Nutrient composition of macroalgae and macrophytes of the Açu lagoon, Rio de Janeiro State, Brazil.

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ABSTRACT: Nutrient composition of macroalgae and macrophytes of the Açu lagoon, Rio de Janeiro State, Brazil. The coastal Açu lagoon is located in the northern region of Rio de Janeiro State, Brazil, between the latitudes 21° and 22° S and longitudes 40° 57' and 41° 00' W. In the north portion of the lagoon, close to the sand bar separating the lagoon from the sea, there is a seasonal growth of opportunist macroalgae, especially Ulva lactuca, generally associated with other red algae. Macroalgae and Ruppia maritima samples were collected from May 2000 to May 2001. Their carbon, nitrogen, phosphate, organic matter, protein and total lipid contents were determined. The seasonal variation of these compounds seems to be correlated to the availability of the inorganic nutrients (N and P) in the water column, especially nitrogen that may be limiting for macroalgal growth in Spring. Variables such as temperature and salinity are strong limiting factors for continuous macroalgal growth in Summer, especially for U. lactuca. Organic matter and protein contents were usually high and evidenced the high nutritional quality of the macroalgae and R. maritima. However, lipid concentrations may be considered as low for high nutritional quality foods item.
Key-words: coastal lagoon; macroalgae; Ulva lactuca; nutritional composition.

RESUMO: Composição nutricional de macroalgas e macrófitas aquáticas da lagoa do Açu, Rio de Janeiro, Brasil. A lagoa costeira do Açu está localizada na região norte do Estado do Rio de Janeiro, Brasil, entre as latitudes 21° e 22° S e longitudes 40° 57' e 41° 00' W. Na porção norte desta lagoa, onde se localiza a barra de areia que a separa do mar, pode-se observar o crescimento sazonal de macroalgas bentônicas oportunistas, especialmente Ulva lactuca, geralmente associada com outras macroalgas vermelhas. Estas macroalgas e Ruppia maritima (angiosperma) foram coletadas no período de maio de 2000 a maio de 2001. Os conteúdos de carbono, nitrogênio, fosfato, matéria orgânica, proteínas e lipídios totais foram determinados. A variação sazonal dos compostos estudados esteve relacionada com a disponibilidade de nutrientes inorgânicos (N e P) na coluna d'água, especialmente nitrogênio que pode ser limitante ao crescimento das macroalgas bentônicas na primavera. Variáveis como temperatura e salinidade foram fatores associados à limitação para o crescimento contínuo das macroalgas bentônicas, especialmente para U. lactuca no verão. Os teores de matéria orgânica e o conteúdo protéico obtidos foram elevados e indicaram uma elevada qualidade nutricional das macroalgas bentônicas e de R. maritima. Entretanto, a concentração de lipídios pode ser considerada baixa para alimentos de elevada qualidade nutricional.
Palavras-chave: lagoas costeiras; macroalgas bentônicas; Ulva lactuca; composição nutricional.

Introduction

In general, coastal lagoons present high productivity rates per area (Knoppers, 1994), a fact that has been attributed to their location on lowlands, between continental and marine environments, and their shallowness, which promotes the growth of dense communities of benthic micro- and macroalgae, aquatic macrophytes and phytoplankton (Malta & Verschuure, 1997). In lagoons with a well developed littoral zone, the macroalgae and macrophytes may play a fundamental role concerning the nutrient dynamics and the balance in such aquatic ecosystems (Bold, 1988; Lee, 1989). Due to the fact that they are generally sessile organisms and are able to accumulate several elements from the surrounding environment, they can be good biological indicators of environmental conditions and evolutionary tendencies of their ecosystems (Borowitzka, 1972; Littler & Murray, 1975; Levine, 1984; Malta & Verschurre, 1997).

The intense growth of macroalgae, especially the opportunistic ones, in coastal lagoons has been connected to the process of eutrophication, related to increases of the inorganic nitrogen availability as both ammonium and nitrate (Da Costa Braga & Yoneshigue-Valentin, 1994; Morand & Briand, 1996; Viaroli et al., 1996; Sfriso & Marcomini, 1997; Menendez & Comin, 2000). The distribution and growth of macroalgae, which have specific strategies for each species, vary not only according to the availability of nutrients, but also with factors such as light, temperature and biological interactions as competition and predation (Viaroli et al., 1996). These factors can control the biochemical content, reproduction, development, morphology and the geographical and seasonal occurrence of algae (Lobban & Harrison, 1994).

