Aquatic macrophytes in the large, sub-tropical Itaipu Reservoir, Brazil

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Abstract: In the last three decades, rapid assessment surveys have become an important approach for measuring aquatic ecosystem biodiversity. These methods can be used to detect anthropogenic impacts and recognize local or global species extinctions. We present a floristic survey of the aquatic macrophytes along the Brazilian margin of the Itaipu Reservoir conducted in 2008 and compare this with a floristic survey conducted ten years earlier. We used ordination analysis to determine whether assemblage composition differed among reservoir arms. Macrophyte species were sampled in each of the 235 sampling stations using a boat, which was positioned inside three places of each macrophyte stand to record species and search for small plants. We also collected submerged plants using a rake with the boat moving at constant velocity for ten minutes. We assigned individual macrophyte species to life form and identified representative species for each life form. A total of 87 macrophyte taxa were identified. The "emergent" life forms contained the highest number of species, followed by "rooted submerged" life forms. The extensive survey of macrophytes undertaken in September 2008 recorded more species than a survey conducted between 1995 and 1998. This could be due to changes in water physico-chemistry, disturbances due to water drawdown and the long period between surveys, which may have allowed natural colonization by other species. Additionally, differences in the classification systems and taxonomic resolution used in the surveys may account for differences in the number of species recorded. Assemblage composition varied among the arms and was affected by underwater radiation (as measured using a Secchi disk) and fetch. Five non-native species were found. Two of these non-native species (*Urochloa subquadripara* and *Hydrilla verticillata*) are of special concern because they have a high frequency of occurrence and occupy large marginal areas of the reservoir. Future surveys should be conducted to determine the habitat most frequently colonized by these species. This would allow management strategies to be developed to protect native aquatic biota and prevent interference with the recreational and commercial uses of the Itaipu Reservoir. Rev. Biol. Trop. 58 (4): 1437-1452. Epub 2010 December 01.

Key words: floristic survey, aquatic plants, life forms, Brazil.

Rapid assessment style surveys have become important tools to assess the status of biodiversity, especially in the last three decades because of the recognition that anthropogenic impacts are leading several species to local or global extinction (Maltchik & Callisto 2004). By conducting floristic surveys, one can quantify species richness, identify possible threats to biodiversity, assess rare species and detect the presence of non-native, nuisance species in an ecosystem.

Macrophytes are important components of freshwater ecosystems because they enhance the physical structure of habitats and biological complexity, which increases biodiversity within littoral zones (Esteves 1998, Wetzel 2001, Agostinho *et al*. 2007, Pelicice *et al*. 2008). For example, fish diversity is positively related to macrophyte diversity in the Upper Paraná River Basin at both the large (between different ecosystems) and fine (within specific ecosystems) spatial scales (Agostinho *et al*. 2003, 2007, Pelicice *et al*. 2008). In addition, both live and dead material (detritus) from aquatic macrophytes may serve as a food resource for aquatic and terrestrial organisms (Lopes *et al*. 2007).

Surveys of macrophytes have been conducted in several types of ecosystems in Brazil, including rivers (Pedralli *et al*. 1993), lakes (Pott *et al*. 1992, Kita & Souza 2003) and reservoirs (Thomaz *et al*. 1999, Martins *et al*. 2008). In addition to quantifying biodiversity, surveys can provide ecological information regarding, for example, the presence of introduced species, increases or decreases in the frequency of native species with time and identify locations that have been colonised by species that could cause excessive, damaging growth and surveys are particularly useful when they are conducted in more than one time period within the same ecosystem. For example, surveys of the Itaipu Reservoir were conducted prior to its construction and 15 years after its construction (Thomaz *et al*. 1999). Because the Itaipu reservoir has been undergoing temporal changes (Thomaz *et al*. 2006), surveys could provide ecological information on the temporal trends of macrophytes within this reservoir.

Different abiotic factors affect aquatic macrophytes. Submerged species, for example, are in general limited by underwater radiation, while floating forms are more limited by nutrients (Bini *et al*. 1999, Camargo *et al*. 2003). Despite the ecological importance of aquatic macrophytes, the excessive growth of some species may be considered a nuisance to some reservoir uses, such as recreation and electrical generation (Pieterse & Murphy 1990). The most frequent impacts are caused by the floating species *Eichhornia crassipes* (Mart.) Solms and *Salvinia* spp. and the submerged species *Egeria densa* Planch. and *Egeria najas* Planch.

The construction of reservoirs causes major changes to rivers; for example, current velocity is reduced, shorelines may become more developed and sediment stability and water transparency may be affected (Agostinho *et al*. 2007). Moreover, depending on the limnological characteristics of the river, the reservoir may undergo rapid eutrophication, which is typically worst in the first reservoir of a series (Barbosa *et al*. 1999). These changes can lead to the invasion and rapid development of different species and life forms of aquatic macrophytes (Pieterse & Murphy 1990). In addition to nutrient contents, other physical characteristics, such as underwater radiation and fetch (a surrogate of wave disturbance), may also affect the composition of macrophyte assemblages (Thomaz *et al*. 2003, Bini *et al*. 1999).

