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INVENTORY OF AQUATIC MACROPHYTE SPECIES IN COASTAL RIVERS OF THE SÃO PAULO STATE, BRAZIL

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Abstract: The coastal region of the São Paulo state (Southeastern Brazil) is marked by the presence of the Serra do Mar, a system of mountain ranges with altitude up to 1,000 m. Due to the difference of proximity of the mountain range to the coastline, the coastal plains have different width. As a consequence, the rivers that cross the plains also have different length, greater or less influence of marine waters and slope variation. We carried on an inventory of aquatic macrophyte species in order to assess the species and life form richness and latitudinal distribution in this region. Macrophytes were inventoried at 100 sampling sites in eight rivers (between 9 and 19 sites per river) in March 2017. General descriptions on taxonomic aspects, life forms and frequency of occurrence of the macrophytes were explored. We recorded 45 taxa of aquatic macrophytes belonging to 24 families. Three species are exotic, but they presented low frequencies of occurrence. The vast majority of the taxa have emergent life form. Floating and submerged macrophytes were found in only two rivers. The most frequent species were *Crinum americanum* L. (Asparagales, Amaryllidaceae), *Spartina alterniflora* Loisel. (Poales, Poaceae) and *Schoenoplectus californicus* (C. A. Mey.) Soják (Poales, Cyperaceae). Most taxa are rare in terms of occurrence. Only four species occurred along a large part of the north-south stretch sampled and these, possibly, have a wide tolerance to the variation in resource requirements and salinity. The north-south gradient of the taxa occurrence may be related to the diversity of environmental characteristics due to differences in the rivers length and coastal plains width.

Keywords: aquatic plants; coastal river basin; estuary; life forms.

INTRODUCTION

Coastal ecosystems, especially the estuarine zones, have great ecological importance for many marine and freshwater species due to the presence of mangroves in most of the Brazilian coast (Pinheiro *et al.* 2008, Pinto-Coelho & Havens 2015). Currently, these ecosystems are among the most impacted environments due to the urban occupation and varied human activities (Pinheiro *et al.* 2008, Pinto-Coelho & Havens 2015). The estuaries are also vulnerable ecosystems to the influence of climate change, mainly by the increasing in sea-level rise and saltwater intrusion and alteration in the amount of freshwater (Scavia *et al.* 2002).

Coastal rivers are marked by the influence of salinity and water level variation due to the tidal regime (Wolanski 2007). In these ecosystems, there are environmental gradients that promote distribution patterns and provide different habitats for the occupation of aquatic vegetation (Bertness 1991). Aquatic macrophyte distribution in estuaries forms a longitudinal gradient in the coastal rivers (from river mouth to headwater), with species adapted to salinity and water level variation in the low river zone and species adapted to oligohaline and freshwater conditions in the upper river zone (Ribeiro *et al.* 2011, Nunes & Camargo 2018). However, salinity may have an influence on plants through the salt spray (Boyce 1954), and thus, even plants occurring in the upper and farther areas from the coastline may be exposed to salt stress (Ribeiro *et al.* 2011).

From the geographical standpoint, there is also a latitudinal distribution of macrophyte species in coastal ecosystems. At global and very wide scales, the processes that drive the macrophyte distribution in low- and high-latitude estuaries are mainly related to the differences of precipitation, temperature and solar radiation (Pennings & Bertness 1999). At these scales, the studies are based on the comparison of single areas (Fariña *et al.* 2017). At more regional and local scales, it is possible to focus on continuous areas and, although the importance of climate gradient is relevant (Fariña *et al.* 2017), the edaphic and geomorphological differences of the aquatic ecosystems may be the principal drivers to the north-south distribution of macrophyte species (Isacch *et al.* 2006, Fariña *et al.* 2017).

In the coastal region of the São Paulo state, southeastern Brazil, there is the Serra do Mar, a system of mountain ranges and escarpments with a length of about 1,000 km and altitude up to 1,000 m. The presence of the Serra do Mar forms a north-south gradient of coastal plain width (IPT 1981, Almeida & Carneiro 1998, Tessler *et al.* 2006). The watersheds located in these plains are influenced by the variation in topography and altitude (Souza & Cunha 2011). They cross areas with different sedimentary formations (Suguio *et al.* 1978) and disembogue on beaches of different typologies (Tessler *et al.* 2006). Due to the diversity of environmental characteristics of the São Paulo coast it is expected that different aquatic macrophyte species and life forms occur in the coastal north-south gradient.

The knowledge on aquatic macrophyte distribution still presents large gaps (Chambers *et al.* 2008) and such studies in coastal regions are even scarcer. Most studies on coastal aquatic ecosystems assess physiological tolerances and ecological interactions among only a few species (Castillo *et al.* 2000, Costa *et al.* 2003, Touchette 2006, Guo & Pennings 2012, Nunes & Camargo 2018), and species lists and inventories are poorly published (Ribeiro *et al.* 2011, Ferreira *et al.* 2017). Species inventories represent a consistent and efficient method to generate information on aquatic macrophytes distribution, to monitor biodiversity, and for conservation actions of species and aquatic ecosystems (Brooks *et al.* 2004, Thomaz *et al.* 2004). Therefore, the aim of this study was to perform an inventory of aquatic macrophyte species in coastal rivers of São Paulo state in order to assess the species and life form richness and latitudinal distribution in this region.

