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Sargassum Cymosum (Phaeophyceae) in Southern Brazil: Seasonality of Biomass, Recovery After Harvest and Alginate Yield

L. L. Mafra Jr.† and S. R. Cunha ‡

† Laboratório de Oceanografia Biológica, CTTMar, Universidade do Vale do Itajaí - UNIVALI, Itajaí, SC, 88302-202, Brasil
luiz.mafra@nrc-cnrc.gc.ca

‡ Laboratório de Ecologia da Vegetação Costeira, CTTMar, Universidade do Vale do Itajaí, Itajaí, SC, 88302-202, Brasil.
simone.cunha@univali.br

ABSTRACT

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This work aimed to assess the seasonal variation of biomass and alginate yield, the period of maximum reproduction and the biomass recovery after harvest of a *Sargassum cymosum* bed in Armação do Itapocoroy Bay, Santa Catarina State, Southern Brazil, in order to evaluate its potential for a managed exploitation. A control and a harvest site were placed along Feia Island. In July 1999, *Sargassum* plants were cut off into the harvest site. *Sargassum* biomass was collected bimonthly from July 1999 to July 2000, using $0.25m^2$ samplers and seven replicates. During the sorting reproductive and vegetative structures and associated algae were separated, dried and weighted. The biomass of *Sargassum* presented a strong seasonal pattern, ranging from 20.88±14.8 g dw m^{-2} (September 1999) to 327.16±84.3 g dw m^{-2} (April 2000). The reproductive peak was simultaneous to biomass peak, reaching 11% of total biomass. Maximum biomass of associated algae also occurred in April 2000, reaching 24.3±15.4g dw m^{-2}. Total recovery of *Sargassum* biomass occurred nine months after harvest. Alginate yield ranged from 28.88 ±2.04% to 22.93±1.62%. Based on this data, we believe *Sargassum cymosum* presents good potential for exploitation, and we suggest harvesting it once a year, during the autumn.

ADITIONAL INDEX WORDS: *Seaweed, management, brown algae* .

INTRODUCTION

The brown alga *Sargassum* is widely distributed along tropical and subtropical coasts (PRINCE and O'NEAL, 1979). It is usually the ecologically dominant species in the coastline, forming large and dense beds from the lower intertidal to subtidal zones of exposed or sheltered coasts. These algae play a remarkable ecological role. It is used as food resource by many macrohebivores (ESTON and BUSSAB, 1990) and mesoherbivores (TARARAM *et al.*, 1978). The complex structure of its branches offers protection from predators and a safe place for settlement of eggs from a variety of animals (LARGO and OHNO, 1993). Other species of seaweeds also strongly depend on *Sargassum* beds (PAULA and OLIVEIRA, 1980). *Sargassum* is also economically important, used mainly as source of alginate, a cell wall polysaccharide of brown seaweed with several industrial uses (LEWIS *et al*., 1988).

There are 11 species of *Sargassum* forming extensive beds along the Brazilian coast, mainly along the southern and southeastern coasts (PAULA, 1988), but its potential of biomass production, its seasonal dynamics of biomass and its alginate yield are poorly known in Brazilian coast. Besides that, the market demand for alginate in Brazil is high and it is increasing (OLIVEIRA, 1997); but this product is imported. No commercial production of alginate occurs in Brazil. The local *Sargassum* harvests are small, scattered and only for therapeutic uses (OLIVEIRA, 1998).

To evaluate the potential for sustainable exploitation of *Sargassum* along the coast of Santa Catarina State, it is necessary to understand its productivity, regeneration capacity, and ecologic interactions. To accomplish part of these goals, we aimed to assess the seasonal variation of biomass and alginate yield, the period of maximum reproduction and the biomass recovery after harvest of a *Sargassum cymosum* bed in Armação do Itapocoroy Bay, Santa Catarina State, Brazil.

METHODS

Study Site

Armação do Itapocoroy Bay (26º44'S, 48º39'W, Figure 1), located at Santa Catarina State, Southern Brazil, is protected from south wind and waves, but strong surge storms are frequent during autumn and winter. The rocky shores present high seaweed diversity and biomass. *Sargassum cymosum* is a very abundant alga, comprising extensive beds. A single bed with area about $175m^2$, with depths ranging from 2 to 5m below low tide, was chosen at the west coast of the Feia Island. Inside the bed an area of $75m^2$ was chosen as the control site, and it was delimited by fixing a 8mm diameter polyester cable on the sea bottom. This cable was marked each meter to allow the positioning of the samples. The area outside the control site was chosen as the site to evaluate biomass recovery, and denominated as harvest site. Randomizing the harvests and controls plots was not possible due to low visibility (always lower than 4m) and very strong local currents, which made impossible to locate small plots in previous tests.

