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# Aquatic macrophyte community varies in urban reservoirs with different degrees of eutrophication

## A comunidade de macrófitas aquáticas varia entre reservatórios urbanos com diferentes graus de eutrofização

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**Abstract: Aim:** Investigate spatial and temporal variation in the aquatic macrophyte community in four urban reservoirs located in Curitiba metropolitan region, Brazil. We tested the hypothesis that aquatic macrophyte community differ among reservoirs with different degrees of eutrophication. **Methods:** The reservoirs selected ranged from oligotrophic/mesotrophic to eutrophic. Sampling occurred in October 2011, January 2012 and June 2012. Twelve aquatic macrophytes stands were sampled at each reservoir. Species were identified and the relative abundance of aquatic macrophytes was estimated. Differences among reservoirs and over sampling periods were analyzed: i) through two-way ANOVAs considering the stand extent (m) and the stand biodiversity – species richness, evenness, Shannon-Wiener index and beta diversity (species variation along the aquatic macrophyte stand); and ii) through PERMANOVA considering species composition. Indicator species that were characteristic for each reservoir were also identified. **Results:** The aquatic macrophyte stand extent varied among reservoirs and over sampling periods. Species richness showed only temporal variation. On the other hand, evenness and Shannon-Wiener index varied only among reservoirs. The beta diversity of macrophyte stands did not vary among reservoirs or over time, meaning that species variability among aquatic macrophyte stands was independent of the stand extent and reservoir eutrophication. Community composition depended on the reservoir and sampling period. **Conclusions:** Our results support our initial expectation that reservoirs of different degrees of eutrophication have different aquatic macrophyte communities. As a consequence, each reservoir had particular indicator species. Therefore, monitoring and management efforts must be offered for each reservoir individually.

**Keywords:** aquatic plants, biodiversity, beta-diversity, temporal variation, eutrophication.

**Resumo: Objetivo:** Investigar variações espaciais e temporais na comunidade de macrófitas aquáticas em quatro reservatórios urbanos localizados na região metropolitana de Curitiba, Brasil. Nós testamos a hipótese que a comunidade de macrófitas aquáticas varia entre reservatórios com diferentes graus de eutrofização. **Métodos:** Os reservatórios selecionados diferem de oligotrófico/mesotrófico à eutrófico. As coletas ocorreram em Outubro de 2011, Janeiro de 2012 e Junho de 2012. Doze bancos de macrófitas aquáticas foram amostrados em cada reservatório. Espécies de macrófitas aquáticas foram identificadas e suas abundâncias relativas foram estimadas. Foram analisados diferenças entre os reservatórios e períodos amostrais: i) através de ANOVAs *two-way* para a extensão (m) e biodiversidade do banco – riqueza de espécies, equitabilidade, índice de Shannon-Wiener e diversidade beta (variação das espécies ao longo do banco de macrófitas aquáticas); e ii) através da PERMANOVA para a composição de espécies. Espécies indicadoras que foram caracterizadas para cada reservatório foram identificadas. **Resultados:** A extensão do banco de macrófitas aquáticas variou entre reservatórios e entre os períodos amostrados. A riqueza de espécies apresentou apenas variação temporal. Em contrapartida, equitabilidade e índice de Shannon-Wiener variaram apenas entre reservatórios. A diversidade beta dos bancos de macrófitas aquáticas não variou entre reservatórios e períodos, indicando que a variação de espécies ao longo dos bancos de macrófitas aquáticas foi independente da extensão do banco e das condições eutróficas do reservatório. A composição da comunidade dependeu do reservatório e período amostrado. **Conclusões:** Nossos resultados suportaram nossas expectativas iniciais de que os reservatórios de diferentes graus de eutrofização possuem diferentes comunidades de macrófitas aquáticas. Como uma consequência, cada reservatório apresentou espécies indicadoras particulares. Portanto, os esforços de monitoramento e manejo devem ser oferecidos para cada reservatório individualmente.

**Palavras-chave:** plantas aquáticas, biodiversidade, diversidade beta, variação temporal, eutrofização.

## 1. Introduction

Aquatic macrophytes play a central structuring role in aquatic ecosystems, forming a heterogeneous and complex habitat that determines the abundance and biodiversity of aquatic flora and fauna (Thomaz and Bini, 2003). In urban reservoirs, restoration and biodiversity promotion is a major focus of managers (Moreno and Callisto, 2006), highlighting the importance of studies on determinants of aquatic macrophyte composition. Therefore, understanding how aquatic macrophyte communities vary in urban reservoirs is central to support management actions and conservation in such degraded ecosystems. Also, variation in aquatic plant community indicate the sources of variation in organic matter of aquatic ecosystems (Pedralli, 2003), given that this community is considered the main source of organic matter in lentic ecosystems (Wetzel, 2001). A general trend is that a progressive eutrophication in aquatic systems, especially in urban reservoirs, provides abundance occurrence of aquatic macrophyte (Pedralli, 2003).

The community of aquatic macrophyte varies between habitats and over time depending on local environmental conditions (Lacoul and Freedman, 2006; Thomaz et al., 2009; Padial et al., 2009). Particularly in reservoirs, eutrophication processes and the appearance of shallow environments, favor the establishment of aquatic plants (Bini et al., 1999). The extent of occurrence and composition may be affected by the size of the lake, the features of physical margins (e.g. slope) and limnological characteristics of the water (e.g. nutrient concentration). Even within the same geographical region, reservoirs with different degrees of eutrophication may be quite variable in aquatic plant communities. Then, describing how aquatic macrophytes vary spatially and temporally in urban reservoirs is of outmost importance. Indeed, one of the big gaps in studies on aquatic macrophyte in the Neotropics is the lack of research addressing the testing of ecological hypotheses (Padial et al., 2008).

In reservoirs for hydroelectricity generation, the highly variable hydrological regime caused by frequent fluctuations can affect species richness (Thomaz et al., 1999; Thomaz and Bini, 1998; Maltchik et al., 2007). However, water supply reservoirs are stable environments where water level is commonly maintained at a fixed level to ensure its functioning. Thus, major temporal changes in the aquatic plant community are not expected in urban reservoirs managed for water supply. Indeed, previous studies have also suggested that aquatic macrophytes have little variation in urban lakes due to water level control (Papastergiadou et al., 2010). In urban reservoirs, it seems that eutrophication is the source of aquatic macrophyte community variation (Hilt et al., 2010; Papastergiadou et al., 2010). In this case, submerged aquatic macrophytes are less common in reservoirs with high level of eutrophication, whereas free-floating and emergent plants become more abundant (Hilt et al., 2010; Papastergiadou et al., 2010). The reasons for such community composition change are related to water turbidity positively related to the degree of eutrophication, decreasing light availability for submerged plants (Hilt et al., 2010). The same pattern is expected for aquatic macrophyte stands, that tends to be long and poorly biodiverse in eutrophic reservoirs (Thomaz and Bini, 1998).

