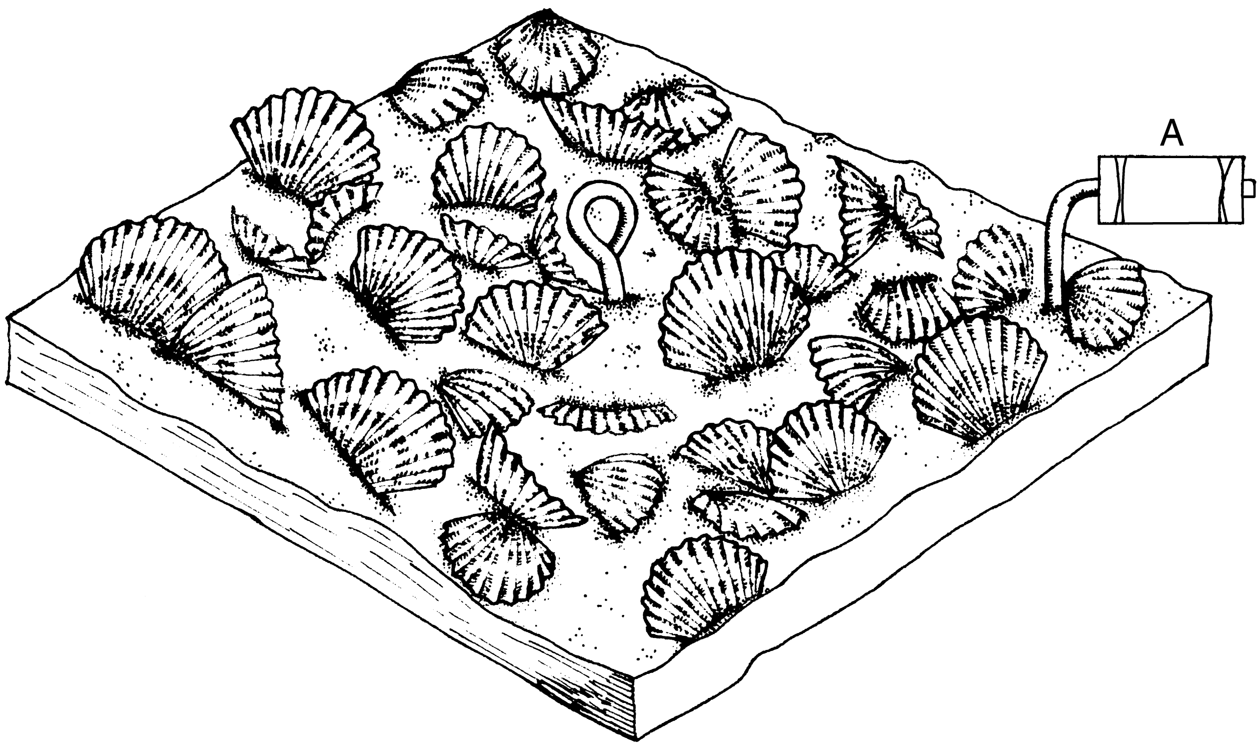

Fig. 2. Concrete block placed for testing the re-attachment of loose *Chondracanthus chamissoi* fronds. Note surface irregularity produced by encrustation of bivalve shells *Argopecten purpuratus* in cement block. Spore settlement plate (*Tagelus dombeii* shell) tied down to hook in the block (A).

using a two-way analysis of variance (ANOVA). Homogeneity of variance was reviewed for all results using the Bartlett test. The Tukey test was used when treatment showed significant differences (Sokal and Rohlf 1981).

RESULTS

Significantly greater numbers of drifting fronds were observed within the algal bed than in the control area ($P < 0.01$). These differences were observed between January 1997 and March 1997 (Fig. 3a). The number of drifting fronds was significantly higher during this period than between the months of April 1997 and January 1998 ($P < 0.01$). A maximum value of 29 ± 23 plants m^{-2} was reached in February 1997. The average did not exceed five plants m^{-2} between April 1997 and January 1998.

A similar situation was observed for re-attached fronds (Fig. 3b). The algal-bed sector had a greater number of re-attached fronds than did the control sector ($P < 0.01$). Re-attachment was highest in February 1997 and March 1997 (129 ± 77 and 72 ± 67 plants m^{-2}, respectively) and lowest between April 1997 and January 1998 (<10 plants m^{-2}; $P < 0.01$).

