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Temporal and spatial variation of limnological variables and biomass of different macrophyte species in a Neotropical reservoir (São Paulo – Brazil)

Variação temporal e especial de variáveis limnológicas e da biomassa de diferentes espécies de macrófitas em um reservatório Neotropical (São Paulo – Brasil)

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Abstract: Aim: This study reports an investigation of limnological characteristics and aquatic macrophyte occurrence in a neotropical reservoir in order to assess the spatio-temporal variation of water and sediment variables and their influence on plant distribution. **Methods**: Macrophytes, water and sediment samples were collected from a Brazilian reservoir in different seasons from four main arms of the reservoir. In total sixteen water-sediment variables were analyzed including N:P ratio and Trophic State Index. The plants were collected using a quadrat sampling procedure and the dry weight per sample was measured. MANOVA was performed to evaluate spatial and temporal variation of environmental variables as well as seasonal biomass differences. To assess the relationship among environmental variables and macrophytes an ordination analysis (using Canonical Correspondence Analysis: CCA) was carried out. **Results:** The spatial and temporal variation of limnological variables generated a heterogeneous system which supports the presence of different species of macrophyte. pH, dissolved oxygen and sediment composition were important predictors of *Polygonum lapathifolium* occurrence while nutrients were associated with *Eichhornia crassipes* and *Pistia stratiotes*. Inorganic substances were related to biomass variation of *Eichhornia azurea* and *Myriophyllum aquaticum*. **Conclusions:** The spatial variation of the environmental variables has caused heterogeneity in the reservoir and it may support the occurrence of different species of macrophyte. Limnological variables highlighted in CCA are important to predict the species occurrence and their control in the study area.

Keywords: environmental variables, *Eichhornia* sp., *Polygonum lapathifolium*, *Myriophyllum aquaticum*, neotropical reservoir.

Resumo: Objetivos: Esse estudo relata uma investigação das características limnológicas e da ocorrência de macrófitas aquáticas em um reservatório Neotropical com o intuito de verificar a variação espaço-temporal das variáveis da água e do sedimento e sua influência sobre a distribuição das plantas. **Métodos:** Amostras de macrófitas, água e sedimento foram coletadas em quatro braços de um reservatório brasileiro nas diferentes estações do ano. No total, dezesseis variáveis foram analisadas, incluindo relação N:P e Índice de Estado Trófico. As plantas foram coletadas com um amostrador quadrado e o peso seco foi obtido. Um teste MANOVA foi realizado para verificar a variação espaço temporal das variáveis limnológicas, bem como da biomassa de macrófitas aquáticas. Para avaliar a relação entre as variáveis ambientais e a biomassa das plantas, uma análise de ordenação foi empregada (Análise de Correspondência Canônica: CCA). **Resultados:** A variação espacial das variáveis limnológicas gerou um sistema heterogêneo que favorece a ocorrência de diferentes espécies de macrófitas. Variáveis como pH, oxigênio dissolvido e composição do sedimento foram importantes para predizer a ocorrência de *Polygonum lapathifolium*, enquanto nutrientes estiveram associados com *Eichhornia crassipes* e *Pistia stratiotes*. Substâncias inorgânicas relacionaram-se com a variação da biomassa de *Eichhornia azurea* e *Myriophyllum aquaticum*. **Conclusões:** A variação espacial das variáveis ambientais causou uma heterogeneidade no ecossistema, permitindo a ocorrência de diferentes espécies de macrófitas. As variáveis limnológicas indicadas na CCA são importantes para predizer a ocorrência de macrófitas e controlar seu crescimento exacerbado no reservatório estudado.

Palavras-chave: variáveis ambientais *Eichhornia* sp., *Polygonum lapathifolium*, *Myriophyllum aquaticum*, reservatório neotropical.

1. Introduction

Prediction of the occurrence and abundance of macrophytes species is a major issue in ecological studies of these plants, so establishing what factors determine their growth and distribution is essential. Macrophyte distribution is related to several environmental and anthropogenic factors (eg. climate, hydrology, geomorphology, nutrient availability, biological interactions, and human activities) (Lacoul and Freedman, 2006; Feldmann and Nõges, 2007; Hrivnák et al., 2009).

In neotropical regions abundant aquatic macrophyte biomass is a usual feature of reservoirs due to slow or near-static water velocity, sediment stability, water level control, shoreline development, high temperatures and often high nutrient availability (Bini et al., 2005). Most Brazilian reservoirs are shallow, with a dendritic morphology, which supports the development of coastal areas (Thomaz and Bini, 1998). The presence of these shallow areas, coupled with the generally favorable growing conditions of the tropics, as well as human activities (i.e. domestic and industrial effluent input, fertilizer use, dam construction) which promote macrophyte growth, all tend to favour abundant macrophyte production in neotropical reservoirs.

According to Dos Santos and Calijuri (2001) many lentic aquatic ecosystems in Sao Paulo State are eutrophic, and as a result an increase of the macrophyte biomass of mainly free-floating species has been reported (Cavenaghi et al., 2005; Martins et al., 2008). Although the benefits of macrophytes for aquatic systems are recognized (Kouki et al., 2009; Hassan et al., 2010; Vymazal, 2011), when growing in high abundance these plants interfere with the utilization of water resources (Pieterse and Murphy, 1993), blocking water flow, depleting oxygen in the water, and causing problems for hydropower generation and navigation. Due to these issues (both benefits and nuisance) the study of aquatic macrophyte communities and the factors which drive their distribution are important for water resource management of reservoir systems. This study aimed to assess the seasonal variation of water and sediment variables and their influence on macrophyte distribution in a Neotropical reservoir.

