POPULATION DYNAMICS AND NET PRIMARY PRODUCTION OF THE AQUATIC MACROPHYTE *Nymphaea rudgeana* C. F. MEY IN A LOTIC ENVIRONMENT OF THE ITANHAÉM RIVER BASIN (SP, BRAZIL)

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(With 6 figures)

ABSTRACT

In this paper we evaluated the population dynamics and obtained estimates of the net primary production of the aquatic macrophyte *Nymphaea rudgeana* in an arm of the Itanhaém River (São Paulo State, Brazil). This species presents, in the studied area, a broad seasonal variation of biomass. As from November (13.1 g DW/m^2) we observed a gradual increase of biomass that reached a maximum in February (163.1 g DW/m^2). Then, the biomass decreased, maintaining low levels until a new growth period. The reduction of biomass is associated to the development of floating aquatic macrophytes (*Pistia stratiotes* and *Salvinia molesta*) and, subsequently to environmental factors (higher salinity values) that are unfavorable to their development. The net primary production of *N. rudgeana* was estimated from the biomass data, and the annual productivity value was estimated between 3.02 and 3.82 t/ha/year.

Key words: Aquatic macrophyte, *Nymphaea rudgeana*, population dynamics, net primary production, Brazil.

RESUMO

Dinâmica populacional e produção primária líquida da macrófita aquática *Nymphaea rudgeana* C. F. Mey em um ambiente lótico da bacia do rio Itanhaém (SP, Brasil)

Neste trabalho, foi estudada a dinâmica populacional e estimada a produção primária líquida da macrófita aquática *Nymphaea rudgeana* em um braço do rio Itanhaém (Estado de São Paulo, Brasil). Esta espécie apresenta uma ampla variação anual de biomassa, em função da estação do ano, no local estudado. A partir do mês de novembro (13,1 g PS/m^2), pode ser observado um aumento gradual da biomassa, atingindo o máximo em fevereiro (163,1 g PS/m^2). Posteriormente, a biomassa diminui, mantendo-se em níveis baixos até um novo período de crescimento. A diminuição de biomassa está associada ao desenvolvimento de macrófitas flutuantes (*Pistia stratiotes* e *Salvinia molesta*) e, subseqüentemente, às condições ambientais desfavoráveis (valores de salinidade elevados) ao seu desenvolvimento. A produção primária líquida de *N. rudgeana* foi obtida a partir dos dados de biomassa e seu valor é estimado entre 3,02 e 3,82 t/ha/ano.

Palavras-chave: Macrófita aquática, *Nymphaea rudgeana*, dinâmica populacional, produção primária líquida, Brasil.

INTRODUCTION

Aquatic macrophytes stand out as one of the main primary producers of shallow aquatic ecosystems, both in lentic environments and in low turbulence areas of lotic environments. Their high production rate contributes to a large storage of nutrients in the biomass, playing a fundamental role in the cycling of matter and energy flow (Esteves, 1988; Camargo & Esteves, 1995).

In tropical environments, studies of population dynamics and primary production of aquatic macrophytes are rare, and in Brazil the papers that stand out are those of Piedade *et al*. (1991), Junk & Piedade (1993), Junk & Piedade (1997) and Enrich-Prast (1998) in the Amazon region, by Penha (1994) in the Pantanal Matogrossense and the one conducted by Coutinho (1989) at the Infernão Lagoon, SP. We should also mention the paper of Menezes *et al*. (1993), on the population dynamics and productivity of *Nymphoides indica* (a species with floating leaves) and *Pontederia cordata*, in the Lobo Reservoir (SP). The latter is the only article undertaken in Brazil that analyses the productivity of a macrophyte species with floating leaves.

