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Urbanization effects on the composition and structure of macrophytes communities in a lotic ecosystem of Pernambuco State, Brazil

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Abstract

Population growth in urban areas changes freshwater ecosystems, and this can have consequences for macrophyte communities as can be seen in the municipalities that border the Capibaribe River, Pernambuco, Brazil. This study reports the effects of urbanization on the composition and structure of macrophyte communities in areas along that river. The following urbanized and non-urbanized sampling sites were chosen: Sites 1 and 2 (municipality of Santa Cruz do Capibaribe), Sites 3 and 4 (municipality of Toritama), and Sites 5 and 6 (metropolitan region of Recife). These sites were visited every two months from January to July 2013 to observe seasonal variation (wet and dry seasons). Thirty-one species were identified. Generally, the non-urbanized sites had a higher number of species. Multivariate analyses indicated significant overall differences between urbanized and non-urbanized areas ($R = 0.044$; $p < 0.001$) and between seasons ($R = 0.018$; $p < 0.019$). Owing to the large variation in physical, chemical, and biological characteristics between urbanized and non-urbanized areas, we found that urbanization significantly influenced the floristic composition and structure of macrophyte communities.

Keywords: aquatic plants, biomass, pollution.

Efeitos da urbanização na composição e estrutura de comunidades de macrófitas aquáticas em um ecossistema lótico do Estado de Pernambuco, Brasil

Resumo

O crescimento populacional em áreas urbanas causa alterações em ecossistemas aquáticos continentais com consequência sobre as comunidades de macrófitas. Este fato vem ocorrendo nos municípios que margeiam o rio Capibaribe, Pernambuco, Brasil. Este trabalho analisa os efeitos da urbanização sobre a composição e estrutura das macrófitas em trechos do referido Rio. Levando em consideração áreas urbanizadas e não urbanizadas, foram escolhidos os seguintes Pontos de Coleta: Pontos 1 e 2 no Município de Santa Cruz do Capibaribe, Pontos 3 e 4 no Município de Toritama, Pontos 5 e 6 na Região Metropolitana do Recife. Estes pontos foram visitados bimestralmente (janeiro – julho/2013), para a observação da variação sazonal (estações seca e chuvosa). Foram identificadas 31 espécies. Geralmente, os pontos das áreas não urbanizadas apresentaram um número maior de espécies. As análises multivariadas indicaram diferenças globais significativas entre áreas urbanizadas e não urbanizadas ($R = 0{,}044$, $p < 0{,}001$) e também entre as estações ($R = 0{,}018$; $p < 0{,}019$). Devido à grande variação física, química e biológica entre as áreas urbanizadas e não urbanizadas, observou-se que o fator urbanização influenciou significativamente na composição florística e na estrutura das comunidades de macrófitas.

Palavras-chave: plantas aquáticas, biomassa, poluição.

1. Introduction

Aquatic macrophytes are plants visible to the naked eye, regardless of taxonomic classification, that present submerged or floating photosynthetic parts in swamps and other aquatic environments. They play an important role in the ecosystem and are the base of the food chain, participating directly in nutrient cycling (Esteves and Camargo, 1986).

Recent studies on aquatic macrophytes in Brazil have focused mainly on lentic and artificial systems (ponds, wetlands, dams, and reservoirs), with fewer studies being devoted to lotic systems (rivers and streams) (Thomaz and Bini, 2003), although important studies on macrophyte seasonal dynamics on the Amazon River have been published by Junk and Piedade (1997) and Piedade et al. (2010). However, the effects of human activity and urbanization on macrophyte communities, both of which are responsible for the disappearance of many species, are still poorly studied. Monitoring and research have thus become increasingly important, along with the identification of bioindicators of environmental impacts (Ferreira et al., 2010).

One of the main environmental problems in aquatic systems is eutrophication, the enrichment of water bodies by nutrients such as phosphates and nitrogen compounds. Eutrophication has disastrous consequences for the environment owing to the excessive increase in the supply of nutrients, the acceleration in productivity, and the consequent undesirable proliferation of macrophyte populations (Neiff, 1990; Esteves, 1998; Machado, 2001; Goulart and Callisto, 2003; Tundisi et al., 2006). Furthermore, the population of weed species can increase as a result of nutrient enrichment from other environmental sources (Demars and Harper, 1998). Eutrophication enables the colonization of vast areas, resulting in changes in water quality and damage to various ecosystem uses (Thomaz, 2002; Pompeo, 2008).

The basin of the Capibaribe River is located in the State of Pernambuco in northeastern Brazil. According to the census of the Brazilian Institute of Geography and Statistics (IBGE), the population of the basin was 3,108,341 inhabitants in 2000, with 86% living in urban areas, and over 45% of those inhabiting the city of Recife, the state capital. In 2007, IBGE conducted a new demographic survey that showed the population had grown to 3,312,972 inhabitants. The reason for this growth, which occurred mainly in urban centers, is economic development in different regions of the basin (PROJETEC-BrLi, 2010a), which has also had a number of environmental impacts due to the close relationship between humans and the Capibaribe River. These environmental impacts have caused a massive disruption in the river system, since 36 municipalities from the 42 that are located in the Capibaribe Basin release their domestic and industrial waste water without proper treatment directly into the river or into its tributaries (Pereira, 2004; PROJETEC-BrLi, 2010a).