MATERIAL AND METHODS

Study area

The São Paulo state coast can be compartmentalized into three main regions according to the coastal plains width. The southern region (from the municipality of Ilha Comprida to the municipality of Praia Grande) is marked by large coastal plains, about 15 km wide, interspersed by hills between the Serra do Mar and the continuous and rectilinear beaches. The northern region (from São Sebastião Island to the municipality of Ubatuba) has narrow coastal plains and crenellated hillside forming small beaches, creeks and bays. And the central region of the coast (from the municipality of Santos to São Sebastião Island) presents characteristics of both northern and southern regions (Tessler *et al.* 2006).

The study area presents a small seasonal variation of climatic characteristics, an absence of flood pulses in the aquatic ecosystems, humid tropical climate, mild winters, rainfall in all months of the year and absence of a defined dry season (Monteiro 1973, Camargo & Florentino 2000). The average annual temperature corresponds to 23.6ºC, with slightly higher averages in the central region (24.6ºC) than in the northern region (21.9ºC) (Embrapa 2015). The average annual rainfall is 2,140 mm, with an average of about 2,500 mm in the northern, 2,000 mm in the central and 1,900 mm in the southern region (Embrapa 2015).

The selection of the rivers was based on the north-south gradient of distancing between the Serra do Mar and the coastline and the coastal plain width, and the occurrence of yet well-conserved estuaries (Table 1). Eight coastal rivers were selected in five municipalities along a coastal stretch of about 280 km. They are: Ubatumirim River, Puruba River and Itamambuca River (municipality of Ubatuba) in the northern region; Una River (municipality of São Sebastião), Guaratuba River and Itapanhaú River (municipality of Bertioga) in the central region; and Itanhaém River (municipality of Itanhaém) and Guaraú River (municipality of Peruíbe) in the southern coast of the São Paulo state (Figure 1).

Data collection

We collected the data in March 2017 and chose to perform a single collecting since most aquatic macrophyte species from estuarine regions are perennial (Engels 2010). We went through the main river of the coastal basins on a small boat from the