We aimed to evaluate spatial and temporal variations of aquatic macrophytes in urban water supply reservoirs in the metropolitan region of Curitiba city, Brazil. Aquatic macrophyte stand extent and biodiversity were compared between four reservoirs which differ mainly in the degree of eutrophication. In addition, temporal variation in the communities was evaluated over three sampling periods. Formally, we tested the following hypotheses: a) the highest biodiversity will be in reservoirs with the lowest degree of eutrophication, b) the aquatic macrophyte community composition will differ among reservoirs; c) there is no temporal variation in biodiversity and community composition. We expect low temporal changes in aquatic macrophytes given the high temporal stability on water level and environmental features that urban reservoirs for water supply may promote.

## 2. Methods

The study was conducted in four urban reservoirs for water supply in the metropolitan region of a major city in South Brazil - Curitiba city (Figure 1): Iraí (25°23'55.85"S; 49°05'57.18"W), Passaúna (25°30'01.35"S; 49°22'20.20"W), Piraquara I (25°29'08.86"S; 49°00'35.66"W) and Piraquara II (25°29'49.01"S; 49°03'55.95"W). Reservoirs are managed by the environmental sanitation company of Paraná State (SANEPAR). A previous report indicates that these water supply reservoirs differ in water quality and degree of eutrophication (IAP, 2009). Considering the trophic degree, the reservoirs can be ranked as: Piraquara I (Mesotrophic/Oligotrophic) < Passaúna (Mesotrophic) < Iraí (Eutrophic) (see IAP, 2009). In this report, the Piraquara II reservoir was not evaluated, but unpublished data also indicated an intermediate degree of eutrophication, i.e., a Mesotrophic level (personal communication with SANEPAR staff). Compared to Piraquara I reservoir, Piraquara II is located in a region with higher level of urbanization, which can explain why Piraquara I (upstream, Figure 1) is considered Oligotrophic/Mesotrophic, and Piraquara II (downstream,

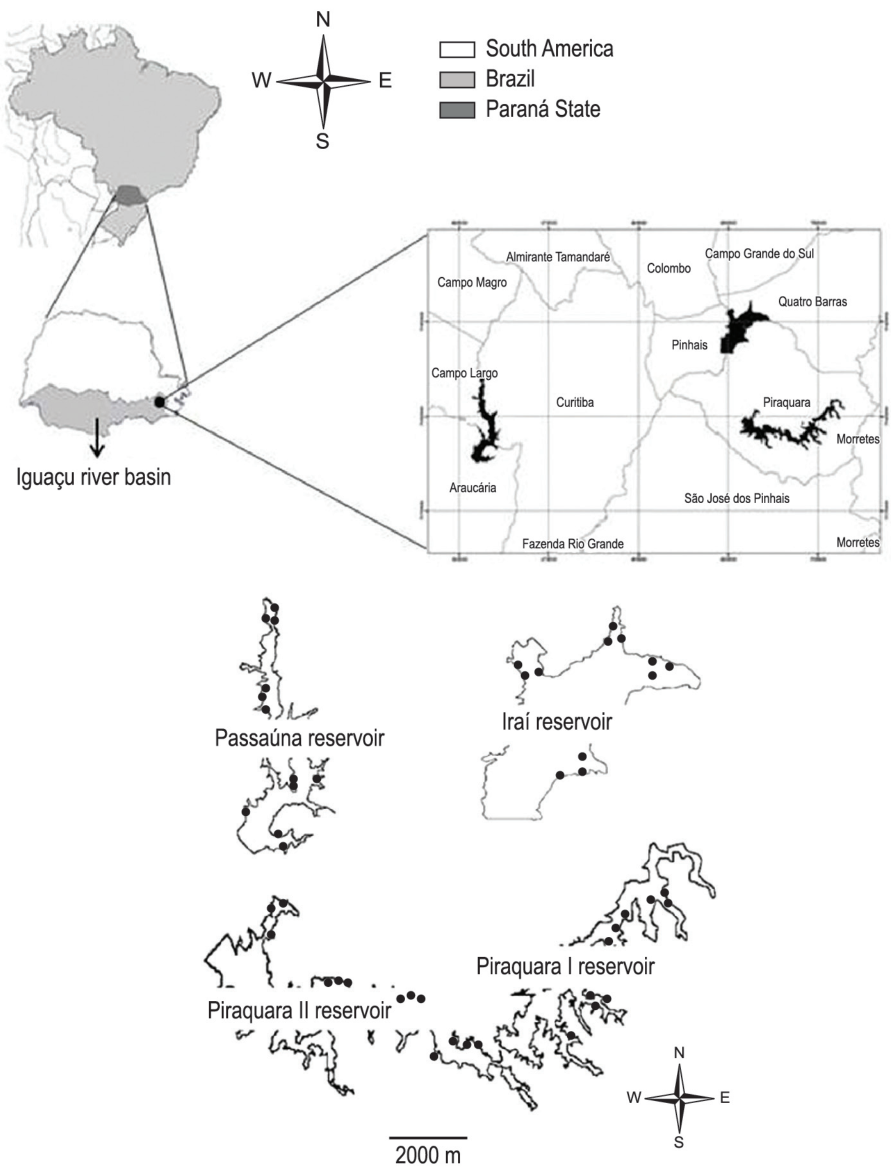



**Figure 1.** Map showing reservoirs geographical position.

Figure 1) is considered here as Mesotrophic. We highlight that we could not properly classify the reservoirs according to their eutrophication degree because we did not have financial resources to carry out nutrient and chlorophyll-*a* analyses. However, we sampled limnological variables to highlight differences between reservoirs and describe the quality of the water over the study period. We used a multi-parameter probe to estimate, *in situ*, the water temperature (°C), dissolved oxygen ($mgO_2\ L^{-1}$), percentage of oxygen saturation ($\%O_2$), electrical conductivity (m*S*), pH and total suspended solids ($mg\ L^{-1}$). The water transparency was checked using the Secchi disk depth (cm). These measurements were conducted with water collected in the middle of each aquatic macrophyte stand. The values of these variables are detailed in the Appendix, and they provide evidence for the degree of eutrophication described above.