Although the Capibaribe River still has potential uses in fishing, agriculture, water supply, and other industrial and service activities, it has suffered from environmental disturbances due to the high level of occupation, the intensive use of land, and also rainfall irregularity, especially in the Upper Capibaribe region (PROJETEC-BrLi, 2010a).

This study aimed to analyze the effects of urbanization on the composition and structure of macrophyte communities along the Capibaribe River, using biomass as a descriptor, and to assess the environmental health and water quality of this river.

2. Material and Methods

The Capibaribe River drainage basin is one of the most important river basins in the state of Pernambuco, covering 42 municipalities and with a total area of 7,454.88 Km^2 in the phytogeographical zones of Agreste, Zona da Mata, and the coastal zone. This sub-regional distribution provides the basin with heterogeneous environments of contrasting climate, relief, soil, and vegetation (PROJETEC-BrLi, 2010a).

Its main river, the Capibaribe, is approximately 253 Km long and rises from the top of the Serra do Jacarará (08° 04' 27.8" S, 36° 34' 05.2" W) at an altitude of 1,100 m above sea level near the municipality of Poção in the Agreste zone of Pernambuco; the river flows into the Atlantic at the Port of Recife (08° 03' 27.4" S, 34° 52' 28.8" W) (PROJETEC-BrLi, 2010b).

We selected four municipalities as botanical collection sites based on population data from the IBGE 2010 census. Two were in the Agreste region of Pernambuco (Santa Cruz do Capibaribe, 07° 56' 31" S, 36° 13' 54" W; and Toritama, 07° 59' 56" S, 36° 03' 07" W), and two were in the metropolitan region of Recife (São Lourenço da Mata, 08° 00' 12" S, 35° 01' 16" W; and Recife, 08° 03' 16" S, 34° 52' 52" W).

A total of six sampling sites were plotted and georeferenced with GPS (Global Positioning System). In the Agreste region, four sampling sites were selected. Two sites (1 and 2) were located upstream and downstream of the urban area of the municipality of Santa Cruz do Capibaribe, respectively. The other two sites (3 and 4) were located upstream and downstream of the urban area of the municipality of Toritama, respectively (Figure 1). This region of the Upper Capibaribe River has a diverse industrial sector with a particular emphasis on textile manufacturing, which generates substantial water pollution (PROJETEC-BrLi, 2010a).

Another two sampling sites were selected in the Lower Capibaribe River region. Because the metropolitan region of Recife is so large and the urban environment is not interrupted between the municipalities of the Lower Capibaribe, one site (5) was chosen upstream of the urban center of São Lourenço da Mata, and another site (6) in the city of Recife itself (Figure 1). The sampling sites were visited every two months between January and March (dry season), and May and July (rainy season) 2013. Thus, a total of four samples were taken at each site, two during the dry season and two during the rainy season.