The Itanhaém River basin (coastal region of the State of São Paulo) drains a considerable area of the coastal plain and the rivers are characterized by presenting low turbulence as a result of the little relief declivity. As a consequence, there is a large development of aquatic macrophytes of different species and ecological types in these lotic environments. Various studies about the ecology of aquatic macrophytes have been carried out in the region such as those of Schiavetti (1991), Luciano (1992) and Siqueira (1993). A species that is abundant in the region is *N. rudgeana*, an aquatic macrophyte with a floating leaf that occurs mainly in the confluence of the Branco, Preto and Itanhaém rivers.

In this paper we quantify the biomass of *N. rudgeana* at monthly intervals, with the aim of estimating the primary production and population dynamics of this species in an arm of the Itanhaém River denominated Rio Acima.

STUDY AREA

Itanhaém River basin is located in the southern coastal region of the State of São Paulo (Brazil) (23°50’ and 24°15’S, 46°35’ and 47°00’W) (Suguio & Martin, 1978), encompassing a wide area of coastal plain. The climate of the region is classified as tropical with no dry season, with an annual rainfall varying between 1,000 and 2,000 mm (Setzer, 1966). The Rio Acima is a meandering canal of approximately 6 km in length, projecting from the Branco River to the Itanhaém River, next to the formation of the latter by the joining of the Branco and Preto rivers (Fig. 1). This region of the hydrographic basin is located approximately 5.0 Km upstream from the mouth of the Itanhaém River in the Atlantic Ocean and therefore, suffers the influence of the tide regime because of the variation in the water level in periods of about 6:00 hours, and by presenting oligohaline waters during certain periods (Camargo *et al*., 1994).

Along the Rio Acima, as well as the emerged macrophytes (grasses, Cyperaceae, etc.) that occupy the margin, the development of *N. rudgeana* occurs in practically all its extension, forming a broad stand in the stretch studied in this paper, that presents a wide littoral region (Fig. 1). The study area comprehends a stretch with a total area of 5.56 ha (700 m in length and 80 m of mean width); the aquatic macrophyte stand occupies an area of 2.5 ha, corresponding to 45% of this area. The littoral region has an average width of 60 m that coincides with the limit of occurrence of *N. rudgeana*, and its maximum depth varies between about 1.5 to 2.0 m, as a function of the pluviometric regime associated to the tides.

N. rudgeana is a dicotyledon of the Family Nymphaeaceae, where the shape of the leaves are elliptic to sub-orbicular, with irregular sinuous-toothed margins. Its flowers are 8 to 15 cm in diameter, and occasionally open at around midnight, usually remaining with only the sepals open. The petals are snowy-cream colored or greenish-white and the stamens are pale yellow as are the anthers (Hoehne, 1979). The plant rhizome is similar to a bulb, without ramification. From this subterranean structure the individual develops, forming leaves, flowers and roots. According to Hoehne (1979) *N. rudgeana* is widely distributed in tropical America.

MATERIAL AND METHODS

Collections were conducted every 30 days, approximately, between November 1994 and September 1995, completing a total of 11 collections.