Thus, it is necessary to know the dynamics of the macroalgae development in order to understand the whole system of the Açu lagoon, where salinity levels allow the seasonal growth of large stands of ephemeral marine macroalgae, especially Ulva lactuca L., intermingled with Cladophora spp. and Hypnea sp., which may be relevant to nutrient cycling within the system.

The seasonal changes in the elementary constitution (C, N, P) of the benthic macroalgae are treated in this study, as well as an account of the variations of nutrient concentrations in the water column. In addition, the wide use of these macroalgae and Ruppia maritima L. as food source for domestic animals has also motivated the study of their nutritional value.

Study area

The origin of the coastal lagoons of the northern region of Rio de Janeiro State, which are geologically founded upon quaternary fluvial marine sedimentary deposits, is attributed to the processes of formation of the delta of the Paraiba do Sul river (Lamego, 1945). The Açu lagoon (Fig. 1) is located in the Campos dos Goytacazes and São João da Barra municipalities, between the latitudes 21° and 22° S and longitudes 40° 57' and 41° 00' W. It has an elongated shape, lying about 10 km parallel to the beach, and inward for more than 10 km in its southern portion. This lowland region presents a hot and humid climate, with a rainy season in summer and a dry one during the winter (Huszar & Esteves, 1988). A large area of its drainage basin is used as pasture, sugar cane monoculture or minor agriculture. This lagoon underwent intermittent artificial connections on its thin sandbar, which separates it from the sea, until the end of the 1990's, resulting in intense water exchange with the adjacent marine environment. Due to these connections, to the marine water percolation through the strip of sand that separates it from the sea, and to the negative balance between precipitation and evaporation in this region, the salinity values of the northern portion of the Açu lagoon are very close or, sometimes even, higher than those in sea water. The high salinity values and the shallowness of the water column (around 50 cm in the study area - north) allows the seasonal development of large stands of Ulva lactuca L., intermingled with patches of other macroalgae (Gracilaria cylindrica Borgesen, Derbesia spp., Hypnea spp., Gracilaria sp., Enteromorpha spp. and Cladophora spp.). The growth of stands of the angiosperm Ruppia maritima, was also observed in this study.

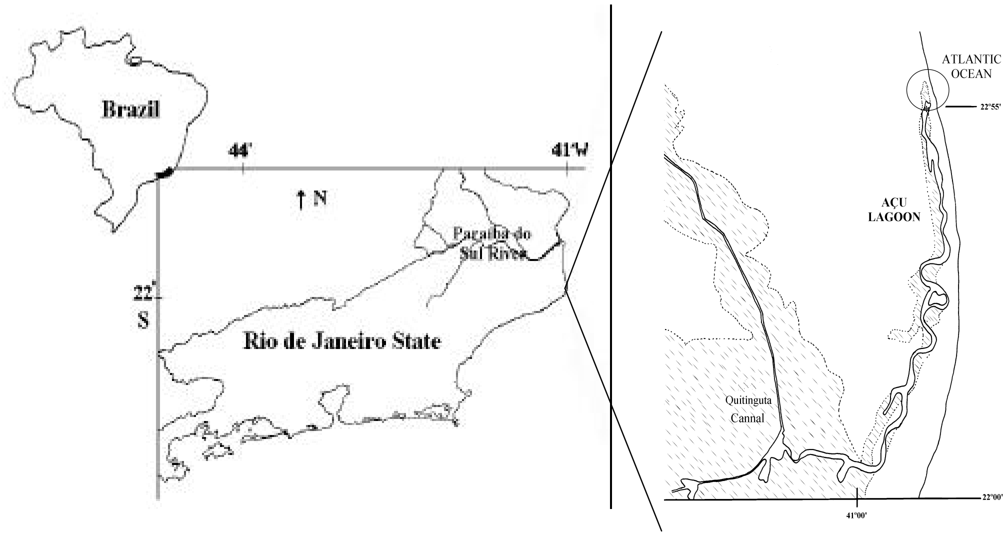

Figure 1: Study area and location of the sampling site (*) in the Açu lagoon.

