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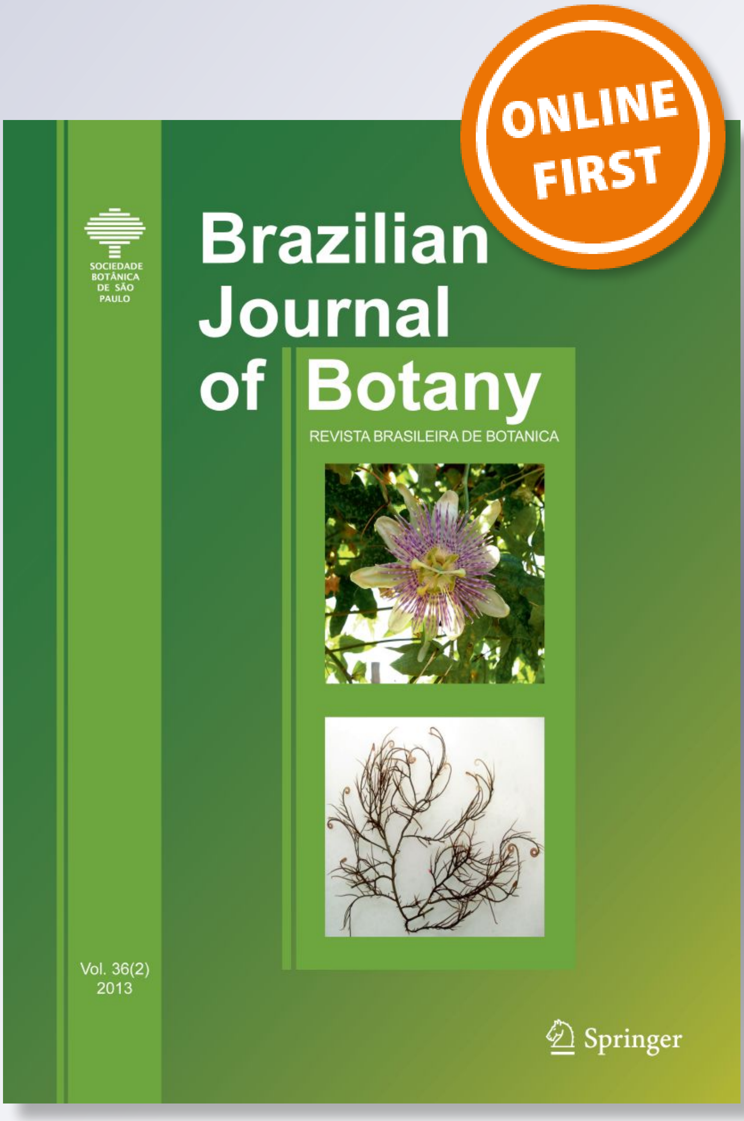

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ORIGINAL ARTICLE

Is there a zonation pattern in aquatic macrophytes communities in the aquatic environments of the Brazilian semiarid?

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Abstract

Communities of aquatic macrophytes are influenced by a series of biotic and abiotic factors that determine which species or life forms will colonize an aquatic environment. Different stretches may harbor a distinct macrophyte diversity within the same drainage basin in response to different local environmental conditions. Thus, we hypothesized a pattern of longitudinal zonation in macrophytes communities in the aquatic environments of the Brazilian semiarid. The study was carried out in the Apodi/Mossoró Hydrographic Basin, in the semiarid region of Rio Grande do Norte State in northeastern Brazil. Four sampling campaigns were carried out in quarterly intervals along 23 sampling sites distributed from the headwaters to the estuarine region. In each sampling station, the presence of macrophytes was recorded and water variables were measured; in addition, water samples were also collected for analyses and plant material was collected for identification. The macrophytes community as a whole did not show a well-established gradient, although some life forms could be related to specific patterns. Some species, such as *Ceratophyllum submersum* L., were restricted to environmental conditions of low nutrient levels and high water transparency, while others, such as *Ipomoea fistulosa* Choisy, were widely distributed. The zonation pattern of aquatic macrophytes was determined by different characteristics of the environment, which ranged from nutrient-rich waters to stretches with high salinity, evidencing the adaptations of each ecological group.

Keywords Hydrographic basin · Macrophyte life forms · Monitoring · Physical and chemical variables

1 Introduction

The relationships between aquatic macrophytes and the environment are well established; however, it is important to identify factors that determine their dynamics and spatial distribution (McElarney and Rippey 2009; Bornette and Puijalon 2011; Dar et al. 2014; Ferreira et al. 2015). The patterns of macrophytes occurrence may be related to environmental factors that determine the presence of different species. Thus, the floristic composition of aquatic plants in a hydrographic basin can be conditioned by abiotic characteristics and the physiological needs of each species (Sass et al. 2010; Ceschin et al. 2012; Chappuis et al. 2014). The general distribution patterns of these plants are mainly related to variables such as luminosity, nutrient availability, temperature, pH, alkalinity, salinity, speed of currents, water level variation, and landscape elements such as geomorphology and shading (Bini et al. 1999; Dawson and Szoszkiewicz 1999; Barendregt and Bio 2003; Daniel et al. 2006; Janauer et al. 2010; Grīnberga 2011; Azzella et al. 2014; Yin et al. 2016; Aoki et al. 2017). Biotic and abiotic variables act together on a population or an individual, and some characteristics function as environmental filters for the occurrence of macrophytes (Neiff and Neiff 2003; Schneider et al. 2015; Ferreira et al. 2015; Bando et al. 2015).