The Itaipu Reservoir is located downstream of many conservation areas on the Paraná River Basin, which has high biodiversity. It is the largest hydroelectric reservoir in the world in terms of electric energy generation, producing 20% of the total energy consumed in Brazil and 94% of the energy in Paraguay. Macrophytes may become detached and obstruct turbines (although it never happened in Itaipu) and consequently, the monitoring of aquatic plants is important to energy production.

In this study, we present a floristic survey of the aquatic macrophytes along the Eastern margin (Brazilian border) of the Itaipu Reservoir; we compared the species composition of aquatic macrophytes in this survey with a floristic register collected between 1995 and 1998. We assigned individual macrophyte species to life form groups to determine the dominant life forms within the reservoir. Finally, using ordination techniques, we compared the composition among the reservoir arms and assessed the influence of abiotic factors (underwater light and fetch) on macrophyte composition. Using Cook's classification, aquatic macrophytes were defined as plants with photosynthetic parts that are permanently or temporarily submerged or floating in water and visible with the human eye (Cook 1990).

MATERIALS AND METHODS

Study Area: This study was conducted in eight arms of the Brazilian margin of the Itaipu Reservoir (Eastern margin; 24°15' and 25°33' S; 54°00' and 54°37' W (Fig. 1). The reservoir was formed in October 1982 in the Paraná River. It has an area of 1 350km^2 at the normal operation water level (ca. 220m.a.s.l.) and a theoretical residence time of approximately 40 days. The water levels are relatively stable and typically fluctuate less than one meter per year; however, a conspicuous water drawdown of five meters occurred between November 1999 and March 2000 (Thomaz *et al.* 2006).

Eight arms formed by lateral tributaries were investigated: Arroio Guaçu River (AG), São Francisco Verdadeiro River (SFV), São Francisco Falso River (SFF), São Vicente River (SV), São João River (SJ), Ocoí River (OC), Pinto River (PR) and Passo Cuê River (PC) (Fig. 1). Five reservoir arms had total phosphorus concentrations lower than 30μg/L and thus were considered them mesotrophic, while in the other three arms (total phosphorus varied from 30 to 90μg/L) as eutrophic (Thomaz *et al.* 2003). Additional limnological data can be found in Thomaz *et al.* (2003).

Sampling: The main results in this study were collected in a survey of aquatic macrophytes conducted from August 28 to September the 11, 2008. Surveys in this reservoir began in 1995 and in 1999, 235 permanent sampling stations were positioned in eight arms on the Brazilian side of the reservoir. Since 1999, surveys were conducted every six months at these stations and euhydrophytes (especially free floating and submerged species) were prioritized in these surveys. In this paper, we used only data obtained in August-September 2008 because during this time, the taxonomic resolution was improved with macrophyte taxonomists participation.

Thirty sampling points were selected in each arm except at the Arroio Guaçu River and Pinto River, where we selected 26 and 29 sampling points, respectively, because their areas are smaller. The points were distributed to maximize the diversity of abiotic conditions (pH, conductivity, turbidity, dissolved oxygen and nutrient availability) within each arm. The geographic position of each sampling point (latitude and longitude) was obtained by GPS (Global Positioning System). Macrophyte species were sampled in each of the 235 sampling stations using a boat, which was positioned inside three places of each macrophyte stand to record species and search for small plants (*Lemna* sp., *Spirodela* sp. and *Utricularia* sp.). The species presence/absence was recorded by three persons from a boat moving at a constant, slow velocity along the shoreline for ca. 80-100m. In order to record data for submerged plants, we lifted these plants out of the water using a rake attached to a 4m long pipe. Although this method may not be precise in terms of covering the surveyed area in each stand, we used this same procedure in all stands. In addition, previous observations have shown that this procedure usually accurately estimates the number of species per stand (data not shown).

Species that could not be identified in the field were collected for later identification in the laboratory and kept in the Herbarium of the University of Maringá (HUEM). The submerged species were fixed in 70% alcohol. Taxonomic identification followed the specialized literature (Cook 1990, Kissman 1997, Kissman & Groth 1999, 2000, Lorenzi 2000, Pott & Pott 2000). Scientific names followed the APG II classification system (2003) and the spelling of names was revised according to the database of the Missouri Botanical Garden (2009).

Species frequencies were obtained by dividing the number of occurrence of a species