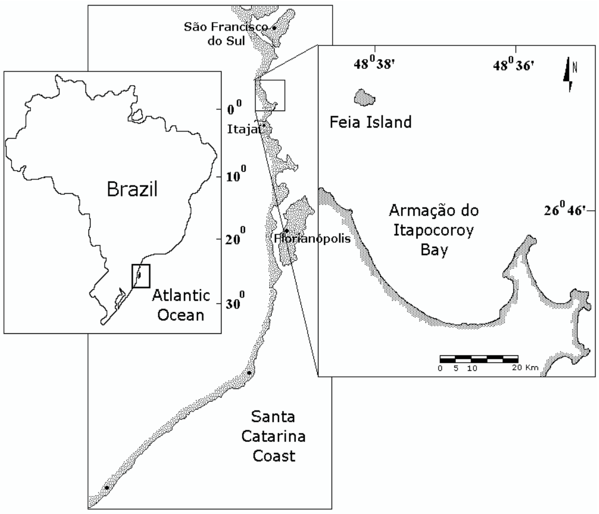

Figure 1. Armação do Itapocoroy Bay, Santa Catarina State, Southern Brazil, including Feia Island, the study site.

Abiotic Data

Water salinity, superficial water temperature and meteorological observations for the bay were obtained daily during the experimental period from the Voluntary Monitoring Program (BONILHA *et al*., 1999). Dissolved nutrient concentrations (ammonium, nitrite, nitrate and phosphate) of surface water into the bay were obtained from Laboratory of Chemical Oceanography/UNIVALI.

Seasonal Pattern of Biomass

Biomass of *Sargassum cymosum* was sampled bimonthly within the control area from July 1999 to July 2000, using $0.25m^2$ samplers and seven replicates. The number of replicates was previously determinate in a pilot test. Spatial location of all bimonthly samples was previously defined using randomly generated numbers, before the beginning of sampling to avoid overlapping during the period. Each sampler was positioned 0.5m far from marked cable and at least 1m from each other.

Inside the samplers, all the *Sargassum* plants were cut off about 1 cm above the holdfast. Each sample was identified and, at the laboratory, preserved by freezing. *Sargassum* was cleaned to remove associated algae and other organisms, weighted, dried in 65ºC and weighted again. Epiphytic and associated algae were sorted by genera, dried at 65ºC and weighted.

Biomass values were expressed as g dry weight m^{-2} (g dw m^{-2}), and rate between fresh and dry weight in percentage.

During the sorting of samples, if reproductive structures (receptacles) were present in *Sargassum*, they were removed, dried and weighed separately. They were expressed as percentage of total dry weight of algae (vegetative plus reproductive structures) in each sample.

Recovery of *Sargassum* Biomass After Harvest

To evaluate the recovery of *Sargassum* biomass after harvest, in July 1999, all algae into the area chosen to harvest were cut off about 1 cm above the holdfast. In the following months, simultaneously to the collection at control site, seven replicates were collected in the harvest site. Positioning and collection of the samples in the harvest area, as well as sorting and weighting, were made as described for the determination of biomass seasonality.

Extraction of Alginate

The alginate yields of *Sargassum cymosum* were measured from samples collected into control area during the study. The alginate extraction was based on RAGAZA and HURTADO (1999). To extract the alginate, 25g of dried and powdered *Sargassum* were treated with 300ml of 1% $CaCl_2$ at 60ºC for 30 min, filtered in a mesh of 300μm. The filtered liquid was discarded and the procedure was repeated. To the solid residue retained by the filter, 300 ml of 1% HCl was added and heated for 30 minutes at 60º C, and filtered. The procedure was made three times, always discarding the liquid residue. To the solid, 300 ml of 1% Na_2CO_3 were added, and left overnight. The following day, the solution was heated at 60º C for two hours and filtered. The solid residue was discarded and the filtered liquid was bleached with 1% NaOCl (2:1 v:v), for 30 minutes. The sodium alginate was precipitated with 95% ethylic alcohol (1:2 v:v), dried at 65ºC, and weighted. It was expressed as percentage of original weight of the alga.