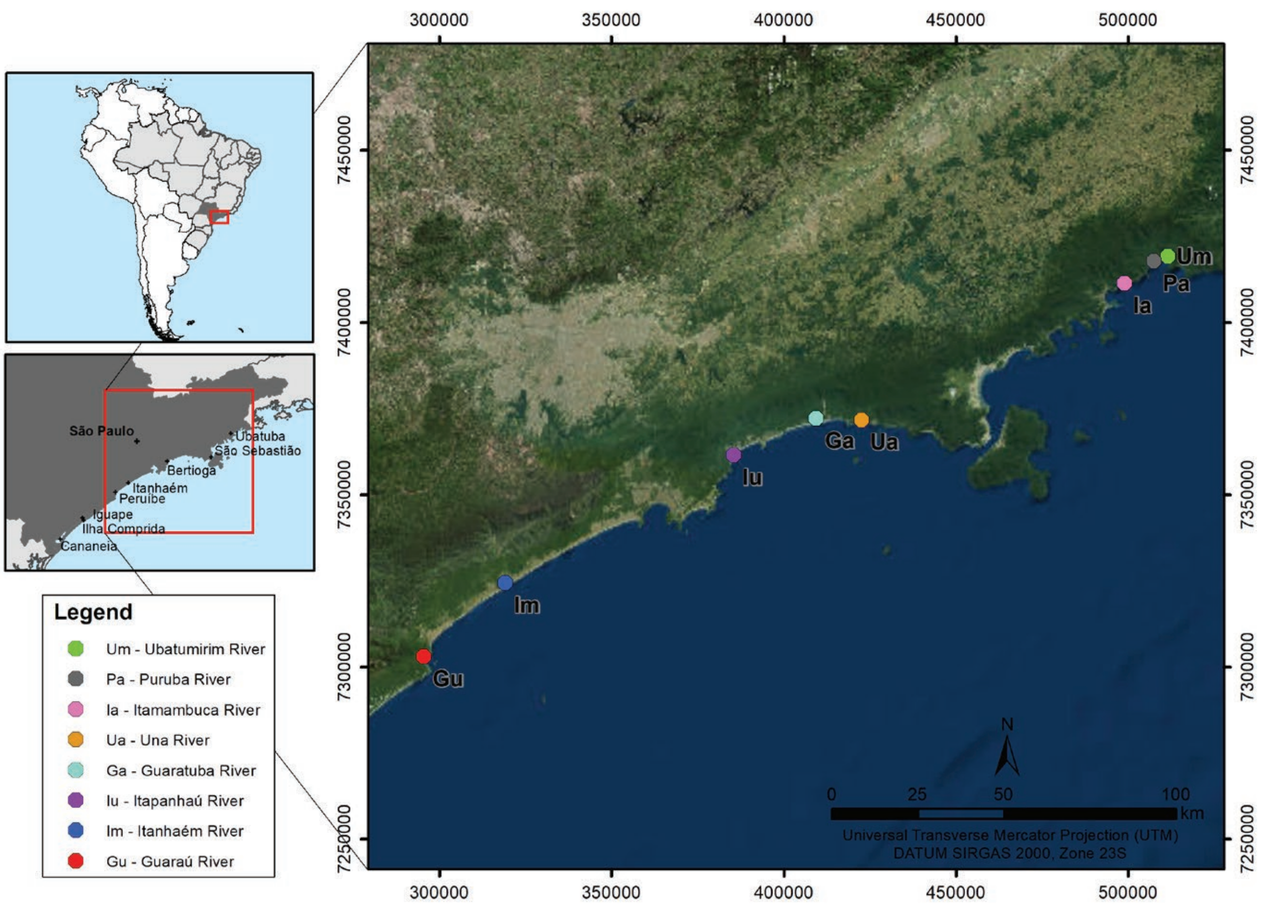

Figure 1. Maps of South America, Brazil and São Paulo State, highlighting the location of the sampled rivers in northern (Ubatumirim, Puruba and Itamambuca), central (Una, Guaratuba and Itapanhaú) and southern (Itanhaém and Guaraú) coastal regions of the São Paulo state, Brazil.

mouth to the farthest point of possible navigation. Then we returned to the river mouth stopping at all observed macrophyte banks and recording the species occurrence. We sampled between 9 and 19 sites per river (Table 1) based on the macrophyte occurrence. In total, we sampled 100 sites along 59.30 km of rivers (Table 1).

Submerged species were sampled using a hook. We included the amphibious plants found on the sandbanks in the river channels and on the margin up to 2 m away from the water bodies. The aquatic macrophyte species found were recorded and when unidentified in the field they were collected and herborized for later identification. The aquatic macrophytes were identified at the lowest possible taxonomic level using the following literature: Pott & Pott (2000), Amaral *et al.* (2008) and Rodrigues *et al.* (2017). The fertile specimens were included in the herbarium HRCB (Herbário Rioclarense, Instituto de Biociências, UNESP).

The taxa were classified into their life forms, according to Chambers *et al.* (2008): emergent (*i.e.*, rooted plants with the vegetative parts emerging above the water surface), free-floating (*i.e.*, plants floating on water surface), rooted floating (*i.e.*, rooted plants with floating leaves and flowers on the water surface), rooted submerged (*i.e.*, plants with predominantly submerged vegetative parts) and free submerged (*i.e.*, plants with submerged vegetative parts, but not rooted in the substrate). In addition, the amphibious (or semiaquatic) species have also been considered, as they colonize wetlands but are able to survive for varying periods on a dry substrate.

Data analysis

The general descriptions for taxonomic aspects, life forms and distribution of the aquatic macrophytes were explored considering the number of taxa per taxonomic family, number of taxa per life form, the frequency of occurrence and latitudinal distribution.

The frequency of occurrence (FO) was calculated from the number of occurrence of each species in relation to the total number of sampling sites. The species were classified as: constant = FO > 50%, common = 10% < FO ≤ 50%, or rare = FO ≤ 10% (Lobo & Leighton 1986).

The graphs were drawn up using the GraphPad Prism 5.0 software (GPW5-066646-RCG7389) (GraphPad Software 2007). The interpolated and extrapolated taxa accumulation curve was developed in the R environment 3.5.1 (R Development Core Team 2018) using the iNEXT package (Hsieh *et al.* 2018) and its sample-size-based protocol (incidence raw data).

RESULTS

We recorded 45 taxa of aquatic macrophytes belonging to 24 families (Table 2; Figure 2). One Cyperaceae taxum could not be identified since it was not fertile when collected. Of the total, 41 taxa are native and the species *Panicum repens* L. (Poales, Poaceae), *Urochloa arrecta* (Hack. ex. T. Durand & Schinz) Morrone & Zuloaga (Poales, Poaceae) and *Hedychium coronarium* J. Koenig

Table 1. Number of sampling sites per river, sampled river length, the rivers length on the coastal plain, and the coastal plain width in each basin, São Paulo state, Brazil

Coastal rivers	Number of sampling sites	Sampled river length (km)	River length on coastal plain (km)	Coastal plain width (km)
Ubatumirim	09	2.13	2.43	2.00
Puruba	10	2.45	2.62	2.80
Itamambuca	10	1.84	1.84	1.50
Una	11	3.60	3.28	3.90
Guaratuba	12	7.65	8.18	6.10
Itapanhaú	17	25.70	35.84	4.90
Itanhaém	19	18.90	19.00	14.50
Guaraú	12	9.20	10.13	5.50

Table 2. List of the aquatic macrophyte species recorded in the coastal rivers of the São Paulo state, Brazil (UM = Ubatumirim; PA = Puruba; IA = Itamambuca; UA = Una; GA = Guaratuba; IU = Itapanhaú; IM = Itanhaém; GU = Guaraú), life forms (LF; EM = emergent; AM = amphibious; FF = free-floating; RF = rooted floating; FS = free submerged; RS = rooted submerged), taxa codes used in Figure 4, Herbarium (HRCB) vouchers, and frequency of occurrence (FO).