The organisms in the aquatic biota carry information accumulated over time; therefore, the richness and composition of aquatic macrophytes communities in different

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stretches of a hydrographic basin is a reflection of direct and indirect relationships to which these plants are and have been submitted (Testi et al. 2009). Thus, aquatic macrophytes communities can be indicators of conditions and pressures of aquatic environments because they: (1) occur in diverse habitats; (2) present a wide range of species and different life forms; (3) form sedentary populations that occur only in specific environments; (4) are organisms that react in varying ways to changes in their habitat (Chambers et al. 2008; Kočić et al. 2008; Penning et al. 2008; Linke et al. 2014; Bolpagni et al. 2016). Understanding how macrophytes react to certain environmental conditions allows their use as biological monitors of the health of a water system. This type of information is increasingly relevant, as demonstrated by the increasing number of ecological quality indexes based on aquatic macrophytes (Bolpagni 2013).

Aquatic plants tend to respond to local environmental conditions (of the river stretch, lake, or basin) faster than other groups of organisms such as fish and insects, a response which determines the presence or absence of certain species and life forms (Manolaki and Papastergiadou 2013; Wasof et al. 2013). It has been demonstrated that local factors such as the environment's physical structure and variability in chemical water variables affect these plants more than other large-scale factors such as climate (Kosten et al. 2012; Alahuhta et al. 2015). The submerged and floating species are more susceptible to environmental factors in the aquatic environment because they are directly in contact with the water, while emergent and amphibian species still have a great dependence on the terrestrial ecosystem (Alahuhta et al. 2013).

In semiarid regions, there are multiple stressors affecting the distribution and richness patterns of aquatic plants, often related to water scarcity, such as nutrient enrichment, eutrophication, and turbidity (Laguna et al. 2016). These conditions are especially determinant for some life forms as the submerged, which usually have low occurrence in these regions (Gómez et al. 2016). Therefore, we hypothesized that a pattern of longitudinal zonation of aquatic macrophytes exists in relation to environmental filters in the aquatic environments of the Brazilian semiarid.

2 Materials and methods

The study area was the Apodi/Mossoró Hydrographic Basin, located in the semiarid region of the State of Rio Grande do Norte in Brazil (Fig. 1). The basin covers 52 municipalities with a total area of 14,276 km^2 and 210 km of extension, which makes it the second largest hydrographic basin in the state. It shows semiarid edaphoclimatic conditions, and the predominant climate type is classified as BSw‘h’ according to the Köppen classification, which characterizes hot and semiarid climates.

Four sampling campaigns were carried out in quarterly intervals along 23 sampling sites distributed from the headwaters to the estuarine region (between the coordinates 38.58093° S/6.51324°W and 37.04344°S/4.88905°W). The basin was divided into sections for comparison among sampling sites: Upper Course from stations one to six; Meadow Course from seven to 11; Lower Course from 12 to 21; and estuarine region from stations 22 to 23. The courses and the number of sampling stations on each course were delimited accordingly to the geomorphological characteristics of the basin as described by Rocha et al. (2009). The following variables were measured *in loco*: pH, dissolved oxygen (DO, $mg\ L^{-1}$), electrical conductivity (EC, $mS\ cm^{-1}$), and total dissolved solids (TDS, $mg\ L^{-1}$). Water samples were collected and stored for analyses of inorganic phosphate ($mg\ L^{-1}$) (Golterman et al. 1978); nitrate ($N–NO_3$, $mg\ L^{-1}$) (Mackereth et al. 1978); nitrite ($N–NO_2$, $mg\ L^{-1}$) (Mackereth et al. 1978); ammoniacal nitrogen (N–Ammonia, $mg\ L^{-1}$) (APHA 2005); and biochemical oxygen demand (BOD, $mg\ L^{-1}$) (APHA 2005).