We carry out samplings in three periods: October 2011 (spring), January 2012 (summer) and June 2012 (winter). We sampled these periods given that, if there is temporal variation, then it should be associated to seasons. Environmental variability across reservoirs and sampling periods are detailed in the Appendix. We recognize that temporal patterns can only be fully described by long term studies, but our goal was to generate evidence (or not) of temporal variation in communities. Samplings within reservoirs were carried out in four sampling points. For that, each reservoir was divided into four sections along their extent (riverine, transition and lacustrine portions). In each section, one sampling point was randomly selected, within which three aquatic macrophyte stands were randomly sampled (Figure 2). The three aquatic macrophytes stands were used only to better represent the sampling point. Thus, 12 aquatic macrophyte stands were sampled in each reservoir (Figure 2), but only the communities of the four sampling points (aggregated across the stands sampled) were used to compare reservoirs and sampling periods. The approximate locations of the sampled aquatic macrophyte stands are shown in Figure 1.

In each aquatic macrophyte stand, squares of 0.5 x 0.5 m were used to estimate the relative abundance and to identify taxa present. The squares were sampled from across the aquatic macrophyte stand at every 2m – measured from the middle of one square to the middle of the next one. The percentage coverage of each taxon within the square was visually estimated.

We used a two-way Analysis of Variance (two-way ANOVA) to compare the extent of aquatic macrophyte stands among reservoirs and sampling periods. Thus, biodiversity were also compared among reservoirs and sampling periods through two-way ANOVAs. The variables used to describe the biodiversity were: species richness, Pielou's evenness index and Shannon-Wiener diversity index. We cannot ignore the possibility that a gradual increase in species richness may be due to a sampling bias. After several samplings, the detection of rare species in aquatic macrophyte stands may became more likely. Nevertheless, all biological material was extensively checked to avoid such bias. Another biodiversity parameter used was the species variation among the aquatic macrophyte stands, i.e., the beta diversity of stands. We expect that variability of species will be high in less degraded

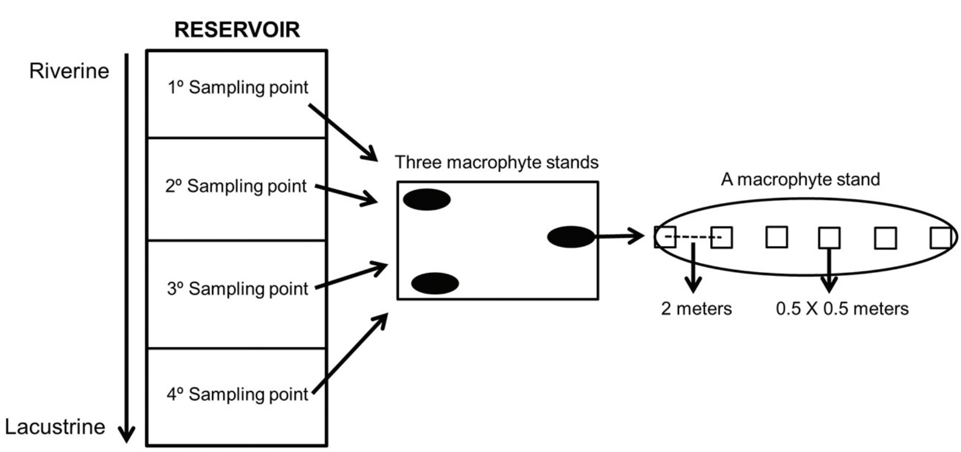



**Figure 2.** Sampling scheme in the reservoirs and in each macrophyte stand. The reservoir area was divided into four sections. In each section, three randomly chosen macrophyte stands were sampled. In each macrophyte stand, sampling quadrats (0.5 X 0.5 m) were placed from the shore to the end of the stand distancing between each other every two meters.

reservoir due to a low probability of nuisance plant development. The index of Whittaker modified by Harrison (βH1) (Magurran, 1988) was used to estimate species variability. This index is suitable to compare beta diversity in aquatic macrophyte stands with different extents. As a possible explanation of the beta diversity, we have also compared the effects of reservoirs and sampling periods on the variability of water depths along aquatic macrophyte stands. The reasoning is that a stand with more depth variability will have more species variability and for this reason we used the coefficient of variation of the depths measured in each quadrat. Finally, we correlated beta diversity with variability in stand depths. We used log-transformations when the assumption of homogeneity of variances (estimated by Levene's test) was not met in two-way ANOVAs.

We performed a Non-parametric Multivariate Analysis of Variance (PERMANOVA) (Anderson, 2001) to evaluate the effect of reservoirs and sampling periods in the community composition of aquatic macrophytes. We also conducted a Non-metric Multidimensional Scaling (NMDS) to visualize differences in community composition. These analyses were made by using Bray-Curtis distance index to generate dissimilarity matrices.

For reservoirs with different community compositions, indicator species were identified using IndVal analysis (Dufrêne and Legendre, 1997). A good indicator species is that has high specificity (i.e. occur only in a certain reservoir) and fidelity (occur in all sampling points of a certain reservoir). In this analysis, matrices of the reservoirs at different periods were analyzed together. Thus, we evaluated species that may be considered indicative of a particular reservoir, independent on the sampling period. We did not identify indicator species per sampling period given that our interest was to propose species that are typical for each reservoir even if there is a temporal variation in community composition. Indeed, temporal variation was not evaluated because it hinders the use of indicator species by those responsible for the management and conservation. We used the software STATISTICA 7.0 (StatSoft Inc., 2005) and the R language and environment for statistical computing (R Development Core Team, 2009) to conduct our analyses.

## 3. Results

The level of variability in aquatic macrophyte stand extent differed between reservoirs and periods (Levene $F = 4.92$, $df = 6$, $P < 0.001$). Even so, there was significant and independent effect of reservoirs and sampling periods on aquatic macrophyte stand extent (Figure 3). The stands were significantly smaller in June 2012 (Figure 3). The largest stands were found in Passaúna and Piraquara II reservoirs, followed by Iraí and Piraquara I (Figure 3).

Species richness differs significantly only over sampling periods. The aquatic macrophyte community became gradually richer in species over time (Figure 3). Evenness differed significantly among reservoirs, but not over sampling periods (see two-way ANOVA results in Figure 3). The interaction between these factors was not significant. Aquatic macrophyte stands in Iraí and Passaúna reservoirs had lower evenness than in Piraquara River reservoirs (Figure 3). This indicates that one or more species is dominating aquatic macrophyte stands in Iraí and Passaúna reservoirs, regardless of the sampling periods. The Shannon-Wiener index also varied among reservoirs, regardless of the sampling period (see two-way ANOVA results in Figure 3). This diversity index was constant over time (Figure 3). Piraquara river reservoirs were more diverse than the Iraí reservoir (Figure 3). Moreover, the Passaúna reservoir was less diverse than the Piraquara II reservoir (Figure 3). The beta diversity of aquatic macrophyte communities was similar between reservoirs ($F = 1.07$, $df = 3$, $P = 0.373$) and constant over sampling periods ($F = 1.06$, $df = 2$, $P = 0.354$). There was also no significant interaction were between these factors ($F = 1.65$, $df = 6$, $P = 0.160$). Not surprisingly, the variability in depth along aquatic macrophyte stands also did not depended on reservoirs ($F = 2.09$, $df = 3$, $P = 0.119$), sampling periods ($F = 1.85$, $df = 2$, $P = 0.171$) and their interaction ($F = 1.41$, $df = 6$, $P = 0.239$). However, variation of depth significantly correlated to beta diversity ($r = 0.287$, $P = 0.048$).