RESULTS

Water temperatures into the bay ranged from 16ºC in August 1999 to 30ºC in January 2000 (Figure 2). Salinity values ranged from 23 to 36.5, but no clear pattern was observed (Figure 2). Water transparency ranged from 1.5 to 4.0m, with the high values occurring in spring and early summer (September to February).

Concentration of inorganic dissolved nitrogen at superficial water presented a tendency of higher values from November 1999 to February 2000m, but there was a large variability on the values. For example, higher total nitrogen values occurred in February 2000 (0.1470 mg l^{-1}) and lower values in March 2000 (0.0176 mg l^{-1}). Average value for NH_4 concentration was

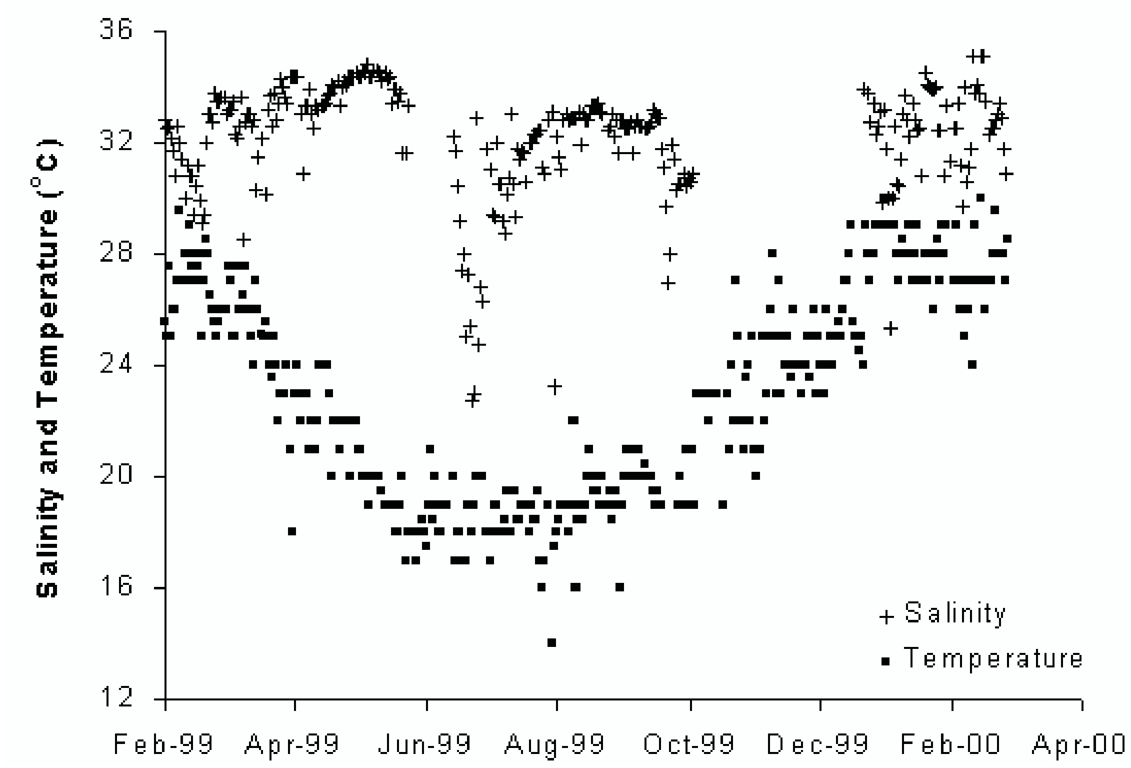

Figure 2. Salinity and superficial water temperature in Armação do Itapocoroy Bay, Santa Catarina State, Brazil, from February 1999 to March 2000.

0.04980.0315 mg l^{-1}; for NO^{2-} was 0.00390.0032 mg l^{-1}; for NO^{3-} was 0.01830.0360 mg l^{-1}; for PO4- was 0.00990.0052 mg l^{-1}; for total dissolved inorganic nitrogen the concentration was 0.06860.0360 mg l^{-1}.

Storms associated with strong winds occurred mainly in May and September 1999 and in May and June 2000.