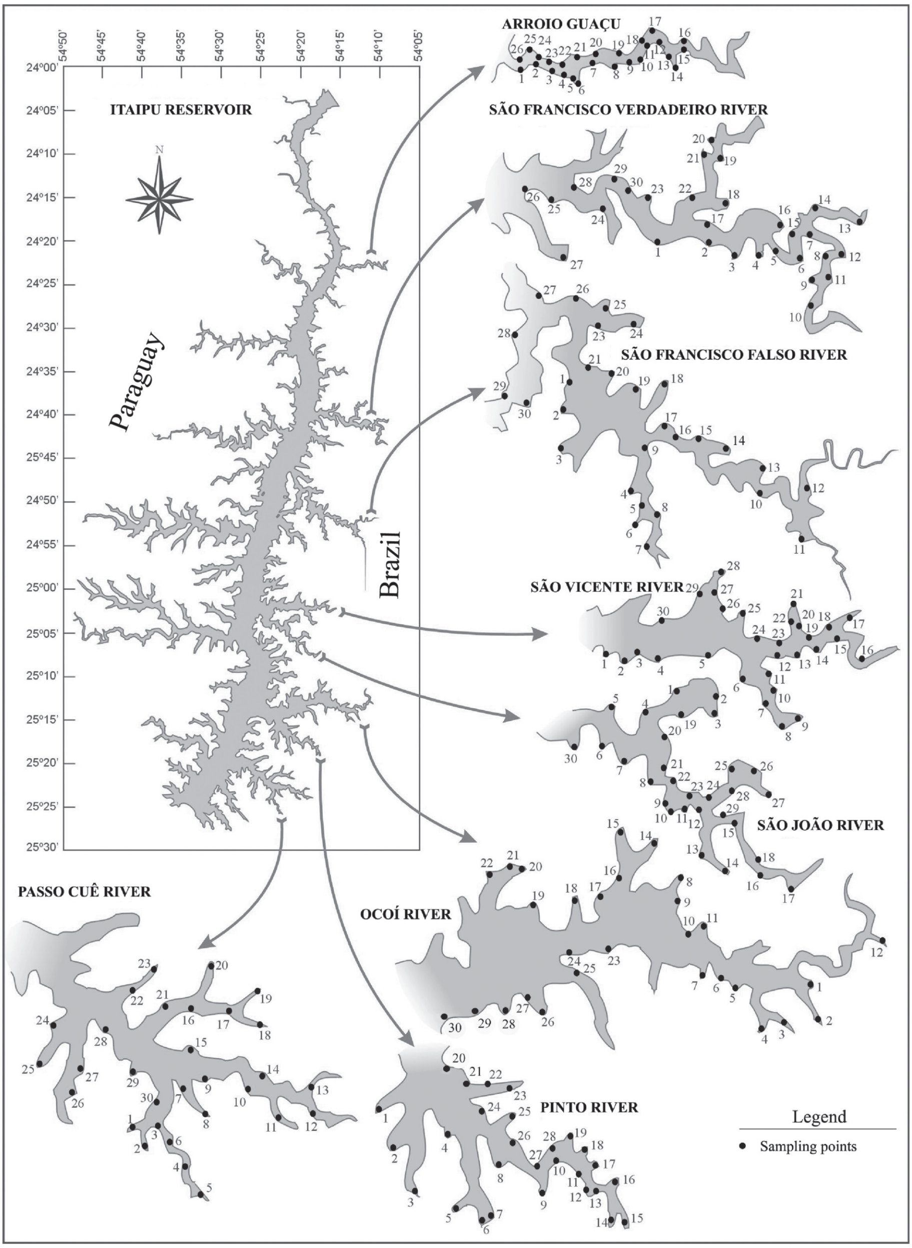

Fig. 1. Sampling points in the eight arms of the Itaipu Reservoir.

by 235 (total number of sampling stations). We also classified species according to their life forms because each life form colonises and uses water and sediment resources quite differently. In fact, different life forms occupy distinct positions in the water column (free floating, submerged and emergent), have different access to light (underwater and/or above-water) and nutrients (sediment and/or water column) and consequently, these groups have different roles (or functions) in littoral regions. We based our seven life forms classification on Pedralli (1990): emergent, rooted submerged, free floating, amphibious, floating leaved, free submerged and epiphyte.

Analysis: To investigate patterns in assemblage composition between reservoir arms, we calculated axis scores using a detrended correspondence analysis (DCA) and used an analysis of variance (ANOVA) to assess if there were significant differences among arms. In addition, correlations between the original data matrix and the DCA scores matrix were calculated and the species correlated to each axis were examined. We correlated the scores of the first (most important) axis of the DCA with two abiotic variables, underwater light (Secchi disk) and effective fetch, to assess if these variables affected macrophyte assemblage composition. Measurements of fetch followed Thomaz *et al*. (2003). We only used these two variables because previous investigations showed that they are important factors in structuring macrophyte assemblages in Itaipu (Bini *et al*. 1999, Thomaz *et al*. 2003) and because measurements of these two variables were obtained in each of the 235 sampling stations.

RESULTS

A total of 87 taxa of aquatic macrophytes belonging to 34 families and 57 genera were identified (Appendix 1). Of these, 60 taxa were identified to species level, but the lack of reproductive structures prevented some plants from being identified to species. The families with the highest number of species were Poaceae (14 taxa), Cyperaceae and Polygonaceae (seven taxa each) and Characeae, Araceae, Hydrocharitaceae, Onagraceae (four taxa each). These families contributed 50.5% of the species recorded and together with Pontederiaceae, Salviniaceae and Potamogetonaceae, had the highest frequencies of occurrence in all arms (Fig. 2a).