2. Material and Methods

2.1. Study area

Itupararanga Reservoir (23° 36' 42" S; 47° 23' 48" W), within the Sorocaba River Basin in São Paulo State, Brazil (Figure 1), is 26 km in length and has an area of approximately 936 km^2. The annual rainfall in the watershed is around 1400 mm, with dry winters and wet summers. The minimum

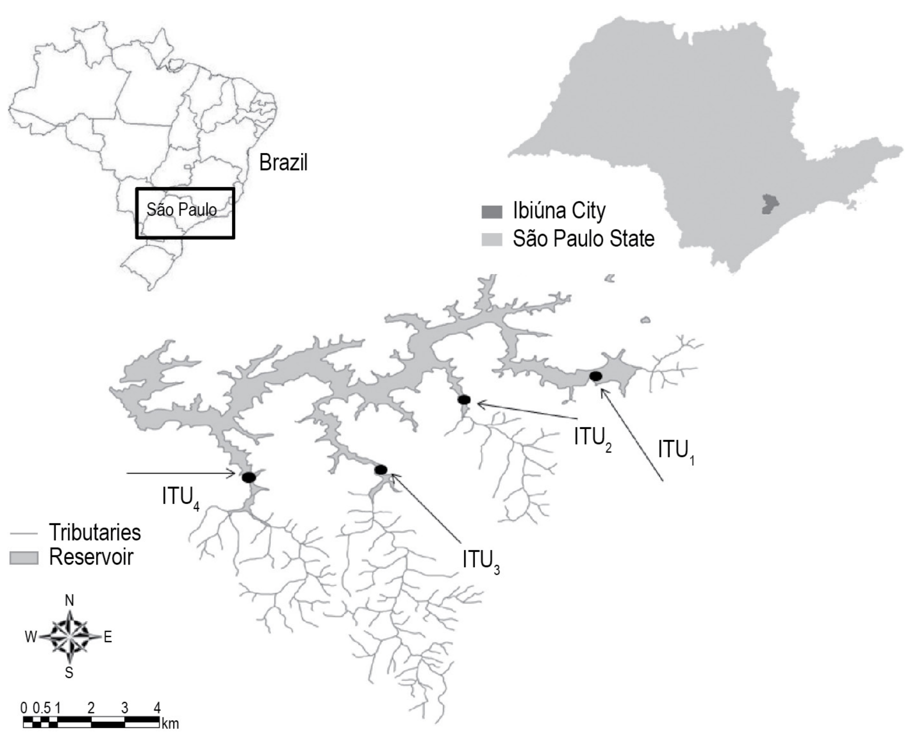

Figure 1. Location of the study area in Brazil, São Paulo State, including a map of the Itupararanga Reservoir with the sampling stations arrowed.

and maximum air temperatures in the area are between 15.0 °C and 24.0 °C and the mean wind speeds range from 1.5 m s^{-1} to 3.0 m s^{-1} (INMET, 2009, 2010). The main uses of the reservoir are public water supply and power generation for an aluminium company. Despite the existence of a permanent preservation area around the reservoir, agriculture (mainly strawberries, onions, potatoes, lettuce and tomato crops) is the predominant land use in the watershed, occupying 42% of the reservoir area (Garcia et al., 1999).

The sampling stations were located in four main arms of Itupararanga Reservoir (Figure 1) which are influenced by rivers running through different parts of Ibiuna city. These arms were coded as ITU_1 (23° 37' 28.3" S; 47° 13' 52.24" W) located near the headwater of the reservoir, and surrounded by small riparian forest, road and building in its sides; ITU_2 (23° 39' 24.65" S; 47° 18' 36.5" W) which has agriculture (lettuce crop) as the main land use in the sub-catchment and Campo Verde Stream is the main tributary of this arm; ITU_3 (23° 37' 42.53" S; 47° 17' 04.62" W) which is influenced by Ressaca Stream and has buildings and roads on its shore lines; and ITU_4 (23° 40' 10.72" S; 47° 21' 21.02" W) which is surrounded by buildings and fishing area, whilst its tributary (Paruru Stream) receives effluent input from a sewage treatment plant.

2.2. Sampling regime

Sampling was carried out in the winter, spring, summer and autumn periods, respectively in August and October 2009 and February and April 2010. Table 1 and Figure 2 show the main differences among the seasons and the hydrological pattern in Itupararanga Reservoir, respectively. *In situ* measurements for water temperature (T), pH, electrical conductivity (EC) and dissolved oxygen (DO) were obtained with a multiparameter probe (Yellow Spring Instruments YSI 556®). Total suspended solids (TSS), organic suspended solids (SSO), inorganic suspended solids (SSI) total phosphorus (TP), nitrite (NO_2) and nitrate (NO_3) were analyzed using standard methods (APHA, 2005). Total Organic Carbon (TOC) and Inorganic Carbon (IC) were analyzed using TOC Analyzer (Shimadzu – SSM 5000 – Combustion Method) Trophic Status was obtained according to Lamparelli (2004). Sediment organic matter (OMS) was analyzed according to Wetzel and Likens (2000), while total phosphorus (TPS) was analyzed following Andersen (1976), and total nitrogen (TNS) following APHA (2005). Granulometric analyses were performed in accordance with Nogueira (2005).

For macrophyte live-biomass analyses, the main plant species (i.e. most abundant species) in the littoral zone were collected within quadrat samples (area 0.25 m^2) (Westlake, 1965). The quadrat was randomly-located (at sites with healthy and mature plants; in triplicate) and aerial and submerged parts of the macrophytes were sampled (including roots in the emerged species) using sickle and hook. The collected biomass was washed with tap water to remove coarse material and dried (60 °C) to constant weight. The plants were weighed to obtain values of mean biomass (calculated per 1 m^2). The main species in ITU_1 were *Eichhornia crassipes* (Mart) Solms and *Pistia stratiotes* L., while in ITU_2 and ITU_3 *Polygonum lapathifolium* L. was predominant and in ITU_4 *Eichhornia azurea* (Sw.) Kunth and *Myriophyllum aquaticum* (Vell.) Verdc.

Temporal and spatial variations of water variables as well as time variation of the biomass were tested using MANOVA (significance level $p<0.05$) (Statistica® Software Version 10.0). The macrophyte environment dataset was analyzed using CCA ordination (CANOCO 4.5) to determine the relative importance of individual environmental factors as predictors of macrophyte distribution in Itupararanga Reservoir.

3. Results

Table 2 shows mean environmental data recorded for the four sampling stations and seasons. MANOVA results suggested a significant difference among sampling stations (spatial variation; $p < 0.05$)

Table 1. Data of Itupararanga Reservoir in different seasons (Winter-August/2009; Spring-October/2009; Summer-February/2010; Autumn-April/2010).

Season	Water Level* (mAMSL**)	Monthly Rainfall (mm)*	Previous Rainfall (mm)***	Upstream Flow* ($m^3.s^{-1}$)	Downstream Flow* ($m^3.s^{-1}$)
Winter	823.74	57.00	0.0	13.41	17.43
Spring	823.06	135.00	76.00	16.83	19.70
Summer	825.15	110.00	22.00	26.43	32.70
Autumn	825.01	79.00	18.00	22.50	27.00

*Data provided by the dam operator; **meters Above Mean Sea Level; ***Seven days before the sampling.