Species	LF	Code	HRCB Voucher	UM	PA	IA	UA	GA	IU	IM	GU	FO (%)
ACANTHACEAE												
Hygrophila costata Nees & T. Nees	EM	Hcos	-						X	X		2
AMARYLLIDACEAE												
Crinum americanum L.	EM	Came	-	X	X		X	X	X	X	X	39
ARACEAE												
Pistia stratiotes L.	FF	Pstr	-						X	X		5
ARALIACEAE												
Hydrocotyle ranunculoides L. f.	EM	Hran	-							X		1
ASTERACEAE												
Pluchea sagittalis (Lam.) Cabrera	AM	Psag	-			X						1
Sphagneticola trilobata (L.) Pruski	AM	Stri	73014				X					1
CABOMBACEAE												
Cabomba furcata Schult. & Schult. f.	RS	Cfur	73002						X	X		5
CYPERACEAE												
Cyperus blepharoleptos Steud.	EM	Cble	-			X				X		2
Cyperus odoratus L.	EM	Codo	73004		X							1
Eleocharis acutangula (Roxb.) Schult.	EM	Eacu	73005			X		X				1
Eleocharis interstincta (Vahl) Roem. & Schul.	EM	Eint	73006		X			X				2
Eleocharis minima Kunth	EM	Emin	-							X		1

Table 2. Continued on next page...

Table 2. ...Continued

Species	LF	Code	HRCB Voucher	UM	PA	IA	UA	GA	IU	IM	GU	FO (%)
Fimbristylis dichotoma (L.) Vahl	AM	Fdic	73007		X	X	X					5
Fuirena umbellata Rottb.	EM	Fumb	73008					X				1
Rhynchospora corymbosa (L.) Britton	EM	Rcor	73013			X		X	X	X	X	8
Schoenoplectus californicus (C.A.Mey.) Soják	EM	Scal	-	X	X	X	X	X	X	X		24
Unidentified	EM	Cype	-	X	X							9
HALORAGACEAE												
Myriophyllum aquaticum (Vell.) Verdc.	EM	Maqu	-							X		1
HYDROCHARITACEAE												
Egeria densa Planch.	RS	Eden	-						X	X		10
Limnobium laevigatum (Humb. & Bonpl. ex Willd.) Heine	FF	Llae	-							X		1
JUNCACEAE												
Juncus cf. *marginatus* Rostk.	EM	Jmar	-				X					1
LENTIBULARIACEAE												
Utricularia foliosa L.	FS	Ufol	-							X		1
NYMPHAEACEAE												
Nymphaea rudgeana G. Mey.	RF	Nrud	-						X	X		3
ONAGRACEAE												
Ludwigia decurrens Walter	EM	Ldec	73010			X						3
ORCHIDACEAE												
Habenaria repens Nutt.	EM	Hrep	-							X		1

Table 2. Continued on next page...

Table 2. ...Continued

Species	LF	Code	HRCB Voucher	UM	PA	IA	UA	GA	IU	IM	GU	FO (%)
PLANTAGINACEAE												
Bacopa monnieri (L.) Pennell	EM	Bmon	73002				X					1
POACEAE												
Hymenachne amplexicaulis (Rudge) Nees	EM	Hamp	73009		X							1
Leersia hexandra Sw.	EM	Lhex	-						X	X		3
Panicum repens L.	EM	Prep	73011				X					3
Paspalidium geminatum (Forssk.) Stapf	EM	Pgem	-	X	X							2
Paspalum virgatum L.	EM	Pvir	-		X							1
Spartina alterniflora Loisel.	EM	Salt	-					X	X	X	X	25
Steinchisma laxum (Sw.) Zuloaga	AM	Slax	-		X	X						6
Urochloa arrecta (Hack. ex. T. Durand & Schinz) Morrone & Zuloaga	EM	Uarr	-							X		4
POLYGONACEAE												
Polygonum acuminatum Kunth	EM	Pacu	-		X	X						4
Polygonum punctatum Elliott	EM	Ppun	73012		X	X						2
Eichhornia azurea (Sw.) Kunth	RF	Eazu	-							X		6
Eichhornia crassipes (Mart.) Solms	FF	Ecra	-						X	X		10
PTERIDACEAE												
Acrostichum danaeifolium Langsd. & Fisch.	AM	Adan	-	X		X	X	X	X	X		9
RICCIACEAE												
Ricciocarpos natans (L.) Corda	FF	Rnat	-							X		1

Table 2. Continued on next page...

Table 2. ...Continued

Species	LF	Code	HRCB Voucher	UM	PA	IA	UA	GA	IU	IM	GU	FO (%)
RUBIACEAE												
Richardia grandiflora (Cham. & Schltdl.) Steud.	AM	Rgra	-				X					1
SALVINIACEAE												
Azolla filiculoides Lam.	FF	Afil	-							X		1
Salvinia molesta D.S. Mitch.	FF	Smol	-						X	X		11
TYPHACEAE												
Typha domingensis Pers.	EM	Tdom	-			X				X		4
ZINGIBERACEAE												
Hedychium coronarium J. Koenig	AM	Hcor	-		X	X						3

(Zingiberales, Zingiberaceae) are exotic (Flora do Brasil 2020 2018).

The families with the highest number of taxa were Cyperaceae (N = 10) and Poaceae (N = 8) (Figure 2). Most species (60%) have the emergent life form (N = 27) (Figure 3). The species *Cyperus blepharoleptos* Steud. (Poales, Cyperaceae) (syn. *Oxycaryum cubense* (Poepp. & Kunth) Lye), often considered epiphytic, was classified in our study as emergent because it was found rooted directly in the river sediment.