The genus with the highest number of species was *Polygonum* (seven species), followed by *Eleocharis* (five), *Ludwigia* and *Panicum* (four species each). Two genera had three species each, ten genera had two species each and 41 genera were represented by a single species. The life form containing the highest number of species was emergent (52.9% of total), followed by rooted submerged (14.9%), amphibious (12.6%), free floating (9.2%), floating leaved (5.7%), free submerged (3.5%) and epiphyte (1.2%). Similarly, the frequency of occurrence of the life forms followed the same sequence (Fig. 2b). The most frequent genera

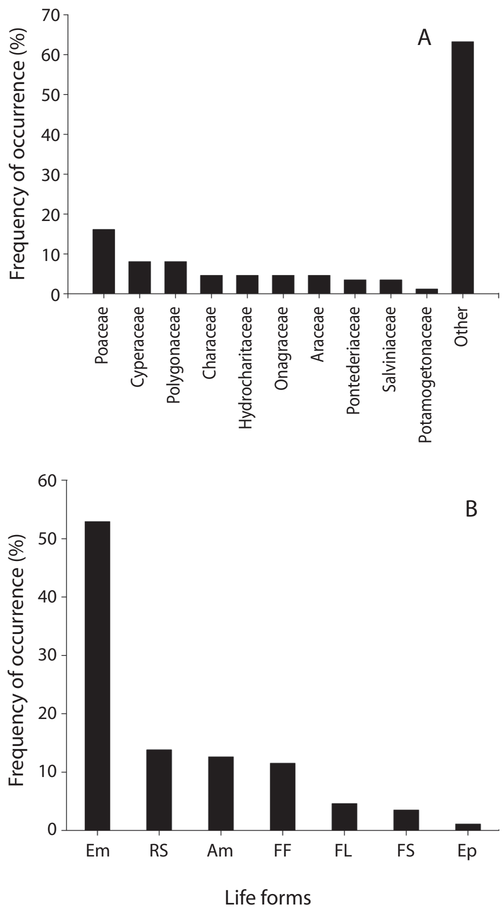

Fig. 2. (**A**) Frequency of families occurrence as recorded in 235 sampling stations in the Itaipu Reservoir; other families were included in the column "others". (**B**) Ranking of life forms occurring in the Itaipu Reservoir. Em=emergent, RS=rooted submerged, Am=amphibious, FF=free floating, FL=floating leaved, FS=free submerged and Ep=epiphyte.

in each life form included the following: emergent – *Hymenachne*, *Urochloa* and *Eleocharis*; rooted submerged – *Chara*, *Nitella*, *Egeria* and *Hydrilla*; free floating – *Eichhornia* and *Salvinia*; amphibious – *Panicum*; floating leaved – *Nymphoides* and *Nymphaea*; free submerged – *Utricularia*; epiphyte – *Oxycaryum*.

The most frequent species were *Hymenachne amplexicaulis* (Rudge) Ness, *Urochloa subquadripara* (Trin.) R.D. Webster and *Egeria densa*, which were found in 70.63%, 70.21% and 49.78% of the sampling points, respectively. *Egeria najas*, *Polygonum ferrugineum* Wedd., *Hydrilla verticillata* (L. f.) Royle, *Panicum repens* L., *Nymphoides humboldtiana* (Kunth) Kuntze, *Panicum pernambucense* (Spreng.) Mez ex Pilg. and *Nitella furcata* subsp. *mucronata* (A. Braun) R.D. Wood were also important (25 to 40% of the sampling points).

It is worth noting that we found five non-native species: *U. subquadripara*, *H. verticillata*, *Nymphaea caerulea* Savigny, *Coix lacryma-jobi* L. and *Hedychium coronarium* J. König. The first species occurred in 165 points and in elevated frequencies in all arms and the second species was recorded in 71 points in five arms. The other three non-native species occurred in low frequencies in the arms (28, three and three sampling stations, respectively). *N. caerulea* occurred in six arms, *C. lacryma-jobi* was recorded only in one arm and *H. coronarium* in two arms. In addition, although the arm with the highest frequency of non-native species was the Arroio Guaçu (all sampling points), the arms with the highest richness of non-native species were Ocoí and Passo Cuê River (four species).

The ordination analysis showed that species composition differed in the different reservoir arms (Fig. 3). The DCA axis 1 shows the reservoir arms ordered according to their longitudinal position along the reservoir main body (riverine-lacustrine gradient): arms farther from the dam (Arroio Guaçu and São Francisco Verdadeiro) were positioned on the right side of axis 1, while arms closer to the dam (Pinto and Passo Cuê) were concentrated on the left side. In fact, there were significant differences among scores of axis 1 (ANOVA, F=60.2, p<0.001). The main species found to be positively correlated to axis 1 were *Lemna valdiviana* Phil. (r=0.85), *Salvinia biloba* Raddi (r=0.64) and *Salvinia minima* Baker (r=0.63).