The sample sites were selected along the river basin, comprehending from preserved headwater streams with low anthropic interference to stretches in the major urban centers across the river, submitted to pollution and other human impacts. At every station, we walked for about 30 min along the shores of the aquatic environments and observed the presence of aquatic macrophytes. Plant material was collected at the margin of each sampling location manually, entering the river when necessary. After collection, the specimens were preserved in herbarium sheets for identification. The presence of aquatic macrophytes species was evaluated by observation at all sampling sites, and all locations were georeferenced with a GPS device (Garmin, eTrex Vista®). Species were identified through taxonomical analytical keys and specialized literature (Hoehne 1979; Velásquez 1994; Pott and Pott 2000); the macrophytes were classified in life forms (Sculthorpe 1985; Esteves 2011), and then the material was stored in the Dárdano de Andrade Lima Herbarium (MOSS) of the Universidade Federal Rural do Semi-Árido (Mossoró-RN). The principal component analysis (PCA) was applied to the values of physical and chemical variables based on the correlation matrix. The Sörensen Similarity Index was calculated on the biological data (presence of macrophytes), and subsequently, the Cluster Analysis (Unweighted Pair-Group Average method—UPGA) was used to group sampling sites based on their floristic composition. All data analyses were conducted in the R v.3.3.1 software (R Core Team 2016).

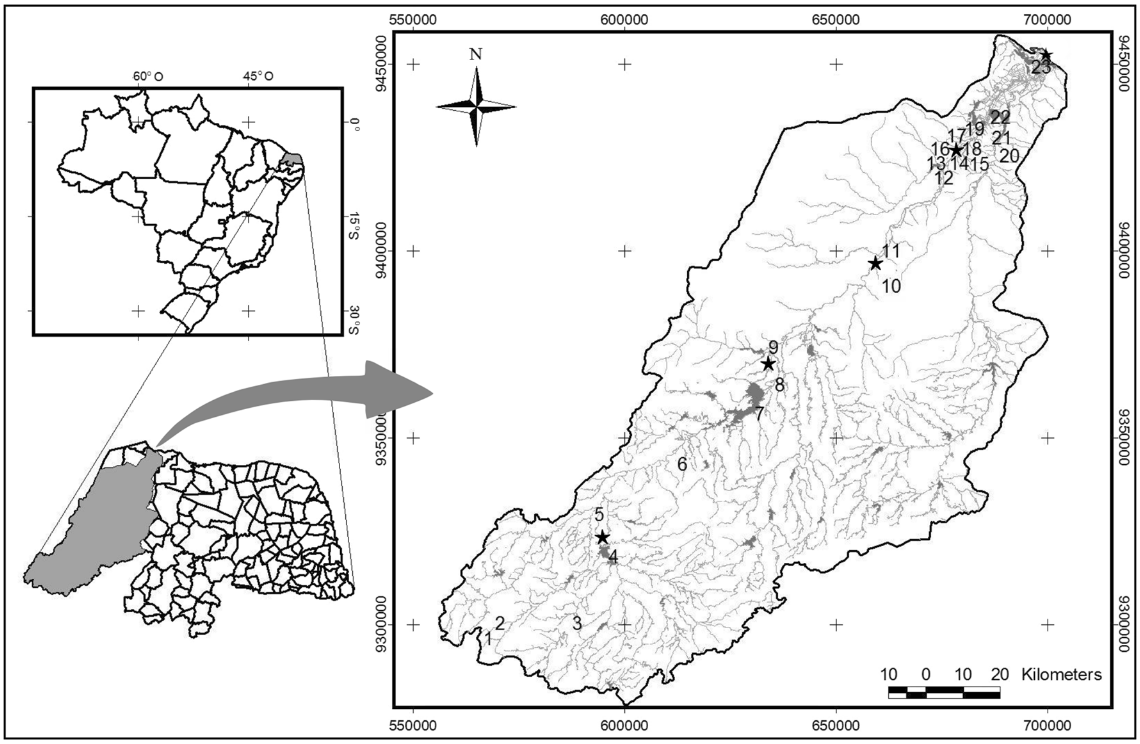

Fig. 1 Location of Apodi/Mossoró hydrographic basin in Rio Grande do Norte, Brazil. Black stars mark the largest urban centers along the main river

3 Results

The PCA explained 62% of the total variation in the data in its first two principal components. Correlations with $r \geq |0.5|$ were considered strong. Therefore, the first principal component was negatively related to the levels of phosphate, N–NO$_2$, and N–ammonia, while the second component was negatively related to electrical conductivity and dissolved total solids (Table 1). The diagram with the

Table 1 Pearson correlation values of the analyzed variables with the first two axes of the PCA

Variables	Axis 1	Axis 2
EC	0.14	*− 0.65*
TDS	0.13	*− 0.65*
pH	0.14	− 0.14
Phosphate	*− 0.51*	− 0.05
N–Nitrate	− 0.26	− 0.32
N–Nitrite	*− 0.47*	− 0.06
N–Ammonia	*− 0.47*	− 0.09
DO	0.17	0.04
BOD	− 0.38	− 0.03
% Explanation	39	23

Correlations with $r \geq |0.5|$ are considered strong, which are shown in italics