The greatest species (N = 25) and life form (N = 6) richness were found in the Itanhaém River. Submerged and floating species were found only in the Itapanhaú and Itanhaém Rivers. In the other rivers, we only recorded the occurrence of emergent and/or amphibious taxa (Table 2).

Crinum americanum L. (Asparagales, Amaryllidaceae), *Spartina alterniflora* Loisel. (Poales, Poaceae) and *Schoenoplectus californicus* (C. A. Mey.) Soják (Poales, Cyperaceae) were the most frequent species (frequency of occurrence respectively 39%, 25% and 24%). These emergent macrophytes along with *Salvinia molesta* D.S. Mitch. (Salviniales, Salviniaceae), *Egeria densa* Planch. (Alismatales, Hydrocharitaceae) and *Eichhornia crassipes* (Mart.) Solms (Commelinales, Pontederiaceae) were classified as common species (13.3% of the total species). The other taxa were classified as rare. No taxum was considered constant in terms of frequency of occurrence (Table 2).

The exotic species *P. repens* and *U. arrecta*, plus eleven native species occurred in only one location. The exotic *H. coronarium* was recorded in two rivers. *Crinum americanum* and *S. californicus* were recorded in seven of the eight sampled rivers (Table 2).

The aquatic macrophyte distribution occurs in a latitudinal gradient, with only four species (*C. americanum*, *S. californicus*, *Acrostichum danaeifolium* Langsd. & Fisch. (Polypodiales, Pteridaceae) and *Rhynchospora corymbosa* (L.) Britton (Poales, Cyperaceae) (8.9% of the total taxa) occurring along much of the north-south stretch sampled. Eleven taxa occurred only in the northern region, six in the central region and ten taxa occurred only in the southern region of the sampled coastal stretch (Figure 4).

The recorded number of aquatic macrophyte taxa increased with the sampling effort, but the

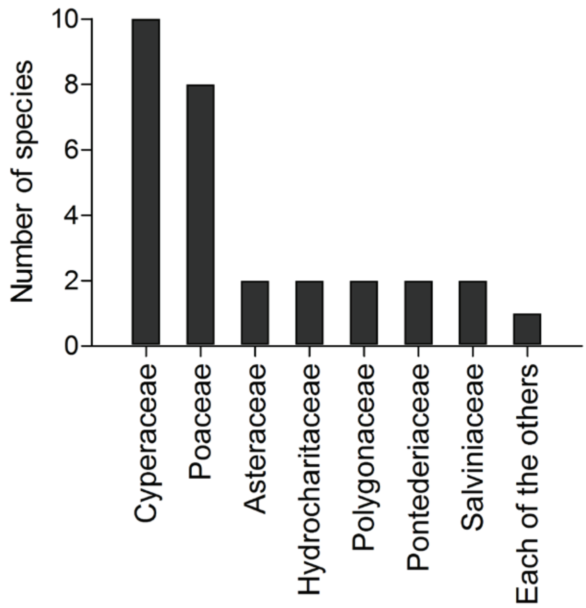

Figure 2. Number of species of aquatic macrophyte per family in coastal regions of the São Paulo state, Brazil.

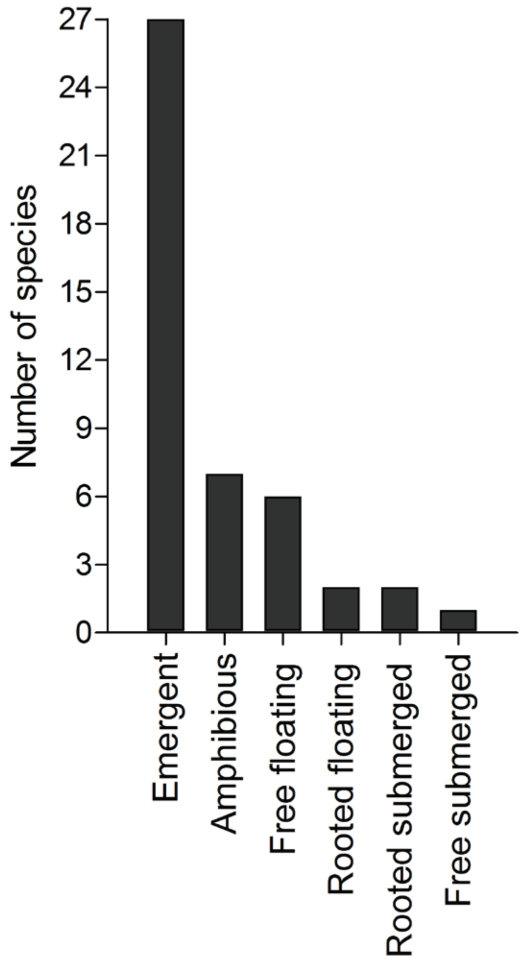

Figure 3. Number of species of aquatic macrophyte per life form in coastal regions of the São Paulo state, Brazil.