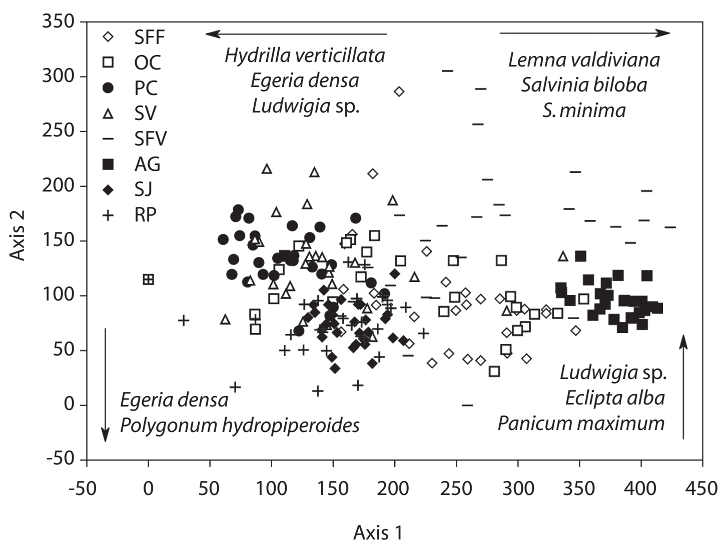

Fig. 3. Ordination graph from the detrended correspondence analysis.

Species negatively correlated to this axis were *H. verticillata* (r=-0.58), *E. densa* (r=-0.45) and *Ludwigia* sp. (r=-0.47) (see Fig. 3).

DCA axis 2 shows the separation between Arroio Guaçu, São Francisco Falso and Ocoí, positioned in the lower part of Figure 3, from São Francisco Verdadeiro arm, positioned in the upper part of this figure. Species that were positively related to axis 2 were *Panicum maximum* Jacq. (r=0.41), *Ludwigia* sp. (r=0.38) and *Eclipta alba* (L.) Hassk. (r=0.37), while *E. densa* (r=-0.33) and *Polygonum hydropiperoides* Michx. (r=-0.3) were negatively correlated to this axis. Scores of axis 2 also differed significantly (ANOVA, F=16.74, p<0.001).

Secchi disk depth varied between 0.5 and 6m and fetch varied between 0.45 and 30km. The scores of axis 1 were significantly and negatively correlated to Secchi disk depth and fetch (r=0.43, p<0.001 and r=-0.36, p<0.001, respectively), indicating that these two abiotic variables are important determinants of macrophyte assemblage composition.

DISCUSSION

Despite conducting the survey in a single, short (15 day) period, we found 87 macrophyte taxa in the eight arms located on the Brazilian side of the Itaipu Reservoir. In the first survey of macrophytes conducted ten years earlier in this reservoir, Thomaz *et al*. (1999) found 62 taxa belonging to 25 families and 42 genera. Among this total, 47 were identified at the species level and 33 species were common between both surveys. Similar to what we found in 2008, the Poaceae family was the best represented in terms of taxa in 1995-1998. There were many *Polygonum* species in both surveys; however, the other most specious genera in 2008 differed from those in 1995-1998. Differences in the number of species and the identity of genera between these two surveys indicate that macrophyte assemblages are still changing and are dynamic in this reservoir. In fact, conspicuous changes due to disturbances caused by water drawdown and alterations in water physico-chemistry (mainly underwater radiation) occurred in the Itaipu Reservoir (Thomaz *et al*. 2006, 2009). The long period between surveys may have also allowed the natural colonization of other species. However, in addition to these environmental causes, differences between the two surveys may be attributable to distinct sampling protocols because the early surveys in the Itaipu Reservoir focused mainly on the euhydrophytes (especially rooted submerged and free floating species), while in the second survey, we followed Cook's classification. In addition, many taxa were identified only to genus in the first survey; therefore, comparisons should be made with caution.

Compared with other reservoirs of the Upper Paraná River Basin, Itaipu has a rich macrophyte assemblage. For example, Martins *et al*. (2008) studied 18 reservoirs and found a total of 39 species in all of them and Thomaz *et al*. (2005) recorded 37 species in the Rosana Reservoir (Paranapanema River). Differences may be due to several non-independent factors, such as differences in area, physico-chemistry and even taxonomic resolution.

The families Poaceae and Cyperaceae, which are among the best-represented families in Itaipu, are also the most important families in other freshwater ecosystems of the Upper Paraná River, like floodplain lakes (Pott *et al*. 1992, Bini *et al*. 1999, Kita & Souza 2003) and reservoirs (Pedralli *et al*. 1993, Martins *et al*. 2008). Despite having similar families, the composition of the macrophyte assemblage in the Itaipu Reservoir differs from natural habitats in other parts of the Upper Paraná River. For example, in one lake in the Upper Paraná River floodplain, the genera *Cyperus*, *Paspalum* and *Solanum* had the highest number of species (Kita & Souza 2003).

It is worth noting that free floating species, like *E. crassipes*, *Salvinia* spp. and *Pistia stratiotes* L., are very common in other Brazilian reservoirs (Carvalho *et al*. 2003, 2005, Gastal Jr. *et al*. 2003, Martins *et al*. 2003) but are not among the most frequent species in Itaipu. Some arms of the Itaipu Reservoir have mesotrophic characteristics (Thomaz *et al*. 2003) and thus the physico-chemistry in the

Itaipu Reservoir is not favourable to this specific life form, which depends on water nutrients. Although considered to be one of the greatest nuisance species of macrophytes, free floating species have rarely grown extensively and caused trouble in the Itaipu Reservoir (Thomaz *et al*. 2003). In contrast to free floating species, *H. amplexicaulis*, an emergent species, is the most frequent species in Itaipu, but it is not common in other reservoirs (Cavenaghi *et al*. 2003, Carvalho *et al*. 2003).

