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Primary production of *Utricularia foliosa* L., *Egeria densa* Planchon and *Cabomba furcata* Schult & Schult.f from rivers of the coastal plain of the State of São Paulo, Brazil

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Abstract

Seasonal variation in gross primary production (GPP) of *Utricularia foliosa* Linnaeus, *Egeria densa* Planchon and *Cabomba furcata* Schult & Schult.f. in rivers of the coastal plain of the state of São Paulo, Brazil was examined in relation to water physico-chemistry. These three species do not affect the multiple uses of the streams and are present throughout the year. The most productive was *U. foliosa* (maximum production 24.7 $mgO_2\ g^{-1}\ DW\ h^{-1}$), while *C. furcata* had an intermediate GPP (maximum production 17.5 $mgO_2\ g^{-1}\ DW\ h^{-1}$) and *E. densa* was lowest at 5.6 $mgO_2\ g^{-1}\ DW\ h^{-1}$. Despite the low amplitude of seasonal variation in this south tropical area, the three species showed seasonal variation in the primary production: GPP was positively correlated with photosynthetic active radiation for *U. foliosa* and *E. densa*, and there was a negative correlation for *C. furcata*. For *U. foliosa*, GPP was positively correlated with temperature and dissolved inorganic carbon and the GPP of *C. furcata* was positively correlated with dissolved inorganic carbon.

Introduction

In the coastal plain of the south of São Paulo State (Brazil) there are many streams with low current velocity that drain very different areas in terms of geology and vegetation. As a result, these streams exhibit different types of water, classified as black, white and clear waters (Camargo et al., 1996; 1997). The stream waters are little impacted by human activities because most of the region is included in a conservation unit (Parque Estadual da Serra do Mar). The climate of this south tropical region has a low amplitude of seasonal variation, with daytime air temperature varying between 15.2 and 30.1 °C and monthly precipitation between 244.7 mm in summer (December, January, March) and 98.3 mm in winter (June, July, August) (Lamparelli & Moura, 1998).

The streams are colonised by many species of aquatic macrophytes of different ecological types. The most abundant submerged species are *Utricularia foliosa* Linnaeus, *Egeria densa* Planchon and *Cabomba furcata* Schult & Schult.f. The three species do not affect the multiple uses of the streams and are present during all the year. *U. foliosa* is a non-rooted submerged of carnivorous habit, abundant in black water streams. *E. densa* and *C. furcata* are submerged rooted species which grow in clear water streams. These species play an important ecological role in these streams, providing favourable conditions for animals (as holdfast sites, surfaces for egg deposition, food source) and contribute to primary production.

The objective of this work was to compare the seasonal variation of the gross primary production of these three species and to determine the relationship between primary production and physical and chemical characteristics of the water.

Materials and methods

Measurements of primary production were conducted in summer (February), autumn (May), winter (August) and spring (November) 1999. Clear (97% transparency) flasks with ca. 2000 ml capacity were filled with stream water using a siphon. Apical branches of each species with ca. 15 cm length were placed in each flask, using triplicate incubations. For further correction of the primary production of the macrophyte, the production and respiration of the phytoplankton was measured from one clear and one dark flask that did not contain the plant. The incubations were made for a period of 4 h (ca. 10:00–14:00 h). Afterwards the water from the flasks was siphoned to 150 ml flasks for measurement of dissolved O_2 (mg l^{-1}) using Winkler's method (Golterman et al., 1978). The titration was made by an electronic burette (Scohtt Gerate, model T 80/10). Dry weight of the apical branches used in the incubations was obtained by drying at 80 °C until constant weight.

Gross and net primary production and respiration were estimated using the equations of Vollenweider (1974):

$$\mathrm{NPP} = (c - i)v/(t \cdot \mathrm{DW})$$

$$R = (i - d)v/(t \cdot \mathrm{DW})$$

$$\mathrm{GPP} = \mathrm{NPP} + R$$

NPP being the net primary production (mgO_2 g^{-1} DW h^{-1}), R is the respiration (mgO_2 g^{-1} DW h^{-1}), GPP is the gross primary production (mgO_2 g^{-1} DW h^{-1}), c is the O_2 concentration in the clear flask and d in the dark flasks (mg l^{-1}), i is the initial O_2 concentration in the flasks (mg l^{-1}), v is the flask volume (L), t is the incubation time (h) and DW is the plant dry weight (g).

At the beginning of the incubation, values of pH, electrical conductivity (μS cm^{-1}), temperature (°C), salinity (%) and turbidity (NTU) were taken in triplicate, using a Horiba (model U10) Water Quality Checker. Photosynthetically-active radiation (PAR) (μmol m^{-2} s^{-1}) was measured with a LiCor light meter (Model 189) coupled to an underwater Licor quantum sensor (Model 192). A 1.0 l water sample was collected for further measurement of the total alkalinity (meq l^{-1}), by titration, and dissolved inorganic carbon (DIC) (mM l^{-1}), according to Mackereth et al. (1978), was sampled from the site where the incubation had been carried out.

