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*Article*

# Effects of an Introduced Benthivorous Fish on Macroinvertebrates Diversity in a Semiarid Shallow Lake

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**ABSTRACT**

The *Cyrinus carpio* Linnaeus, 1758 (common carp) is a widely introduced species for commercial purposes. However, its detrimental effects on lakes and reservoirs, such as a decrease in water quality, abundance and richness of macrophytes, and macroinvertebrate abundance, are also known. In this study, we investigated the effect of common carp introduction on the macroinvertebrate community in a shallow lake in the Brazilian semiarid region. The study in Panati lake took place between 2002 and 2008 with the introduction of common carp in 2004. Shallow lakes from Our results showed that after common carp introduction, there was a significant reduction in the richness and diversity of the macroinvertebrate community, as well as an increase in the dominance of certain groups, such as chironomids. The decrease in richness and diversity is likely a result of the decline in abundance of key dominant benthic groups and species, such as the gastropods *Pomacea lineata* (Spix, 1827), *Biomphalaria straminea* (Dunker, 1848), *Aplexa marmorata* (Guilding, 1828) and *Plesiophysa ornata* (Haas 1938), oligochaetes, and ostracods, as well as several insect families. This decline may also lead to increased variability (destabilizing effect) among gastropods, annelids, and crustaceans, as well as an increase in the variability of richness and diversity among benthic macroinvertebrate species.
**Keywords:** *Cyprinus carpio*; shallow lakes; non-native species; benthos; community stability.

**RESUMO**

*Cyrinus carpio* Linnaeus, 1758 (Carpa comum), é uma espécie amplamente introduzida para fins comerciais. No entanto, também são conhecidos seus efeitos deletérios em lagos e reservatórios, como redução da qualidade da água, abundância e riqueza de macrófitas e abundância de macroinvertebrados. Neste estudo, investigamos o efeito da introdução de carpas comum na comunidade de macroinvertebrados em um lago raso no semiárido brasileiro. O estudo na Lagoa Panati ocorreu entre 2002 e 2008 com a introdução da Carpa comum em 2004. Nossos resultados mostraram que após a introdução da carpa comum, houve uma redução significativa na riqueza e diversidade da comunidade de macroinvertebrados, bem como um aumento na dominância de certos grupos, como os quironomídeos. A diminuição na riqueza e diversidade é provavelmente resultado do declínio na abundância de grupos e espécies bentônicas dominantes, como os gastropodes *Pomacea lineata* (Spix, 1827), *Biomphalaria straminea* (Dunker, 1848), *Aplexa marmorata* (Guilding, 1828) e *Plesiophysa ornata* (Haas 1938), oligoquetas e ostracodes, bem como várias famílias de insetos. Esse declínio também pode levar a um aumento da variabilidade (efeito desestabilizador) entre gastrópodes, anelídeos e crustáceos, bem como um aumento na variabilidade de riqueza e diversidade entre as espécies de macroinvertebrados bentônicos.
**Palavras-chave:** *Cyprinus carpio*; lagos rasos; espécies exóticas; bentos; estabilidade da comunidade.

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## Introduction

Shallow lakes from semiarid regions are unique ecosystems with distinctive characteristics, including high water level fluctuations due to high evaporation rates, high temperatures, and irregular and poor rain, conditions that make them particularly vulnerable to eutrophication mainly when have low depth (Bouvy et al. 2000; Bucak et al. 2012; Brasil et al. 2016; da Costa et al, 2016; Menezes et al. 2018). Among the types of shallow lakes in semiarid regions, ephemeral lakes are particularly diverse and valuable for studying adaptations of organisms to seasonal fluctuations. These lakes are characterized by periodic flooding and drying events, which create significant changes in physical and chemical conditions that affect the organization of the ecosystem (Williams 1997; Maltchik 2003; Maltchik & Medeiros 2006). High fluctuations in water level can cause disturbances in the substrate, altering substrate availability and disrupting habitats for macrophytes, fish refuges and benthic invertebrates (Evtimova & Donohue 2016; Janssen et al. 2014). These changes may also make the area more vulnerable to invasion or establishment by non-native species (Zohary & Ostrovsky 2011).