Two peaks in spore-based recruitment were observed in the *C. chamissoi* bed (Fig. 3c). The first occurred between January 1997 and March 1997 (maximum 18 ± 14 sporelings cm^{-2}), and the second occurred between September 1997 and January 1998 (maximum 7 ± 3 sporelings cm^{-2}). These values were significantly higher than those observed in the remaining months of the study ($P < 0.01$). A gradual decrease was observed during the second period (October 1997–January 1998), when the minimal value was reached (Fig. 3c). Low numbers of plantlets were recruited from spores in the control sector, with a maximal value of 3 ± 0.08 sporelings cm^{-2} in February 1997.

A large portion of the *C. chamissoi* biomass was lost in August 1997 due to agitation by heavy swells caused by North winds (Anonymous 1997).

DISCUSSION AND CONCLUSIONS

The three variables measured in the present study had similar annual variation, characterized by increases during the warmest months. These results are consistent with other studies, which reported increases in total biomass of *C. chamissoi* beds in spring and summer months (González *et al.* 1997; Vásquez and Vega 2001). Bulboa and Macchiavello (2001) attributed it to growth in response to environmental factors, mainly temperature.

Although it has been reported that drifting plants are capable of re-adhesion to the substrate, little is

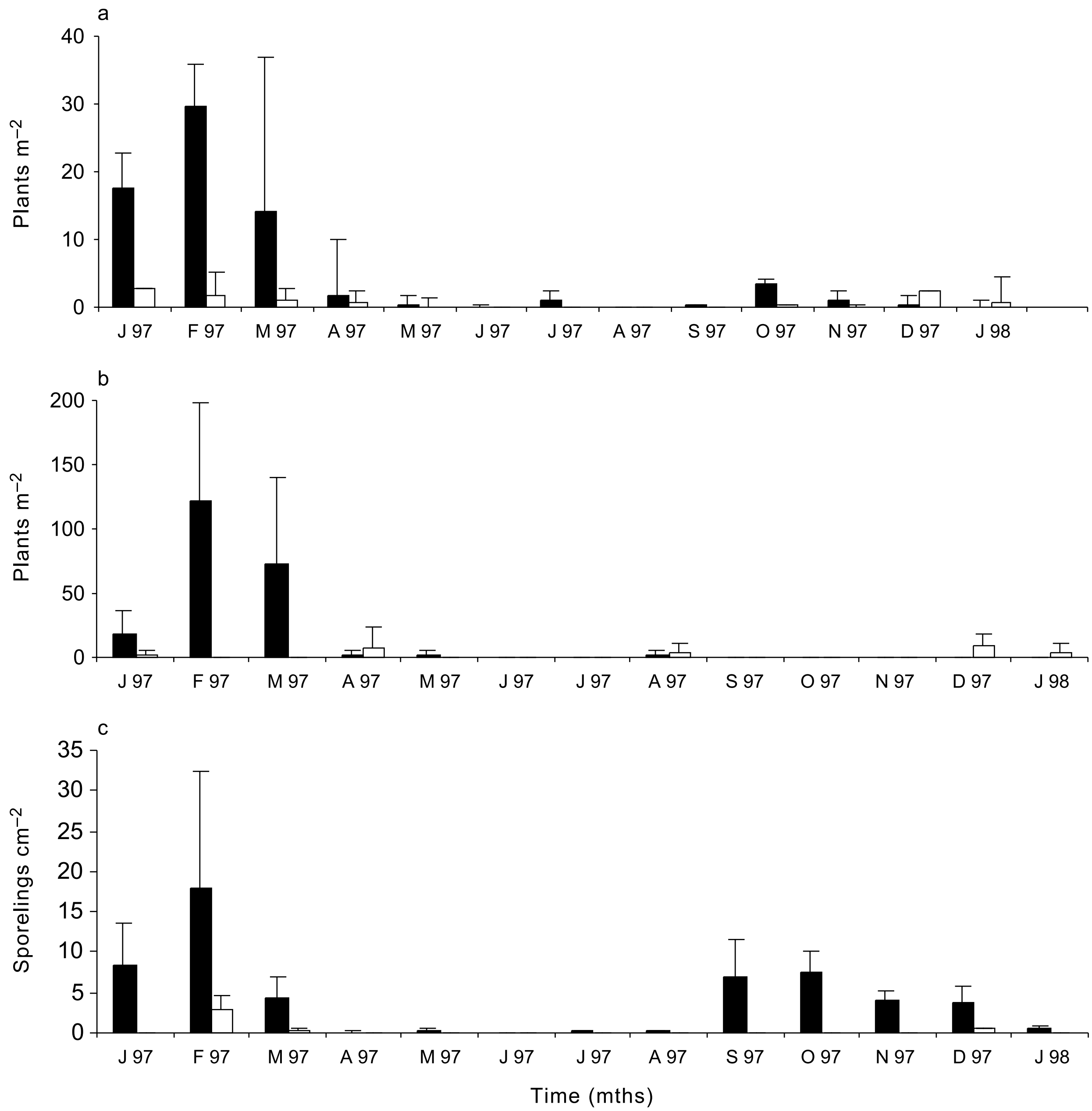

Fig. 3. Seasonal sampling within a bed of *Chondracanthus chamissoi* (■) and a 'control' sector outside the algal stand (□). (a) Drifting fronds. (b) Re-attached fronds. (c) Spore-based recruitment.

known about the distance these fragments may travel or their relative importance as propagules (Hoffmann 1987). Vegetative propagation has been reported as an efficient means of dispersion for some tropical red algae (Rodgers and Cox 1999). González *et al.* (1997) proposed that re-attachment of fronds of *C. chamissoi* might be an important mechanism in maintaining natural populations of this species. Our results confirm that fronds of this species can re-attach within existing beds. However, re-attachment does not appear to be a significant mechanism of seasonal regeneration; rather it depends of the abundance of the initial biomass stock. Vegetative regeneration may have been important in maintaining production of the bed by avoiding total loss of fragmented biomass during the period of maximal biomass accumulation (spring and summer) at a time when the bed suffers other major reductions in the form of herbivory and human harvesting.

The two peaks in spore-based recruitment (spring and summer) were consistent with previous studies at Puerto Aldea, which showed that the total biomass of *C. chamissoi* vary seasonally. Reproductive plants represented 30% of the total biomass during summer months (González *et al.* 1997). The increase in total biomass implies an increase in the total number of sporangia present on the bed.