Material and methods

Monthly samplings of water, macroalgal and Ruppia maritima were performed from May 2000 to May 2001 in the north area of the Açu lagoon. Temperature, pH, dissolved oxygen and salinity were measured directly at the subsurface (30 cm depth) of the water column by the use of portable equipments (multiparameter YSI 63 and YSI Dissolved oxygen 55). Water samples were collected manually, directly into 1L plastic bottle, from the same area to determine the inorganic dissolved nutrients (orthophosphate, ammonium, nitrate and nitrite), according to protocols widely used in limnological studies (orthophosphate – molybdenum blue; ammonium - indophenol blue; Strickland & Parsons, 1972 and Grasshoff et al., 1983), except for nitrite and nitrate, which were determined using an automatic flow injection analyser (ASIA Ismatec System methods – red azo-dye), always in triplicate.

The macroalgae with relevant biomass (visually estimated) were collected and immediately washed in distilled water, in order to evaluate the nutrient stock. They were conditioned in plastic bags and kept in ice until carried to the laboratory and then frozen (Thomas & Harrison, 1987). Some specimens collected were preserved in 4% formaldehyde prepared with water from the sampling site (isotonic) for posterior identification. Identification of macroalgal material was made according to the taxonomical classification of Wynne (1998) by phycologists from Federal University of Rio de Janeiro (UFRJ). For chemical analysis, the samples were dried at 40ºC in an air circulation oven until constant weight, ground and conditioned in plastic containers for later analysis. Due to the low biomass, the genera Derbesia, Cladophora, Hypnea and Enteromorpha were composed in one sample each by month.

The elementary composition of carbon and nitrogen were determined using the Perkin Elmer 2004 Elementary Analyzer CHNS. The equipment was calibrated using Acetanilide; analyses were performed in duplicate with around 95% of precision. Sensitivity for C was 0.02% and 0.03% for N, calculated following Skoog & Leary (1992). The total phosphate was quantified in triplicate after acid digestion (sulphuric acid + hydrogen peroxide + selenium) of the powder by colorimetry (Delgado et al., 1994). The content of organic matter was determined in triplicate by gravimetry after sample calcination in muffle furnace to 550ºC for 4 hours (Sfriso et al., 1994).

For lipid extraction, in triplicate, solution of chloroform and methanol (1:2) was used and contents obtained by gravimetry (Thomaz & Esteves, 1984). Proteins were estimated by multiplying the nitrogen content by the factor 6.25 (Jones, 1931).

The Pearson correlation coefficient was used to test relationship between abiotic variables and macroalgal nutrient contents. Nutrient contents data were submitted to one-way analysis of variance (ANOVA) to check for differences among seasons (Zar, 1999).

Results and discussion

Macronutrients

In shallow brakish waters, the cycle of nutrients depends mainly on the sediment and benthic activities (Viaroli et al., 1993). In these environments, the macroalgae are usually the predominant source of organic matter (Summers, 1980). The seasonal growth of the opportunistic macroalgae in the Açu Lagoon, especially U. lactuca (Tab.I)

Table I: Seasonal occurrence of species of macroalgae and macrophytes in the Açu lagoon, from May 2000 to April 2001.