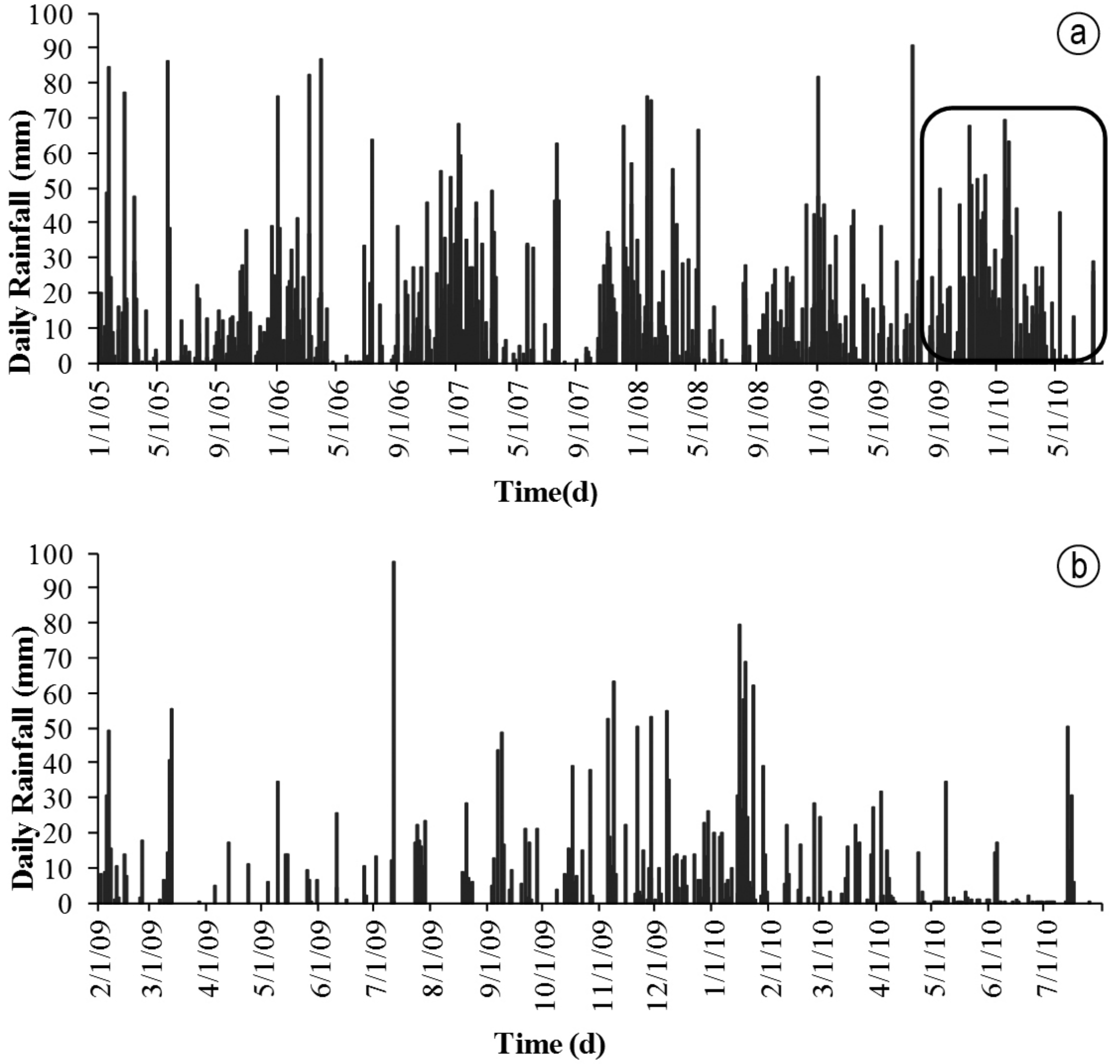

Figure 2. Rainfall in Itupararanga Reservoir: a) Five years daily rainfall with the study period outlined; b) rainfall during the study period (Winter-August/2009; Spring-October/2009; Summer-February/2010; Autumn-April/2010).

as well as among periods (temporal variation; $p < 0.01$). In general the main differences among the arms (spatial variation) were recorded for pH, DO, SSI, TP, T, OMS and TPS; the variables responsible for seasonal differences (temporal variation) were pH, T, NO_3, TOC, OMS, TPS, TNS (Table 3).

In relation to the thermal structure ITU_3 was stratified in the summer and micro-stratifications occurred in the other periods (Figure 3). The highest water temperature (27-29 °C) and pH (7.67-9.8) occurred in the summer. DO concentrations were generally high in all sampling stations mainly in the winter (6 $mg.L^{-1}$ to 8 $mg.L^{-1}$). Electrical conductivity ranged from 54 $\mu S.cm^{-1}$ to 81 $\mu S.cm^{-1}$ and the highest values were recorded mainly in spring, as well as the SST concentrations (9.7-57 $mg.L^{-1}$). Moreover in the same period there was a predominance of SSI (maximum value: 77.1% in ITU_4) while the SSO ranged from 51% to 87.1% in other seasons. In general the TP and NO_2 concentrations were higher in spring except for TN. ITU_4 showed the highest nutrient concentration. The N:P ratio was generally higher in autumn and the lowest values ranged between winter and spring and the Trophic Status Index (TSI) was on average mesotrophic for the four arms.

The CCA results (Figure 4) showed that ISS has significant relation with pH, TSS, NO_2, IC and TP, whilst NO_2 is related with TSS, IC and TP; TP with IC, and TSS with IC and TP ($p < 0.05$).

The sediment analyses indicated significant spatial and temporal variation of PTS ($p = 0.01$) with higher values in the spring (maximum concentration: 3.0 $\mu g.g^{-1}$ in ITU_3). The highest

Table 2. Mean data of environmental variables in four arms of Itupararanga Reservoir. EC: Electrical Conductivity ($\mu S.cm^{-1}$); DO: Dissolved Oxygen ($mg.L^{-1}$); TP: Total Phosphorus ($mg.L^{-1}$); TN; Total nitrogen ($mg.L^{-1}$); NO_2: Nitrite ($\mu g.L^{-1}$); TSS: Total Dissolved Solids ($mg.L^{-1}$); ISS: Inorganic Solids ($mg.L^{-1}$); TOC: Total Organic Carbon ($mg.L^{-1}$); IC: Inorganic Carbon ($mg.L^{-1}$); TN:TP: Total Nitrogen and Total Phosphorus molecular ratio; TSI: Trophic Status Index; MOS: Organic Matter in Sediment (%); TPS: Total Phosphorus in Sediment ($\mu g.g^{-1}$); TNS: Total Nitrogen in Sediment ($\mu g.g^{-1}$).