The species composition of aquatic macrophytes varied among reservoirs depending on sampling periods, according to PERMANOVA (Figure 4). From a NMDS ordination, it was observed that there is always some reservoir that differs from the others, but which reservoir was different was not always the same in all sampling periods (Figure 4). In October 2011, the Passaúna reservoir had a distinct community composition. In January and June 2012, the Iraí reservoir was the most different, while the two Piraquara river reservoirs had similar aquatic macrophyte compositions. Although factors interact in PERMANOVA, temporal variation can be observed for all reservoirs (Figure 4). Spatial variability of compositions was particularly low in

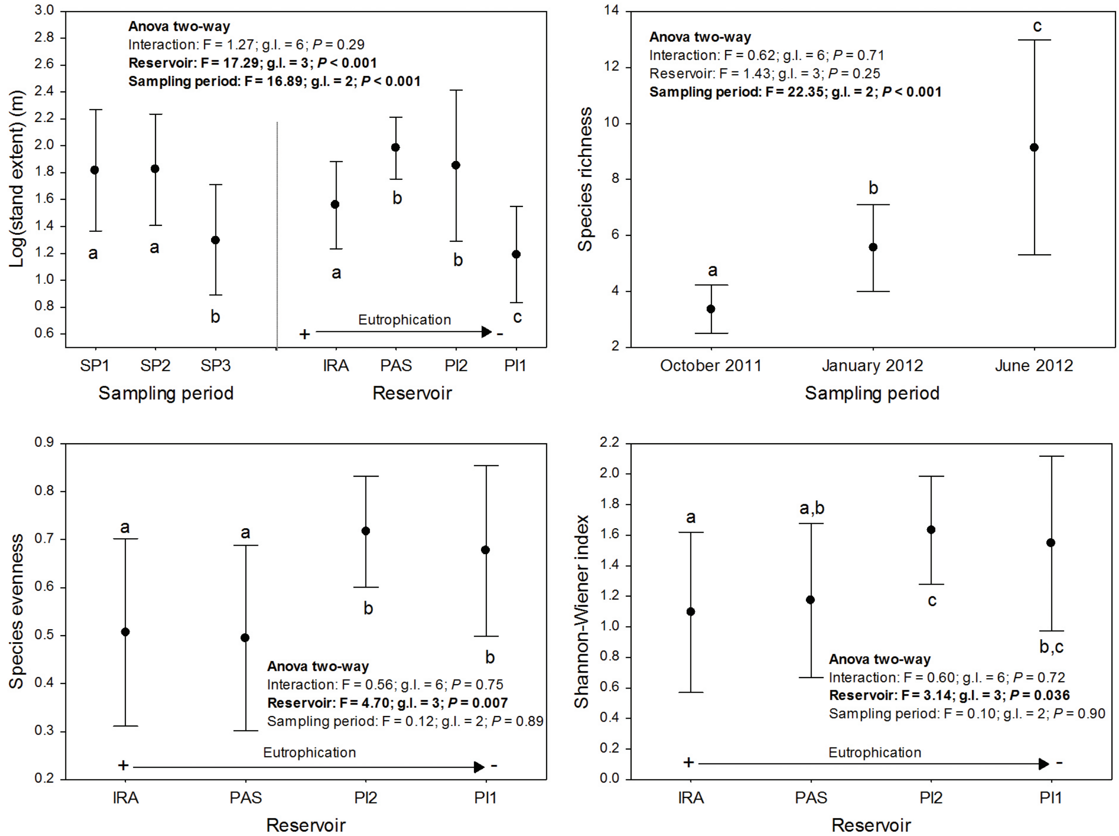


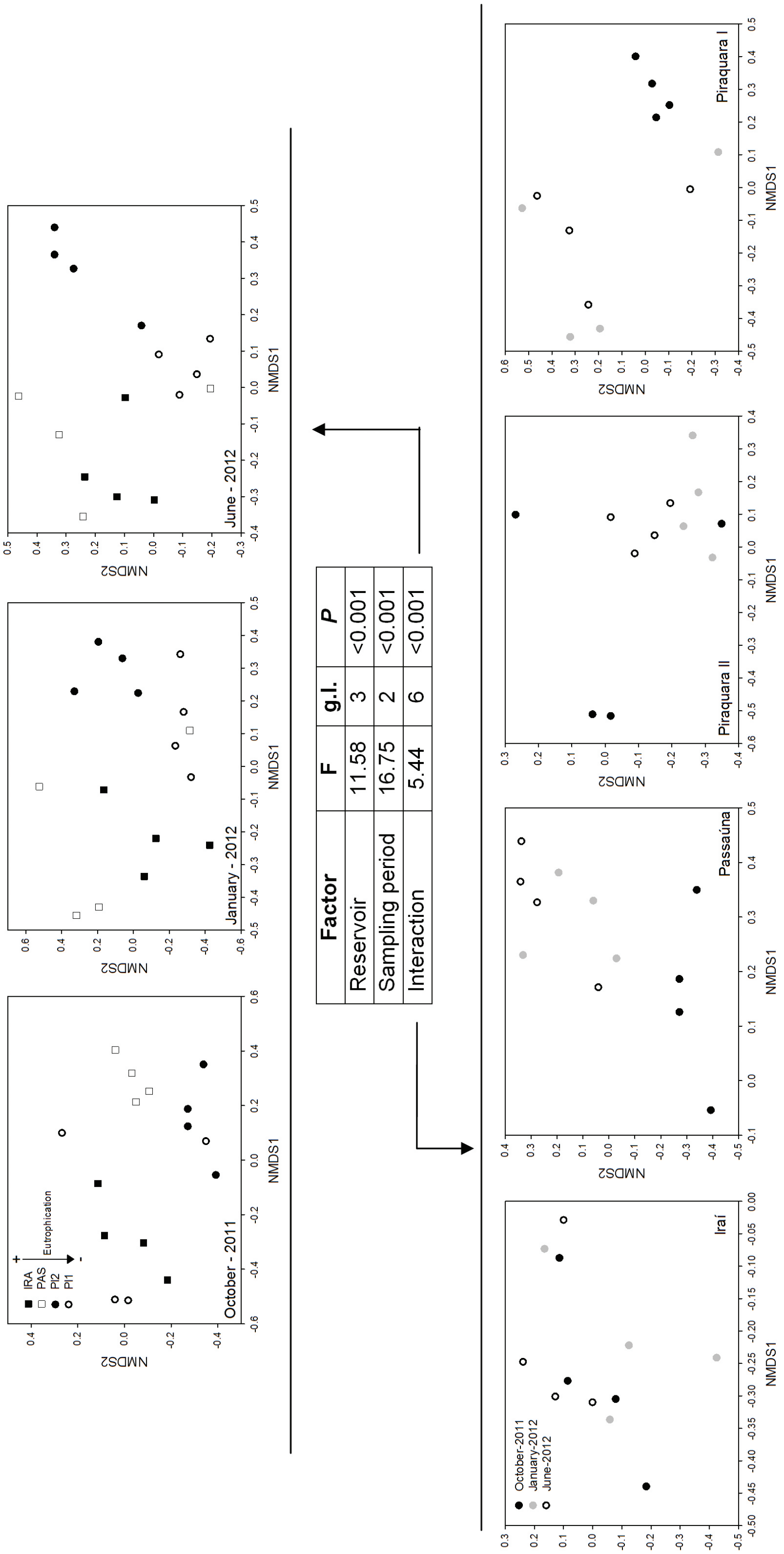

**Figure 3.** Mean ± standard deviation of the log-transformed extent of aquatic macrophyte stands (m) within reservoirs and within sampling periods; species richness over sampling periods; species evenness within reservoirs; Shannon-Wiener diversity within reservoirs. Results of an ANOVA two-way are shown in the graph. Different letters indicate statistically different values according to a Fisher's LSD test (P <0.05). If interaction is not significant, then the graph shows difference only for the significant factor. SP1 = October 2011; SP2 = January 2012; SP3 = June 2012; IRA = Iraí reservoir (the highest degree of eutrophication); PAS = Passaúna reservoir; PI2 = Piraquara II reservoir; PI1 = Piraquara I reservoir (the lowest degree of eutrophication).

Piraquara I reservoir in October 2011 (see Figure 4). Moreover, composition of the reservoir Piraquara II was more homogeneous in January and June 2012 compared to October 2011 (Figure 4).

According to IndVal analysis, the four reservoirs had different indicator species (Table 1). Given that most indicator species were emergent, there was no life form (i.e., emergent, fixed with floating leaves, free-floating, and submerged, see Thomaz and Bini, 2003) that was indicative of high or low degrees of eutrophication (Table 1).

## 4. Discussion

According to our initial expectations, we found clear spatial variation in aquatic macrophytes, suggesting that the degree of eutrophication is a major driving force of the aquatic plant biodiversity and composition in urban reservoirs. We also found evidence of temporal variability in some of the metrics used to describe the aquatic macrophyte community. One explanation for the low temporal variability may be due to the short time span. Long-term data may reveal clearer temporal patterns in aquatic macrophyte composition (Thomaz et al., 2009). Taken together, our results have great theoretical and practical importance for the management and conservation of aquatic biodiversity. We generated evidence that conservation efforts and management aiming to improve aquatic biodiversity should focus on reducing anthropic eutrophication independent on temporal variation. In fact, the sources of spatial and temporal variation on aquatic communities have been intensively studied (Junk et al., 1989; Maltchik et al., 2007; Thomaz et al., 2009; Padial et al., 2012), including studies carried out in reservoirs (Bini et al., 1999; Carvalho et al., 2003; Martins et al., 2003; Mormul et al., 2010).