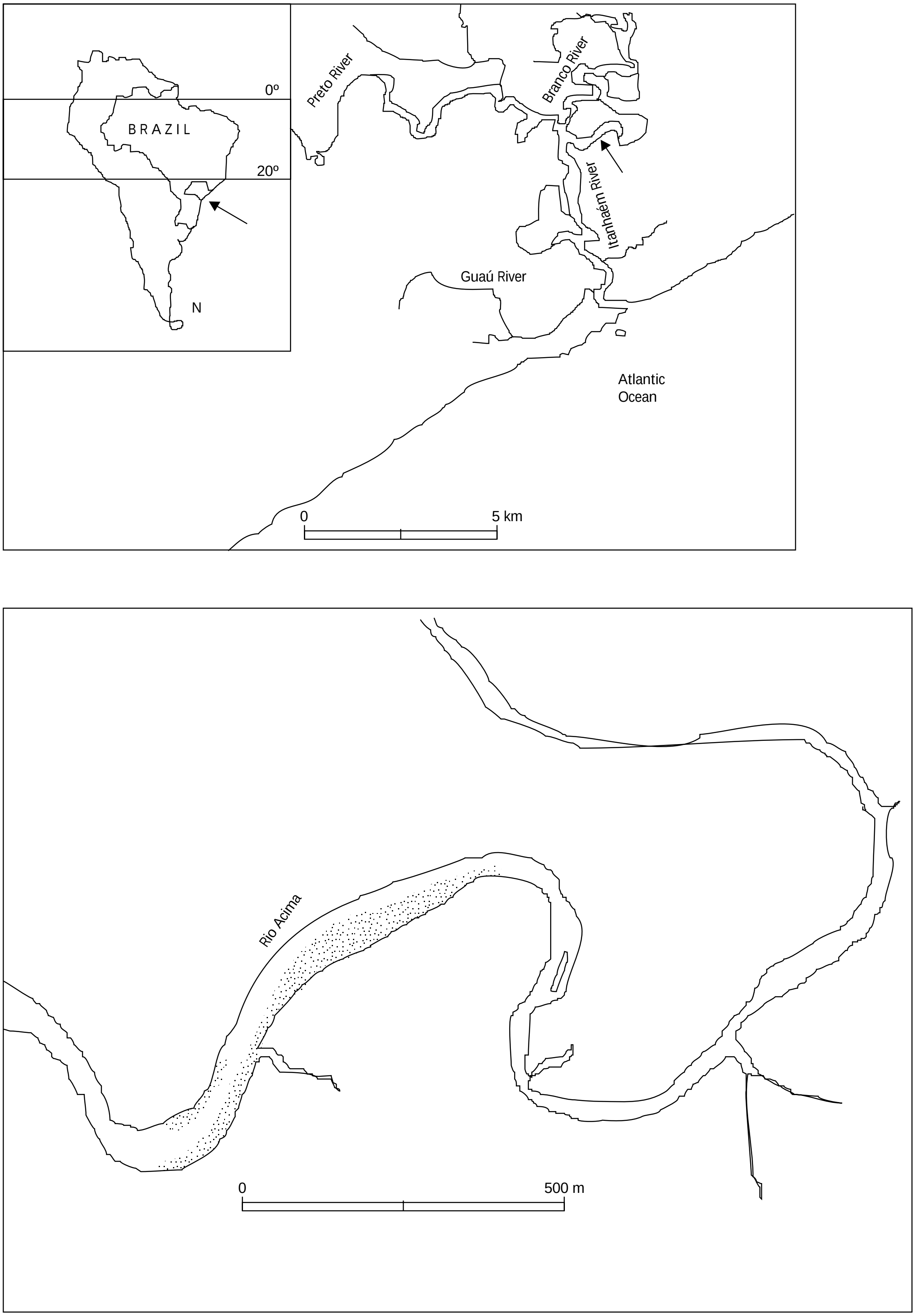

Fig. 1 — Location of the area of investigation. ⬚ stand of *N. rudgeana*.

In each collection we sampled five quadrants of 0.5 m wide by 2.0 m long (1 m^2) along the stand. All the sampled individuals were measured from the point of the root to the base of the leaf lamina of the longest petiole. The measured individuals were classified by size (class 1 – up to 0.4 m, class 2 – between 0.4 and 1.0 m (inclusive) and class 3 – greater than 1.0 m). We also obtained the total number of individuals and the number per size class to estimate the relative density of the three classes and the total density (individuals/m^2) of each quadrant. In the laboratory, the plants were rinsed in running water; separated by petiole, leaf lamina, root, rhizome, floral peduncle, floral button, and dead biomass and than placed in an oven at 60°C until they reached a constant weight. With the dry weight values, the biomass of each part of the plant was estimated, as well as the total biomass in each collection date in g DW/m^2.

Between January/95 and June/95, other macrophyte species that came to occur in the study area were also collected, including: *Pistia stratiotes*, *Salvinia molesta* (floating) and *Utricularia foliosa* (submerged-free). In this case, the three species were collected in the sample quadrants of *N. rudgeana*, and in monospecific banks using a sampler with a 0.25 m^2 area.