Species	M/00	J	J	A	S	O	N	D	J/01	F	M	A
Ruppia maritima	X	X	X	-	X	X	X	X	X	X	X	X
Chlorophyta												
Cladophora brasiliana	-	X	X	-	X	X	-	-	X	X	-	X
Cladophora rupestris	X	X	X	-	X	X	-	X	-	-	X	X
Derbesia marina Solier	-	-	-	-	X	-	X	X	-	X	-	X
Derbesia tenuissima P. Crouan & H. Crouan	-	-	-	-	X	-	X	-	-	-	-	-
Enteromarpha flexuosa J. Agardh	-	-	-	X	X	-	-	-	X	-	-	-
Enteromorpha clathrata Grev.	-	-	X	-	X	-	-	-	-	-	-	-
Enteromorpha compressa Nees	-	X	-	-	X	-	X	-	-	-	X	-
Enteromorpha intestinalis Nees	-	-	-	-	X	X	-	-	X	-	X	-
Enteromorpha lingulata J. Agardh	X	X	-	-	X	-	-	-	X	X	X	-
Rhizoclonium hookeri Kütz.	-	-	-	-	X	-	X	X	-	-	-	X
Rhizoclonium kerneri Kütz.	X-	-	-	-	X	-	-	-	-	-	-	-
Rhizoclonium riparium Kütz.	-	-	X	-	X	-	-	-	-	-	X	-
Rhizoclonium tortuosum Kütz.	X	-	-	-	X	X	-	X	X	X	-	X
Ulva lactuca L.	X	X	X	X	X	X	X	X	X	-	X	-
Rhodophyta												
Gracilaria cylindrica	-	-	X	-	X	-	-	X	X	X	X	X
Gracilaria sp.	-	-	X	-	X	X	X	-	X	X	X	-
Hypnea cervicornis Kützing	X	-	-	-	X		X	-	-	-	-	-
Hypnea spinella Kützing	-	X	X	X	X	X	X	-	X	-	X	X
Polysiphonia subtilissima	-	X	X	-	X	X	-	X	X	-	-	-
Stylonema alsidii	-	-	X	-	X	X	X	X	-	-	X	-
Phaeophyta												
Acinetospora crinita	-	-	X	-	X	-	-	-	-	-	-	-
Feldmania irregularis	-	-	-	-	X	X	-	-	-	-	-	-
Hincksia mitchelliae	-	-	-	-	X	X	-	X	-	-	-	-

was higher during the winter and spring (milder temperatures), which covers most of the bottom sediment of the northern region, extending up to 2 km from the bar. This macroalgal growth and the intense wind action in the region, predominantly from the northeast quadrant, presumably kept high oxygenation of the water column, with values up to 170% saturation of dissolved oxygen (Fig. 2a). The influence of the adjacent marine environment and the atypical hydrological period, due to a low pluviosity during the summer, resulted in high values of salinity (maximum value = 43 psu – Fig. 2b) and pH values usually above 8.0 (Fig. 2c).