| Factor | F | g.l. | P |
|---|---|---|---|
| Reservoir | 11.58 | 3 | <0.001 |
| Sampling period | 16.75 | 2 | <0.001 |
| Interaction | 5.44 | 6 | <0.001 |

**Figure 4.** Results of a PERMANOVA and non-metric multidimensional scaling (NMDS) showing differences between the composition of aquatic macrophytes over sampling periods for each reservoir (reservoirs degree of eutrophication decrease from left to right) and among reservoirs for each sampling period. The amount of stress for the first two axes is 17.82. IRA = Iraí reservoir (the highest degree of eutrophication); PAS = Passaúna reservoir; PI2 = Piraquara II reservoir; PI1 = Piraquara I reservoir (the lowest degree of eutrophication).

**Table 1.** Indicator value index and associated probability of type I error (*P*) for the species identified as being significant bioindicators for each reservoir analyzed. Life form (Thomaz and Bini, 2003) of indicator species is also shown.

| Species | Life form | Reservoir | Indicator Value | *P* |
|---|---|---|---|---|
| *Panicum aquaticum* | Emmergent | Iraí | 0.583 | 0.001 |
| *Leersia hexandra* | Emmergent | Iraí | 0.333 | 0.011 |
| *Alternanthera philoxeroides* | Emmergent | Iraí | 0.424 | 0.047 |
| *Ludwigia leptocarpa* | Emmergent | Passaúna | 0.282 | 0.035 |
| *Salvinia minima* | Free-floating | Piraquara I | 0.333 | 0.011 |
| *Cyperus luzulae* | Emmergent | Piraquara I | 0.413 | 0.019 |
| *Carex brasiliensis* | Emmergent | Piraquara II | 0.333 | 0.006 |
| *Paspalum mandiocanum* | Emmergent | Piraquara II | 0.367 | 0.008 |
| *Myriophyllum aquaticum* | Submerged | Piraquara II | 0.591 | 0.046 |

In reservoirs with high water level stability, such as managed urban reservoirs (Papastergiadou et al., 2010), it is expected that the number of species increase over sampling time, explaining our results. Beyond promoting an increase of aquatic plants, reservoirs have impacts on aquatic biodiversity given they can act as stepping-stones for biological invasions (Havel et al., 2005). Reservoirs increase the area of standing waters and are favorable ecosystems for aquatic plants (Thomaz, 2002). The low intensity of environmental variability can promote co-existence of species which gradually colonize the reservoir (Papastergiadou et al., 2010). After major disturbances, it is expected that the regional community is "homogenized" (Thomaz et al., 2007), causing local extinction of rare species (Glenn and Collins, 1992). Our results also indicate that the relative dominance of species is temporally invariable, suggesting that the arrival of new species does not change the general abundance distribution of the community. Consequently, the Shannon-Wiener index also remained unchanged.