In the past century, fish species have often been introduced aiming to improve fishing and aquaculture (Bueno et al. 2021). However, such introductions have frequently had negative impacts on natural communities, resulting in decreased species diversity and lower water quality (Zambrano et al. 1998; Canonico et al. 2005; Attayde et al. 2011; Menezes et al. 2012; Hayden et al. 2013; Badiou & Goldsborough 2015; Bajer et al. 2016). The common carp (*Cyprinus carpio* L.) is one of the main introduced fish species, native to Eastern Europe and Asia (Bajer et al. 2016). known as an omnivorous-benthivorous species, primarily feeding on benthic macroinvertebrates but also consuming macrophytes and sediment (Rahman et al. 2008; Rahman et al. 2010; Zambrano & Hinojosa, 1999). This feeding behavior can cause significant bottom-up effects on the food chain by the sediment resuspension, as nutrients are released from the sediment the phytoplankton biomass increases, which also can lead to a decrease in macrophyte cover. Common carps are well known for their negative effects on water quality, macrophytes cover and species richness (Breukelaar et al. 1994; Roberts et al. 1995; Zambrano & Hinojosa 1999; Badiou & Goldsborough 2015; Bajer et al. 2016; Oliveira Junior et al. 2019; Matsuzaki et al. 2009; Chumchal et al. 2005), besides the reductions in the abundance of invertebrates in lakes and ponds (Zambrano & Hinojosa 1999; Zambrano et al. 1998; Miller & Crowl 2006).

Fish are an essential component of community dynamics, and the common carp, as an omnivorous-benthivorous fish, plays a significant role in aquatic community functioning by acting as an ecosystem engineer (Matsuzaki et al. 2009). Theoretical studies suggest that omnivory can decrease the variability of resource dynamics (McCann & Hastings 1997; Gellner & McCann 2012), but the stabilizing effect on temporal variability is dependent on the strength of interaction (Vandermeer 2006; Gellner & McCann 2012). Omnivorous fish can distribute its effects among distinct trophic levels avoiding significant reductions in food resources and promoting higher persistence and stability of populations. However, strong omnivorous interactions can destabilize community dynamics leading to a high probability of extinction (Polis & Strong 1996; Emmerson & Yearsley 2004; McCann & Hastings 1997; McCann et al. 1998). Despite being an omnivorous species, common carp is known for its significant indirect negative impact on the community, primarily due to the sediment resuspension caused by the benthivore behavior. The indirect effect of the sediment disturbance and the direct effect of the consumption can potentially have a strong negative effect and destabilize the community.

Despite the significant economic value of common carp, it can have detrimental effects on water quality and species diversity (Zambrano et al. 1998; Zambrano & Hinojosa 1999; Barthelmes & Brämick 2003; Miller & Crowl 2006; Badiou & Goldsborough 2015; Vilizzi et al. 2015; Bajer et al. 2016). Therefore, this study aimed to assess the impact of *C. carpio* introduction on the abundance, diversity and stability of a macroinvertebrate community subject to high fluctuations in water level. This study was carried out in Panati lake, a small shallow lake, as part of a long-term ecological research program from August 2002 to April 2008. During our study, the local farmer who owned the property introduced the common carp at the end of 2004. We then continued to monitor the lake until 2008, to verify the differences in macroinvertebrate community before and after common carp introduction. Although common carp are omnivorous fish that can potentially stabilize communities, we hypothesized that their effects on sediment disturbance together with the consumption would result in a significant negative impact on macroinvertebrates, leading to a decrease in richness and diversity and destabilization of the community. To test this hypothesis, we tested the macroinvertebrate abundance, richness, and diversity and analyzed the changes in community dynamics before and after common carp introduction.

## 2. Material and Methods

### *2.1. Study Area*

The Panati lake is located in the semiarid region of the State of Paraíba, Brazil, within the Paraíba River basin and the Taperoá River sub-basin (Figure 1) (Brasil 2005). This natural lagoon is intermittent and is blocked by State Highway PB-238, with a maximum length and width of 353m and 318m, respectively, and a depth not exceeding 3 meters. The area is within the Caatinga Biome and experiences a Rainy Tropical climate with a dry summer. The rainy season begins in January/February and may persist until May, while the rest of the year is characterized by irregular precipitation (Brasil 2005).