Variable	Station	Winter	Spring	Summer	Autumn	Variable	Station	Winter	Spring	Summer	Autumn
T	ITU_1	18.79	19.95	26.82	22.18	ISS	ITU_1	2.67	7.31	1.09	1.73
	ITU_2	20.34	20.46	28.63	23.88		ITU_2	1.78	5.66	0.68	1.70
	ITU_3	20.05	21.18	29.15	23.58		ITU_3	4.49	11.39	1.29	0.78
	ITU_4	18.69	19.52	27.52	22.33		ITU_4	8.20	44.12	3.00	2.00
pH	ITU_1	6.24	5.89	7.99	6.75	TOC	ITU_1	6.04	5.47	5.54	4.03
	ITU_2	6.45	6.35	8.48	6.95		ITU_2	4.60	4.26	5.18	3.91
	ITU_3	6.90	6.54	10.06	7.48		ITU_3	4.23	4.16	4.78	3.99
	ITU_4	6.34	6.21	7.34	7.18		ITU_4	3.75	3.73	35.70	3.48
EC	ITU_1	58.0	56.0	79.60	56.40	IC	ITU_1	10.90	11.64	12.34	7.02
	ITU_2	62.50	93.75	53.25	52.50		ITU_2	7.15	8.13	7.28	6.47
	ITU_3	58.50	59.50	48.33	56.00		ITU_3	9.47	12.68	8.72	7.26
	ITU_4	74.75	105.00	76.00	81.75		ITU_4	16.73	22.61	17.76	11.01
DO	ITU_1	7.21	1.870	6.43	5.64	N:P	ITU_1	3.00	2.00	4.00	44.00
	ITU_2	7.58	6.50	7.17	7.01		ITU_2	6.30	1.00	27.00	15.50
	ITU_3	8.94	7.32	8.11	6.93		ITU_3	17.00	39.00	26.00	7.00
	ITU_4	5.86	3.80	6.92	6.09		ITU_4	3.50	2.00	17.00	1.00
TP	ITU_1	77.2	77.5	73.2	34.41	TSI*	ITU_1	E	M	E	M
	ITU_2	35.46	55.80	33.04	23.05		ITU_2	E	M	M	M
	ITU_3	54.03	50.78	30.05	40.92		ITU_3	M	M	M	M
	ITU_4	70.43	88.88	46.08	28.09		ITU_4	E	O	M	M
TN	ITU_1	0.095	0.07	0.14	0.70	OMS	ITU_1	16.40	6.40	1.90	3.40
	ITU_2	0.1	0.02	0.40	0.16		ITU_2	19.00	14.00	26.00	18.50
	ITU_3	0.42	0.04	0.35	0.13		ITU_3	19.00	18.50	20.00	12.20
	ITU_4	0.11	0.07	0.36	0.01		ITU_4	8.00	3.60	5.00	14.00
NO_2	ITU_1	0.32	0.22	0.17	0.27	PTS	ITU_1	1.3	2.0	0.2	0.15
	ITU_2	0.15	0.12	0.06	0.07		ITU_2	0.24	1.75	2.20	1.30
	ITU_3	0.26	0.29	0.03	0.06		ITU_3	0.30	3.00	2.15	1.40
	ITU_4	0.48	1.21	0.43	0.58		ITU_4	0.20	0.18	0.37	2.00
TSS	ITU_1	9.29	9.74	7.24	5.24	TNS	ITU_1	1465	952	336	280
	ITU_2	7.26	10.01	5.62	6.07		ITU_2	2277	2510	4648	2333
	ITU_3	10.65	16.68	5.80	6.04		ITU_3	1777	2445	2193	1484
	ITU_4	14.30	56.88	9.40	6.51		ITU_4	270.00	298.00	438.00	952.00

Table 3. Main variables responsible for spatio-temporal variation in Itupararanga Reservoir. Results from MANOVA (significance level $p < 0.05$).

Variable	Spatial variation	Variable	Temporal variation
OMS	p=0.007	OMS	p=0.01
TPS	p=0.01	TPS	p=0.01
DO	p=0.017	pH	p=0.012
T	p=0.019	T	p=0.028
ISS	p=0.039	NO_3	p=0.03
TP	p=0.046	TNS	p=0.03
pH	p=0.047	TOC	p=0.044

percentages of OMS were recorded in both ITU_2 and ITU_3 while TN showed high concentration in ITU_2 (Table 2). From the CCA we found significant correlation ($p < 0.05$) between OMS and DO; OMS and TP; OMS and TPS; OMS and TNS as well as between TNS and NO_2 and TNS and TPS. Figure 5 shows the results of sediment granulometric analyses. Silt was the predominant fraction in all sampling stations and seasons (90% to 60.8%), while gravel occurred mainly after rainfall but in small proportion. The variation in