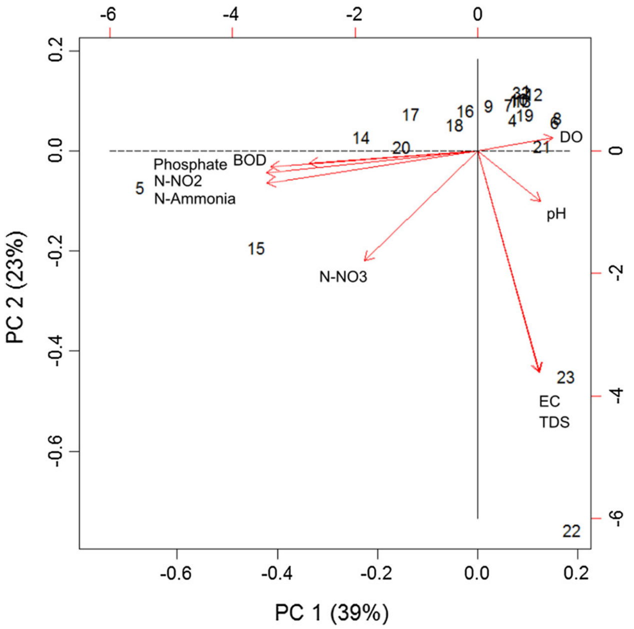

Fig. 2 Principal component analysis of the sampling sites in the Apodi/Mossoró Hydrographic basin with mean values for the months of August/2007, November/2007, February/2008, and May/2008. *EC* electrical conductivity, *TDS* total dissolved solids, *DO* dissolved oxygen, *BOD* biochemical oxygen demand, *PC* principal component. Red arrows indicate the direction in which variables increase in value. (Color figure online)

Table 2 Values for the environmental variables evaluated

SS	EC	TDS	pH	Phosp.	N–Nitrate	N–Nitrite	N–Amm.	DO	BOD
1	187.00	397.00	6.91	0.88	4.86	0.09	0.05	7.50	0.57
2	205.58 (52.39)	197.75 (68.77)	7.03 (1.04)	0.31 (0.13)	4.74 (1.95)	0.03 (0.02)	0.02 (0.02)	5.75 (1.98)	4.74 (2.31)
3	687.50 (396.88)	516.00 (285.91)	6.86 (0.34)	0.23 (0.12)	4.73 (1.16)	0.01 (0.01)	0.03 (0.02)	4.65 (0.71)	5.78 (5.36)
4	422.25 (140.74)	323.75 (142.53)	8.02 (0.60)	0.37 (0.23)	5.17 (1.92)	0.04 (0.06)	0.04 (0.04)	7.22 (2.35)	10.48 (9.97)
5	1008.00 (510.81)	654.25 (332.14)	7.48 (0.40)	6.38 (5.96)	8.10 (3.56)	0.41 (0.5)	1.36 (1.70)	6.74 (5.63)	23.61 (21.61)
6	570.00 (459.24)	479.67 (299.68)	8.29 (1.02)	0.44 (0.28)	5.47 (1.05)	0.06 (0.05)	0.03 (0.02)	8.18 (3.75)	2.48 (1.88)
7	270.75 (48.09)	103.00 (95.40)	7.76 (1.15)	0.30 (0.26)	3.11 (1.40)	0.03 (0.03)	0.01 (0.01)	6.78 (1.22)	12.36 (14.04)
8	275.33 (47.06)	235.25 (148.43)	8.50 (0.75)	0.37 (0.3)	3.68 (1.49)	0.03 (0.02)	0.01 (0.01)	9.29 (2.50)	6.44 (5.28)
9	581.50 (308.72)	273.00 (117.97)	7.22 (0.26)	0.62 (0.07)	4.48 (0.88)	0.10 (0.14)	0.01 (0.02)	1.74 (1.43)	6.04 (4.33)
10	531.25 (177.90)	323.25 (107.06)	7.35 (0.24)	0.39 (0.25)	3.76 (1.63)	0.04 (0.03)	0.02 (0.02)	5.07 (1.51)	6.58 (6.55)
11	544.25 (190.48)	356.50 (139.77)	7.48 (0.45)	0.41 (0.38)	3.27 (1.10)	0.03 (0.03)	0.01 (0.02)	5.40 (0.59)	7.87 (7.43)
12	848.75 (493.14)	812.75 (616.08)	7.28 (1.59)	0.37 (0.29)	2.87 (1.63)	0.02 (0.03)	0.02 (0.03)	7.28 (1.86)	6.12 (5.19)
13	995.50 (650.26)	849.25 (624.47)	7.30 (0.41)	0.41 (0.21)	3.69 (1.32)	0.03 (0.02)	0.03 (0.04)	6.24 (1.56)	6.79 (5.90)
14	1395.50 (892.79)	781.25 (480.84)	7.34 (0.47)	3.47 (1.78)	5.18 (1.09)	0.35 (0.64)	0.34 (0.37)	3.69 (1.56)	8.03 (8.73)
15	1884.25 (1048.43)	1083.50 (598.18)	7.12 (0.14)	4.53 (2.56)	33.80 (21.11)	0.36 (0.21)	0.37 (0.46)	1.55 (1.67)	9.43 (7.13)
16	1291.00 (872.82)	1014.75 (847.72)	7.08 (0.10)	3.12 (4.61)	4.51 (0.53)	0.02 (0.02)	0.10 (0.07)	1.78 (2.60)	3.57 (4.03)
17	1200.50 (788.53)	528.33 (192.11)	6.89 (1.14)	2.35 (1.12)	4.37 (1.29)	0.09 (0.13)	0.38 (0.49)	3.08 (3.24)	9.84 (7.43)
18	1198.75 (792.90)	733.50 (496.45)	7.73 (1.02)	1.80 (1.66)	4.97 (1.24)	0.23 (0.19)	0.10 (0.08)	10.32 (5.20)	10.54 (8.35)
19	1242.00 (800.44)	865.50 (333.20)	8.03 (0.72)	1.25 (1.25)	3.63 (1.36)	0.02 (0.03)	0.03 (0.02)	10.66 (6.59)	9.48 (7.00)
20	1407.00 (888.66)	581.25 (538.77)	8.09 (0.81)	3.69 (3.65)	6.07 (3.73)	0.36 (0.38)	0.17 (0.18)	7.73 (1.47)	7.04 (8.22)
21	3512.00 (5793.04)	2551.75 (2584.53)	8.26 (0.72)	0.43 (0.31)	6.81 (3.46)	0.04 (0.03)	0.06 (0.05)	7.45 (1.82)	5.08 (3.71)
22	66,613.25 (44,566.42)	47,371.25 (31,886.69)	7.83 (0.48)	0.36 (0.35)	11.25 (8.77)	0.03 (0.05)	0.12 (0.19)	5.63 (1.51)	5.71 (5.76)
23	52,845.75 (34,918.27)	23,986.50 (26,272.05)	7.87 (0.58)	0.43 (0.34)	8.90 (5.74)	0.03 (0.04)	0.01 (0.02)	7.10 (1.29)	6.48 (6.41)