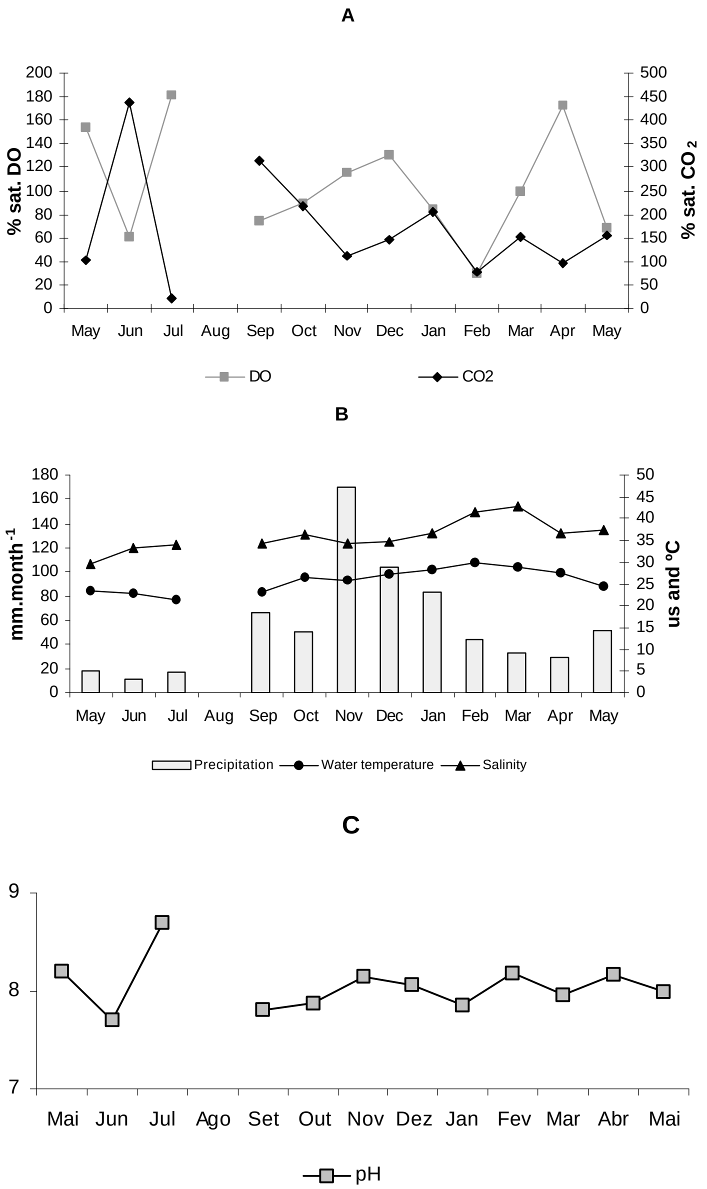

Figure 2: Seasonal variation of (A) dissolved oxygen and CO_2 saturation, (B) precipitation, water temperature and salinity and (C) pH in the water column of the Açu lagoon during the period May 2000 to May 2001.

According to Atkinson & Smith (1983), nutrient content in the macroalgal tissues may provide reliable information about the nutrient status of the plant. Carbon content in the macroalgal biomass in the Açu lagoon showed minimum values of 217 $mg.g^{-1}$DW in Derbesia spp. and maximum of 410 $mg.g^{-1}$DW in R. maritima (Fig. 3a). Along the study period, the values of carbon found in different macroalgae did not show significant variation between different seasons (ANOVA, $p>0.05$), showing that the proportion of carbon compounds was not altered significantly with the time and the stages of development of the macroalgae. The average content of carbon in U. lactuca (310 $mg.g^{-1}$DW) was higher than the content found in Ulva sp. by Menendez & Comin

(2000) (~210 $mg.g^{-1}DW$), in a coastal lagoon on the Mediterranean, and in U. rigida by Sfriso (1995) and Sfriso & Marcomini (1999) in the Venice lagoon (~285 $mg.g^{-1}DW$).

The average nitrogen contents in the macroalgae tissues were the following: U. lactuca, 24 $mg.g^{-1}DW$; Gracilaria sp. 28 $mg.g^{-1}DW$; Hypnea spp. 32 $mg.g^{-1}DW$, Derbesia spp. 35 $mg.g^{-1}DW$, and the angiosperm R. maritima 29 $mg.g^{-1}DW$ (Fig. 3b). They showed a decreasing tendency in concentrations during winter, an increase in spring and stability in summer, correlating negatively ($r = -0.8$, $p<0.05$) to the contents of dissolved inorganic nitrogen (Fig. 4) in the water column.