Approximately 0.5 l of the water sample was filtered (Whatman GF/C) in the field laboratory, kept in polyethylene flasks and frozen to −20 °C. Non filtered samples (0.5 l) were also frozen in the same manner. The concentration of ammoniacal nitrogen (ammoniacal-N) (μg l^{-1}) (Koroleff, 1976), nitrite (NO_2–N) (μg l^{-1}), nitrate (N–NO_3–N) (μg l^{-1}) and total dissolved nitrogen (TDN) (mg l^{-1}) (Mackereth et al., 1978) as well as total dissolved phosphorus (TDP) (μg l^{-1}) and orthophosphates (PO_4–P) (μg l^{-1}) (Golterman et al., 1978) were measured from the filtered samples in the Laboratory of Aquatic Ecology of the Department of Ecology of UNESP/Rio Claro-SP. The non-filtered water samples were used to determine total nitrogen (TN) (mg l^{-1}) (Mackereth et al., 1978) and total phosphorus (TP) (μg l^{-1}) (Golterman et al., 1978).

For the analysis of variance (ANOVA) the statistical software SYSTAT (version 5.03) was used (Wilkinson, 1990). For the analysis of variance differences were considered significant when $p < 0.05$. A Newman–Keuls post-hoc test was used for mean-separation with statistically-significant relationships.

Results

Figure 1 shows the mean values and standard deviations of the primary production of the three species in the four seasons of the year. GPP of *U. foliosa* showed marked seasonal variation, with mean values significantly higher in summer (24.7 mg O_2 g^{-1} DW h^{-1}) intermediate values in spring (17.6 mg O_2 g^{-1} DW h^{-1}) and significantly lower values in autumn (8.5 mg O_2 g^{-1} DW h^{-1}) and winter (7.2 mg O_2 g^{-1} DW h^{-1}). For *E. densa* significantly higher values of GPP occurred in autumn (5.6 mg O_2 g^{-1} DW h^{-1}) than in spring (4.9 mg O_2 g^{-1} DW h^{-1}), summer (3.8 mg O_2 g^{-1} DW h^{-1}) or winter (3.0 mg O_2 g^{-1} DW h^{-1}). The GPP of *C. furcata* also varied seasonally, with significantly higher values in summer (17.5 mg O_2 g^{-1} DW h^{-1}), intermediate values in autumn (11.3 mg O_2 g^{-1} DW h^{-1}) and winter (10.7 mg O_2 g^{-1} DW h^{-1}), and significantly lower values in spring (6.5 mg O_2 g^{-1} DW h^{-1}). The differences between the primary production of the three species is clear: *U. foliosa* is the most productive, *C. furcata* has an intermediate GPP and *E. densa* had the lowest GPP during the year.

Analysing the relation between GPP and physical and chemical variables, of the three species, some correlations are evident. GPP of *U. foliosa* and *E. densa* is positively correlated with PAR and GPP of *C. furcata* is negatively correlated with PAR. For *U. foliosa*, GPP is correlated positively with temperature and concentrations of DIC. The GPP of *C. furcata* is correlated with concentrations of DIC (Fig. 2). The other abiotic variables, such as TN and TP, were not significantly correlated with the primary production of the three species.

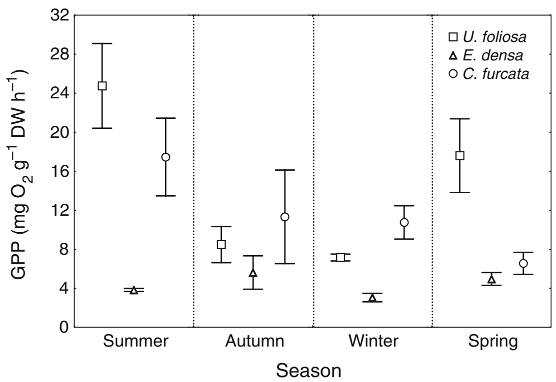

Figure 1. Gross primary production (GPP) of *U. foliosa*, *E. densa* and *C. furcata* in four seasons of the year.

Discussion

In temperate regions aquatic macrophytes present a seasonal variation of primary production that is a function of temperature and photoperiod (Payne, 1986). In tropical regions seasonal variation of primary production is related to rainfall and level of water, usually produced by a flood pulse (e.g., Camargo & Esteves, 1995). In the south coast region of São Paulo State the climate is homogeneous in terms of temperature and rain, which are well distributed during the year and a flood pulse does not occur (Camargo et al., 1997). However the three species still showed evidence of seasonal variation in primary production. The seasonal maxima and minima GPP differed between the three species. For *U. foliosa* the highest GPP was measured in summer and the lowest in winter, for *C. furcata* highest in summer and lowest in spring, and for *E. densa* highest in autumn and lowest in winter.

Light intensities, temperature and concentration of DIC are important variables that control the primary production of submerged aquatic macrophytes (Sand-Jensen, 1989). Probably, these variables are important factors that control the primary production of the three species in rivers of the São Paulo coastal plain, because the results showed correlations between these variables and primary production. In fact, there is evidence that the low values of PAR, temperature and DIC in winter are limiting to primary production of *U. foliosa* in this season. The lower values of PAR, in winter, appear to limit the production of *E. densa*. On the other hand the higher values of PAR, and lower values of DIC, in winter and spring limited the production of *C. furcata*.