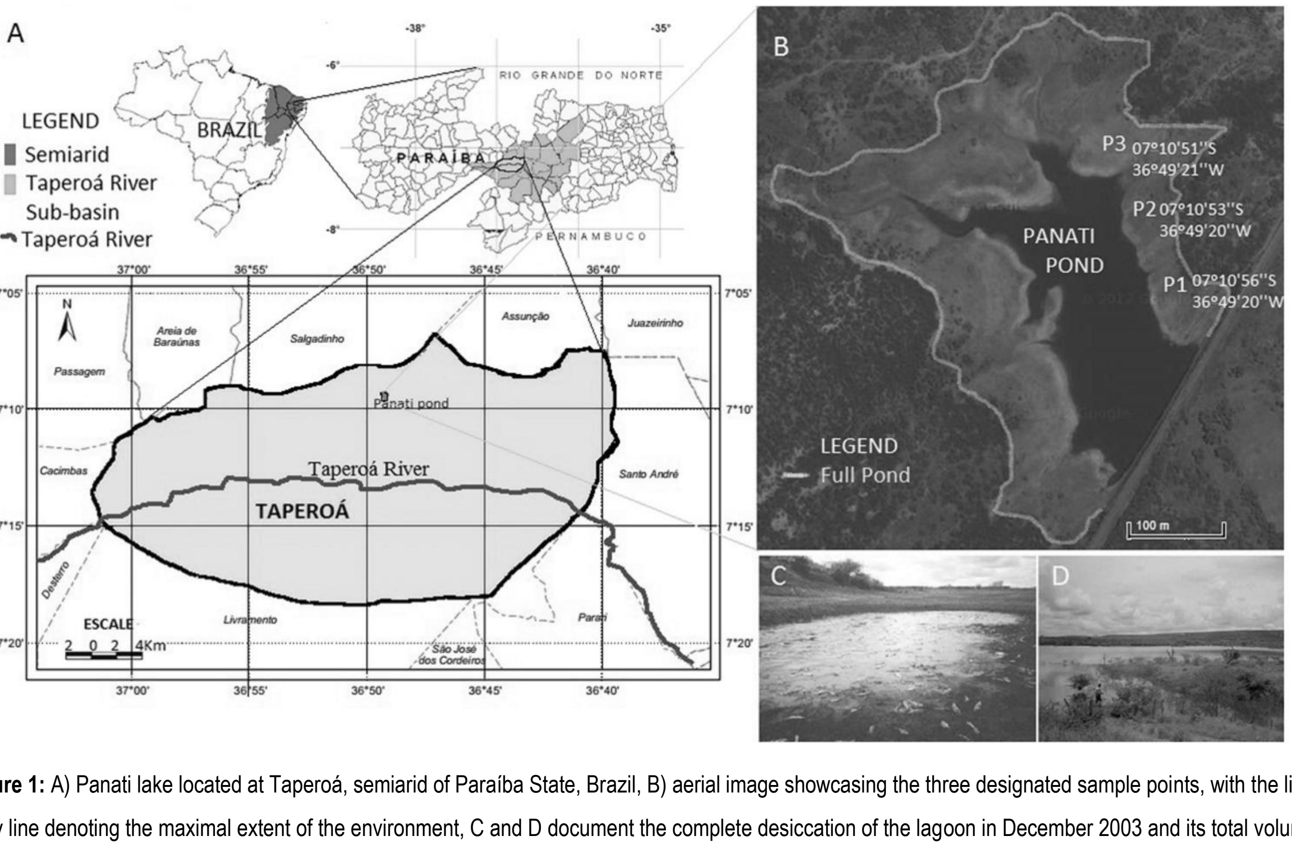


**Figure 1:** A) Panati lake located at Taperoá, semiarid of Paraíba State, Brazil, B) aerial image showcasing the three designated sample points, with the light gray line denoting the maximal extent of the environment, C and D document the complete desiccation of the lagoon in December 2003 and its total volume during the rainy period of February 2004, respectively. Source: Adapted from BRASIL (2005) and Google Earth 2013. Pictures: Authors

### *2.2. Sampling and Data Acquisition*

We carried out collections every two months, between August 2002 and April 2008, at three different sampling points in the lagoon. For each sampling point three replicates were performed. The same preestablished schedule was followed at 10:00 AM. We obtained the rainfall data from Agência Executiva de Gestão das Águas - AESA (AESA 2020).

We sampled benthic macroinvertebrates in the coastal regions using a 35cm x 35cm manual Delta-type catcher with a 500µm mesh. The collected sediment was transferred to plastic bags and fixed in 10% formaldehyde in the field. In the laboratory, the samples were washed with tap water and separated using 1mm, 500µm, and 250µm mesh sieves. The retained material was then fixed in 10% formaldehyde in plastic pots. The sorting of the material was carried out using illuminated plastic trays, and the obtained specimens were placed in glass vials and stored in 70% alcohol. The identification of benthic invertebrates was done up to family level using a stereomicroscope and identification keys (Merrit & Cummins 1984; Brinkhust & Marchese 1989; Lopretto & Tell 1995a; 1995b; Epler 2001; 2006; 2010; Trivinho-Strixino 2011).

We measured the water quality parameters using the following methods: Water temperature by a mercury thermometer with a precision of 0.5°C. pH was measured using a HORIBA B-213 pH meter. Electrical conductivity was determined using either a portable digital conductivity meter (Cole-Parmer brand) or an ANALYSER conductivity meter. Alkalinity was determined by titration using the method described by (Golterman et al. 1978). Total Water Hardness was determined by titration using the method described by (Eaton et al. 1997). Dissolved oxygen concentration was determined using the classic WINKLER method described by (Golterman et al. 1978). To determine the organic matter content in the sediment, we used the dry ignition method. We took a 5-gram sample that had been previously dried in an oven at 105°C for 12 hours and burned it in a muffle at 600°C for two hours. The percentage of organic matter was calculated by finding the difference between the sample's weight before and after burning.