These plants were also rinsed and dried for estimating the biomass. The values of temperature (mercury thermometer) and water salinity (Corning salinometer model PS 18) were taken monthly at three points of the stand twice a day (high tide and low tide).

The Net Primary Production (NPP) of *N. rudgeana*, was estimated with the formula used by Junk & Piedade (1993) for aquatic macrophytes of the Amazon region.

$$\mathbf{NPP = NPP}\ {}^{to}\!\int_{o} \mathbf{dB} + p.\mathbf{B.d}t \qquad \text{if dB>0}$$

$$\mathbf{NPP = NPP}\ {}^{to}\!\int_{o} p\mathbf{B.d}t \qquad \text{if dB>0}$$

NPP = Increase of Net Primary Production (*t*)
***p* = Percentage**
B (*t*) = Biomass as function of time

RESULTS

The values of temperature and water salinity in the high tide and low tide periods are given in Fig. 2. A great variation in salinity can be observed between the different periods of the year as can a large amplitude between high and low tides. The highest salinity values were registered in July/95, with $5{,}23^{o}/_{oo}$ at high tide and $3{,}34^{o}/_{oo}$ at low tide. The lowest values were observed in February, March, and April, and did not show great variation between high and low tides ($0{,}053$ to $0{,}087^{o}/_{oo}$). We

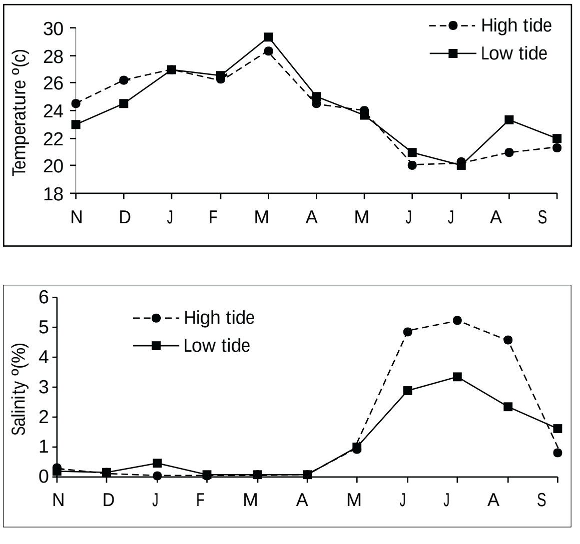

Fig. 2 — Values of temperature (°C) and salinity ($^{o}/_{oo}$) in the high tide and low tide periods, between Nov/94 and Sep/95.

did not observe great amplitudes of temperature values between high and low tides.

The highest temperature values were registered between December/94 (24.5ºC, low tide) and March/95 (29.3ºC, low tide). As from June, lower values were registered varying between 20 and 23.3ºC.

The values of the population demographic density of *N. rudgeana* are presented in Fig. 3. The maximum population density occurred in December/94 (36.6 ind./m^2), after which there was a gradual reduction with the lowest values occurring in April and May/95 (2.4 ind./m^2). An increase in the demographic density was observed in June (7.2 ind./m^2) with a fall in the subsequent month. Class 1 presented greatest density in November/94, with 27.7 ind./m^2; in February, March and April no individuals of this class were detected, although they occurred again in May. For classes 2 and 3, the largest values were registered in December/94, with 6.0 and 19.4 ind./m^2, respectively. Individuals of class 2 were not detected in March and April and individuals of class 3 were not registered in August.