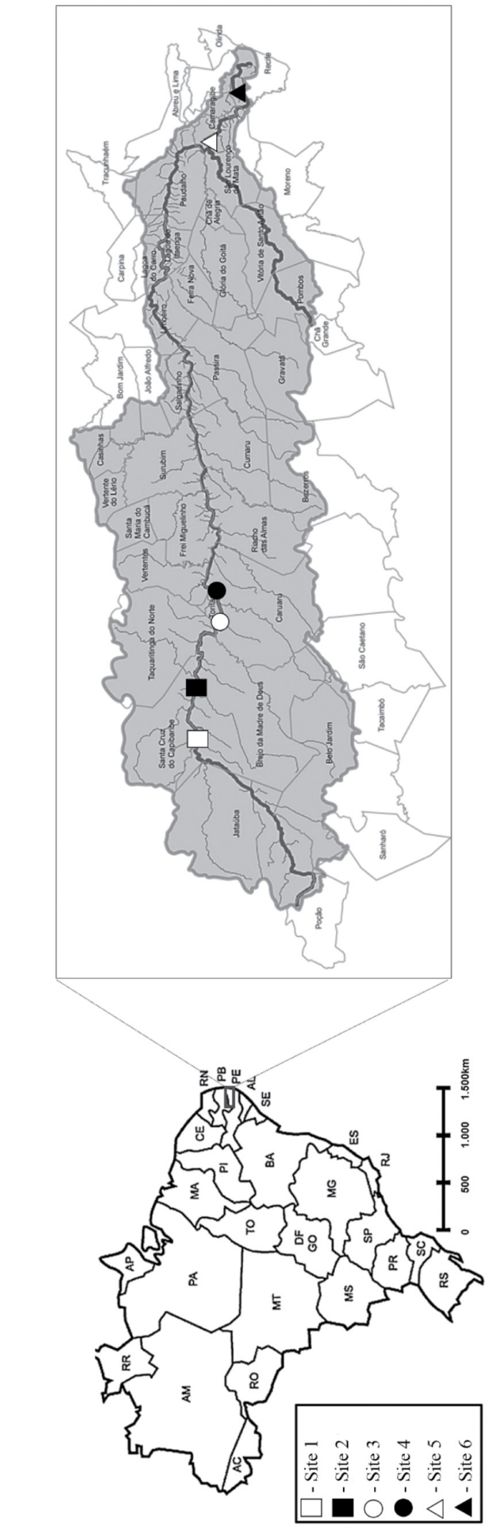

Figure 1. Location map of Rio Capibaribe Basin, Pernambuco, Brazil, indicating the municipalities of the sampling sites of Santa Cruz do Capibaribe - PE (square), Toritama - PE (circles) and the Metropolitan Region of Recife (triangle). White symbols: not urbanized area; black symbols: urbanized area.

Individuals of each species found at the sampling sites were collected and pressed in duplicate; identifications were made using analytical keys and specialized literature, including Hoehne (1948), Sculthorpe (1967), Cook (1974, 1996), Scremin-Dias et al. (1999), and Pott and Pott (2000). Whenever necessary, comparisons were also made with herbarium specimens from two herbaria, PEUFR at the Federal Rural University of Pernambuco, and UFP at the Federal University of Pernambuco. After identification, the species nomenclature was updated using the botanical information system at the Missouri Botanical Garden. Families were updated following the Angiosperm Phylogeny Group (APG) III system.

At each sampling site three 9.75 m transects were plotted at 10 m intervals beginning 50 cm from the site margin. The samples were collected at a distance of one meter from the river border. For each transect three quadrats (0.25 m × 0.25 m) were positioned three meters from each other. All macrophytes that occurred within the quadrat were collected, placed in labeled plastic bags, and transported to the laboratory for taxonomic identification. The macrophytes were individually separated and washed to remove material adhering to their surfaces. The samples were then dried in a greenhouse at 70 °C where they remained until a constant dry weight was observed. The samples were weighed in a digital semi-analytical scale.

The frequency of occurrence of each species was calculated based on Accioly (2012), comparing the number of samples in which the taxon occurred with the total number of samples. The species were classified into the following categories: very frequent: ≥ 85%; frequent: < 85% to ≥ 50%; infrequent: < 50% to ≥ 15%; and rare: < 15%.

Hydrological variables were analyzed throughout the collection period in order to evaluate the influence of abiotic factors on the macrophyte communities. Analyses were made in triplicate. The physical parameters analyzed were: transparency, using a Secchi disk; water temperature, using a field thermometer; and water turbidity, using a turbidimeter. Nutrient analyses were also performed. For these analyses water samples were collected in duplicate at each sampling site, stored in plastic containers, and placed in thermal boxes with ice during transportation to the laboratory where the analyses were performed. Analyses followed the methodology proposed by Valderrama (1981), and Strickland and Parsons (1965), and determined total phosphorus, orthophosphate, nitrate, nitrite, and ammonia concentrations.

The ecosystems were characterized using the Index of Trophic State (ITS) for tropical regions based on the total phosphorus concentrations observed in water samples (Cunha et al., 2013). The ITS can be rated as ultraoligotrophic (≤51.1), oligotrophic (51.2-53.1), mesotrophic (53.2-55.7), eutrophic (55.8-58.1), supereutrophic (58.2-59.0), and hypereutrophic (≥59.1).

The Mann-Whitney U test was used to evaluate possible differences between the variables of water quality and between urbanized and non-urbanized areas. The Kruskal-Wallis H test followed by a multiple comparison test was used for comparisons of the alpha diversity index between sites. These procedures were performed with STATISTICA 7.0 software (Statsoft Inc., 2004).

Similarity analyses (ANOSIM) were performed with the biomass data to evaluate the possible differences between urbanized and non-urbanized areas and between the dry and wet seasons, using the program PRIMER 6 (PRIMER-E Ltd., Plymouth Marine Laboratory, Plymouth, United Kingdom). Dissimilarity matrices by Euclidean distance were generated using all samples with untransformed data, and qualitative analyses were performed using the Sorensen coefficient. Data obtained from each sample quadrat were treated as replicates. The percent contributions of each species to the observed differences between areas and seasons were determined using similarity percentage analysis (SIMPER) (Clarke, 1993).

3. Results

We identified 31 species of macrophytes along the Capibaribe River, belonging to the divisions Monilophyta and Magnoliophyta. The Monilophyta were represented only by *Salvinia auriculata* and *Azolla filiculoides*, both belonging to the Salviniaceae. Among Magnoliophyta the most abundant families were Poaceae, with four species, followed by Amaranthaceae, Araceae, Asteraceae, Cyperaceae, Nymphaeaceae, Onagraceae, and Polygonaceae, each with two species. Families represented by only one species were Acanthaceae, Aizoaceae, Alismataceae, Araliaceae, Commelinaceae, Convolvulaceae, Gratiolaceae, Hydrocharitaceae, Hydroleaceae, Pontederiaceae, and Typhaceae (Table 1).