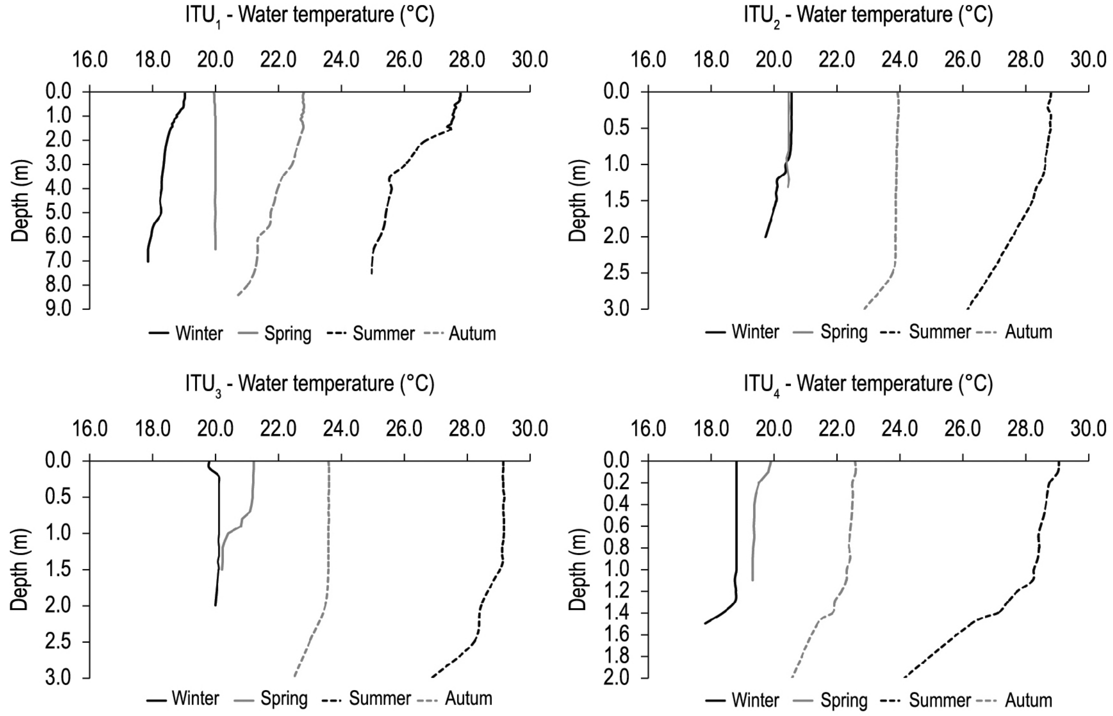

Figure 3. Vertical variation of water temperature (°C) in four arms of Itupararanga Reservoir in different seasons (Winter-August/2009; Spring-October/2009; Summer-February/2010; Autumn-April/2010).

substrate fractions did not show seasonal significant differences.

Macrophyte biomass varied seasonally as showed by MANOVA (Table 4). The highest biomass of *Polygonum lapathifolium* was recorded in ITU_2 in the winter and in the autumn (966 $gDW.m^2$ and 917 $gDW.m^2$ respectively) while *Eichhornia crassipes* and *Pistia stratiotes* showed high biomass values in ITU_1 in the spring and summer, respectively. In ITU_4 the stands of *Eichhornia azurea* and *Myriophyllum aquaticum* were senescent in both summer and autumn.

The CCA analysis (total variance: 90%) suggests that ITU_1 sampling station was influenced by TP and TOC in all periods while DO, pH, OMS, TPS and TNS were related with ITU_2 and ITU_3. TOC was associated with ITU_4 in winter and with NO_2, TSS and ISS in the spring. So the species distribution was correlated with these variables (Figure 4) which explained almost 63% of data variability on the first axis of the CCA (eigenvalue: 0.89). The most important variables for Factor 1 were TP, DO, pH, MOS, TPS, NTS, *P. lapathipholium*, *E. crassipes* and *P. stratiotes*.

4. Discussion

Water temperature followed the normal seasonal pattern and DO concentrations were highest in the summer due probably to phytoplankton activity. CE, TSS, ISS, IC and TP are likely to be related to the rainfall in spring (76 mm) while high pH values may be associated with high photosynthesis rates in summer, which is usual in tropical reservoirs. Both TOC and IC showed lowest concentrations when the pH values were relatively neutral. Probably the tributaries and runoff provide a constant TN load to the reservoir since this variable did not show temporal variation in either water or sediment. Our TSI results are in agreement with Pedrazzi et al. (2013) although the differences between methods used. Previous research concluded the seasons and rainfall pattern are important to predict the heterogeneity of Itupararanga Reservoir (Pedrazzi et al., 2013).

Granulometric analysis showed the prevalence of silt in sediment and in rainy periods (mainly in the spring) there was increased gravel occurrence which may be from tributary drainage, due to high flows (see Table 1). Sediment variables (mainly OMS and TPS) were the main responsible for spatio-temporal heterogeneity in Itupararanga Reservoir suggesting the influence of different land covers in the arms (see item 2.1).

The patterns of aquatic macrophyte cover are strongly dependent on the spatial and temporal heterogeneity of aquatic ecosystems (Jeffries, 2008). This statement corroborates with the results given