Although there is little threat from the fast growth of native species, two non-native species of macrophytes in Itaipu are of great concern: the emergent species, *U. subquadripara*, which has floating stems and the rooted submerged species, *H. verticillata*. *U. subquadripara* was also very frequent in the reservoir during a previous survey, but it was mistakenly named by Thomaz *et al*. (1999) as *Urochloa plantaginea* (Link) R.D. Webster. *U. subquadripara* is native to Africa and is one of the most common species in Itaipu and in several other Brazilian reservoirs (e.g., Carvalho *et al*. 2003, 2005, Martins *et al*. 2003, 2008). In Itaipu, it covers large areas and creates extensive stands, which compromise access to the water table and reduces the diversity of native species of macrophytes (Michelan *et al*. 2010). *U. subquadripara*, recorded since the first survey in 1995, is continuously increasing in frequency of occurrence and is colonizing new areas in Itaipu (Thomaz *et al*. 2009).

In contrast with *U. subquadripara*, *H. verticillata* was recorded only in the second extensive survey (2008). *H. verticillata* was registered for the first time in Itaipu in January 2007 (Thomaz *et al*. 2009) and has quickly colonized new sites since then. The invasion by *H. verticillata*, which is native to Asia and North Africa, has been facilitated in Itaipu since 2001 by increase in underwater radiation, which enables the rapid growth of this macrophyte (Thomaz *et al*. 2009). According to Thomaz *et al*. (2009), *H. verticillata* arrived from the main river (Paraná River), where this species was recorded earlier than it was recorded in this reservoir. Together with *U. subquadripara*, *H. verticillata* causes concern because it can affect native aquatic assemblages (Hofstra *et al*. 1999, Mony *et al*. 2007, Theel *et al*. 2008).

N. caerulea (native to South Africa), *C. lacryma-jobi* (native to Asia) and *H. coronarium* (native to the Himalayas and Madagascar) were rare in Itaipu and despite being non-native, cannot be considered invasive in this reservoir. This also appears to be the case in other reservoirs in the Upper Paraná Basin, where they have not been recorded (Cavenaghi *et al*. 2003, Carvalho *et al*. 2005, Martins *et al*. 2008). However, *H. coronarium* has been found in natural ecosystems in the State of Minas Gerais (Santos *et al*. 2005).

Differences in the species composition between arms showed a pattern of organization along the reservoir main axis. Assemblages were preferentially composed by free floating species in the arms closer to the riverine zone and by submerged species in the arms positioned from the middle portion of the reservoir down to the dam. These differences may reflect the higher inputs of nutrients in the first arms through the Paraná River and higher light penetration in the others. In fact, there is a conspicuous gradient of sedimentation along the Itaipu Reservoir, with higher inputs of solids and nutrients carried by the Paraná River (Pagioro & Thomaz 2002). Both solids and nutrients decrease as the distance to the dam decreases, resulting in higher water transparency in the lacustrine zone of this reservoir (Pagioro & Thomaz 2002). In accordance with this finding, the underwater light (measured with the Secchi disk) was negatively correlated to scores of the DCA axis 1 and thus, positively correlated with the predominance of two of the most important submerged species: *E. densa* and *H. verticillata*. It shows that underwater light is an important determinant of macrophyte assemblage composition in the Itaipu Reservoir.

Fetch was also an important variable in determining assemblage composition. Fetch is a surrogate of waves, which represent a disturbance to macrophytes; a correlation between fetch and the attributes of macrophyte populations and assemblages have been shown elsewhere (Chambers 1987, Rea *et al*. 1998). Earlier investigations in the Itaipu Reservoir, for example, showed that macrophyte richness was negatively affected by fetch (Thomaz *et al*. 2003).

In summary, the extensive survey of aquatic macrophytes conducted in September 2008 recorded more species than the survey conducted in 1995-1998. The increased number of species may be primarily due to changes in the water physico-chemistry and water drawdown disturbances, although differences in classification systems (s*ensu* Cook 1990) and taxonomic resolutions between the surveys may also account for such differences in species data between the years. Additionally, five of the 87 species recorded were non-native. Two of these non-natives are of special concern because they occur frequently and occupy large marginal areas in the reservoir. Finally, assemblage composition varied among arms and was at least in part determined by underwater radiation and fetch. Future surveys should examine the effects of other abiotic factors (e.g., nutrients) on assemblages and examine assemblage alterations in sites that have been colonized by exotic species. Together with our results, those of such future studies will help provide a scientific basis for the management of aquatic macrophytes and could be used to avoid damage to the reservoir biota and also to the potential water source that is the Itaipu Reservoir.