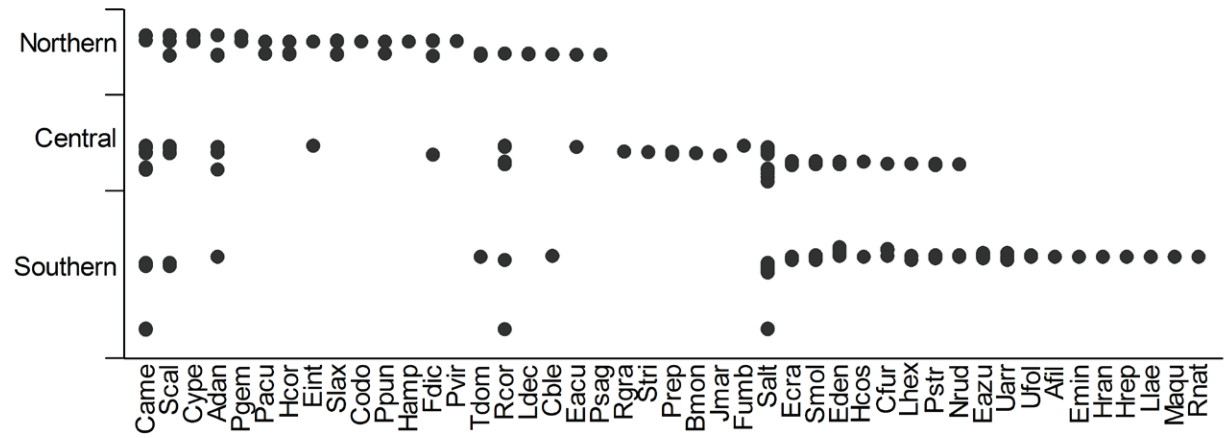

Figure 4. Occurrence of aquatic macrophyte species in the coastal rivers in northern, central and southern coastal regions of the São Paulo state, Brazil. Taxa codes are shown in Table 2.

interpolated taxa accumulation curve did not reach an asymptote (Figure 5). The extrapolation-sampling curve indicated that other eleven species could still be recorded doubling the number of sampling sites, totaling 56 species (Figure 5). Nevertheless, in 100 sampling sites we recorded 80.36% of the macrophyte species richness in the coastal rivers. Our survey was limited to the main rivers of the coastal basins and whether the sampling was expanded to the tributaries the richness would increase in 19.64%.

DISCUSSION

From the total taxa recorded in the coastal rivers of São Paulo, 51.1% of these taxa were also found in the Guarapiranga Reservoir, in the São Paulo state Metropolitan Region (Rodrigues *et al.* 2017), 35.5%

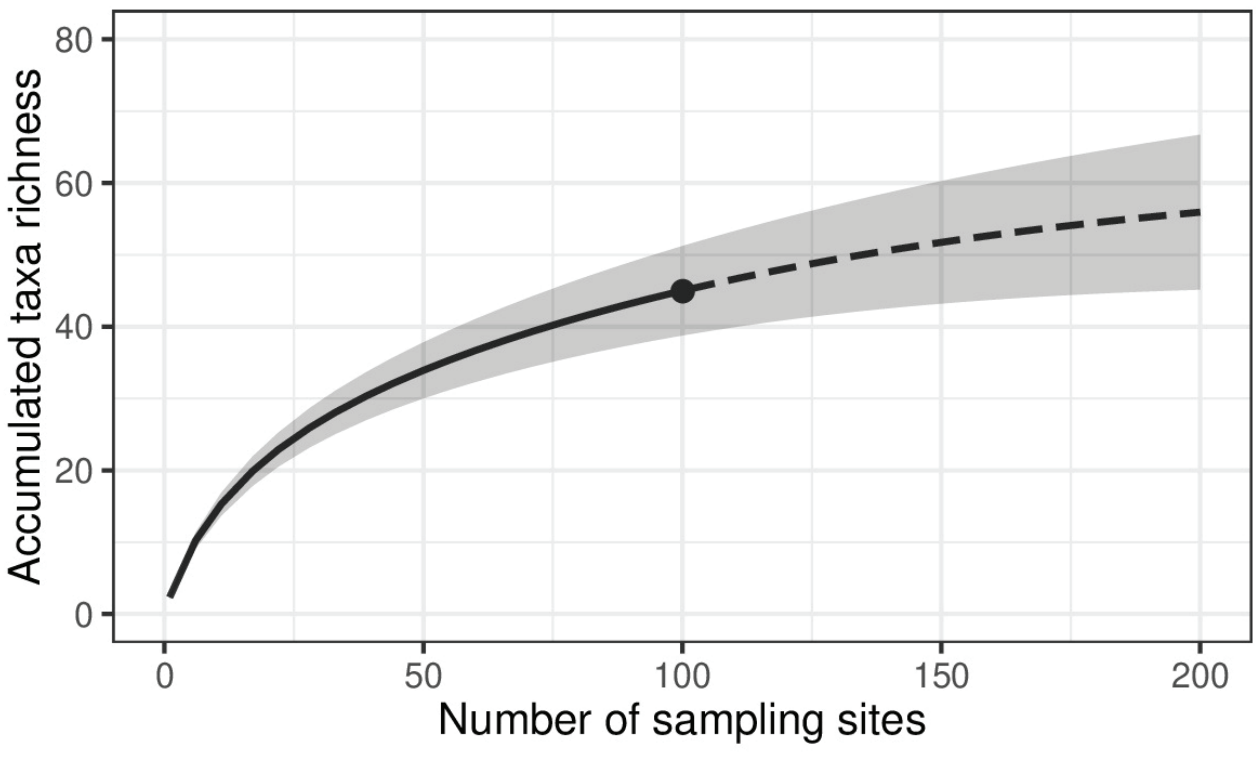

Figure 5. Taxa accumulation curve of the aquatic macrophytes sampled in coastal regions of the São Paulo state, Brazil. The solid line is the interpolated rarefaction curve, the dashed line represents the extrapolation-sampling curve and the grey highlight represents the confidence interval (95%) around the curve.