### *2.3. Introduction of Common Carp*

According to an informal conversation with local fishermen, the owner of the property where Panati lake is located introduced *Cyprinus carpio* (Common carp) for economic purposes in late 2004. Therefore, we continue to monitor water parameters and macroinvertebrates.

### *2.4. Statistical analysis*

We tested for the effect of common carp introduction, precipitation, and time on environmental variables (precipitation, dissolved oxygen, hardness, temperature, organic matter, alkalinity, pH, electrical conductivity), macroinvertebrates abundance, diversity, and community stability. We used as response variables the abundance of total macroinvertebrates, the abundance by taxa (Annelida, Crustacea, Mollusca, and Insecta) and the most common groups (Chironomidae, Conchostraca, Ostracoda, and Oligochaeta), and the richness index, Evenness, Shannon-Wiener diversity and dominance of the macroinvertebrate species. For that, we used the General Least Squares Regression method (GLS). Temporal autocorrelation in ecological data can inflate Type I errors in statistical analyses, therefore, we used time as the autocorrelation factor (Zuur et al. 2009). Before the analysis we checked the assumptions of normality of the residuals and homogeneity of variance. Data were transformed when necessary.

To access variables that most explain the changes in macroinvertebrate abundance and diversity, we used the Model Average method. Just models with delta AIC $< 2$ were accepted, and there is substantial evidence (Burnham & Anderson 2004). The environmental matrix was standardized to a z-scale to transform all variables into the same unit of measurement. The multicollinearity among predictive variables was tested using the variation inflation factor. VIF values larger than 10 mean autocorrelations among variables. Variables with VIF $>$ 10 were eliminated from the model.

The temporal stability was measured as the inverse of the coefficient of variation (CV) (Stability = mean/standard deviation) over time. Therefore, we measured the inverse CV on the time before and after common carp introduction, and we calculated the effect size over the inverse CV ($Effect\ size\ on\ Stability = \ln\left(\frac{inv\ CV_{after}}{inv\ CV_{before}}\right)$). Negative results on the effect size mean an increase in variability, that is destabilization, positive results mean an increase in stability, and zero means no effect. The CV gives clear biological meaning enabling comparisons between dependent variables with different averages and scaling, because is a proportional measure (Ives et al. 2000; Tilman et al. 1998). The use of log ratio method (Osenberg et al. 1997) for effect size over CV does not requires equilibrium assumptions and gives information on strength ecological interactions (Berlow et al. 1999; Osenberg, et al. 1997). We also calculated the effect size on the abundance of main groups and species, using the same procedure ($Effect\ size\ on\ Abundance = \ln\left(\frac{Abundance_{after}}{Abundance_{before}}\right)$). The effect size over abundance and CV was calculated for each combination of time before and after common carp introduction, producing a vector of effects for each variable. Then, we applied a resampling procedure to calculate de mean and confidence interval (95%) of the effect. Data was resampled 1000 times.

All analyses were performed on R version 3.4.3., using the packages *vegan* for diversity indexes (Richness, Shannon-Wiener, Evenness and Dominance), *nlme* for the GLS analysis, and *MuMIn, AICcmodavg*, and *glmulti* for model selection by the Model Average method. We used the packages *simpleboot* and *boot* for the randomization procedure, with the functions *one.boot* and *boot.ci* to calculate the mean and confidence interval of the effect sizes.

**Results**

We found a significant increase in alkalinity ($p < 0.05$) and electrical conductivity ($p < 0.05$) after common carp introduction, and an interaction between common carp and precipitation for organic matter ($p < 0.05$) and pH ($p < 0.05$). Precipitation decreases organic matter, but in de presence of common carp, the organic matter slightly increases (Figure 2, Table 1). There was no difference in mean temperature, dissolved oxygen concentration, hardness and electrical conductivity before and after common carp carp introduction.

Total macroinvertebrate abundance decreased over time and after common carp introduction, but the effect of common carp was just marginally significant ($p = 0.06$) (Figure 3, Table 2). However, when we remove Chironomidae abundance, we observe a significant effect on common carp ($p < 0.05$) (Supplementary Information: Figure S1, Table S2). Besides, we found a significant decrease in macroinvertebrate richness ($p < 0.001$), evenness ($p < 0.01$) and diversity ($p < 0.001$) after common carp introduction and a significant increase in dominance ($p < 0.001$) (Figure 3, Table 2). The effect of common carp on macroinvertebrate diversity indexes was independent of time.