As expected, biodiversity differed among reservoirs, particularly in evenness. The most plausible explanation for these results is related to the fact that aquatic macrophyte are clearly affected by variables related to the degree of eutrophication of ecosystems (Lacoul and Freedman, 2006). In fact, the oligo-mesotrophic reservoirs (Piraquara I and II) were more diverse than reservoirs with the highest degree of eutrophication (Iraí and Passaúna).

The size of stands may also indicate the nutrient status of the reservoirs, given that in reservoirs with high nutrient concentrations, aquatic macrophytes can develop large stands (Pieterse and Murphy, 1990). However, our results do not support the expectation that eutrophic reservoirs have larger macrophyte stands. Probably, an increase in nutrients will lead to an extensive algae and free-floating plant growth, reducing the transparency of the water (Barbosa et al., 1999). Then, aquatic macrophyte stands can be smaller in eutrophic reservoirs than those located in reservoirs with low nutrient concentration. Thus, our initial expectation about the extent of aquatic macrophyte stands might be conceptually mistaken when we do not evaluate differences in life forms. In this case, only the extent of emergent and free-floating stands should be higher in eutrophic reservoirs.

Despite the difference in relation to biodiversity, reservoirs had the same pattern of beta diversity along stands. The stability of the local organization of aquatic macrophyte is directly related to environmental changes (Padial et al., 2009). Although reservoirs vary between each other considering the degree of eutrophication, they have the same pattern of local organization. Depth variability from the littoral to the limnetic zone reflects the slope of marginal areas, which could also explain beta-diversity along an aquatic macrophyte stand (i.e. aquatic macrophyte zonation, see Thomaz and Bini, 2003). Beta-diversity should be high when depth variability is high. Indeed, the correlation between depth variability and beta-diversity was significant, albeit weak (see results). Nevertheless, depth variability was similar among reservoirs. The study of beta-diversity is a complex challenge that has recently inspired ecologists (Melo et al., 2011). Our study was not designed to understand how beta-diversity varies at different spatial scales. Even so, we can observe by the dispersion of points in NMDS graphs that species variation among sampling points may depend on reservoir and sampling period.

The mechanisms that cause variation in species composition between local communities of a metacommunity are generally grouped into those related to the niche and those related to dispersal limitation (Beisner et al., 2006; Nabout et al., 2009). While it will require further analysis to determine (see Peres-Neto et al., 2006), our results suggest that both mechanisms may be important in explaining variations among reservoirs and over sampling periods. For example, differences among the reservoirs Iraí, Piraquara I and II should be related to local environmental differences, given that individuals and species can be easily dispersed between these reservoirs that are separated by only few kilometers (see Figure 1). On the other hand, differences between Passaúna and the other reservoirs can also be explained by dispersal limitation, since Passaúna reservoir is located on the opposite side of the city, and there is no watercourse along which plants can easily disperse without a physical barrier. Since aquatic macrophytes disperse mostly *via* vegetative propagules (Thomaz and Bini, 1998), a long distance is indeed a barrier for the dispersal of individuals. The mechanisms driving metacommunities should be further studied in urban reservoirs. Furthermore, another great challenge is to understand the mechanisms driving temporal variation on metacommunities, since the magnitudes of differences between the sampling periods depended on the reservoir. Indeed, we observed that reservoirs having different community composition in a certain sampling period can be similar among each other in another sampling period. This may indicate that either aquatic macrophyte dispersal among reservoirs is temporal variable, or environmental heterogeneity among reservoirs depends on time (see also Padial et al., 2009).

As expected, differences between reservoirs were also evident in them having distinct indicator species. Such information, in addition to providing evidence of what kind of vegetation exists in each reservoir, can also be useful for the management and conservation of water resources in urban reservoirs. The focus here was to identify the species typical for each reservoir. However, these species are only a starting point for identifying the environmental indicators of these distinct reservoirs. In fact, aquatic macrophytes are commonly used to indicate environmental conditions (Pedralli, 2003). The indicator species (Table 1) did not allow us to draw any generalization about the life forms that occurs in reservoirs that are more or less eutrophic. We have low biological information of the species in Table I to state that those occurring in Iraí reservoir are typical from ecosystems with high degree of eutrophication and those occurring on Piraquara II reservoir are typical from oligo/mesotrophic ecosystems. Among the species in Table 1, *Alternanthera philoxeroides* was already identified as typical from ecosystem with high degree of dissolved nutrients in Australian rivers (Sainty et al., 1998). Also, the only submerged species that was selected as a good indicator was *Myriophyllum aquaticum*. This species was an indicator of the Piraquara II reservoir, the one with the least amount of eutrophication. Indeed, submerged aquatic macrophytes may develop mainly in waters with low biogenic turbidity, whereas eutrophic reservoirs are expected to have a high biogenic turbidity (Hilt et al., 2010). Beyond trying to find generalizations about the indicator species, our results can stimulate further studies about plant physiology. Such studies could explain how the indicator species identified here can thrive in high levels of eutrophication.

Reservoirs for water supply of the metropolitan region of Curitiba are considered areas of high concentration of biodiversity (IAP, 2009). The importance of studies in these habitats is highlighted by the fact that the watercourses of Curitiba are among the most polluted in Brazil (data from IBGE, 2010). Aquatic macrophyte community is central to the management and conservation effort given their central role in promoting diversity in various types of aquatic bodies and other aquatic communities (Thomaz and Bini, 2003). In summary, our results highlight that the aquatic macrophyte community, even in stable systems as reservoirs, and even in ecosystems in close proximity, have a significant spatial variability. Our findings provides evidence that co-existence of a high diversity of species occurs in urban habitats of a major metropolitan region. A high diversity of aquatic macrophytes may promote regional diversity of several biological groups that interact directly and indirectly with this community (Thomaz and Bini, 2003). Another implication of our findings is that monitoring and management efforts must be planned for each reservoir individually (Padial et al., 2012). Indeed, we found evidence that the degree of eutrophication of the reservoirs drives aquatic macrophyte community variation. Also, the short time period examined here did not allow us to identify clear temporal patterns, such as seasonality on community composition and diversity. This emphasizes the need for continued monitoring of aquatic plants in urban reservoirs of Curitiba metropolitan region, and suggests that generalizations for management cannot be obtained from sampling over only short time spans.

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## Appendix

The values of limnological variables at each sampling period are shown in Table 1. From the means for each reservoir, it is clear that Iraí reservoir had the lowest Secchi disk depth (cm), corroborating that this is the reservoir with the highest degree of eutrophication. Environmental variables such as Secchi disk depth (cm), total suspended solids (mg $L^{-1}$) and electric conductivity (m*S*) also corroborate the conclusion by the sanitation company of Paraná State (see manuscript), that the Piraquara I reservoir has the lowest degree of eutrophication. The variables measured show that Passaúna and Piraquara II reservoirs have intermediate degree of eutrophication.