in the Upper Paraná River (Floodplain ecosystems in Southern Brazil) (Souza *et al.* 2017a) and 24.4% in coastal lakes in the Santa Catarina state (Southern Brazil) (Ferreira *et al.* 2017). Although the aquatic environments are quite distinct, that is, coastal rivers, reservoir, floodplain and coastal lakes; the greatest similarity occurs due to the geographically close locations. Many aquatic macrophyte species found in the São Paulo coast have extensive geographical distributions and are native to tropical America (Lorenzi 2000), such as: *S. californicus*, *E. crassipes* and *P. stratiotes* (Flora do Brasil 2020 2018).

The most frequent species in our study were also found in coastal ecosystems in southern Brazil and in the Atlantic coast of North America. In the Patos Lake estuary, *S. californicus* and *S. alterniflora* are two of the three main aquatic macrophyte species (Hickenbick *et al.* 2004). In the San Francisco Estuary (West Coast, USA), Watson & Byrne (2009) also recorded the occurrence of *S. californicus*. *Spartina alterniflora* is dominant in estuarine regions on the Atlantic coast of North America (Valilela *et al.* 1978, Adair *et al.* 1994), however its occurrence in Brazil is more restricted to the southeast coast (Flora do Brasil 2020 2018). Although these species are directly influenced by salinity because they occur in stands close to the river mouth, the other species can withstand the salt spray action at different distances of the river mouth and the coastline (Boyce 1954).

We observed that Cyperaceae and Poaceae species corresponded to 22.2% and 17.7% of the total species recorded in the coastal rivers of São Paulo. Similar percentages of Cyperaceae were recorded by Ribeiro *et al.* (2011) (23.7%) and by Ferreira *et al.* (2017) (21.5%) in coastal ecosystems. Cyperaceae and Poaceae are two of the three richer families in aquatic macrophyte species currently known in the main biogeographical areas (Chambers *et al.* 2008). The great occurrence of these families in the coastal rivers is due to the fact that Cyperaceae includes a large number of facultative halophytic species (Sabovljevic & Sabovljevic 2007, Aslam *et al.* 2011) and Poaceae is one of the principal families in which species with great variation in terms of salt tolerance are found (Marcum 2008, Aslam *et al.* 2011, Flowers & Colmer 2015).

We found similar species richness, but greater life form richness than the inventory of aquatic and amphibious plants (50 taxa classified as herbaceous plants in macrophyte banks) made by Ribeiro *et al.* (2011) only in the Massaguaçu River (Northern coast of São Paulo). This river is characterized for being an irregular estuary, that is, it remains some periods without connection with the ocean and, therefore, it frequently presents characteristics of lentic environments (Ribeiro *et al.* 2013). Besides that, in irregular estuaries opportunistic amphibious species may occur in addition to their aquatic ones (Ribeiro *et al.* 2011). The coastal rivers we sampled have regular estuarine zones, that is, they are always connected to the ocean and, therefore, they are lotic environments (L. S. C. Nunes, personal communication). The longitudinal gradient of salinity and flooding in rivers with regular estuaries may be limiting for species richness (Smith *et al.* 2002, Crain *et al.* 2004). However, the marine influence and the different rivers length can promote life form richness and diversity of species composition among the studied coastal region.

The species richness recorded in inventories is varied and this variation may be related to the sampling effort, approach and area (Moura-Júnior *et al.* 2013), as well as the aquatic ecosystems heterogeneity (Souza *et al.* 2017b) and habitat diversity (Moura-Júnior *et al.* 2013). For example, Souza *et al.* (2017a) sampled the main river channel, tributaries and floodplain lakes in the Upper Paraná River (Southern Brazil) totaling 230 km of river stretch and 71 taxa; and Henry-Silva *et al.* (2010) sampled 40 macrophyte taxa in about 210 km long of the Apodi/Mossoró River Basin (Northeast Brazil). We sampled only the main rivers of the coastal basins totaling less than 60 km of rivers and, nevertheless, we found species richness (N = 45) in the same order of magnitude of these other inventories. Thus, we suggest that the diversity of environmental characteristics of the São Paulo coastal rivers favors the aquatic macrophyte richness and diversity in the entire region.

In relation to the sampling effort, we observed from the extrapolation of species richness provided by the taxa accumulation curve that more than 80% of the total expected richness of the coastal region was sampled in our study. Similar percentage was also sampled by Souza *et al.* (2017a). Thus, probably increasing the sampling effort we would record other rare species in some tributaries. Perhaps it would be more interesting that future investigations in this coastal region include other rivers rather than expanding the sampling in these basins that have already been inventoried.