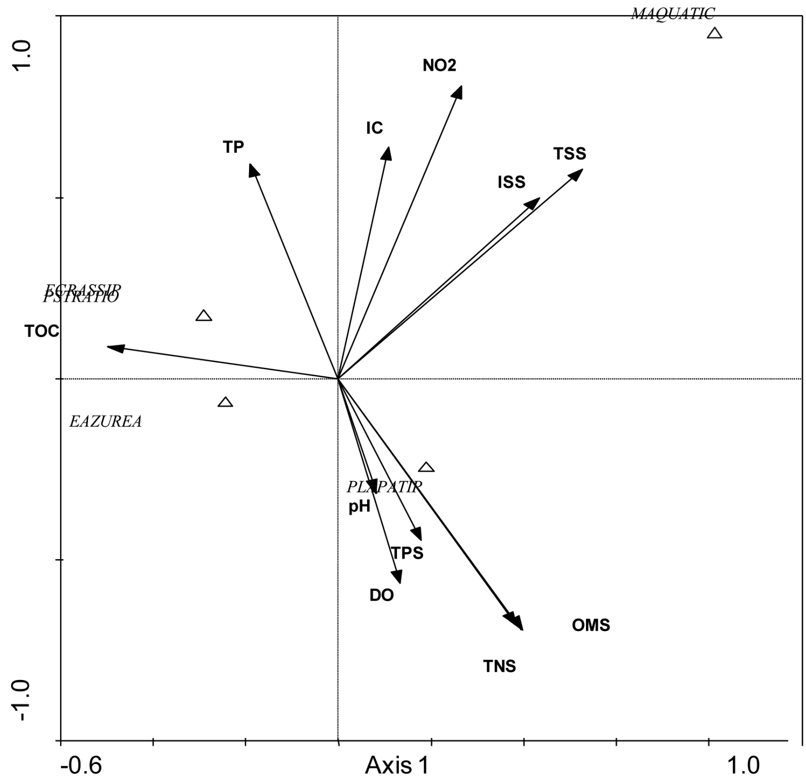

Figure 4. CCA ordination plot on Axis 1 (horizontal) and Axis 2 (vertical) of 5 macropyte species and 11 environmental samples. Species codes: EAZUREA: *Eichhornia azurea*; ECRASSIP: *Eichhornia crassipes*; PSTRATIO: *Pistia stratiotes*; MAQUATIC: *Myriophyllum aquaticum*; PLAPATIP: *Polygonum lapathifolium*. Environmental codes: TOC: Total Organic Carbon ($mg.L^{-1}$); TP: Total Phosphorus ($mg.L^{-1}$); IC: Inorganic Carbon ($mg.L^{-1}$); NO_2: Nitrite ($\mu g.L^{-1}$); ISS: Inorganic Suspended Solids ($mg.L^{-1}$); TSS: Total Suspended Solids ($mg.L^{-1}$); DO: Dissolved Oxygen ($mg.L^{-1}$); TPS: Total Phosphorus in Sediment ($\mu g.g^{-1}$); TNS: Total Nitrogen in Sediment ($\mu g.g^{-1}$); OMS: Organic Matter in Sediment (%). Ordination statistics: Monte Carlo significance tests: Axis 1: F-ratio 2.329, P=0.03; all canonical axes: F-ratio 4.037, P=0.006; Eigenvalues: Axis 1 (horizontal): 0.893; Axis 2 (vertical): 0.867; Cumulative explained variation of species data (on Axes 1-4) = 86.6%; of species-environment.

here, which suggested a substantial amount of spatial and seasonal variation of water and sediment variables, and macrophyte occurrence. So we may point out the macrophyte cover is related mainly to the spatial habitat heterogeneity of Itupararanga Reservoir. We suppose the influence of different land covers and streams (tributaries) running through different areas were responsible to generate the limnological differences among sampling stations (Table 3). In this regard different macrophyte species grew on the arms studied.

Indeed some researches have reported the influence of water variables on macrophyte growth and distribution, for instance TP concentration and *E. crassipes* and P. *stratiotes* presence (Bini et al., 1999; Lacoul and Freedman, 2006); sediment variables and Poligonaceae occurrence (Takamura et al., 2003). It is possible to assess the importance of spatial variation of limnological variables for aquatic macrophytes through the CCA analysis. The results of the Canonical Correspondence highlighted the relationship of variables responsible for spatial heterogeneity and macrophyte species.

E. crassipes and *P. stratiotes* were influenced by TP and TOC in Itupararanga Reservoir. It is known these species are associated with high nutrient concentration (Henry-Silva et al., 2008) and are abundant in eutrophic ecosystems: ITU_1 was the sampling station with eutrophic conditions for most of the study period. Although not clear in CCA analysis, the maximum *P. stratiotes* biomass coincided with the highest TN concentration and this species growth is influenced by nitrogen concentration (Henry-Silva et al., 2008).

The senescence of *P. stratiotes* in the spring may be related to the competition process with *E.*

Table 4. Aquatic macrophyte biomass ($gDW.m^{-2}$) in different arms and seasons in Itupararanga Reservoir.

Species	Winter	Spring	Summer	Autumn	*p* MANOVA
			ITU_1		
Eichhornia crassipes	409.07	721.30	508.53	882.30	$p < 0.05$
Pistia stratiotes	219.30	*	591.6	551.07	$p < 0.05$
			ITU_2		
Polygonum lapathifolium	966.30	391.07	512.30	917.10	$p < 0.05$
			ITU_3		
Polygonum lapathifolium	506.30	487.60	407.30	541.50	$p < 0.05$
			ITU_4		
Eichhornia azurea	617.30	*	*	*	-
Myriophyllum aquaticum	*	317.07	*	*	-

*The macrophyte stand was senescent.

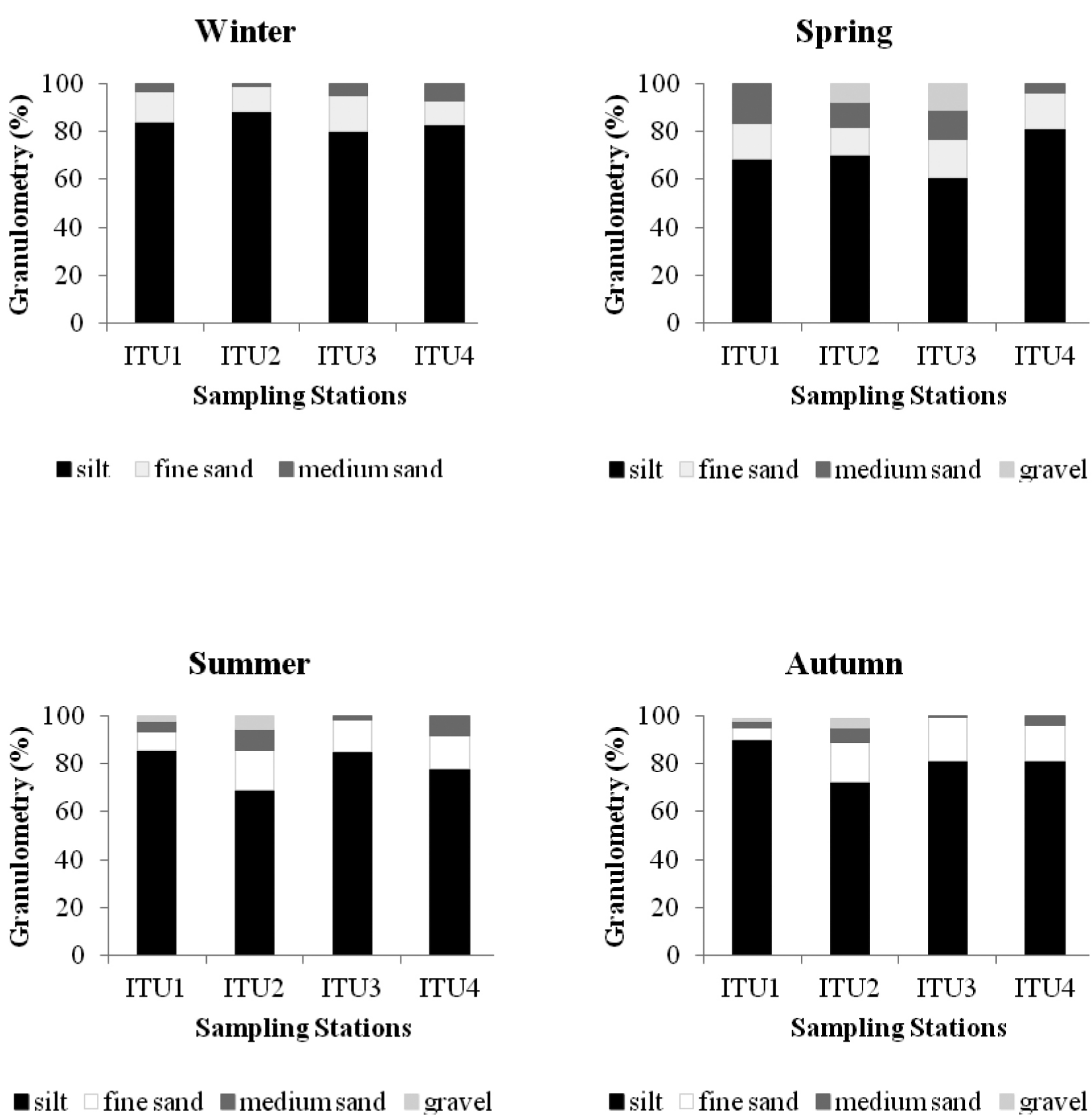

Figure 5. Granulometric fractions in different arms and seasons in Itupararanga Reservoir.