Values in parentheses are the standard deviations. For sampling station 1, there was only water in one of the sampling expeditions, thus having no standard deviation

EC, electrical conductivity (mS cm^{-1}); TDS, total dissolved solids (mg L^{-1}); pH; Phosp., phosphate (mg L^{-1}); N–Nitrate (mg L^{-1}), N–Nitrite (mg L^{-1}); N–Amm., ammoniacal nitrogen (mg L^{-1}); DO, dissolved oxygen (mg L^{-1}); BOD, biochemical oxygen demand (mg L^{-1}); and SS, sampling stations first two main components allowed ordering the sites (Fig. 2).

The means for all environmental factors are presented in Table 2. The stations 5, 14, 15, 17 and 20 were characterized by high values of phosphate, N–NO_2, N–ammonia and BOD, with stations 5 and 15 showing the highest values among all stations. The majority of the sample sites were located near the zero coordinates of the PCA, comprehending sites in the Upper, Meadow, and Lower Courses of the hydrographic basin; those were generally characterized by relatively low values of all analyzed limnological variables except for DO, for which they showed the highest values. The last two sampling stations in the basin are close to the estuarine region (22 and 23) and presented high values of TDS and EC.

The cluster analysis grouped the sampling sites according to their floristic similarity (Fig. 3). The dendrogram analysis defined five distinct groups, selected using the linkage distance of 0.65, with stations one, two, and six grouped together to facilitate discussion. Group I was formed by sites one, two, and six, Group II by sites three, four, eight, 11, and 12, Group III by a variety of sites in the Meadow and Lower Courses of the hydrographic basin, Group IV only by sites in the Lower Course, and Group V by sites 22 and 23, close to the estuarine region. Group I predominantly contained emergent aquatic macrophytes and generally showed low average values of N–NO_2 (from 0.03 to 0.09 mg L^{-1}), N–ammonia (from 0.02 to 0.05 mg L^{-1}), and phosphate (from 0.3 to 0.9 mg L^{-1}). The aquatic plants observed in each group are shown in Table 3.

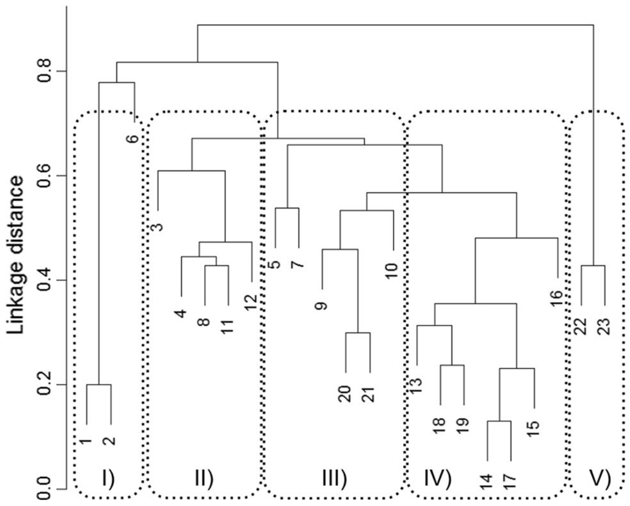

Fig. 3 Dendrogram from the cluster analysis of the floristic similarity between sampling sites in the Apodi/Mossoró River using the Sörensen Index and grouping by the unweighted pair-group average method. The cophenetic coefficient was 0.57