Our results can also be explained by the increase of reproductive tissues and index of spores liberated in the spring (Vásquez and Vega 2001). Laboratory results confirm that *C. chamissoi* has increased liberation, settlement, and germination of spores during the summer months (González and Meneses 1996).

Based on previous data presented for *C. chamissoi* (González and Meneses 1996; González *et al*. 1997; Bulboa and Macchiavello 2001; Vásquez and Vega 2001), as well as our own data obtained during the first months of this study, an increase was expected both in the numbers of re-attached fronds and spore-based recruitment from September 1997 to January 1998. However, increases were noted only in spore-based recruitment, which may be related to the occurrence of unusual and unexpected inclement sea conditions (wave and swell) in August 1997 (Anonymous 1997), which caused the loss of a large portion of the *C. chamissoi* bed at Puerto Aldea and could have swept away fronds that had re-attached to the blocks. Unfavorable hydrodynamic conditions possibly also interfered with normal seasonal recovery of the bed, probably due to the total removal of the sporelings that grew over the natural substrate (pers. obs., Macchiavello, J. and Bulboa, C., 1997).

The seasonal increase in biomass appears to be the only factor responsible for the increase in drifting and re-attachment of fronds observed in this study. An increase in biomass and size of thalli offers higher resistance to wave motion, which causes a higher degree of breakage. However, the seasonal increase in biomass reported in the present study is the result of the previous development of sporelings, which were abundant in the field at that time, and each year at the end of the winter (pers. obs., Macchiavello, J. and Bulboa, C., 1997). The origin of these sporelings (2–3 cm in length) during August would correspond with what occurred during the spring–summer season, or to the permanence of adhesive disks, as was suggested by González *et al*. (1997). The high number of spore-based recruitment per unit of area observed over the offered substrate in the present study quantitatively demonstrates the importance and effectiveness of these mechanisms for the seasonal regeneration of biomass in the *C. chamissoi* bed.

The results of the present study show that both strategies (spore-based recruitment and vegetative propagation) would participate in the maintenance of the biomass of *C. chamissoi*. Re-attachment of fronds may have been important in maintaining production of the bed during the period of maximum biomass accumulation, however, spore-based recruitment could be an important mechanism of seasonal regeneration of biomass in the *C. chamissoi* bed.

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