In general, macrophytes were observed at all sampling points during the study period. In Santa Cruz do Capibaribe, the urban area (Site 2) had a higher occurrence of species when compared to the non-urban area (Site 1) in the same municipality, with five (15.6% of all recorded species) and one (3.12%) species, respectively. In the non-urban area, the almost total absence of macrophytes was due to the absence of water and of any vegetation in the river bed in the dry season between the months of January and March 2013. In the metropolitan area we observed a similar number of species in the non-urban area (Site 5) in São Lourenço da Mata, with 11 species (34.4%), and in the urban area (Site 6) in the municipality of Recife, with 12 species (37.5%). In the sampling sites of Toritama, the non-urban area (Site 3) presented a higher number of species compared to the urban area (Site 4), with 17 and three species, respectively, representing 53.1% and 9.4% of the total.

With respect to the urbanization factor and the ecological index of alpha diversity, all sampling sites showed significant differences between urbanized and non-urbanized areas. This difference is due to the difference in diversity of macrophytes found in these sites, with no species in common between urban and non-urban areas in the municipalities of Santa Cruz do Capibaribe (Sites 1 and 2; $p < 0.00$) and Toritama (Sites 3 and 4; $p < 0.00$). Among the sampling sites in the metropolitan region of Recife (Sites 5 and 6), although there were eight species in common (Table 1) there was also a significant difference between the urban and non-urban area ($p < 0.035$).

With respect to frequency of occurrence, no species was classified as very frequent. *Ipomoea asarifolia, Eichhornia crassipes*, and *Paspalum* sp. 1 were categorized as frequent, with percentage of occurrences of 58.3%, 54.2%, and 50%, respectively. This low-level occurrence of common species can be explained by the wide range of environments found in the study area. About 48.4% of all species were classified as infrequent, with *S. auriculata* (37.5%) and *Pistia stratiotes* (33.3%) being the most remarkable. The other species exhibited a frequency of occurrence lower than 30% (Table 1).

Another factor that also influenced the frequency of occurrence of some species was seasonality. Some species classified as rare occurred only during the rainy season between the months of May and July, such as *Echinochloa polystachia* (8.3%), which grew on floating islands of *E. crassipes* at Sites 5 and 6; *Enydra radicans* (4.2%), *Nymphaea* sp. (8.3%), and *Stemodia maritima* (4.2%) at Site 3; and *Sesuvium portulacastrum* (4.2%) at Site 1. The macrophyte *Cyperus odoratus*, despite being considered infrequent (21.9%), was also recorded only during the rainy season at Site 4. Other species, however, were recorded in the dry season, including *Commelina obliqua* (9.4%) and *Limnocharis flava* (6.2%) at Site 6, and *Egeria densa* (9.4%) at Site 3. Some species classified as infrequent and frequent also occurred only in the dry season in some of the sampling sites. Among them were *E. crassipes* (53.1%) at Site 4, and *P. stratiotes* (31.2%) and *S. auriculata* (37.5%) at Site 6 (Table 1).

With respect to the Shannon-Wiener index there were no significant differences between the sampling sites (Table 2). However, multivariate analyses of similarity (ANOSIM) based on biomass data indicated significant overall differences between urban and non-urban areas ($R = 0.044$; $p < 0.001$). The largest contributions to these differences, according to SIMPER, were made by *E. crassipes* (51.23%), *Paspalum* sp. 1 (22.0%), and *Paspalum* sp. 2 (18.36%) (Table 1). With respect to seasonality, significant differences were also observed ($R = 0.018$; $p < 0.019$). The main species responsible for these differences were the same, with *E. crassipes* contributing 50.17%, *Paspalum* sp. 1 contributing 22.37%, and *Paspalum* sp. 2 contributing 19.73% (Table 1).

These data can be compared with the abiotic data analyzed, which in general also showed significant differences between non-urban and urban areas. These differences can be seen in nitrate, with concentrations that showed significant differences between the sampling sites of Santa Cruz do Capibaribe ($p < 0.0005$); in nitrite, with differences between the sites of the metropolitan region of Recife ($p < 0.005$) and Santa Cruz do Capibaribe ($p < 0.01$); and in ammonia in the metropolitan region of Recife ($p < 0.01$). Turbidity was also higher in urban areas, both in the dry and rainy seasons. Orthophosphate

Table 1. Summary of macrophytes species found in the Capibaribe River (PE) during the period from January to July 2013 with their families, life forms, Frequency of Occurrence, Similarity Analisis (ANOSIM) related to urbanization and seasonality (dry and wet periods) and occurrence of species by sampling sites.