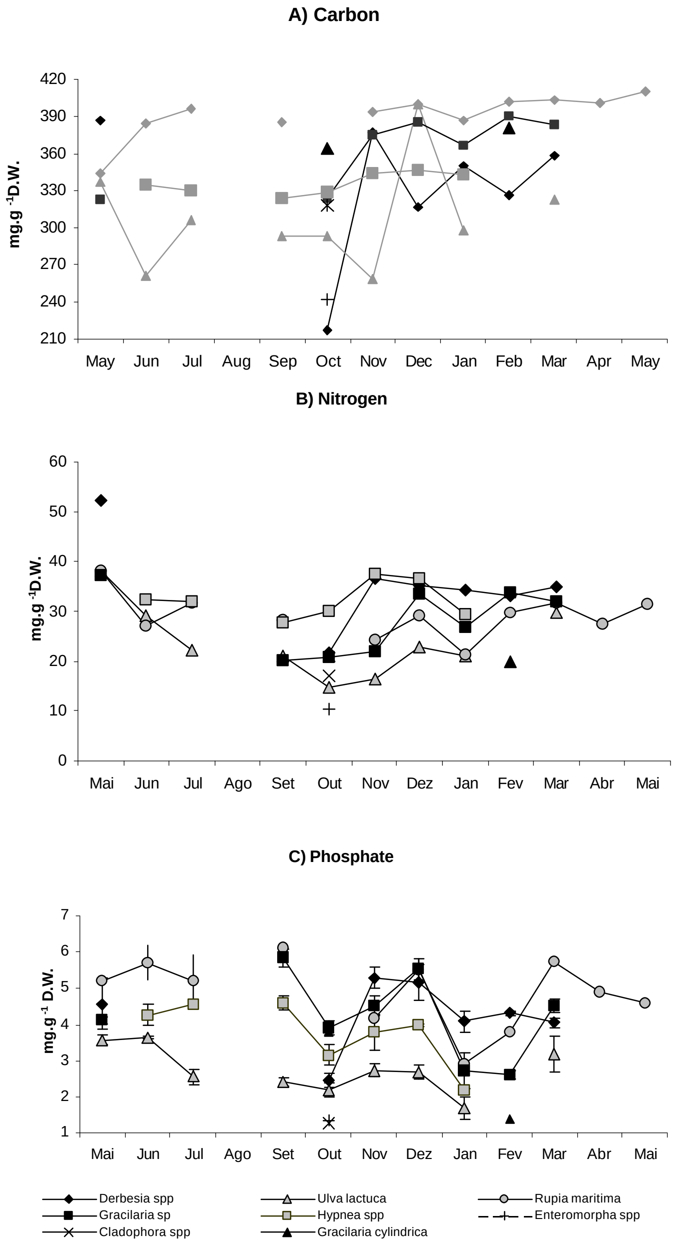

Figure 3: Seasonal variation in (A) carbon, (B) nitrogen and (C) phosphorus contents in macroalgae and R. maritima from the Açu lagoon during the period of May 2000 to May 2001. Carbon and nitrogen in duplicate; phosphorus in triplicate – vertical lines indicate standard error.

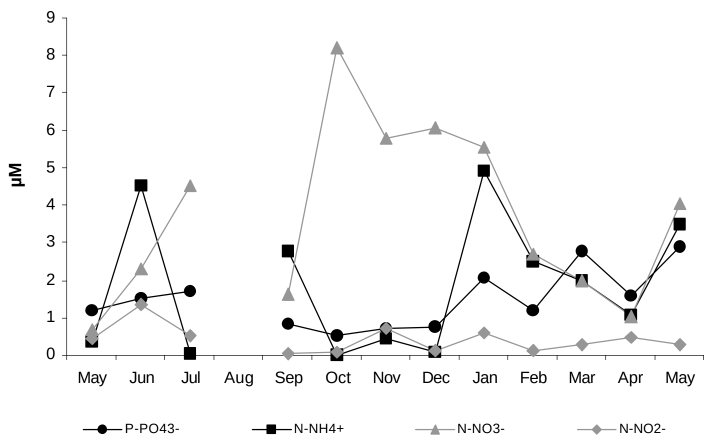

Figure 4: Seasonal variation of inorganic nutrient concentrations in the water column of the Açu lagoon during the period of May 2000 to May 2001. Vertical lines indicate standard error (n=3).

The negative and significant correlation ($r=-0.84$; $p<0.05$; $n=9$) between the nitrogen content of U. lactuca and nitrate concentration in the water column suggests that this macroalga, which shows a high growth rate in winter and early spring, absorbs and stores (luxury consumption) the oxidized form of inorganic nitrogen (Da Costa Braga & Yoneshigue-Valentin, 1994; Viaroli et al., 1996), using it during its maximum growth period. In addition, the decrease in about 60% of the tissue nitrogen stock of this macroalga (from 38 to 15 $mg.g^{-1}DW$) suggests that the external supply may have acted as a limiting factor during spring. The lowest value for N in the algal tissue of Ulva was below that considered critical for its active development (Fujita et al., 1989; Lavery & McComb, 1991). The increase in nitrogen content of macroalgal tissue during summer, which was a senescence period for Ulva, may be connected to the leaching of N-free compounds (Pugnetti et al., 1992).

The higher average values of nitrogen in red algal tissues as compared to those found in green algae, suggest that the red algae were more efficient for N assimilation. Due to the considerable decrease in N concentration in the tissues of U. lactuca during spring, the C:N ratio values were high (up to 23.4), exceeding the average value for C:N found for R. maritima (16.1), which tends to show a higher carbon content in the tissues. Since, R. maritima is a vascular plant with a root-rizome system, it can actively take up nutrients from the surface sediment and the water column, keeping high levels of N content.