The following variables decreased over time in Iraí reservoir: electrical conductivity, total suspended solids, and pH. In January 2012, the concentration of dissolved oxygen and oxygen percentage showed the highest values. For the Passaúna reservoir, total suspended solids (mg $L^{-1}$) remained stable over time. The lowest value for the concentration of dissolved $O_2$ (mg/$O_2$ $L^{-1}$) and percentage of oxygen saturation (%$O_2$) was observed in January 2012, while the highest values

**Table 1.** Values of limnological variables measured in all sampling points of each reservoir during the three sampling periods (October 2011, January 2012 and June 2012). Reservoirs are organized according to their degree of eutrophication - Iraí with the highest, and Piraquara I with the lowest degree eutrophication.

| Reservoir | Period | | Air T°C | Water T°C | Cond. | TSS | Oxi1 | Oxi2 | pH | Secchi |
|---|---|---|---|---|---|---|---|---|---|---|
| IRAÍ RESERVOIR (the most eutrophic) | October/2011 | 1° Point | 14.85 | 16.6 | 219.3 | 113.6 | / | 58.5 | 8.17 | 100 |
| | | 2° Point | 19.25 | 20.3 | 253.6 | 131.3 | 3.56 | 37.6 | 8.06 | / |
| | | 3° Point | 21.05 | 21.25 | 129.3 | 68.5 | 2.1 | 21.6 | 8.09 | 50 |
| | | 4° Point | 19 | 19.65 | 86 | 45 | 3.06 | 29.3 | 8.39 | 30 |
| | | **Mean** | **19** | **19** | **216** | **112** | **2.9** | **25** | **8.13** | **60** |
| | January /2012 | 1° Point | 28.5 | 25.2 | 58.2 | 31 | 7.86 | 70.5 | 6.6 | 40 |
| | | 2° Point | 32.5 | 24 | 143 | 75 | 4.86 | 62.3 | 6.9 | 50 |
| | | 3° Point | 34 | 28.5 | 101.3 | 58.5 | 5 | 71.6 | 6.7 | 48.3 |
| | | 4° Point | 33 | 33.5 | 67 | 23.1 | 5 | 58 | 6.5 | 40 |
| | | **Mean** | **33.5** | **24** | **105** | **53** | **5** | **58** | **6.6** | **43.3** |
| | June/2012 | 1° Point | 21 | 16.4 | 36 | 17.6 | 4.5 | 29 | 7 | 50 |
| | | 2° Point | 23.6 | 18.33 | 56.43 | 67 | 1.58 | 10.5 | 6.2 | 50 |
| | | 3° Point | 25.5 | 19.5 | 75.5 | 39.4 | 2.98 | 24.5 | 5.93 | 110 |
| | | 4° Point | 21.9 | 19.5 | 52 | 20.43 | 4.16 | 16 | 6 | 70 |
| | | **Mean** | **23** | **18.43** | **55** | **36** | **3.3** | **20** | **6.3** | **70** |
| | | **OVERALL MEAN** | **25.2** | **20.47** | **125.3** | **67** | **3.73** | **34.3** | **7.01** | **57.76** |
| | | | **Air T°C** | **Water T°C** | **Cond.** | **TSS** | **Oxi1** | **Oxi2** | **pH** | **Secchi** |
| PASSAÚNA RESERVOIR | October/2011 | 1° Point | 28.2 | 22.2 | 171.3 | 91 | 3.2 | 35.3 | 6.77 | 170 |
| | | 2° Point | 35.8 | 25.3 | 117.5 | 62.5 | 5.51 | 61.5 | 7.4 | 40 |
| | | 3° Point | 25.7 | 26.9 | 120.6 | 63.6 | 4.08 | 52.6 | 7.15 | 230 |
| | | 4° Point | 25.3 | 24.7 | 120.5 | 64 | 4.93 | 48 | 7.4 | 250 |
| | | **Mean** | **34.5** | **25** | **122** | **71** | **4.4** | **52** | **7.18** | **156** |
| | January/2012 | 1° Point | 31.5 | 29.8 | 141 | 73.3 | 3.6 | 40.6 | 7.5 | 150 |
| | | 2° Point | 35.8 | 30.8 | 125.3 | 65 | 4.75 | 47 | 8 | 140 |
| | | 3° Point | 30.5 | 29.2 | 151 | 79.3 | 2.5 | 45 | 7.75 | 290 |
| | | 4° Point | 30 | 24.4 | 139.6 | 74 | 3 | 35.6 | 8 | 300 |
| | | **Mean** | **30** | **28.5** | **146** | **69.5** | **3** | **46** | **8** | **220** |
| | June/2012 | 1° Point | 22 | 17.3 | 167.3 | 89.6 | 7.57 | 77.5 | 6.3 | 150 |
| | | 2° Point | 24.6 | 19.3 | 124.3 | 66.7 | 5.76 | 69 | 6.9 | 180 |
| | | 3° Point | 25.1 | 20 | 130 | 69.3 | 4.73 | 55.5 | 6.24 | 330 |
| | | 4° Point | 28 | 21.2 | 129.7 | 55.3 | 1.86 | 27 | 7 | 220 |
| | | **Mean** | **24.9** | **19.45** | **137.8** | **70.2** | **4.98** | **57.25** | **6.61** | **220** |
| | | **OVERALL MEAN** | **29.8** | **24.3** | **135.2** | **70.2** | **4.12** | **51.75** | **7.26** | **198** |

*Water and air temperature (T°C); Cond. - Electrical conductivity (m*S*); TSS -Total Suspended Solids (mg $L^{-1}$); Oxi1 - Dissolved Oxygen (mg$O_2$ $L^{-1}$); Oxi2 - Percentage Oxygen Saturation (%$O_2$), Potential Hydrogen (pH), Secchi disk depth (cm).