Seasonal Pattern of *Sargassum* Biomass

Sargassum cymosum biomass (vegetative plus reproductive) at the control site presented a clear seasonal pattern, ranging from 20.88±14.80 g dw (dry weight) m^{-2} in September 1999 to 327.16±84.26 g dw m^{-2} in April 2000 (Figure 3A). Biomass strongly decreased again after April 2000, and its values in July 2000 were very similar to those observed in the previous year (July 1999). The rate between wet and dry weigh of *Sargassum* biomass was about 15.77±1.52%.

Recovery of *Sargassum* Biomass After Harvest

There was a significant exponential correlation between biomass and water temperature (r^2=0.93; $p<0.05$). No significant correlation was observed between biomass and dissolved inorganic nutrients (ammonium, nitrate, nitrite, total nitrogen, phosphate, ratio N/P) concentrations at the Bay during the study.

At the harvest site, the recovery of *Sargassum* biomass was initially slow. Two months after the harvest (September 1999), biomass was 3.34±3.5 g dw m^{-2} (Figure 3B), about 16% of biomass at control site. *Sargassum* grew fast in the spring and summer, reaching biomass of 75.85±10.79 g dw m^{-2} (about 65% of the biomass at the control site; Figure 3C). Between February and April of 2000, *Sargassum* coverage and biomass became very homogeneous and the biomass of the treatment area was equivalent to that of the control area (Figure 3C). A total biomass recovery occurred 9 months after harvest.

As biomass at harvest site presented the same seasonal pattern observed at control site, there was also a significant exponential correlation between biomass at harvest site and water temperature (r^2=0.95; $p<0.05$).

Reproductive Peak of *Sargassum*

Reproductive structures of *Sargassum* occurred during the entire year at the control site, and seasonal pattern of reproductive structures was similar to vegetative biomass. The period of maximum reproductive investment coincided with that of greatest biomass (April 2000), when about 11.9% of the algal biomass was comprised of reproductive structures. In all the other months it represented less than 4%. At the harvest site, however, plants with reproductive structures were not observed until February 2000, six months after harvest. After this, it became similar to the control site.

Seasonal Pattern of Associated Algae

Biomass of epiphytic and associated algae at the control site was always very low, ranging from 3.27±1.89 g dw m^{-2} (July 1999) to 24.30±15.41 g dw m^{-2} (April 2000). Its seasonal pattern was very clear (Figures 4A and 4B), similarly to that observed for *Sargassum*.

Three genera comprised more than 60% of biomass of the associated algae at both sites: *Spyridia* (*S. hypnoides*), *Hypnea* (mainly *H. musciformis,* but other species were also found) and *Dictyopteris* (*D.delicatula*) (Figures 5A and 5B). *Dictyota* sp presented its higher relative contribution to biomass (but with low absolute biomass) at the harvest site just after the harvest. At the control site it presented very low relative contribution. *Ceramium* spp presented high frequency, but its biomass was always very low. Other algae also found were: *Padina* sp., *Lobophora variegata, Cladophora* spp., *Ulva fasciata, Centroceras clavulatum, Pterosiphonia* sp., *Polysiphonia* spp., *Gelidium* spp., *Plocamium brasiliensi, Chondracanthus teedii* and *Amphiroa* sp.

Alginate Yield

Alginate yield presented low variability along the year, with no marked seasonal pattern (Figure 6). Averaged annual yield (all months, all samples) was 24.59 ±2.58%, ranging from 28.88 ± 2.04 % (November 1999) to 22.93±1.62% (April 2000). Despite the coincidence of maximum yield with low *Sargassum* biomass, and minimum yield with high biomass, no significant correlations between alginate yields and *Sargassum* biomass were observed.

DISCUSSION

The strong seasonal pattern observed for *Sargassum cymosum* biomass at Armação do Itaporocoroy Bay, as well its high correlation with temperature, indicates that high growth rates occur in spring and summer, when water temperature and transparency are high. Late summer, when *Sargassum* reaches its maximum reproductive and vegetative biomass, the currents and storm may easily affect it. Peaks of maximum biomass were also recorded at this time of the year in *Sargassum* beds from the states of Rio de Janeiro and São Paulo (Southeast Brazilian coast, SZECHY, 1996), the central Philippines (LARGO *et al*., 1994)