The season of higher and lower GPP for the three species is different, probably due to the characteristics of the species and the physical and chemical characteristics of the water. These characteristics of the water depend of the alternation between sunny and rainy days, in all seasons of the year.

The most productive species in rivers of the target area is *U. foliosa*, a submerged non-rooted species. The carnivorous habit is an important additional source of nutrients for this species (Pott & Pott, 2000) and probably for this reason the GPP is not limited by the low total

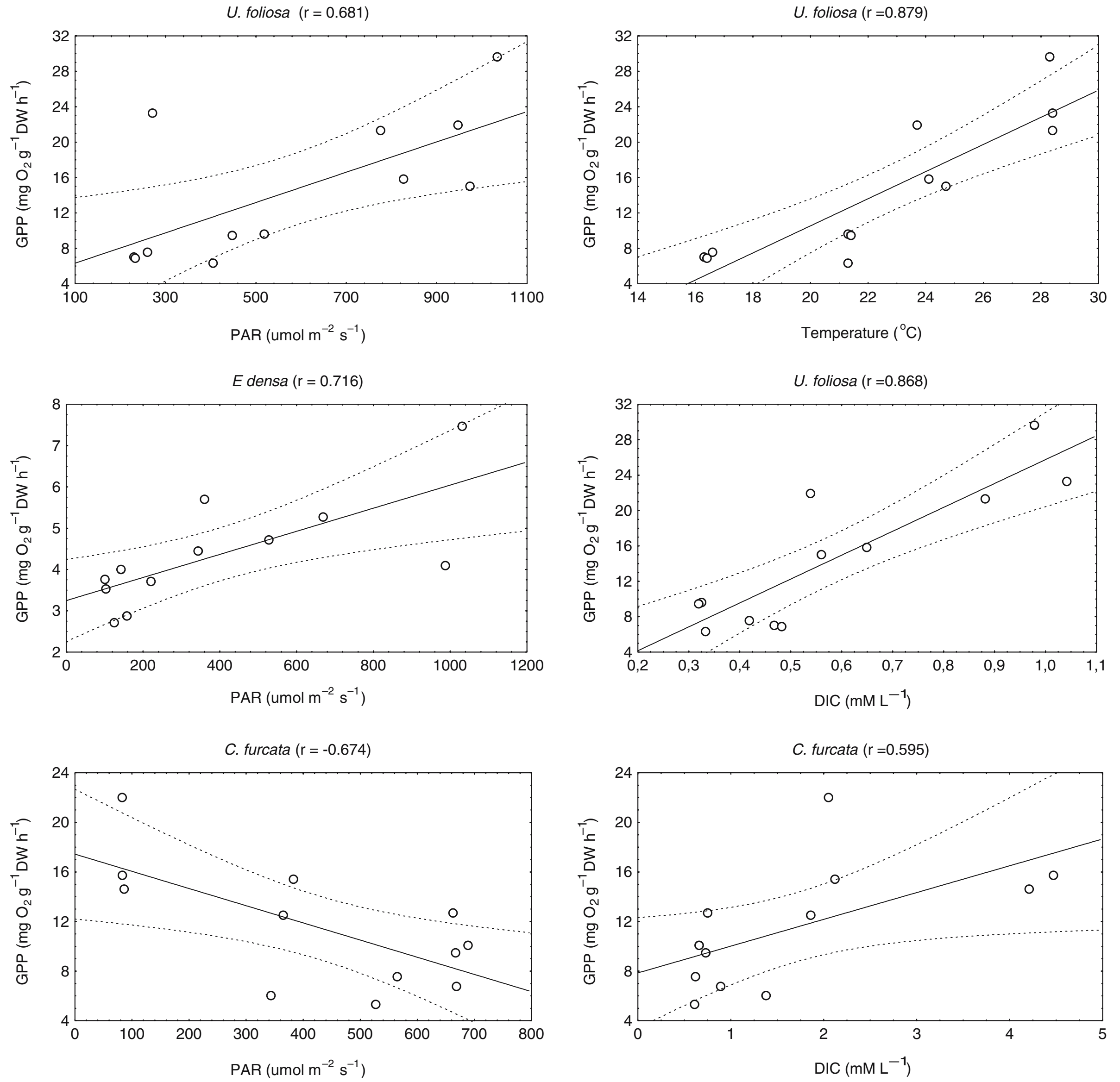

Figure 2. Relation between gross primary production (GPP) and photosynthetic active radiation (PAR), temperature and dissolved inorganic carbon (DIC).

nitrogen and total phosphorus concentration in water.

Although *E. densa* has a tendency to form large detached masses of vegetation which interfere with the utilisation of water resources in many aquatic ecosystems (Barreto et al., 2000), but in the streams of the south coast of São Paulo state, it does not causes problems. Probably, the low light intensities restrict the GPP of *E. densa* and consequently this species does not interfere with the uses of aquatic resources in the region.

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