Common carp exert a strong negative effect on mollusks ($p < 0.001$) and annelids ($p < 0.05$), and an effect dependent on precipitation on crustaceans ($p < 0.001$) (Figure 4B and C, Table 2). Analyzing the most abundant groups, Ostracoda ($p < 0.01$) and Oligochaetes abundance ($p < 0.05$) decreased significantly after common carp introduction (Figure 4G and H, Table 2, Figure 6A). The decrease in Conchostraca abundance was dependent on precipitation ($p < 0.001$) (Figure 4F, Table 2, Figure 6A). Chironomids increased after common carp introduction (Figure 4E, Figure 6A), but the isolated effect of common carp was not significant (Table 2) (see Table S1 for mean and standard deviation of other common species or groups before and after common carp).

The model selection indicated that common carp introduction was the main factor for the reduction in total macroinvertebrates abundance, total Mollusca, total Crustacea, and total Annelida, and for richness, evenness and Shannon-Wiener diversity decline (Table 3), besides the significant increase in dominance. Common carp was the main factor for the decrease in Ostracoda and Oligochaeta, but also was important for Conchostraca reduction and the increase in Chironomidae abundance. Precipitation, hardness, temperature and Alkalinity were also important for macroinvertebrates abundance. Precipitation and Alkalinity affected the diversity indexes as well (Table 3).

The introduction of common carp destabilized the abundance, richness, Shannon's diversity and evenness, and decreased the variability of the dominance (stabilizing effect) (Figure 5A). Common carp destabilized Mollusca, Annelida and Crustacea groups, and stabilized the abundance of Insects (Figure 5B). All mollusk species: *Pomacea lineata* (Spix, 1827); *Biomphalaria straminea* (Dunker, 1848); *Aplexa marmorata* (Guilding, 1828) and *Plesiophysa ornata* (Haas 1938), and annelid families found (Oligochaeta and Glossofoniidae) were negatively affected by common carp and showed increased temporal variability after its introduction (Figure 6A and B). Despite the reduction of both groups of crustaceans found (Ostracoda and Conchostraca) (Figure 4F and G, Figure 6A), carp exerted a destabilizing effect in ostracods, and a stabilizing effect in Conchostraca (Figure 6B). Most insect families declined and showed an increase in variability after carp introduction (Figure 6A and B). However, the decrease in variability in total insect abundance is probably a result of the increase in abundance and stability of Chironomids, the dominant species of insect (Figure 4E, Figure 6A and B).

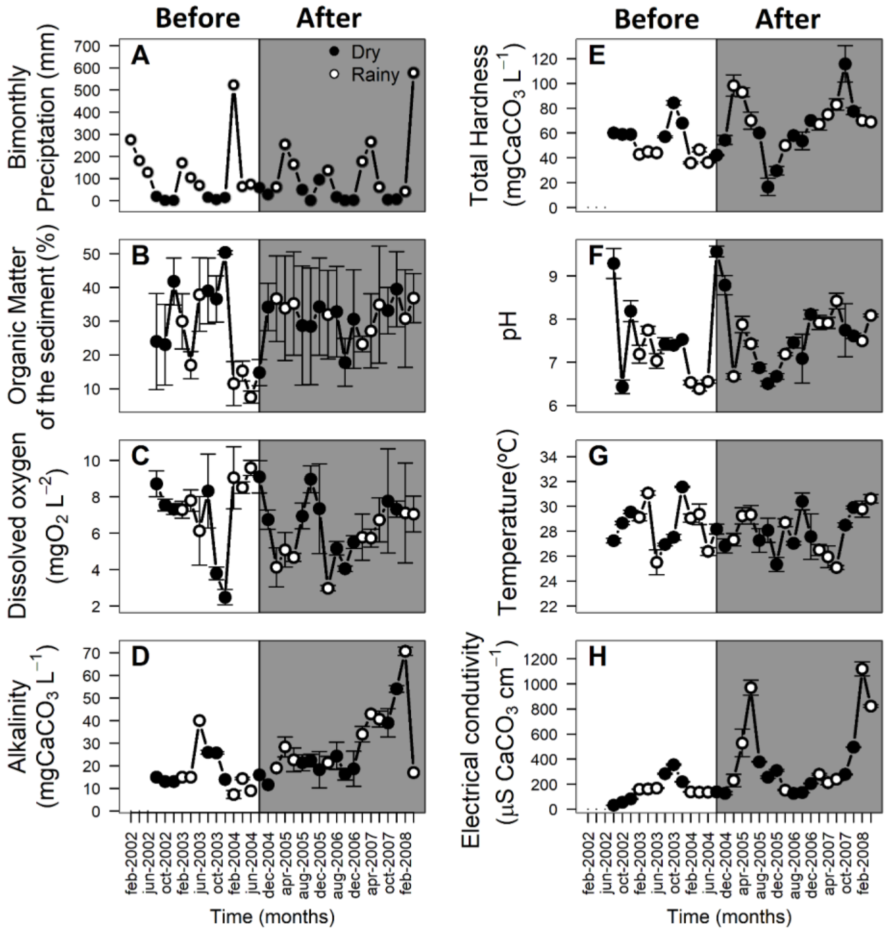


**Figure 2:** Temporal variation of precipitation (A), organic matter (B), dissolved oxygen concentration (C), alkalinity (D), hardness (E), pH (F), temperature (G) and electrical conductivity (H) before (white box) and after (gray box) *C. carpio* introduction in Panati Lake between 2002 and 2008. Source: Authors.