Family	Species	F.O. (%)	ANOSIM Urb. (Contrib%)	ANOSIM Est. (Contrib%)	Sampling Sites: Santa Cruz do Capibaribe		Toritama		Metropolitan Region	
					N.Urb.	Urb.	N.Urb.	Urb.	N.Urb.	Urb.
Salviniaceae	*Azolla filiculoides* Lam.	16.67	0.00	0.00	-	-	x	-	-	-
	Salvinia auriculata Aubl.	37.50	0.08	0.07	-	-	x	-	x	x
Acanthaceae	*Dianthera comata* (L.) Lam	16.67	0.00	0.00	-	-	-	-	-	x
Aizoaceae	*Sesuvium portulacastrum* (L.) L.	4.17	0.00	0.00	x	-	-	-	-	-
Alismataceae	*Limnocharis flava* (L.) Buchenau	4.17	0.00	0.00	-	-	-	-	-	x
Amaranthaceae	*Blutaparon portulacoides* (A.St.-Hil.) Mears	16.67	0.51	0.55	-	x	-	-	-	-
	Alternanthera philoxeroides (Mart.) Griseb.	29.17	4.57	3.98	-	-	-	-	x	x
Araceae	*Lemna valdiviana* Phil.	29.17	0.00	0.00	-	x	x	-	x	x
	Pistia stratiotes L.	33.33	0.00	0.00	-	-	x	-	x	x
Araliaceae	*Hydrocotile ranunculoides* L.f.	33.33	0.00	0.00	-	-	-	-	x	x
Asteraceae	*Eclipta prostrata* (L.) L.	12.50	0.00	0.00	-	-	x	-	-	-
	Enydra radicans (Willd.) Lack	4.17	0.04	0.04	-	-	x	-	-	-
Commelinaceae	*Commelina obliqua* Vahl	12.50	0.00	0.00	-	-	-	-	-	x
Convolvulaceae	*Ipomoea asarifolia* (Desr.) Roem. & Schult.	58.33	0.00	0.00	-	-	x	-	-	-
Cyperaceae	*Cyperus articulatus* L.	16.67	0.00	0.00	-	-	x	-	-	-
	Cyperus odoratus L.	25.00	0.00	0.00	-	-	x	x	-	-
Plantagaceae	*Stemodia maritima* L.	4.17	0.00	0.00	-	-	x	-	-	-
Hydrocharitaceae	*Egeria densa* Planch.	8.33	0.00	0.00	-	-	x	-	-	-
Hydroleaceae	*Hydrolea spinosa* L.	4.17	0.00	0.00	-	-	-	-	-	x
Nymphaeaceae	*Nymphaea ampla* (Salisb.) DC.	16.67	1.88	1.90	-	-	x	-	-	-
	Nymphaea sp.	8.33	0.00	0.00	-	-	x	-	-	-
Onagraceae	*Ludwigia elegans* (Cambess.) H.Hara	4.17	0.00	0.00	-	-	x	-	x	-
	Ludwigia octovalvis (Jacq.) P.H.Raven	4.17	0.00	0.00	-	-	x	-	-	-
Poaceae	*Paspalum* sp.1	50.00	22.00	22.37	-	-	x	-	x	x
	Paspalum sp.2	16.67	18.36	19.63	-	x	-	-	-	-
	Paspalidium geminatum (Forssk.) Stapf	16.67	0.07	0.08	-	x	-	-	-	-
	Echinochloa polystachia (Kunth) Hitchc.	8.33	0.00	0.00	-	-	-	-	x	x
Polygonaceae	*Polygonum ferrugineum* Wedd.	16.67	1.15	1.11	-	-	-	-	x	-
	Polygonum acuminatum Kunth	16.67	0.09	0.10	-	-	-	-	x	-
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms	54.16	51.23	50.17	-	x	-	x	x	x
Typhaceae	*Typha domingensis* Pers.	12.50	0.00	0.00	-	-	x	x	-	-
Total species number per sampling site					1	5	17	3	11	12

FO = Frequency of Occurrence; N.Urb = non-urbanized site; Urb = Urbanized site; - = Absence; x = Presence.

concentration and total phosphorus presented no significant differences between non-urban and urban sites in each city studied (Figure 2).

Taking into consideration the Index of Trophic State (ITS) and the environmental health of the sampling sites, the high levels of nutrients observed demonstrate that all points studied were hypereutrophic. The lowest index (ITS = 60.977) occurred at Site 5 in São Lourenço da Mata (non-urban area of the metropolitan region of Recife), and the highest (ITS = 72.069) at Site 2 (urban area of Santa Cruz do Capibaribe) (Table 2).