The Fig. 4 presents mean biomass values for the different structures of *N. rudgeana* in each sampled month. Through the figure we observe that the flowering period is restricted to the interval between January and July with the largest biomass in February (12.8 g DW/m^2 of floral peduncle and 11.9 g DW/m^2 of flower button). The largest lamina biomass was observed in January (48.6 g DW/m^2), whereas the greatest biomass of the petioles, roots and rhizomes was detected in February (16.7; 15.5 and 59.2 g DW/m^2, respectively). For all the plant parts we observed the same pattern of seasonal variation, that is, an increase from November to January or February, followed by a gradual reduction until May, a slight increase in June and a later fall in July and August, with a new increase in September. We observe from the Fig. 4 an increase in total biomass between November and February, in which month we observed greatest

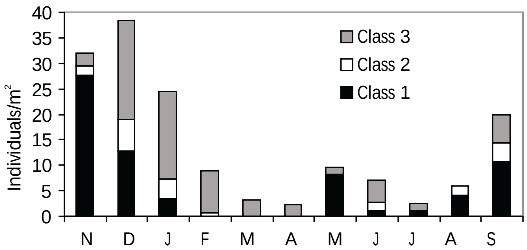

Fig. 3 — Demographic density (ind./m^2) of *N. rudgeana*. Class 1 – up to 0.4 m, class 2 – between 0.4 and 1.0 m (inclusive) and class 3 – greater than 1.0 m.

total biomass value (mean of 163.1 g DW/m^2), followed by a gradual reduction until May.

In July we verify a moderate increase of biomass with a subsequent fall. The detritus biomass presents the same seasonal behaviour of total biomass, although it is late by one month. The largest value of detritus biomass occurred in March (11.9 g DW/m^2), that presents much lower values than the live biomass.

The temporal variation of biomass of the species associated to *N. rudgeana* (*P. stratiotes*, *S. molesta* and *U. foliosa*) in the mixed and monospecific stands is presented in Fig. 5. The greatest values of biomass in the mixed stands of *P. stratiotes* occurred in March (16.9 g DW/m^2), of *S. molesta* in April (14.2 g DW/m^2), and of *U. foliosa* in June (22.5 g DW/m^2).

In the monospecific stands we observed little monthly variation of biomass and much higher values than those of the mixed stands (205.3 g DW/m^2 for *P. stratiotes*, 96.3 g DW/m^2 for *S. molesta* and 70.4 g DW/m^2 for *U. foliosa*). It is important to note that the species associated to *N. rudgeana* vary mainly in relation to occupation area. Between February and April we observe an expansion of the area covered by the two floating species, and at the

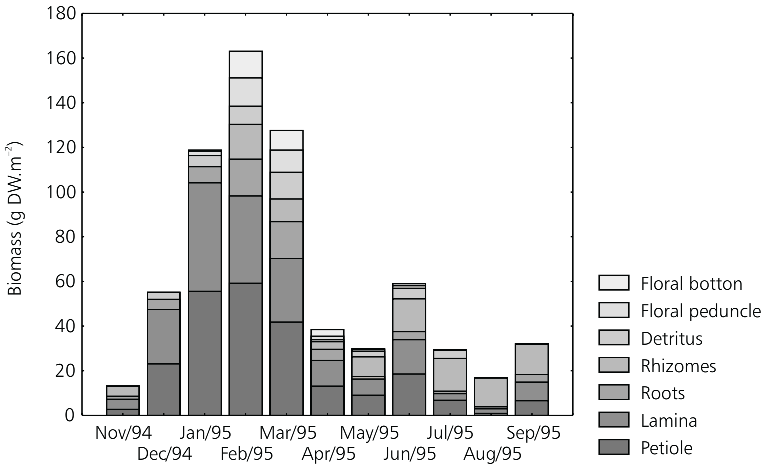

Fig. 4 — Mean biomass values (g DW/m^2) for the different structures of *N. rudgeana* in each sampled month.