**Table 1:** Average, standard deviation and t-test (using GLS) results of environmental variables before and after *C. carpio* introduction.

| | Mean (±sd) | | *Carp* | | *Preciptation* | | *Carp*Precip* | |
|---|---|---|---|---|---|---|---|---|
| | Before | After | *β* | p | *β* | p | *β* | p |
| Preciptation | 89.54 (137.9) | 107.4 (141.6) | 0.39 | 0.320 | - | - | - | - |
| Diss. Oxygen | 7.62 (1.98) | 6.05 (1.92) | -0.96 | 0.190 | 0.004 | 0.196 | -0.005 | 0.222 |
| Hardness | 51.7 (12.7) | 68.03 (23.64) | 0.34 | 0.524 | -0.003 | 0.121 | 0.005 | 0.086 |
| Temperature | 28.19 (1.62) | 28.03 (1.81) | -0.05 | 0.534 | -0.0001 | 0.943 | 0.0001 | 0.898 |
| Organic matter | 25.53 (14.27) | 31.65 (13.17) | 0.20 | 0.568 | -0.004 | 0.016*** | 0.004 | 0.026*** |
| Alkalinity | 17.35 (8.58) | 29.03 (15.40) | 0.39 | 0.047*** | -0.001 | 0.054 | 0.001 | 0.199 |
| pH | 7.57 (1.04) | 7.47 (0.59) | -0.001 | 0.408 | -1.08 | 0.113 | -0.00 | 0.047*** |
| Electrical Condutivity | 155.6 (83.3) | 381.4 (292.6) | 0.60 | 0.029*** | 0.003 | 0.805 | 0.001 | 0.322 |

***Significant values

† Transformed variables: Hardness (sqrt), Temperature (sqrt), Alkalinity (log), Electrical Conductivity (log), and Organic matter (sqrt). Source: Authors.

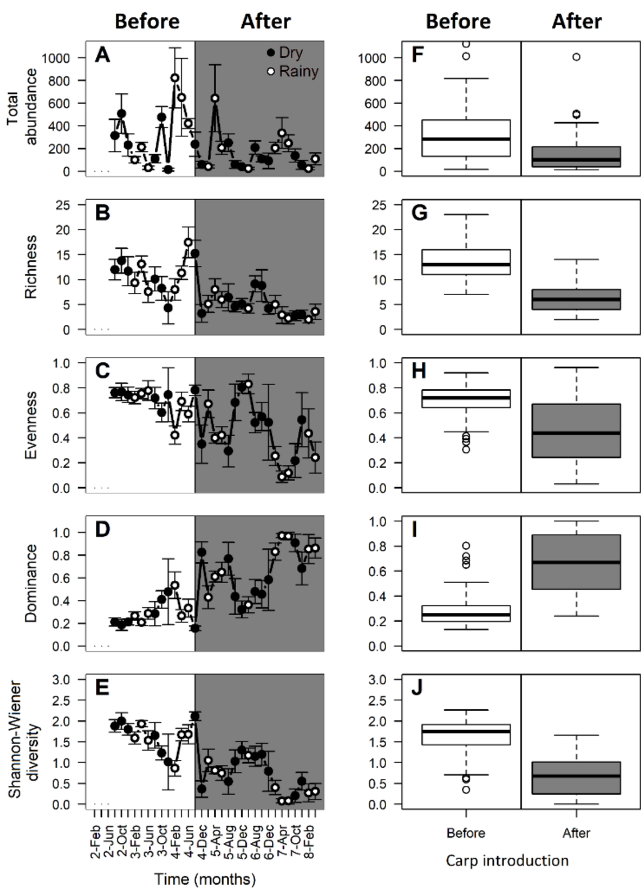


**Figure 3:** Temporal variation and boxplot of macroinvertebrate abundance (A), richness (B), dominance index (C), evenness (D) and Shannon-Wiener diversity (E) before (white box) and after (gray box) *C. carpio* introduction in Panati Lake between 2002 and 2008. Source: Authors.