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RESUMEN

En las últimas tres décadas, las evaluaciones ecológicas rápidas se han convertido en un método importante para medir la biodiversidad de los ecosistemas acuáticos. Estos métodos se pueden utilizar para detectar los impactos antropogénicos y reconocer las extinciones locales o globales de las especies. Se presenta un estudio florístico de las macrófitas acuáticas a lo largo del margen brasileño del embalse Itaipú en 2008 y se compara con un estudio florístico realizado diez años atrás. Se utilizó un análisis de ordenamiento para determinar si hay diferencias en la composición de asociaciones de especies entre los brazos del embalse. Se tomaron muestras de las especies de macrófitos en cada una de las 235 estaciones de muestreo utilizando una embarcación, que fue colocada en tres lugares por punto para registrar las especies de macrófitos y buscar plantas pequeñas. También se recolectaron plantas sumergidas mediante un barrido con la embarcación, moviéndose a velocidad constante durante diez minutos. A las especies de macrófitas individuales se les asignó una forma de vida y se identificaron especies representativas de cada una. Un total de 87 táxones de macrófitas fueron identificados. Las formas de vida "emergentes" tienen el mayor número de especies, seguido por las formas de vida "con raíces sumergidas". Un estudio amplio de los macrófitos realizado en septiembre de 2008 registró más especies que el estudio realizado entre 1995 y 1998. Esto podría deberse a cambios físico-químicos del agua, perturbaciones debidas al nivel del embalse y el largo período de tiempo que hay entre ambos estudios, que pudo haber permitido la colonización natural por otras especies. Además, diferencias en la clasificación de los sistemas y la resolución taxonómica usada en los estudios, que podría producir diferencias en el número de especies registradas. La composición de la asociación de especies varió entre los brazos y se vio afectada por la radiación bajo el agua (medido utilizando un disco de Secchi) y la obtención de información. Se encontraron cinco especies no nativas. Dos no son nativas (*Urochloa subquadripara* y *Hydrilla verticillata*) son de especial preocupación debido a que tienen una alta frecuencia de ocurrencia y ocupan grandes zonas marginales del embalse. Se deben llevar a cabo futuros estudios para determinar el hábitat más frecuentemente colonizado por estas especies. Esto permitiría desarrollar estrategias de manejo para proteger la biota acuática nativa y evitar interferencias con los usos recreativos y comerciales del embalse Itaipú.

Palabras clave: evaluaciones florísticas, plantas acuáticas, forma de vida, Brasil, embalse.

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APPENDIX I

List of taxa registered in Itaipu Reservoir in 2008 (Current) and between 1995 and 1998 (Earlier)

TAXA	LF	Current	Earlier
Characeae			
Chara braunii Gmel	RS		X
Chara guairensis R. Bicudo	RS	X	X
Chara sp.	RS	X	X
Nitella acuminatta C.A.Braun ex. Wallman	RS		X
Nitella furcata (Roxb. Ex Bruz.) Ag., en R.D. Wood	RS		X
Nitella furcata subsp. *mucronata* (A.Braun) R.D. Wood	RS	X	X
Nitella subglomerata A.Braun	RS		X
Nitella sp.	RS	X	
Pteridaceae			
Pteridium sp.	Am	X	
Salviniaceae			
Salvinia auriculata Aubl.	FF	X	X
Salvinia biloba Raddi	FF	X	
Salvinia minima Baker	FF	X	
Thelypteridaceae			
Thelypteris interrupta (Willd.) K. Iwats.	Em	X	
Acanthaceae			
Hygrophila guianensis Nees.	Em		X
Alismataceae			
Echinodorus grandiflorus (Cham. & Schltdl.) Micheli.	Em	X	X
Echinodorus tenellus (Mart. ex Schult. & Schult. f.) Buchenau	RS	X	
Sagittaria montevidensis Cham. & Schltdl.	Em	X	X
Amaranthaceae			
Alternanthera philoxeroides (Mart.) Griseb.	Em	X	X
Alternanthera tenella Colla	Am	X	
Alternanthera sp.	Em		X
Amaryllidaceae			
Crinum sp.	Am	X	
Apiaceae			
Eryngium sp.	Em	X	X
Araceae			
Lemna valdiviana Phil.	FF	X	X
Pistia stratiotes L.	FF	X	X
Spirodela intermedia W. Koch	FF	X	X
Wolffia brasiliensis Wedd.	FF	X	X
Araliaceae			
Hydrocotyle cf. *pussilla* A. Rich.	FL	X	X
Hydrocotyle cf. *ranunculoides* L.	Em		X
Asteraceae			
Eclipta alba (L.) Hassk.	Em	X	
Eupatorium sp.	Am	X	
Gnaphalium spicatum Mill.	Am	X	

APPENDIX I (Continued)