Group II showed species with a restricted distribution that do not occur in other regions of the hydrographic basin such as the submerged *Egeria densa* Planch., *Chara indica* Bertero ex Spreng., *Ceratophyllum submersum* L., and *Hydrotrix gardneri* Hook.f. These sampling sites have similar values for reduced values of nutrients, total dissolved solids, electrical conductivity, and biochemical oxygen demand. The similarity between sites within group III was due to the presence of emergent and amphibian species. The sites in this group include stretches with reduced nutrient concentrations in the Upper and Meadow Courses of the basin. The greatest richness of aquatic macrophytes was recorded in this group with representatives of all the life forms considered.

Free floating species were the most frequent life form in group IV, the emergent and amphibian forms occurred with fewer species, while submerged and rooted with floating leaves species were not found in this group. The sites in this group are characterized by high nutrient values, especially nitrite, phosphate, and ammoniacal nitrogen as well as high BOD values. Group V, formed by sites 22 and 23, showed the least similarity between sampling sites, a fact that can be explained by the occurrence of only four species: *Sesuvium portulacastrum* (L.) L. and *Blutaparon portulacoides* (A. St.-Hil.) Mears occurred in both stations, *Alternanthera philoxeroides* (Mart.) Griseb. occurred only in site 22, and *Ruppia maritima* L. only in site 23. The electrical conductivity values were high in this group mainly due to the proximity of these sites to the estuary in the hydrographic basin.

4 Discussion

We did not observe a zonation pattern in the aquatic plants community of the Apodi/Mossoró river basin, but some life forms or species did show a gradient of occurrence, thus partially confirming our hypothesis. Occurrence patterns differed depending on the species and a life form of collected macrophytes. The identified patterns were from generalist species to groups of aquatic plants with restricted occurrence. However, no distribution pattern was observed in the group of emergent plants. The presence of individuals from this life form was not related to any of the environmental factors considered. This was probably because these plants use nutrients from the sediment (Thomaz and Esteves 2011). The emergent species found in this study showed few habitat restrictions, occurring in a wide distribution pattern from the headwaters to the estuarine region, corroborating the high frequency of occurrence reported in the literature (Mackay et al. 2010). Emergent species such as *Stemodia maritima* L. and *Ipomoea fistulosa* (Mart. ex Choisy) D. F. Austin were found

Table 3 Species of aquatic macrophytes found in sampling sites in the Apodi/Mossoró hydrographic basin