In large geographical scales, environmental factors such as climate and salinity are responsible for the spatial variation of species occurrence and ecological processes among aquatic macrophytes in estuarine areas (Pennings & Bertness 1999, Fariña *et al.* 2017). For example, Fariña *et al.* (2017) observed that over a latitudinal gradient of 2,000 km in the Pacific coast of Chile the variation in the macrophyte species distribution in the aquatic ecosystems is explained by the variation of climatic and edaphic factors and by the tidal regime variation. Those authors also observed that only one species occurs throughout the studied stretch. In our study conducted on a reduced geographical scale, we also observed a north-south gradient of species occurrence that is probably related to the coastal plains width and estuaries characteristics. The species richness of the northern (N = 20) and central-southern regions (N = 25) is not very different, however, the species composition differs greatly between the northern and southern. The species found in the central region are common to the other regions. We observed that few species occur along the entire north-south sampled stretch. These species possibly have a wide tolerance to variation in resource requirements and to salinity.

Although the species richness did not show much variation among the coastal regions, the life form richness did. We found greater life form richness in the central and southern than in the northern region. Emergent and amphibious species were recorded in all regions, but floating and submerged species were not found in the northern. Floating and submerged macrophytes were recorded only in the two largest rivers, possibly because they present backwater and semi-abandoned meandering areas with lower current velocity and sediment deposition due to the greatest rivers length and coastal plains width. Although well distributed in Neotropical aquatic ecosystems (Pott *et al.* 2011, Souza *et al.* 2017a), floating species can be limited by salt (Paudel *et al.* 2018) and water flow (Camargo *et al.* 2003) in coastal lotic ecosystems. Some submerged macrophyte species may be salt tolerant, but they occur in lower richness in coastal areas (Adair *et al.* 1994, Abu-Hena *et al.* 2010, Henry-Silva *et al.* 2010, Ferreira *et al.* 2017).

As also observed by other authors in coastal lotic ecosystems of different geographical regions (Hickenbick *et al.* 2004, Rumrill & Sowers 2008, Watson & Byrne 2009, Ribeiro *et al.* 2011, Janousek & Folger 2014), emergent life form was the dominant one among aquatic macrophytes in the sampled coastal rivers. Emergent species, especially estuarine ones, have propagation, growth and persistence strategies through clonal shoots and long-term rhizomes or stolons (Bertness & Ellison 1987). Many species are tolerant of water level variation (Santos & Esteves 2004, Zhou *et al.* 2018) and the species occurring near the coastline can be positively related to salinity (Janousek & Folger 2014). The amphibious macrophytes, second most frequent life form group in our study, are also tolerant of water stress and have adaptations to occupy dry and wet substrates (Matias *et al.* 2003). However the amphibious are in disadvantage comparing to the emergent ones in terms of growth strategies (Lycarião & Dantas 2017). In relation to these two life forms, there are still difficulties and controversies about the most appropriate classification and characterization for each environment (Bove *et al.* 2003).

Of the total species recorded in the coastal rivers of São Paulo state, only three species are exotic. These species had low frequency of occurrence and were restricted to certain coastal regions. *Urochloa arrecta* was recorded in the Itanhaém River (southern region), *P. repens* in the Una River (central region), and *H. coronarirum* in the Ubatumirim and Puruba Rivers (northern region). These exotic species have been reported as aggressive invaders in aquatic ecosystems of other tropical and subtropical regions, negatively affecting the richness, diversity and abundance of native aquatic macrophytes (Fernandes *et al.* 2013, Michelan *et al.* 2013, Amorim *et al.* 2015, Castro *et al.* 2016, Overholt & Franck 2017).

The African Poaceae *U. arrecta* (syn. *Brachiaria arrecta* (Hack. ex T.Durand & Schinz) Morrone & Zuloaga and *B. subquadripara* (Trin.) Hitchc.) has already been recorded in all Brazilian regions (Flora do Brasil 2020 2018) and it has been observed in different aquatic ecosystems such as Pantanal wetlands (Pott *et al.* 2011), reservoirs (Michelan *et al.* 2010, Rodrigues *et al.* 2017) and coastal rivers and lakes (Amorim 2015, Ferreira *et al.* 2017). *Panicum repens* is native to Australia and it is considered an invasive of difficult control in the southern United

States (Sutton 1996). In Brazil, this species was recorded in disturbed flooding areas of the Pantanal (Pott *et al.* 2011) and reservoirs in the Paraná River Basin (Agostinho *et al.* 2005) however, its invasive status is still less documented in the country. The amphibious *H. coronarium* is native to Tropical Asia and it has been very common in the Brazilian coastal zone where it is invasive in wetlands, along water courses and in the sub-forest of the Atlantic Rainforest (Soares & Barreto 2008). Although these three exotic species did not present expressive frequencies of occurrence in the São Paulo state coast, their monitoring and management can be actions to avoid their dispersion and establishment in new areas, and consequently avoid changes in ecosystem functioning (Bove *et al.* 2003, Souza *et al.* 2017a).

In conclusion, we observed a north-south gradient of macrophyte species distribution in the coastal rivers of São Paulo state. Only three species and only emergent and amphibious life forms occur along the entire sampled coastal stretch. We found the greatest life form richness in the central-southern region, although the species richness of the northern and central-southern is not very different. Thus, we suggest that the macrophytes diversity and the north-south gradient of species distribution may be related to the diversity of environmental characteristics of the coastal rivers due to differences in the coastal plains width and rivers length by the presence of the Serra do Mar.

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