TAXA	LF	Current	Earlier
Cleomaceae			
Cleome hassleriana Chodat	Am	X	X
Commelinaceae			
Commelina cf. *erecta* L.	Em	X	
Commelina nudiflora (L.) Brenan	Em		X
Commelina sp.	Em	X	
Convolvulaceae			
Ipomoea cairica (L.) Sweet	Em	X	
Ipomoea carnea subsp. *fistulosa* (Mart. ex. Choisy) D.F. Austin	Em	X	
Ipomoea sp.	Em		X
Cucurbitaceae			
Undetermined	Am	X	
Cyperaceae			
Cyperus sesquiflorus (Tor.) Mattf. et Kiik	Em		X
Cyperus ferax Rich.	Em		X
Cyperus diffusus Vahl.	Em		X
Eleocharis minima Kunth	RS	X	
Eleocharis acutangula (Roxb.) Schult.	Em	X	
Eleocharis interstincta (Vahl) Roem. & Schult.	Em	X	
Eleocharis montana (Kunth) Roem. & Schult.	Em	X	
Eleocharis sp.	Em	X	X
Oxycaryum cubense (Poepp. & Kunth) Palla	Ep	X	
Rhynchospora corymbosa (L.) Britton	Em	X	
Scleria sp.	Em		X
Euphorbiaceae			
Caperonia castaneifolia (L.) A. St. -Hil.	Em	X	X
Haloragaceae			
Myriophyllum aquaticum (Vell.) Verdc.	RS	X	X
Hydrocharitaceae			
Egeria densa Planch.	RS	X	X
Egeria najas Planch.	RS	X	X
Hydrilla verticillata (L. f.) Royle	RS	X	
Limnobium laevigatum (Humb. & Bonpl. ex Willd.) Heine	FL	X	
Ottelia sp.	RS		X
Fabaceae			
Aeschynomene sp.	Em	X	
Mimosa sp.	Am	X	
Vigna sp.	Em	X	
Lentibulariaceae			
Utricularia foliosa L.	FS	X	
Utricularia gibba L.	FS	X	
Utricularia sp.	FS	X	X
Malvaceae			
Hibiscus sororius L.	Em	X	
Menyanthaceae			

APPENDIX I (Continued)

TAXA	LF	Current	Earlier
Nymphoides humboldtiana (Kunth) Kuntze	FL	X	X
Nymphaeaceae			
Nymphaea amazonum Mart. & Zucc.	FL	X	
Nymphaea caerulea Savigny	FL	X	
Nymphaea sp.	FL		X
Onagraceae			
Ludwigia helminthorrhiza (Mart.) H. Hara	Em	X	
Ludwigia lagunae (Morong) H. Hara	Em	X	
Ludwigia leptocarpa (Nutt.) H. Hara	Em	X	
Ludwigia suffruticosa (L.) H. Hara	Em		X
Ludwigia sp.	Em	X	
Phyllanthaceae			
Phyllanthus sp.	Em	X	
Plantaginaceae			
Bacopa sp.	RS	X	
Poaceae			
Andropogon bicornis L.	Am	X	X
Coix lacryma-jobi L.	Em	X	X
Echinochloa sp.	Em	X	
Eriochloa punctata (L.) Desv.	Em		X
Hymenachne amplexicaulis (Rudge) Ness	Em	X	X
Panicum dichotomiflorum Michx.	Em	X	X
Panicum maximum Jacq.	Am	X	X
Panicum mertensii Roth	Em		X
Panicum pernambucense (Spreng.) Mez ex Pilg.	Em	X	X
Panicum repens L.	Em	X	X
Paspalum conspersum Schrader ex. Schulter	Em		X
Paspalum cf. *morichalense* Davidse, Zuloaga & Filg.	Em	X	
Paspalum repens P.J. Bergius	Em	X	X
Pennisetum purpureum Schum	Am	X	X
Setaria sp.	Em	X	X
Urochloa subquadripara (Trin.) R.D. Webster	Em	X	
Urochloa plantaginea (Link) R. D. Webster *	Em		X
Undetermined	Em	X	
Polygonaceae			
Polygonum acuminatum Kunth	Em	X	X
Polygonum ferrugineum Wedd.	Em	X	X
Polygonum hydropiperoides Michx.	Em	X	X
Polygonum meisnerianum Cham. & Schltdl.	Em	X	
Polygonum punctatum Elliott	Em	X	X
Polygonum stelligerum Cham.	Em	X	
Polygonum sp.	Em	X	
Pontederiaceae			
Eichhornia azurea (Sw.) Kunth	Em	X	X
Eichhornia crassipes (Mart.) Solms	FF	X	X

APPENDIX I (Continued)

TAXA	LF	Current	Earlier
Heteranthera cf. *limosa* (Sw.) Willd.	RS	X	
Pontederia cordata L.	Em		X
Potamogetonaceae			
Potamogeton obtusifolius Mert. & W. D. J. Koch	RS		X
Potamogeton pusillus L.	RS		X
Potamogeton sp.	RS	X	X
Rubiaceae			
Emmeorhiza umbellata (Spreng.) K. Schum.	Em	X	
Typhaceae			
Typha domingensis Pers.	Em	X	X
Zingiberaceae			
Hedychium coronarium J.König	Em	X	

(LF=life forms: Em=emergent; RS=rooted submerged; FF=free floating; Am=amphibious; FL=floating leaved; FS=free submerged and Ep=epiphyte.)
*=Corrected to *Urochloa subquadripara*.