Group I (1, 2, 6)	Group II (3, 4, 8, 11, 12)	Group III (5, 7, 9, 10, 20, 21)	Group IV (13, 14, 15, 16, 17, 18, 19)	Group V (22, 23)
Ceratophyllum submersum L. (6)	*Alternanthera philoxeroides* (Mart.) Griseb. (11)	*Alternanthera philoxeroides* (Mart.) Griseb. (5, 9, 10, 20, 21)	*Alternanthera philoxeroides* (Mart.) Griseb. (13, 15, 16, 18, 19)	*Alternanthera philoxeroides* (Mart.) Griseb. (22)
Cyperus esculentus L. (2)	*Blutaparon portulacoides* (A. St.-Hil.) Mears (12)	*Alternanthera philoxeroides* (Mart.) Griseb. (7)	*Blutaparon portulacoides* (A. St.-Hil.) Mears (13, 14, 15, 17, 18, 19)	*Blutaparon portulacoides* (A. St.-Hil.) Mears (22, 23)
Cyperus gardneri Nees (1, 2)	*Borreria alata* (Aubl.) DC. (3)	*Blutaparon portulacoides* (A. St.-Hil.) Mears (21)	*Chloris barbata* Sw. (14, 15, 16, 17, 18)	*Ruppia maritima* L. (23)
Echinodorus grandiflorus (Cham. & Schltdl.) Micheli (1, 2, 6)	*Cenchrus echinatus* L. (3)	*Ceratophyllum submersum* L. (7)	*Cyperus esculentus* L. (15)	*Sesuvium portulacastrum* (L.) L. (22, 23)
Eleocharis geniculata (L.) Roem. & Schult. (1)	*Ceratophyllum submersum* L. (8)	*Ceratophyllum demersum* L. (7)	*Cyperus ligularis* L. (15)	
Hydrolea spinosa L. (1, 2)	*Ceratophyllum demersum* L. (8)	*Chara indica* Bertero ex Spengel (7)	*Echinochloa polystachya* (Kunth) Roberty (14, 15, 17)	
Hydrotrix gardneri Hook f. (6)	*Chloris barbata* Sw. (8)	*Chloris barbata* Sw. (21)	*Eclipta alba* (L.) Hassk. (13)	
Ipomoea fistulosa Mart. ex Choisy (6)	*Cyperus esculentus* L. (3)	*Cyperus esculentus* L. (9, 21)	*Eichhornia crassipes* (Mart.) Solms (13, 14, 15, 16, 17, 18, 19)	
Ludwigia helminthorrhiza (Mart.) H. Hara (6)	*Cyperus esculentus* L. (4, 8, 11, 12)	*Cyperus gardneri* Nees (10)	*Eleocharis geniculata* (L.) Roem. & Schult. (17)	
Stemodia maritima L. (1, 2)	*Cyperus gardneri* Nees (3)	*Egeria densa* Planch. (7)	*Heteranthera seubertiana* Solms (13)	
	Cyperus ligularis L. (8, 12)	*Eichhornia crassipes* (Mart.) Solms (5)	*Ipomoea fistulosa* Mart. ex Choisy (13, 14, 17, 19)	
	Cyperus surinamensis Rottb. (3)	*Eleocharis acutangula* (Roxb.) Schult. (9, 10, 21)	*Lemna valdiviana* Phil. (14, 15, 17)	
	Echinodorus grandiflorus (Cham. & Schltdl.) Micheli (3)	*Eleocharis geniculata* (L.) Roem. & Schult. (20, 21)	*Ludwigia helminthorrhiza* (Mart.) H. Hara (18, 19)	
	Echinodorus grandiflorus (Cham. & Schltdl.) Micheli (4)	*Heteranthera seubertiana* Solms (10)	*Ludwigia peploides* (Kunth) P.H. Raven (13, 14, 15, 16, 17, 18)	
	Eclipta alba (L.) Hassk. (3)	*Hydrotrix gardneri* Hook.f (7)	*Paspalidium paludivagum* (Hitchc. & Chase) Parodi (18)	
	Eclipta alba (L.) Hassk. (4, 8)	*Ipomoea fistulosa* Mart. ex Choisy (5, 9, 10, 20, 21)	*Paspalum vaginatum* Sw. (13, 14, 15, 17, 18, 19)	
	Eichhornia crassipes (Mart.) Solms (12)	*Ipomoea fistulosa* Mart. ex Choisy (7)	*Pistia stratiotes* L. (13, 14, 15, 16, 17, 18, 19)	
	Eleocharis acutangula (Roxb.) Schult. (3)	*Lemna valdiviana* Phil. (5)	*Ruellia paniculata* L. (17, 18)	
	Eleocharis acutangula (Roxb.) Schult. (4, 12)	*Ludwigia helminthorrhiza* (Mart.) H. Hara (5, 9)	*Salvinia auriculata* Aubl. (17, 18, 19)	
	Eleocharis geniculata (L.) Roem. & Schult. (4, 8, 11, 12)	*Ludwigia peploides* (Kunth) P.H. Raven (10)	*Stemodia maritima* L. (13, 14, 15, 17, 18, 19)	

Table 3 continued

Group I (1, 2, 6)	Group II (3, 4, 8, 11, 12)	Group III (5, 7, 9, 10, 20, 21)	Group IV (13, 14, 15, 16, 17, 18, 19)	Group V (22, 23)
	Eleocharis interstincta (Vahl) Roem. & Schult. (3)	*Neptunia plena* (L.) Benth. (9, 20, 21)		
	Heteranthera seubertiana Solms (3)	*Paspalidium paludivagum* (Hitchc. & Chase) Parodi (5, 9, 21)		
	Heteranthera seubertiana Solms (4, 11, 12)	*Paspalum vaginatum* Sw. (20, 21)		
	Hydrocleys parviflora Seub. (3)	*Pistia stratiotes* L. (9, 10, 20)		
	Hydrotrix gardneri Hook.f (8, 11, 12)	*Salvinia auriculata* Aubl. (9)		
	Ipomoea fistulosa Mart. ex Choisy (3)	*Sesuvium portulacastrum* (L.) L. (20, 21)		
	Ipomoea fistulosa Mart. ex Choisy (4, 8, 11, 12)	*Stemodia maritima* L. (5, 9, 10, 20, 21)		
	Lemna valdiviana Phil. (4)	*Wolffia brasiliensis* Weddell (9)		
	Limnocharis flava (L.) Buchenau (4)			
	Ludwigia helminthorrhiza (Mart.) H. Hara (4, 8, 11)			
	Ludwigia peploides (Kunth) P.H. Raven (12)			
	Nymphaea alba L. (3)			
	Nymphaea alba L. (4)			
	Paspalidium paludivagum (Hitchc. & Chase) Parodi (12)			
	Salvinia auriculata Aubl. (4, 8, 12)			
	Stemodia marítima L. (3)			
	Stemodia maritima L. (4, 8, 11, 12)			
	Stylosanthes guianensis (Aubl.) Sw. (3)			

in environments with oligotrophic characteristics and places impacted by organic pollution, demonstrating that these plants can meet their nutritional needs in a wide range of environmental conditions. Thus, this life form seems to be more affected by terrestrial ecosystem conditions than by the characteristics of the aquatic environment, showing no relationship with the abiotic characteristics of the aquatic ecosystems in the basin.