**Table 2:** Average, standard deviation, and results of GLS for the effect of the introduction of *C. carpio* and precipitation on macroinvertebrates abundance and diversity indexes.

| | Mean (±sd) | | *Carp* | | *Preciptation* | | *Carp* Preciptation* | |
|---|---|---|---|---|---|---|---|---|
| | Before | After | *β* | p | *β* | p | *β* | p |
| Abund. Total Macroinv. | 334.0 (272.3) | 158.1 (170.8) | -4.81 | 0.062 | 0.02 | 0.087 | -0.01 | 0.511 |
| Abund. byPhilum | | | | | | | | |
| Insecta | 208.9 (131.9) | 131.2 (136.5) | -2.67 | 0.305 | -0.01 | 0.269 | 0.02 | 0.0632 |
| Mollusca | 20.27 (20.27) | 0.87 (1.65) | -3.36 | <0.001*** | -0.00 | 0.562 | 0.001 | 0.799 |
| Crustacea | 93.01 (192.7) | 10.6 (9.28) | -0.36 | 0.766 | 0.04 | <0.001*** | -0.04 | 0.001*** |
| Annelida | 44.83 (32.6) | 21.01 (41.3) | -1.54 | 0.023*** | 0.001 | 0.603 | -0.00 | 0.809 |
| Abund. most abundant | | | | | | | | |
| Chironomidae | 79.41 (118.9) | 117.7 (149.7) | 14.04 | 0.633 | -0.16 | 0.300 | 0.49 | 0.072 |
| Conchostraca | 52.43 (117.3) | 10.70 (16.43) | -25.08 | 0.150 | 0.73 | <0.001*** | -0.75 | 0.001*** |
| Ostracoda | 48.78 (117.5) | 2.35 (6.34) | - 3.81 | 0.002*** | 0.55 | 0.001*** | -0.56 | 0.007*** |
| Oligochaeta | 37.74 (37.7) | 16.22 (16.21) | -19.57 | 0.036*** | 0.02 | 0.561 | -0.03 | 0.670 |
| Diversity Index | | | | | | | | |
| Richness | 11.2 (3.82) | 4.79 (2.62) | -7.48 | <0.001*** | -0.007 | 0.347 | 0.006 | 0.542 |
| Evenness | 0.69 (0.12) | 0.45 (0.24) | -0.25 | 0.006*** | -0.00 | 0.065 | 0.000 | 0.917 |
| Dominance | 0.26 (0.11) | 0.65 (0.23) | 0.37 | <0.001*** | 0.000 | 0.085 | -0.00 | 0.865 |
| Shannon diversity | 1.64 (0.39) | 0.67 (0.45) | -1.03 | <0.001*** | -0.001 | 0.013*** | 0.00 | 0.385 |

*** Significant values.

† Transformed variables: Total macroinvertebrates (sqrt), Insecta (log), Mollusca (log), Crustacea (log), Annelida(log), Chironomidae (log), Conchostraca (log), Ostracoda (log), Olighochaeta (log), richness (log). Source: Authors.