The highest average biomass values were recorded in May 2013 (rainy season) for *E. crassipes* at Site 5, with 637.39 g DW/m^2. At Site 6 in January 2013 (dry season) the same species showed only 260.46 g DW/m^2 (Tables 3 and 4). These biomass values are directly related to the increase in nutrients, since in the non-urban areas there was a higher concentration of nutrients during the rainy season, and in

Table 2. Shannon-Wiener index, with their standard deviations, the quantitative data of macrophytes, average trophic state index and trophic state ranking of the studied areas in the Capibaribe River, Pernambuco, Brazil, during the period from January to July 2013.

Sampling Sites	Shannon-Wiener			ITS_{PT}	Classification ITS
Toritama (N.Urb.)	0.29	±	0.264412	68.409	Hipereutrophic
Toritama (Urb.)	0.00		0	70.078	Hipereutrophic
Santa Cruz do Capibaribe (N.Urb.)	0.00		0	67.925	Hipereutrophic
Santa Cruz do Capibaribe (Urb.)	0.15	±	0.281503	72.069	Hipereutrophic
Metropolitan Region (N.Urb.)	0.59	±	0.319083	60.977	Hipereutrophic
Metropolitan Region (Urb.)	0.58	±	0.185921	66.52	Hipereutrophic

Table 3. Average biomass values of macrophytes, with their standard deviations, occurring in the sampling site 6 (urban area of the Metropolitan Region of Recife, Pernambuco, Brazil), in the period between January and July 2013.

Species	Dry season						Rainy season					
	January 2013			March 2013			May 2013			July 2013		
	Biomass (g.DW/m^2)			Biomass (g.DW/m^2)			Biomass (g.DW/m^2)			Biomass (g.DW/m^2)		
Alternanthera philoxeroides	11.00	±	23.65	215.54	±	155.30	189.99	±	64.05	181.28	±	48.09
Eichhornia crassipes	260.46	±	133.65	0.00	±	0.00	0.00	±	0.00	0.00	±	0.00
Hydrocotile ranunculoide	2.36	±	5.40	0.00	±	0.00	0.00	±	0.00	0.00	±	0.00
Dianthera comata	0.00	±	0.00	3.47	±	6.98	0.00	±	0.00	1.37	±	0.74
Paspalum sp.1	145.35	±	137.03	344.87	±	180.93	325.32	±	145.50	247.20	±	29.62
Pistia stratiotes	3.18	±	9.37	0.00	±	0.00	0.00	±	0.00	0.00	±	0.00
Salvinia auriculata	0.04	±	0.11	0.00	±	0.00	0.00	±	0.00	0.00	±	0.00

Table 4. Average biomass values of macrophytes, with their standard deviations, occurring in the sampling site 5 (non-urban area of the Metropolitan Region of Recife, Pernambuco, Brazil), in the period between January and July 2013.

Species	Dry season						Rainy season					
	January 2013			March 2013			May 2013			July 2013		
	Biomass (g.DW/m^2)			Biomass (g.DW/m^2)			Biomass (g.DW/m^2)			Biomass (g.DW/m^2)		
Alternanthera philoxeroides	1.78	±	3.87	0	±	0	1.01	±	3.04	0	±	0
Eichhornia crassipes	333.9	±	415.29	310.8	±	360.55	637.39	±	415.89	526.99	±	592.16
Paspalum sp.1	241.97	±	160.76	250.79	±	160.18	137.5	±	112.35	161.15	±	154.48
Polygonum acuminatum	0	±	0	21.48	±	52.51	0	±	0	0	±	0
Polygonum ferrugineum	46.77	±	73.15	72.66	±	124.07	62.61	±	75.50	24.20	±	44.41
Salvinia auriculata	15.8	±	10.08	21.93	±	25.64	20.94	±	23.68	15.80	±	12.10