Submerged aquatic plants are more sensible to the environmental conditions in the aquatic environment than other life forms such as free floating, emergent and rooted with floating leaves. This sensitivity restricts the occurrence of these macrophytes to those sites that meet their luminosity and nutrient requirements. The distribution of species of this life form was related to aquatic environments with low nitrate concentrations (Rosso and Fernández Cirelli 2013) in addition with conditions of low organic pollution and reduced eutrophication (Kolada 2010). In fact, submerged macrophytes may not only be indicative of environments with lower nutrient concentrations but might also act as an active mechanism in maintaining these low concentrations and high transparency (van Donk and van de Bund 2002; Jackson 2003). We observed that the occurrence of these macrophytes was correlated with sites with oligotrophic characteristics such as high water transparency and low concentrations of nutrients.

Although free floating macrophytes usually occur in eutrophic environments (Bini et al. 1999; Jampeetong and Brix 2009; Sass et al. 2010; Manolaki and Papastergiadou 2013), our results did not show this pattern. In the Apodi–Mossoró river basin, free floating species such as *P. stratiotes* and *E. crassipes* were observed both in sites with high concentrations of nutrients and in places with low concentrations. Probably, the presence of these species in places with few nutrients is due to the high temperatures and solar radiation of the semiarid region and in places with moderate current velocity. In fact, tropical environments with moderate current favor the reproduction and growth of free floating macrophytes, often leading to infestations (Henry-Silva et al. 2008). The presence of floating species in sites with high and low nutrient concentrations in the basin is responsible for the absence of a macrophyte distribution gradient.

Places with high concentrations of nutrients showed a higher richness of aquatic macrophytes than river stretches with oligotrophic conditions. This direct relationship between nutrients and total species richness is well established (Wersal and Madsen 2011); however, the richness pattern observed in this study shows that the number of species is low in the headwaters, increases in the lower course of the basin, and decreases with proximity to the estuarine region. The low nutrient load in the Upper Course and estuarine region, together with increased shading and current speed, probably imposes physical and nutritional barriers to the development of the aquatic macrophytes communities. With the increased order in the main river and consequent tendency of nutrient concentration in the water, the community of macrophytes develops and shows increased richness. This trend of increasing richness with increasing nutrient concentration has already been experimentally observed; it is noteworthy that the phosphate and nitrate levels are two of the most important factors in this trend (Chappuis et al. 2014; Schneider et al. 2015). Thus, the high nutrient load in the Meadow and Lower Courses of the basin supports a rich community of macrophytes as observed by Neiff et al. (2014) in the Paraná River Basin. Conversely, the abiotic conditions in the estuarine region, especially those with high salinity values, determine the exclusion of many species, which cease to occur at these sites.

Most aquatic macrophytes show an inhibition in their development in regions with moderate or high salinity because the population displays reduced growth and survival, while resistant species can continue to grow even in oceanic saline conditions (Munns and Tester 2008). Our results corroborate this pattern because a decrease in species' richness was observed in the environments closer to the estuarine region, reaching a total absence of aquatic macrophytes in the estuary. As demonstrated by Nunes and Camargo (2016), when approaching the estuarine region the abiotic stress (nutrients concentrations and salinity) alongside with competition for resources with other species is the main factor causing species exclusion. Thus, the low nutrient levels and high salinity of the stations 22 and 23 may be the main factor causing the species' richness reduction.

In this study, four major patterns were identified in aquatic macrophytes species. Some species, such as the submerged *C. demersum* and *E. densa*, showed occurrence restricted to environments with the lowest nutrient concentrations and high transparency. Conversely, free floating species such as *E. crassipes* and *P. stratiotes* were common in environments both with high levels of nutrients and with low levels. Other species, such as *I. fistulosa* and *S. maritima*, showed wide distribution and were found in the Upper, Meadow, and Lower Courses of the basin, showing high adaptability to various environmental conditions and low habitat restriction. These findings corroborate with the "Individualistic Concept of the Plant Association" (Gleason 1926), which states that the distribution of plants in space depends upon its individual characteristics of dispersion behavior and environmental requirements. Finally, species with tolerance to high salt concentrations, such as *R. maritima* and *S. portulacastrum*, showed occurrence restricted to the estuary region where the other aquatic macrophytes do not occur.

We can conclude that there are patterns of occurrence for some species and life forms of aquatic macrophytes in aquatic environments in the semiarid, even though the community as whole do not showed a distribution pattern. The patterns of species distribution and richness gradients along the river longitudinal dimension found in this study corroborate the findings in the literature for other climates and other regions. These patterns tend to occur in a range of climates, and changes in the assemblages occur accordingly with climate changes with more or less intensity for each species/life form (Hossain et al. 2016). Thus, the distribution of certain species and life form within their climate range of occurrence probably are more determined by local environmental factors regarding the aquatic ecosystem and the watershed, being not strictly climate related.

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