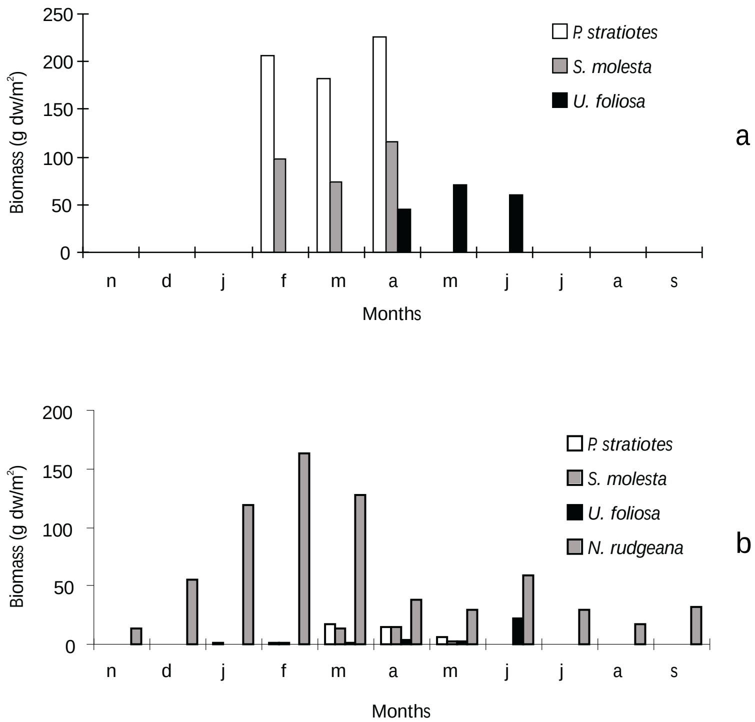

Fig. 5 — Temporal variation of biomass (g DW/m^2) of *P. stratiotis, S. molesta and U. foliosa* in the monospecific (a) and mixed (b) stands.

end of this period, covered great part of the Rio Acima.

The Net Primary Production (NPP), in tons per hectare (assuming monthly losses of biomass by decomposition of 10% and 25%) of *N. rudgeana*, estimated in the 303-day period (from 05 November 1994 to 23 September 1995), is represented in Fig. 6, together with the curve of biomass variation in t/ha. At the end of the 303 days, the NPP was 2.51t/ha, for the 10% rate of loss and 3.17 t/ha for the 25% rate of loss. As can be observed by the NPP curve, the period of greatest productivity is situated between November/94 and February/95 (time = 78 days), in which the NPP of *N. rudgeana* was 2.0 t/ha (25% rate of loss) and 1.8 t/ha (10% rate of loss).

The mean daily productivity estimated for the 10% rate of monthly loss was 0.828 g DW/m^2/day and for the p = 25%, 1.046 g DW/m^2/day. Since this species occupies the stand during a one-year period, the values of productivity were extrapolated to t/ha/year. Thus, we obtained the estimates of primary productivity as 3.02 t/ha/year (p = 10%) and 3.82 t/ha/year (p = 25%).

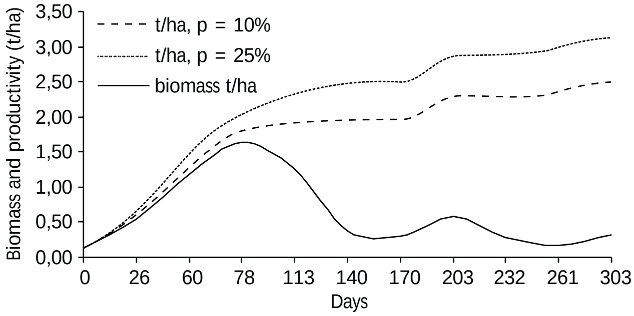

Fig. 6 — Net primary production and biomass (t/ha) of *N. rudgeana* at Rio Acima.