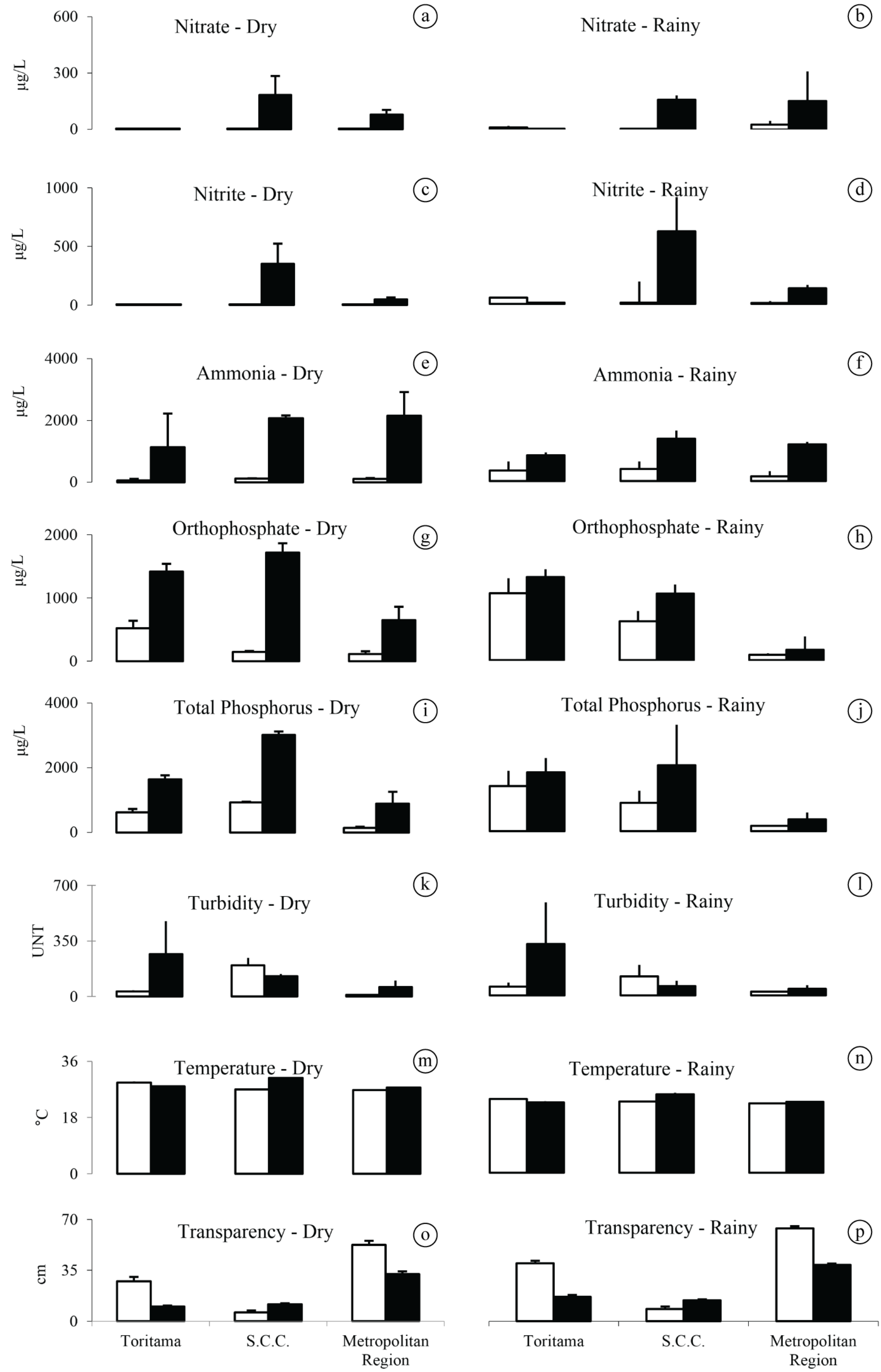

Figure 2. Mean physical-chemical data of sampling sites in the Capibaribe River relative to dry (January to March 2013) and rainy (May to July 2013) seasons. Urbanized sites (white bars) and non-urbanized sites (black bars).

the urbanized areas there was a higher concentration in the dry season (Figure 2).

The two species of the genus *Paspalum* also presented high biomass values. *Paspalum* sp. 1 achieved high average biomass in the non-urban sites of Toritama (Point 3) and the metropolitan region of Recife (Point 5), with 382.08 and 250.79 g DW/m², respectively (Tables 4 and 5), and *Paspalum* sp. 2 in the urban site of Santa Cruz do Capibaribe, with 559.70 g DW/m² (Table 6).

4. Discussion

In analyzing the differences between urban and non-urban areas near tributaries of the River St. John in Florida (USA), Chadwick et al. (2010) commented that urbanization can affect macrophyte species diversity in stream ecosystems at different spatial scales, and they stressed the importance of management. The representativeness of families occurring in a study area can also be impaired by urbanization. Poaceae had good representation in our study, as it did in the study of Carvalho et al. (2005), which evaluated the level of macrophyte infestation on the Tiete River and recorded five species (33.3% of the total), and also in the study of Henry-Silva et al. (2010), which identified five species (11.36% of the total) of this family in river ecosystems of the Brazilian semi-arid region.

With respect to the low diversity of macrophytes found in an intermittent stretch of the Capibaribe River, Ferreira et al. (1998) showed that rainfall irregularity exerts a great influence on the number of macrophytes. Pedro et al. (2006) analyzed the hydrological cycle and the dynamics of macrophytes in intermittent rivers of the semi-arid region of Paraíba (northeastern Brazil) and found that the occurrence of seasonality (dry and rainy season) is a determining factor that is related to the strength and resilience of these plants. Comparing the number of species in urban and non-urban areas of the Cuyahoga River (Ohio, USA), Balanson et al. (2005) observed that there was no apparent correlation between the nutrient content of the streams and the degree of impact

Table 5. Average biomass values of macrophytes, with their standard deviations, occurring in the sampling site 3 (urban area of the municipality of Toritama, Pernambuco, Brazil), in the period between January and July 2013.