crassipes during this period (*P. stratiotes* is known to be a fairly weak competitor with other tropical free-floating macrophytes: e.g. Agami and Reddy, 1990). *P. stratiotes* was senescent when the *E. crassipes* biomass increased 56% approximately. *E. crassipes* specimens normally have advantages due to their intensive growth, more efficient use of solar radiation and higher capacity of absorbing nutrients when they are abundant (Agami and Reddy, 1990; Henry-Silva et al., 2008).

The CCA species-environmental analyses showed a positive relationship between *P. lapathifolium* (in both ITU_2 and ITU_3) and pH and DO. Higher pH values were recorded in sampling stations with *P. lapathifolium* presence. In addition TP was inversely correlated with that species while the results suggest that the sediment is an important factor for *P. lapathifolium* development and probably drives the distribution of this plant. According to Takamura et al. (2003) Polygonaceae are important to restrain the P loadings from the sediment due to high DO concentration in the stands with these plants, even in the bottom as in Itupararanga Reservoir (from 6.5 to 8.94). Both ITU_2 and ITU_3 have shown mesotrophic condition in almost all seasons and had relatively high TPS concentration when the biomass of *P. lapathifolium* was high.

In ITU_4 *M. aquaticum* was correlated with solids and NO_2 while *E. azurea* and TOC were associated with the presence of this plant. Interestingly *E. azurea* was absent when the pH and SST concentrations were high, as also noted by Bini et al. (1999) in another Brazilian reservoir (Itaipu). On the other hand *M. aquaticum* occurrence coincided with the highest concentrations of solids and with the SSI predominance period. Both inorganic compounds and probably electrical conductivity appear to be predictors of *Myriophyllum* presence (see also Lacoul and Freedman, 2006).

The importance of anthropogenic activities for predicting macrophyte presence should be highlighted. For example, Cheruvelil and Soranno (2008) have recorded a link between agricultural activities and emergent macrophyte presence, as well as between road density and floating macrophyte cover. These findings support the results presented here since *P. lapathifolium* was present in sampling stations surrounded by rural activities while *E. crassipes* and *P. stratiotes* were in the headwater of the reservoir, near to the city and roads. Many species of Polygonaceae are recognized as ruderal species (R-strategists: Grime, 1979), which establish soon after disturbance and they are tolerant of pollution, for example compounds draining from agricultural areas (Lacoul and Freedman, 2006). Similarly Pozo et al. (2011) have concluded that emergent and floating macrophytes composition is best explained by land use variables within the catchment. Due to the proximity of stream mouths to the sites with macrophyte biomass we propose too that the fluvial activity has an important role on biomass development. This fact is relevant when comparing the occurrence of the same macrophyte species in the whole river basin (Tietê River Basin: e.g. Cavenaghi et al., 2005; Martins et al., 2008).

In summary, variables like pH, DO, TOC, IC, NO_2, ISS, TSS, TPS, TNS and OMS were more important to predict the macrophyte occurrence and may be used as a tool for water management. The variables highlighted here may be useful to control macrophyte excessive growth since the nutrients increasing is a problem in Brazilians reservoirs mainly in Tietê River Basin. In this regard we suggest that *P. lapathifolium* generates different redox conditions influencing phosphorus release from the sediment. *E. crassipes* may be considered as indicating high trophic status while *E. azurea* and *M. aquaticum* are indicative of inorganic compounds in the water. Moreover *P. lapathifolium* and *E. crassipes* presence may be also associated with different land uses. The heterogeneity of the ecosystem due to spatial variation of environmental variables may be more important than seasonal variation to predict the occurrence of different macrophyte species. The composition of the species did not range with the temporal variation of the environmental variables. However water and sediment variables were important to predict biomass development and although land use data were not available we supposed they have an important role in macrophyte distribution.

This study has demonstrated in general way the factors driving the macrophytes distribution in Itupararanga Reservoir. Our results may support future researches in similar environments and to contribute to the water resources management.

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References

AGAMI, M. and REDDY, KR. 1990. Competition for space between *Eichhornia crassipes* (Mart.) Solms and *Pistia stratiotes* L. cultured in nutrient-enriched water. *Aquatic Botany*, vol. 38, p. 195-208. http://dx.doi.org/10.1016/0304-3770(90)90005-6

American Public Health Association - APHA. 2005. *Standard Methods for the examination of water and wastewater*. 21th ed. Washington.

ANDERSEN, JM. 1976. An ignition method for determination of total phosphorus in lake sediments. *Water Resources*, vol. 10, p. 329-31.

BINI, LM., THOMAZ, SM., MURPHY, KJ. and CAMARGO, AFM. 1999. Aquatic macrophyte distribution in relation to water and sediment conditions in Itaipu Reservoir, Brazil. *Hydrobiologia,* vol. 415, p. 147-154. http://dx.doi.org/10.1023/A:1003856629837

BINI, LM; OLIVEIRA, LG., SOUZA, DC., CARVALHO, P. and PINTO, MP. 2005. Patterns of the aquatic macrophyte cover in Cachoeira Dourada Reservoir (GO-MG). *Brazilian Journal of Biology*, vol. 65, no. 1, p. 19-24. PMid:16025899. http://dx.doi.org/10.1590/S1519-69842005000100004

CAVENAGHI, AL., VELINI, ED., GALO, MLBT., CARVALHO, FT, NEGRISOLI, E., TRINDADE, MLB. and SIMIONATO, JLA. 2005. Caracterização da qualidade da água e sedimento relacionados com a ocorrência de plantas aquáticas em cinco reservatórios da bacia do rio Tietê. *Planta daninha*, vol. 21, p. 43-52.