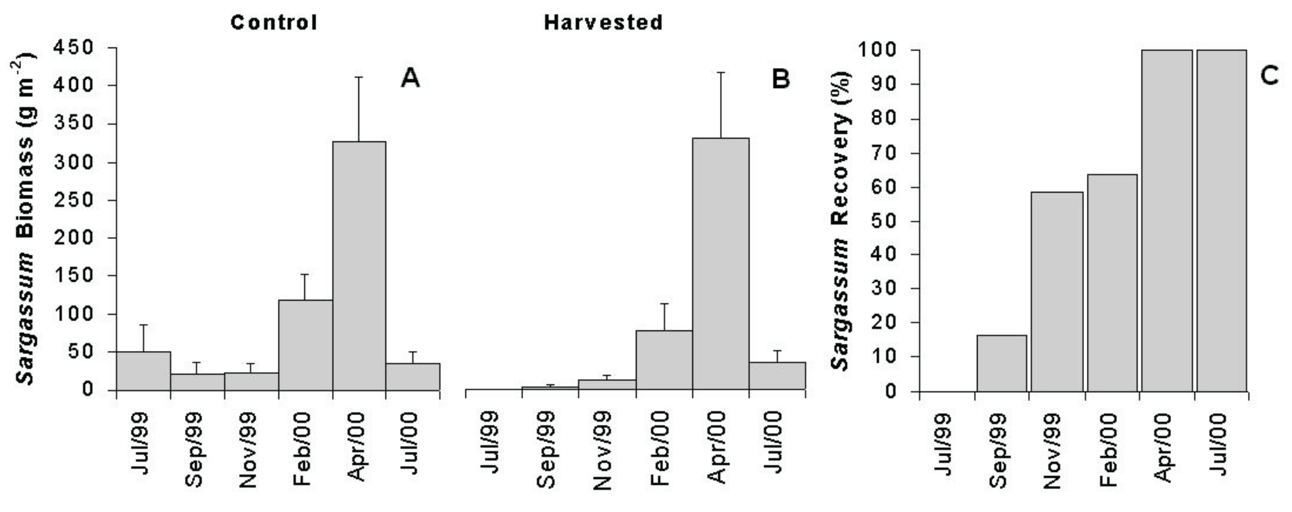

Figure 3. Biomass of *Sargassum cymosum* (g dw m^{-2}; average and standard deviation) for (A) control and (B) harvest sites. (C) Recovery of *Sargassum* biomass at harvest site, as a percentage of the biomass at control site.

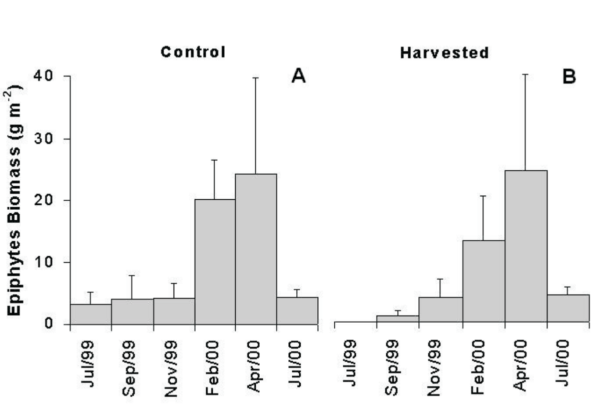

Figure 4. Biomass of associated algae (g dw m^{-2}; average and standard deviation) for (A) control and (B) harvest sites.

the Northern Philippines (HURTADO and RAGAZA, 1999). ANG (1985) and KOH *et al.* (1993) also observed the coincidence of maximum growth of other *Sargassum* species with high water temperature and transparency. Maximum growth was also attributed to rainfall period, which increases pluvial influx and, consequently, nutrient concentration in seawater (SZECHY, 1996). This does not seem to be the case in Armação Bay, once there were no correlations between biomass and nutrient concentration in seawater. In order to better evaluate the influence of nutrients and temperature on *Sargassum* growth, one must improve both spatial and temporal data collection. Measurements of individual growth need to be done to provide more insights about the interactions between *Sargassum* and environmental factors.