DISCUSSION

Although *N. rudgeana* occurs during an entire period of an annual cycle at Rio Acima, the results obtained show a broad seasonal variation in biomass of this species. The largest biomass values occurred in the months of January, February and March and are about three times greater than the values verified for the other months of the year. Several authors, cited in Camargo & Esteves (1995), verified wide seasonal variation of biomass of aquatic macrophytes in tropical regions of Brazil. These variations in biomass are due mainly to the seasonal variation of the water level in aquatic environments as observed by Junk (1986), Junk & Piedade (1993), among others in the Amazon region, Da Silva & Esteves (1993) in the Pantanal Matagrossense and Camargo & Esteves (1996) in an oxbow lake of the Mogi-Guaçu River, State of São Paulo. In the Itanhaém River basin there is no seasonal change in the water level of aquatic environments. Actually, rainfall is relatively well-distributed throughout the year, so that a rainy period and a dry period cannot be characterised. The variation in the water level of the rivers of the Itanhaém River basin are small (usually less than 1.0 m) and occur as a function of the tide or rainfall variation during short time periods.

In this way, the seasonal variation of the biomass of *N. rudgeana* at Rio Acima cannot be attributed to water level variation. In temperate regions, the seasonal variation of the biomass presented by aquatic macrophytes occurs mainly because of the seasonal variation of the temperature (Esteves, 1988). The seasonal variation of the water temperature at Rio Acima is also reduced and the minimum water temperatures are high (20^{o}C) and are probably not responsible for the seasonal variation observed for the biomass. Other factors, however, must account for the variation of the biomass of *N. rudgeana*.

With the development of the bank of *N. rudgeana* (greater biomass, greater number of individuals and larger individuals) as from

December, favourable conditions appear for the installation and development of the floating species *P. stratiotis* and *S. molesta*. Individuals of these two species, derived from higher regions of the hydrographic basin, install themselves in between the leaf laminae of *N. rudgeana* and begin to reproduce intensely. The results obtained show that as from January, *P. stratiotis* and *S. molesta* begin a process of colonisation of the area occupied *by N. rudgeana*, reaching a greater occupation in April and May. These floating species bring about the reduction of the biomass of *N. rudgeana*, which is probably due to the shading and competition for space. With the reduction in the biomass of *N. rudgeana* between March and May, the physical support for the development of the floating species diminishes and, because it is an environment with running water, the floating species are exported to the lower part of the hydrographic basin. In fact, the results obtained show a reduction of these floating species as from April/May. In June there is a slight increase in biomass and relative density of *N. rudgeana*, probably due to the disappearance of the floating species. These events also favour the growth of the free living submerged species *U. foliosa* that develops due to the support provided by the petioles of *N. rudgeana*. However, *N. rudgeana* does not begin to develop subsequently, and there is a new decrease in density and biomass in August. Other factors must be responsible for the low biomass of *N. rudgeana* until a new growth period.

The results obtained for the relative densities of the three size classes, corroborate the biomass data and demonstrate that the regulation of the population of *N. rudgeana* is due to the development of the floating species as well as the population regulation dependent on density (reduction in the number of individuals with an increase in biomass). In fact, from the beginning of the study, we observe a gradual decrease in density of individuals of *N. rudgeana* associated to the increase in biomass and size of the individuals, until April and May. With the development of the floating species, both the biomass and the density of *N. rudgeana* decrease, probably because of interspecific selective pressure (shading and competition for space). In May, with a new reduction of the biomass and area occupied by the floating species, we observe a new increase in the density of individuals of *N. rudgeana*. The density of small individuals (< 0.4 m) indicates the beginning of a new growth period for this species. However, in July and August there is a new reduction in density and biomass.

The area studied in this paper is influenced by the daily variations of water level conferred by the tide regime and by the daily and seasonal variation of water salinity.

The existence of a season with more rainfall (December to March) and one with less rainfall (May to August) in the region, determine a seasonal variation in the salinity of the water. Greatest values of salinity occurs in the less rainy season of the year, probably being a limiting factor for the development of *N. rudgeana*, consequently decreasing its productivity. The salinity results obtained did demonstrate a clear seasonal variation, with greater salinity in the winter period of this area of the Itanhaém River basin.