CHERUVELIL, KS. and SORANNO, PA. 2008. Relationships between lake macrophyte cover and lake and landscape features. *Aquatic Botany*, vol. 88 p. 219-227. http://dx.doi.org/10.1016/j.aquabot.2007.10.005

DOS SANTOS, ACA. and CALIJURI, MC. 2001. Temporal variations in phytoplankton primary production in a tropical reservoir (Barra Bonita, SP – Brazil). *Hydrobiologia*, vol. 445 p.11-26. http://dx.doi.org/10.1023/A:1017554829992

FELDMANN, T. and NÕGES, P. 2007. Factors controlling macrophyte distribution in large shallow Lake Võrtsjärv. *Aquatic Botany*, vol. 87, no. 1, p. 15-21. http://dx.doi.org/10.1016/j.aquabot.2007.01.004

GARCIA, JPM, FREITAS, NP and SILVA FILHO, NL. 1999. *Caracterização geo-ambiental da Represa de Itupararanga.* Available from: <http://IPE.ibrc.unesp.br/cbhsmt/projeto.html>. Access in: Dec 2009.

GRIME, JP. 1979. *Plant strategies and vegetation processes*. Chichester: John Wiley and Sons. 222 p.

HASSAN, S., SCHMIEDER, K. and BÖCKER, R., 2010. Spatial patterns of submerged macrophytes and heavy metals in the hypertrophic, contaminated, shallow reservoir Lake Qattieneh/Syria. *Limnologica*, vol. 40, p. 54-60. http://dx.doi.org/10.1016/j.limno.2009.01.002

HENRY-SILVA, GG., CAMARGO, AFM. and PEZZATO, MM. 2008. Growth of free-floating aquatic macrophytes in different concentrations of nutrients. *Hydrobiologia*, vol. 610, no. 1 p. 153-160. http://dx.doi.org/10.1007/s10750-008-9430-0

HRIVNÁK, R., OŤAHE'OVÁ, H. and GÖMÖRY, D. 2009. Seasonal dynamics of macrophyte abundance in two regulated streams. *Central European Journal of Biology*, vol. 4, no. 2, p. 241-249. http://dx.doi.org/10.2478/s11535-009-0004-6

Instituto Nacional de Meteorologia - INMET. *Dados climáticos sobre temperatura do ar, precipitação e ventos.* INMET, 2009. Available: <http://www.inmet.gov.br>. Access in: Dec 2009.

Instituto Nacional de Meteorologia - INMET. *Dados climáticos sobre temperatura do ar, precipitação e ventos.* INMET, 2010. Available from: <http://www.inmet.gov.br>. Access in: July 2010.

JEFFRIES, M. 2008. The spatial and temporal heterogeneity of macrophyte communities in thirty small, temporary ponds over a period of ten years. *Ecography*, vol. 31, no. 6, p. 765-775. http://dx.doi.org/10.1111/j.0906-7590.2008.05487.x

KOUKI, S., M'HIRI, F., SAIDI, N., BELAÏD, S. and HASSEN, A., 2009. Performances of a constructed wetland treating domestic wastewaters during a macrophytes life cycle. *Desalination*, vol. 246, p. 452-467. http://dx.doi.org/10.1016/j.desal.2008.03.067

LACOUL, P. and FREEDMAN, B. 2006. Environmental influences on aquatic plants in freshwater ecosystems. *Environmental Reviews*, vol. 136, p. 89-136. http://dx.doi.org/10.1139/a06-001

LAMPARELLI, MC. 2004. *Graus de trofia em corpos d´água do estado de São Paulo*: avaliação dos métodos de monitoramento. Universidade de São Paulo. 238 p. [Tese de Doutorado].

MARTINS, D., COSTA, NV., TERRA, MA. and MARCHI, SR. 2008. Caracterização da comunidade de plantas aquáticas de dezoito reservatórios pertencentes a cinco bacias hidrográficas do estado de São Paulo. *Planta Daninha*, vol. 26, no.1 p.17-32. http://dx.doi.org/10.1590/S0100-83582008000100003

NOGUEIRA, JB. 2005. Análise Granulométrica. In NOGUEIRA, JB. *Mecânica dos solos – Ensaios de laboratório*. EESC/USP/Departamento de Geotecnia. p. 93-107.

PEDRAZZI, FJM., CONCEIÇÃO, FT., SARDINHA, DS., MOSCHINI-CARLOS, V. and PÔMPEO, MLM. 2013. Spatial and temporal quality of water in Itupararanga Reservoir, Alto Sorocaba Basin (SP), Brazil. *Journal of Water Resource and Protection*, vol. 5, p. 64-71. http://dx.doi.org/10.4236/jwarp.2013.51008

PIETERSE, AH. and MURPHY, KJ. 1993. *Aquatic weeds: the ecology and management of nuisance aquatic vegetation*. Oxford: Oxford University Press. 593 p.

POZO, R., FERNÁNDEZ-ALÁEZ, C. and FERNÁNDEZ-ALÁEZ, M. 2011. The relative importance of natural and anthropogenic effects on community composition of aquatic macrophytes in Mediterranean ponds. *Marine and Freshwater Research*, vol. 62, no. 2, p. 101-109.

TAKAMURA, N., KADONO, Y., FUKUSHIMA, M., NAKAGAWA, M. and KIM, BHO. 2003. Effects of aquatic macrophytes on water quality and phytoplanktonic communities in shallow lakes. *Ecological Research*, vol. 18 p. 381-395. http://dx.doi.org/10.1046/j.1440-1703.2003.00563.x

THOMAZ, SM. and BINI, LM. 1998. Ecologia e manejo de macrófitas aquáticas em reservatórios. *Acta Limnologica Brasiliensia*, vol. 10, no. 1, p. 103-116.

VYMAZAL, J. 2011. Long-term performance of constructed wetlands with horizontal sub-surface flow: Ten case studies from the Czech Republic. *Ecological Engineering,* vol. 37, p. 54-63. http://dx.doi.org/10.1016/j.ecoleng.2009.11.028

WESTLAKE, DF. 1965. Some basic investigation of the productivity of aquatic macrophytes. *Memorie dell?Istituto Italiano di Idrobiologia*, vol. 18, p. 229-248.

WETZEL, RG. and LINKENS, GE. 2000. *Limnological analysis.* New York: Springer-Verlag. 429 p.

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