The total phosphate contents in macroalgae (Fig. 3c) and ortophosphate in the water column (Fig. 4) didn't show any correlation ($r<0.3$), suggesting that the concentration of dissolved phosphate in the environment was not a limiting factor for the growth of these algal. This nutrient could be stored in the form of polyphosphate in the cells, as corroborated by high concentrations of phosphate in the tissue of U. lactuca of Açu lagoon (average = 2.7 $mg.g^{-1}$ DW), as compared to other studies (Sfriso, 1995; Viaroli et al., 1996; Sfriso & Marcomini, 1999). Other average values are the following: 3.7 $mg.g^{-1}$ DW for Hypnea sp.; 4.2 $mg.g^{-1}$ DW for Gracilaria sp.; 5.5 $mg.g^{-1}DW$ for Derbesia sp. and 4.9 $mg.g^{-1}DW$ for R. maritima. As the Nitrogen, the concentration of P in the macroalgal tissues showed a tendency of decrease in spring.

The N:P ratio, with an average value of 19:1, also corroborates the tendency of growth limitation of the U. lactuca in the Açu lagoon due to nitrogen compounds (Atkinson & Smith, 1983; Viaroli et al., 1996).

Nutritional value

Among the macroalgae and R. maritima usually found in the lagoon, the contents of organic matter (OM) were mostly high (› 70% - Fig. 5a). The higher values of OM were found in Gracilaria sp. (~92% DW) and the lower ones were in Derbesia spp. (~70% DW), which also showed a wide variation in the OM values (43 – 80% DW).

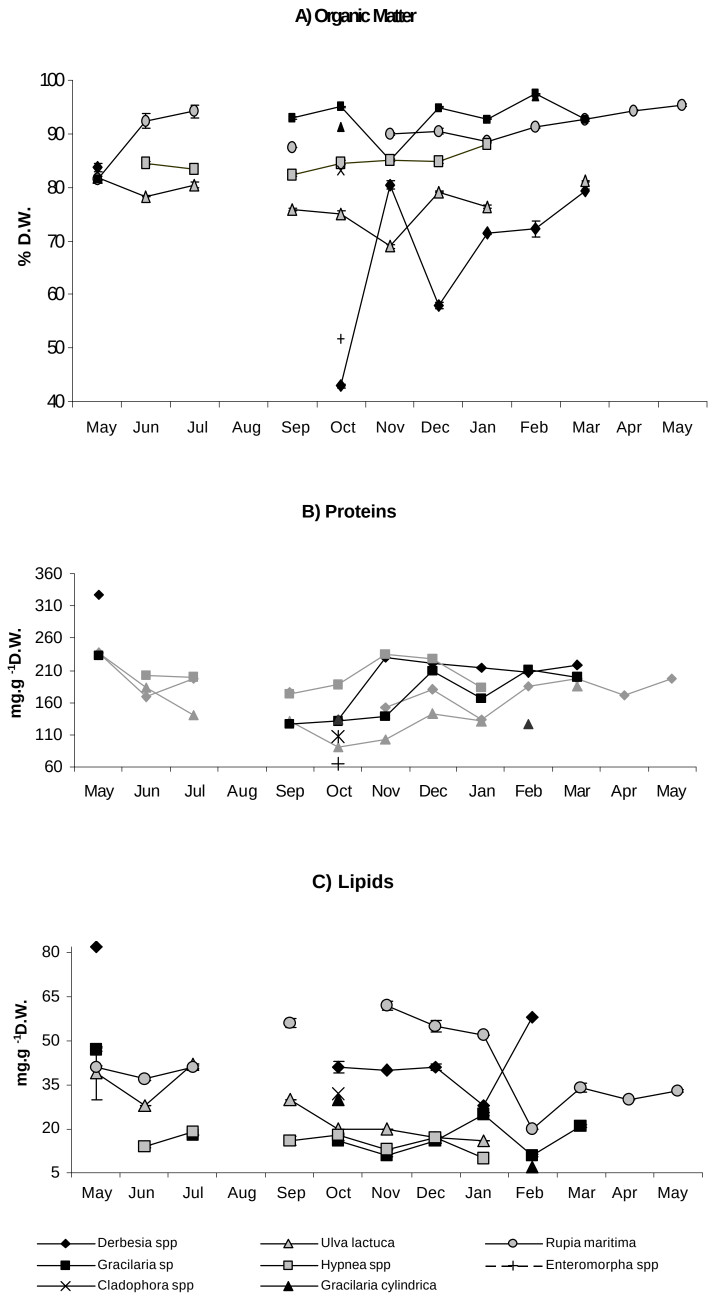

Figure 5: Seasonal variation in (A) organic matter, (B) protein and (C) lipid content of macroalgae and R. maritima from the Açu lagoon during the period of May 2000 to May 2001. Protein in duplicate; organic matter and lipids in triplicate - vertical lines indicate standard error.