| | | | Air T°C | Water T°C | Cond. | TSS | Oxi1 | Oxi2 | pH | Secchi |
|---|---|---|---|---|---|---|---|---|---|---|
| PIRAQUARA II RESERVOIR | January/2012 | 1° Point | 25 | 25 | 26 | 14.8 | 4.3 | 50 | 6 | 130 |
| | | 2° Point | 32 | 21 | 25.3 | 13.3 | 5 | 54.3 | 6.6 | 110 |
| | | 3° Point | 32 | 29.7 | 25.1 | 19 | 5 | 64 | 6.3 | 110 |
| | | 4° Point | 30 | 30.3 | 31 | 68.3 | 4.1 | 49.3 | 6 | 120 |
| | | **Mean** | **29.75** | **23** | **26.85** | **19** | **5** | **57** | **6** | **117.5** |
| | June/2012 | 1° Point | 19.3 | 16.7 | 19.3 | 10.5 | 10.9 | 113 | 6.04 | 70 |
| | | 2° Point | 25.3 | 19 | 18.8 | 10 | 3.8 | 40 | 4 | 100 |
| | | 3° Point | 24.3 | 20 | 18.5 | 10 | 3.8 | 43 | 3.8 | 100 |
| | | 4° Point | 23.1 | 18.4 | 29.4 | 15.8 | 8.15 | 103.5 | 6.08 | 150 |
| | | **Mean** | **23** | **18.5** | **21.5** | **11.5** | **6.66** | **74.8** | **4.98** | **105** |
| | | **OVERALL MEAN** | **26.3** | **20.75** | **24.1** | **28.85** | **5.8** | **66** | **5.5** | **111** |
| | | | **Air T°C** | **Water T°C** | **Cond.** | **TSS** | **Oxi1** | **Oxi2** | **pH** | **Secchi** |
| PIRAQUARA I RESERVOIR (the least eutrophic) | October /2011 | 1° Point | 25.9 | 21.7 | 22.6 | / | 7 | 43 | 6.13 | 280 |
| | | 2° Point | 35.8 | 25.2 | / | 18.75 | 9.5 | 3.1 | 6.28 | 260 |
| | | 3° Point | 24.2 | 21.7 | 20.7 | 11.1 | 5 | 172 | 6.34 | 250 |
| | | 4° Point | 25.6 | 24.2 | 20.6 | 11.1 | 4.58 | 51.1 | 6.33 | 250 |
| | | **Mean** | **29** | **22** | **21** | **13.65** | **6** | **71** | **6.4** | **260** |
| | Jauuary/2012 | 1° Point | 30 | 26.9 | 18 | 12.9 | 4.4 | 51.5 | 6 | 270 |
| | | 2° Point | 31.3 | 28.3 | 19.7 | 10.3 | 5.6 | 71 | 7 | 250 |
| | | 3° Point | 29 | 28 | 19.7 | 10.5 | 5.6 | 70.6 | 6.6 | 200 |
| | | 4° Point | 30 | 29 | 16 | 9.3 | 5.7 | 78 | 7 | 300 |
| | | **Mean** | **29.6** | **28.5** | **17** | **10.75** | **5.3** | **74.5** | **6.6** | **255** |
| | June/2012 | 1° Point | 28.4 | 21 | 20.8 | 11.4 | 9.1 | 98.5 | 5.5 | 300 |
| | | 2° Point | 25 | 21 | 21.6 | 11.6 | 4.28 | 67 | 6.28 | 300 |
| | | 3° Point | 25 | 20.6 | 21.5 | 11.4 | 3.55 | 37 | 6 | 370 |
| | | 4° Point | 27.2 | 22.7 | 19.8 | 10.9 | 5.45 | 50 | 5.8 | 370 |
| | | **Mean** | **26.4** | **21.3** | **20.9** | **11.3** | **5.5** | **63** | **5.8** | **335** |
| | | **OVERALL MEAN** | **28.3** | **24** | **19.6** | **11.9** | **5.6** | **69.5** | **6.2** | **284** |

*Water and air temperature (T°C); Cond. - Electrical conductivity (m*S*); TSS -Total Suspended Solids (mg $L^{-1}$); Oxi1 - Dissolved Oxygen ($mgO_2$ $L^{-1}$); Oxi2 - Percentage Oxygen Saturation ($\%O_2$), Potential Hydrogen (pH), Secchi disk depth (cm).

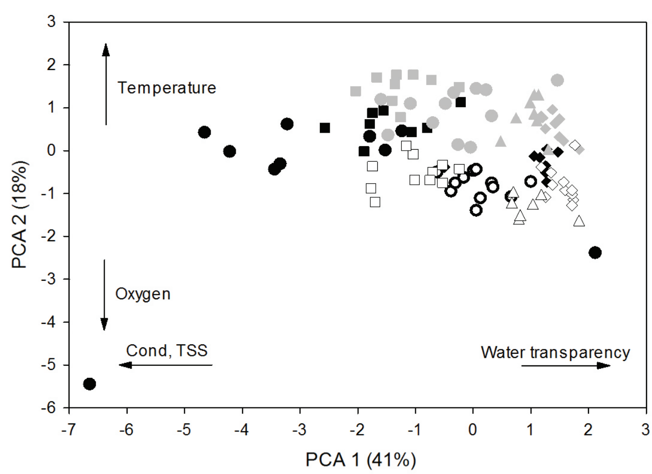


**Figure 1.** Principal component analysis evidencing abiotic differences among reservoirs. Circles are Iraí reservoir' sampling points in October 2011 (black), January 2012 (grey) and June 2012 (blank). Squares are Passaúna reservoir' sampling points in October 2011 (black), January 2012 (grey) and June 2012 (blank). Diamonds are Piraquara I reservoir' sampling points in October 2011 (black), January 2012 (grey) and June 2012 (blank). Triangles are Piraquara II reservoir' sampling points in January 2012 (grey) and June 2012 (blank). For this reservoir, there is no sampling in October 2011. Water transparency = Secchi disk depth (cm); Temperature = the water temperature (°C); Oxygen = dissolved oxygen ($mgO_2$ $L^{-1}$); Cond = electrical conductivity (m*S*); TSS = total suspended solids (mg $L^{-1}$).

for these variables were observed in June 2012. In contrast, the pH had the highest value for January 2012 and the lowest for June 2012 (Table 1). The Piraquara II reservoir did not have the physical and chemical analyzes performed on October 2011 due to technical problems in the multi-parameter probe. For the two periods analyzed (January 2012 and June 2012), only $mgO_2 L^{-1}$ and $\%O_2$ showed an increase in their concentrations over time. Conductivity, total suspended solids and pH had higher values in January 2012. For all reservoirs, except for the Iraí, the pH and the temperature (°C) increased while $\%O_2$ decreased overtime (Table 1). The Piraquara I reservoir had the lowest values for electrical conductivity, total suspended solids and dissolved oxygen in January 2012. These same variables had highest values in October 2011. The pH and $\%O_2$ had highest values in January 2012 (Table 1).

A Principal Component Analysis with standardized abiotic data (see Figure 1) also evidenced that Piraquara reservoirs are those with highest water transparency and lowest suspended soils and conductivity. This data suggest that the degree of eutrophication is lower in such reservoirs than in the others. On the other hand, Passaúna and, particularly, Iraí reservoirs are those with lowest water transparency and highest suspended soils and conductivity, suggesting that they are the most eutrophic. There is also a clear temporal variation in abiotic features, but mainly related to water temperature and dissolved oxygen.