Species	Dry season						Rainy season					
	January 2013			March 2013			May 2013			July 2013		
	Biomass (g.DW/m²)			Biomass (g.DW/m²)			Biomass (g.DW/m²)			Biomass (g.DW/m²)		
Nympheae ampla	92.60	±	209.14	85.12	±	35.83	34.68	±	42.16	25.55	±	45.62
Azolla filiculoides	0	±	0	0	±	0	0	±	0	0.04	±	0.07
Egeria densa	0	±	0	0.14	±	0.43	0	±	0	0	±	0
Lemna valdiviana	0	±	0	0.00	±	0	0	±	0	0.18	±	0.13
Paspalum sp.1	295.89	±	240.58	51.11	±	43.79	218.86	±	143.48	382.08	±	215.94
Pistia stratiotes	0.11	±	0.32	0.00	±	0	0	±	0	0	±	0
Salvinia auriculata	0	±	0	0.07	±	0.21	0.11	±	0.23	0.64	±	1.39

Table 6. Average biomass values of the weeds, with their standard deviations, occurring in the sampling site 2 (urban area of the municipality of Santa Cruz do Capibaribe, Pernambuco, Brazil), in the period between January and July 2013.

Species	Dry season						Rainy season					
	January 2013			March 2013			May 2013			July 2013		
	Biomass (g.DW/m²)			Biomass (g.DW/m²)			Biomass (g.DW/m²)			Biomass (g.DW/m²)		
Eichhornia crassipes	228.87	±	101.50	0.26	±	0.46	0	±	0	10.44	±	22.52
Blutaparon portulacoides	0	±	0	0	±	0	0	±	0	61.99	±	119.72
Enydra radicans	0	±	0	0	±	0	0	±	0	16.50	±	32.74
Ipomea sp.	0.84	±	2.51	0	±	0	0	±	0	0	±	0
Paspalidium geminatum	0	±	0	0	±	0	0	±	0	26.52	±	42.26
Paspalum sp.2	6.36	±	12.27	0.00	±	0.01	0	±	0	559.70	±	563.86

on macrophyte communities. Nevertheless, these authors observed a complete loss of macrophyte diversity in lower water quality sites.

The variation in the distribution and diversity of macrophytes seen in our study areas (Table 1) may be directly related to biotic factors such as herbivory, dispersal, and competition, and also to abiotic factors such as climatic conditions, water turbidity, and nutrient availability; the latter can stimulate opportunistic species growth through the eutrophication process (Thomaz, 2002; Bianchini-Junior, 2003).

According to the methods for assessing the quality of water bodies developed by UNESCO (1996), the most common form of combined nitrogen in natural ecosystems is nitrate, but under anaerobic conditions nitrate is reduced to nitrite. Nitrate and nitrite concentrations are generally quite low, not exceeding concentrations of 5 mg/L and 1 mg/L, respectively. However, excess concentrations of these ions are usually associated with domestic and industrial discharges; this explains the high concentrations found in this study, especially in the urban areas of the Capibaribe River. The high concentrations of ammonia found are related to large discharges of domestic and industrial effluents, especially in the dry season in urban areas (Brasil, 2012).

Analyzing the growth of *Eichhornia crassipes* in the middle Paraná River (Argentina), Fitzsimons and Vallejos (1986) found an average annual productivity of 108 to 164 g FW/m^2/d. Téllez et al. (2008) studied this species as an invasive macrophyte in the Guadiana River basin in Spain, and found that the growth rate of *E. crassipes* can be as high as 400-700 tons/ha/d. These authors comment that this high biomass productivity is associated with a great input of nutrients into aquatic ecosystems. This species is referred to in the literature as a weed, but it also has the ability to remove large amounts of nutrients (a bioremediation process; Patton and Starnes, 1970), which may explain the lower concentration of nutrients in non-urban areas of the metropolitan region of Recife. We therefore suggest the use of this macrophyte species, with periodical management, as a bioremediation tool in aquatic ecosystems of urbanized areas. The high productivity of species of the genus *Paspalum* was also verified by Conserva and Piedade (2001) and Meirelles et al. (2013). These authors identify these plants as potential forage species.

Lacoul and Freedman (2006) state that in lotic environments, in general, the macrophyte communities are better developed and have a higher supply of nutrients. However, when analyzing the biomass of sampling sites in the Toritama area (Sites 3 and 4) and in the metropolitan region of Recife (Sites 5 and 6), we found a greater biomass of macrophytes in the rainy season in non-urban areas (Tables 3, 4, and 5). In this context, Neiff (1990) has shown that there is a close relationship between water level and the productivity of herbaceous vegetation in rivers, demonstrating a strong biological response to the hydrodynamics of these ecosystems, where production rates can be three to 10 times higher in winter than in the rest of the year.

Urbanization influenced the structure of macrophyte communities along the Capibaribe River with respect to floristic composition and biomass. There was no homogeneity in the studied ecosystems due to the large physical, chemical, and biological differences between the urban and non-urban areas. Despite this lack of homogeneity, urbanization did have a consistently negative effect on aquatic species richness in the Capibaribe River areas studied.

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