The marked decrease on *Sargassum* biomass just after its peak (a loss of about 293 g dw m^{-2}, 90% of the biomass from April to July) is certainly a consequence of the storm during that period. In late autumn and winter, Santa Catarina Coast is usually affected by cold fronts from South, which have strong effects on waves and tides (meteorological tides). Around Feia Island the currents are usually strong. Armação Bay is an open bay, and its hydrodynamics is very affected by these meteorological events. These events occur when *Sargassum* plants are about 50cm long and very branched, presenting high friction coefficients against water currents. When storm occur, the plants are broken and detached. Evidence of this process is the huge amounts of *Sargassum* and other algae stranded on the beaches along Santa Catarina Coast. In Armação do Itapocoroy Bay, these amounts can easily reach more than 6 kg m^{-2} fresh weight (CUNHA, S. R; unpublished data) after the strongest events.

A similar phenomenon is observed in the region of the Southwest Pacific, where an incidence of waves generated by monsoon and storm winds in specific periods of the year causes a considerable reduction in both biomass of beds and individual size of *Sargassum* plants (LARGO and OHNO, 1993).

The presence of reproductive structures of *Sargassum* all over the year indicates that *Sargassum* could continuously colonize the substrate. The similarity of vegetative and reproductive biomass pattern was expected, because larger plants can allocate more biomass to reproduction. Considering that vegetative and reproductive biomass presented high correlation with temperature, this seemed to be the main factor controlling *Sargassum* dynamics. LARGO *et al.* (1994), REED (1996), SZECHY (1996) and HURTADO and RAGAZA (1999) also observed similar results for other *Sargassum* species. These authors suggested that seasonal variation of biomass and reproductive development are controlled by physical-chemical environmental factors and life history.

Despite of suggesting potential for *Sargassum* exploitation, few investigations have emphasized the biomass recovery after harvest. In this study we observed a complete recovery of harvested *Sargassum cymosum* after nine month. This period of recovery was similar to that observed by a PAULA and ESTON (1987) for *Sargassum stenophylum*. This alga was able to recover and dominate the community within eight months. These authors evaluated the invasive potential of *Sargassum* species along the Brazilian coast, and observed high growth rates as well as high regeneration capacity of *S. stenophylum*.

At Armação do Itapocoroy Bay, the observed recovery after harvest was quite similar to the increase in biomass at control site. Our harvest was coincident with a period of low biomass and low temperatures, when growth rates are probably low. We believe the recovery time could be shorter if the harvest occurs in late spring or summer, when physical-chemical conditions are more favorable for growth. We also believe that a good time to harvest could be in the middle autumn, when biomass is closest to its maximum, and the plants have already produced and released large amounts of reproductive structures. By that moment, the storms are usually frequent and the plants are more susceptible to be broken and stranded on the beach. So, harvest at this time could provide the maximum biomass and probably the lower impact on natural communities of *Sargassum* beds. Additional work must test this time of harvest.

The potential of *Sargassum* for harvest at Armação do Itapocoroy Bay were also suggested by MAFRA JR. and CUNHA (2002), because of the high biomass they found while measuring different *Sargassum* beds inside the bay.

The algae associated to *Sargassum* beds were mainly epiphytic. Very low biomass seemed to be able to grow under *Sargassum*, mainly because of low light, or maybe because of whipping by *Sargassum* blades. Some algae are very abundant, but they are very delicate, presenting low biomass, such as *Ceramium* and *Centroceras*. The abundance of *Hypnea musciformis* and *Spyridia hypnoides* on the beds is a consequence of their hooks, which attach themselves to *Sargassum* plants. The presence of these algae can increase the friction coefficients of *Sargassum* against water currents, increasing its breakage, especially during periods of high biomass, (i.e. autumn).

There was no significant influence of harvest on associated algal community, certainly because it occurred in the period of low biomass of associated algae.

The alginate content of the genera *Sargassum* is known to be quite variable, depending on the species, the extraction methods applied, the reproductive stage, the geographic area, and also