The results obtained in this study show that *N. rudgeana* plays an important role in this aquatic system, constituting a key species for the development of emerged free floating and submerged-free floating aquatic macrophytes. However, the constant increase in the area occupied by *P. stratiotes* and *S. molesta*, as a retro-interaction mechanism, provokes the fall of the population of *N. rudgeana* and consequently the disappearance of the floating species by drift. Junk & Piedade (1993) observed a similar mechanism in the mixed stands of aquatic macrophytes in the Camaleão lake (Amazon region) where emerged macrophytes limit the growth of floating ones by the effect of shade.

One must emphasise the increase in biomass and occurrence of *U. foliosa* in June. The disappearance of the floating aquatic macrophytes and consequent elimination of shading over the water column must have favoured the increase in biomass and occurrence number of *U. foliosa* associated to *N. rudgeana*. In July and August, when the biomass of *N. rudgeana* is still reduced and there are chiefly class 1 individuals, *U. foliosa* also loses its physical support and is probably transported by the current, disappearing totally from the Rio Acima.

The biomass data obtained for *N. rudgeana*, like the minimum of 13.051 (November/94) and the maximum of 163.126 g DW/m^2 (February/95), give evidence for the great amplitude of annual variation in biomass, and the mean annual values (62.1 g

DW/m^2) are low when compared to other species with floating leaves. Menezes (1984) observed a mean annual biomass of 193.3 g DW/m^2 for *Nymphoides indica* (322.3 to 190.4 g DW/m^2) and Da Silva (1990) observed a mean annual biomass of 188.9 g DW/m^2 for *Ludwigia natans* (640.0 to 56.0 g DW/m^2), both aquatic macrophytes with floating leaves.

The Net Primary Production (NPP) of *N. rudgeana* estimated from the biomass data is also relatively low, when compared to other aquatic macrophyte species. Table 1 lists the productivity values of aquatic macrophytes in different Brazilian aquatic environments. One verifies that with a NPP evaluated between 3.02 and 3.82 t/ha/year, *N. rudgeana* was hardly productive in relation to *N. indica* (7.6 t/ha/year) studied by Menezes (1984). It is important to consider that the favourable conditions for the development of *N. rudgeana* at Rio Acima are restricted to a short time period (November to March).

This relatively low productivity value, as well as the low biomass values, are probably due to the competitive pressure expended by the floating macrophytes over *N. rudgeana* and to abiotic factors. In fact, after a little increase of biomass in June we observe low values in July, August and September. In this period the temperature is lower and salinity higher. The higher salinity of water in the Rio Acima, in this period of the year, in due to the entrance of estuarine waters because of the lower pluviosity. Probably, the salinity limit the growth of this species during this period of the seasonal cycle and only in December another cycle of growth begin.

TABLE 1

Productivity values (t/ha/year) of aquatic macrophytes in different Brazilian aquatic environments. EM = emergent, FL = floating leaves. Modified from Camargo & Esteves (1995).

Specie	Ecologycal Type	Locality	P	Author
Paspalum fasciculatum	EM	Várzea do Rio Solimões	70,0	Junk & Piedade (1993)
Paspalum repens	EM	Costa do Baixio	31,0	Junk & Piedade (1993)
Luziola spruceana	EM	Lago Camaleão	7,6	Junk & Piedade (1993)
Oryza perennis	EM	Lago Camaleão	27,0	Junk & Piedade (1993)
Nymphoides indica	FL	Represa do Lobo	7,6	Menezes (1984)
Pontederia cordata	EM	Represa do Lobo	3,8	Menezes (1984)
Eichhornia azurea	EM	L. Dom Helvécio	17,5	Ikushima & Gentil (1987)
Eichhornia azurea	EM	Lago Jacaré	6,6	Ikushima & Gentil (1987)
Eichhornia azurea	EM	Lagoa Carioca	8,4	Ikushima & Gentil (1987)
Eichhornia azurea	EM	Lagoa do Infernão	3,5	Coutinho (1989)
Pontederia lanceolata	EM	Pantanal Matogrossense	9,7	Penha (1994)
Nymphaea rudgeana	FL	Rio Acima	3,8	this paper

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