The values for Hypnea spp. and R. maritima were kept steady during most studied period, with values around 85 and 90 % DW, respectively. U. lactuca showed narrow variations (69 - 82% DW). As compared to the macroalgae that grow in the Tancada lagoon (Mediterranean) (Menéndez & Comín, 2000), the organic matter contents of the macroalgae of Açu are quite high, suggesting a better nutritional value (Kaehler & Kennish, 1996). The OM content showed a positive and significant correlation ($r = 0.87$; $p<0.05$) with the carbon content of the macroalgae, except for Gracilaria sp. and U. lactuca ($p=0.21$; $p=0.10$).

The protein content of the macroalgae studied was within the expected range, according to Fleurence (1999) who described concentrations for green and red algae varying from 100-470 mg g^{-1}DW (Fig. 5b). These values are also corroborated by several other authors (Abdel-Fattah & Sary, 1987; Wahbeh, 1997; Ventura & Catanon, 1998; Haroon et al, 2000). However, other authors have found lower values for algae from South Africa and in the southeastern Asia (Foster & Hodgson, 1998; Norziah & Ching, 2000; Wong & Cheung, 2000).

Lipid contents (Fig. 5c) of Açu lagoon's macroalgae are within the values reported in the literature (Wahbeh, 1997; Foster & Hodgson, 1998; Norziah & Ching, 2000; Haroon et al., 2000; Wong & Cheung, 2000) and, as nitrogen, a decreasing tendency in spring was observed. The highest values for lipids were found in Derbesia spp (82 mg.g^{-1}DW) and the lowest ones in Gracilaria cylindrica, (around 7 mg.g^{-1}DW). Hypnea spp. and Gracilaria sp. showed narrow variation during the study period. R. maritima showed the highest values in spring, with a maximum of 62 mg.g^{-1}DW and the lowest in summer (20 mg.g^{-1}DW). U. lactuca had the highest values in winter (42 mg.g^{-1}DW) and the lowest ones in summer (16 mg.g^{-1}DW).

Conclusion

Despite the accounts on literature about the rapid growth and decrease of the opportunist macroalgae biomass, the factors that lead to the flourishing and death have not been completely understood. The decrease of biomass and the coverage of macroalgae at the end of summer have been connected to the increased salinity values, temperature and pH, and to the decrease of dissolved CO_2 (Peckol et al., 1994; Rivers & Peckol, 1995; Menéndez & Comín, 2000). However, the pH values (average = 8.0) and CO_2 saturation (average = 170 % sat) found in Açu lagoon (Fig. 2) do not seem to be enough to minimize the macroalgal growth, suggesting that variables such as temperature and salinity are supposedly strong limiting factors for macroalgal growth, especially for U. lactuca.

The macroalgae and the macrophyte R. maritima of the Açu lagoon can be an important source of organic matter for the trophic chains due to their growth, especially from winter to early summer. The seasonal variation of the studied compounds, found in macroalgal tissue, seems to be connected to the availability of the inorganic nutrients, especially nitrogen. However, the lack of similar studies in coastal lenthic environments hampered the comparison of our data. Yet, the collection of additional data on the spacial and temporal distribution patterns of the chemical composition of macroalgae in Brazil is necessary.

The nutritional quality of foods may be determined by taking into account their digestibility, amount of nutrients and energy for herbivores per food weight (Fleurence, 1999). The organic matter contents and protein contents evidenced the high nutritional quality of the macroalgae and the R. maritima from Açu lagoon, according to the index published by Foster & Hodgson (1998). However, the lipid concentrations may be considered low for foods with high nutritional quality. The nutritional composition of the macroalgae from Açu lagoon points out to the fact that they may be used as potential food supplements, especially in winter, when the amounts of protein and lipids are higher.

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