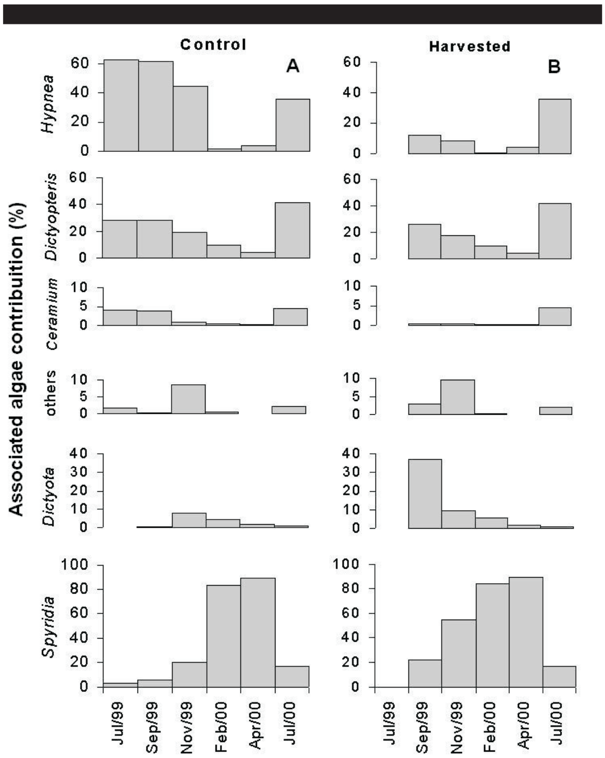

Figure 5. Contribution (%) of the most abundant associated algae for total biomass at (A) control and (B) harvest sites.

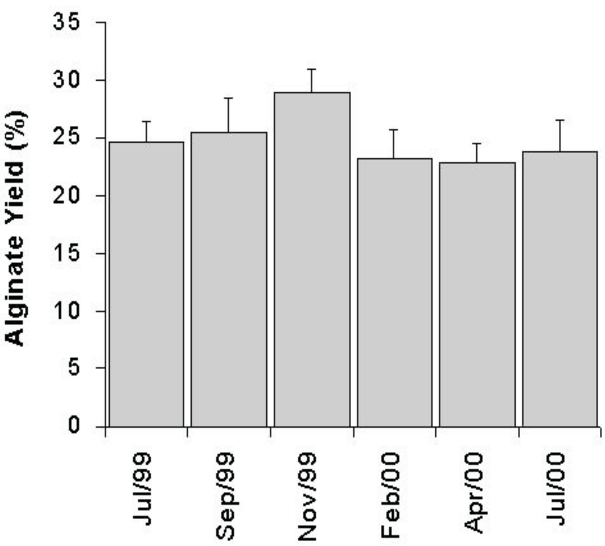

Figure 6. Seasonal variation in alginate yield (%) in the seaweed *Sargassum cymosum*. Ilha Feia, Santa Catarina State, Brazil, 1999-2000.

the environmental conditions. Even though no general correlation, was found, maximum and minimum values of alginate presented inverse relation with, those maximum and minimum values of *Sargassum* biomass. Therefore, we may assume that during the maximum growth, the alga allocates more energy into somatic growth, with less energy left for alginate production. Alginate yields can also vary from one part of the plant to another. In a previous work, MAFRA JR. and CUNHA (2002) observed higher alginate yield in reproductive structures than in vegetative branches.

The alginate yields observed for *Sargassum cymosum* at Armação do Itapocoroy Bay (22.93±1.62% to 28.88 ±2.04%) were very similar to those observed in the literature for the genera. Alginate yields found by CHENNUBHOTLA *et al*. (1982) for *Sargassum myriocystum* were the most similar to our results, ranging from 22.3% to 30.8%. Lower values were observed by GUEVARA and PALMA (1983), which obtained from 18.7% to 20.4% of alginate yields. Higher values, ranging from 32% and 35% were observed by OMAR *et al*. (1988). Very large ranges were found by RAGAZA and HURTADO (1999) when they tested the alginate yield for three different species of *Sargassum*. Their values ranged from 10% to 41%.

Although the alginate yields observed in this work were satisfactory, additional analysis of alginate quality is still needed.

CONCLUSIONS

Sargassum cymosum presented high potential for economic exploitation, due to its high biomass, high alginate yield and high capacity to recover after harvest in Armação do Itapocory Bay. Based on the results, we believe that the best time to harvest would be in autumn, when higher biomass can be attained and less impact would be made, compared to natural situation. We also believe that harvest should not be done more than once a year, to assure adequate recovery of the biomass.

Next steps we suggest to develop a management plan for *Sargassum* exploitation in Armação do Itapocory Bay are: 1) the evaluation of biomass recovery after harvesting in different periods of the year; 2) evaluation of recovery after different frequencies of harvest; 3) evaluation of the effects of harvest on associated fauna; 4) evaluation of alginate quality. When evaluating biomass recovery, it is necessary to assess the interferences of the harvest on the reproductive structures.

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