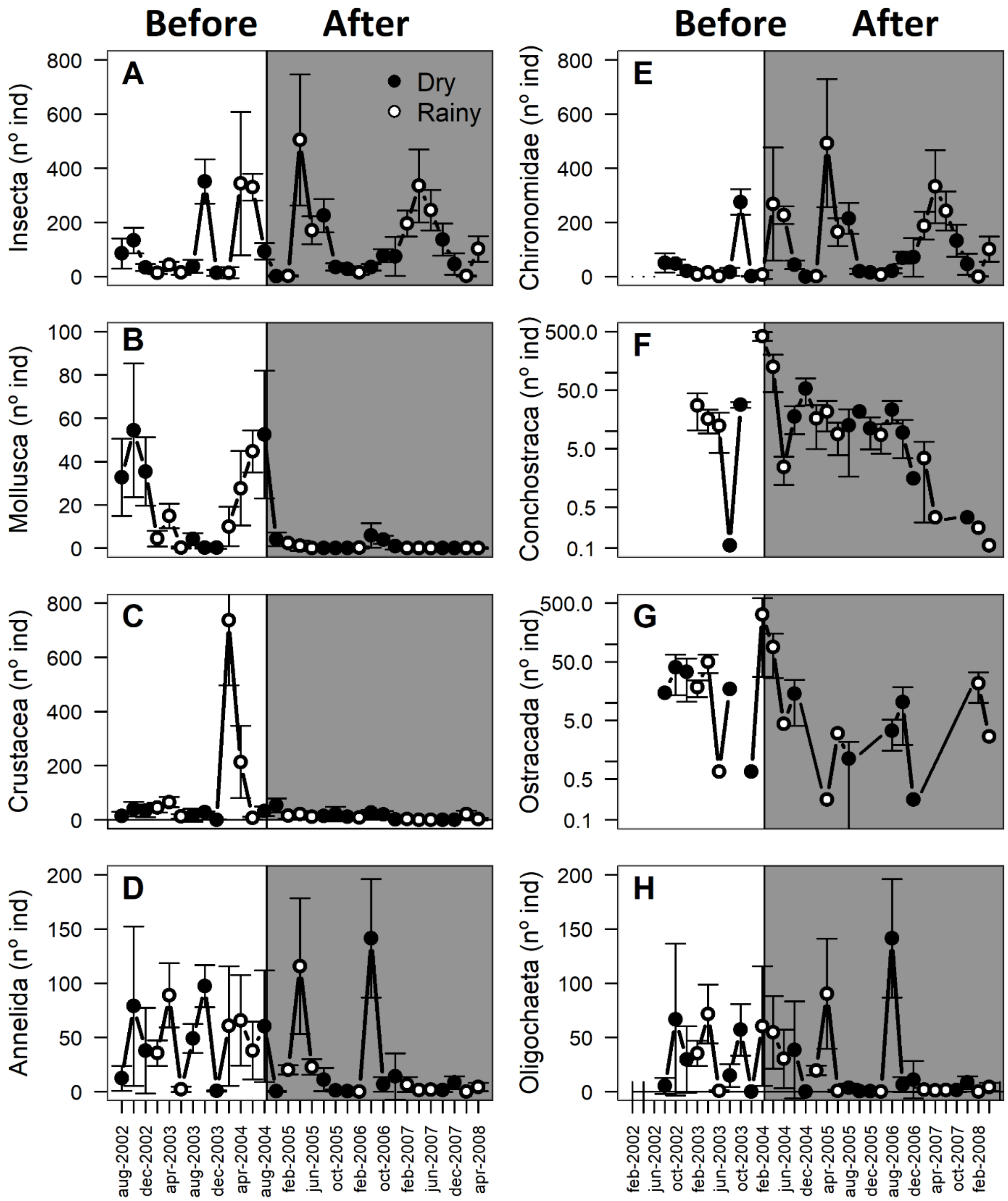


**Figure 4:** Temporal variation of the abundance of macroinvertebrates philum and main groups before (white box) and after (gray box) *C. carpio* introduction in Panati Lake between 2002 and 2008. By Philum: A) Insecta; B) Mollusca; C) Crustacea; D) Annelida. By most abundant groups: E) Chironomidae; F) Conchostraca; G) Ostracoda; H) Oligochaeta. Source: Authors.

**Table 3:** Model Average results of the Generalized Least Squares (GLS) regressions for the effects of *C. carpio* introduction and environmental variables on macroinvertebrates abundance, richness, equitability dominance and Shannon diversity. Precip = Precipitation, D.O. = Dissolved oxygen, Hard = Hardness, Temp = Temperature, O.M. = Organic matter, Alk = Alkalinity, E.C. = Electrical conductivity. All the important values by the model selection are shown.

| | Carp | Precip. | D.O. | Hard. | Temp | O.M. | Alk. | pH | E.C. |
|---|---|---|---|---|---|---|---|---|---|
| Abund. Total Macroinv. | -0.77*** | 0.30 | - | - | - | - | - | - | - |
| Abund. by Philum | | | | | | | | | |
| Insecta | -0.01 | - | -0.20 | 0.39 | - | - | - | - | -0.27 |
| Mollusca | -1.78*** | - | - | - | - | - | - | - | -0.22 |
| Crustacea | -1.13*** | 0.30 | - | -0.21 | - | - | -0.59 | - | 0.25 |
| Annelida | -1.92*** | - | - | - | 0.86 | - | - | - | -1.00*** |
| Abund. of most abundant | | | | | | | | | |
| Chironomidae | 0.33 | - | - | 0.38 | - | - | 0.32 | - | - |
| Conchostraca | -0.15 | 0.34 | - | -0.38 | -0.26 | - | -0.45 | - | - |
| Ostracoda | -2.0*** | 0.34 | 0.26 | - | 0.35 | - | - | -0.26 | 0.26 |
| Oligochaeta | -1.45*** | - | - | 0.33 | 0.38 | - | - | -0.49*** | - |
| Diversity Index | | | | | | | | | |
| Richness | -0.64*** | - | - | - | - | - | -0.14*** | - | -0.12 |
| Evenness | -0.14*** | -0.07*** | - | -0.06*** | - | - | -0.07*** | - | - |
| Dominance | 0.22*** | 0.06*** | - | - | - | - | 0.05*** | - | - |
| Shannon div | -0.36*** | -0.12*** | - | - | - | - | -0.11*** | - | - |

***Significant values on multiple regression

† Transformed variables: Total macroinvertebrates (sqrt), Insecta (log), Mollusca (log), Crustacea (log), Annelida(log), Chironomidae (log), Conchostraca (log), Ostracoda (log), Olighochaeta (log), richness (log). Source: Authors.

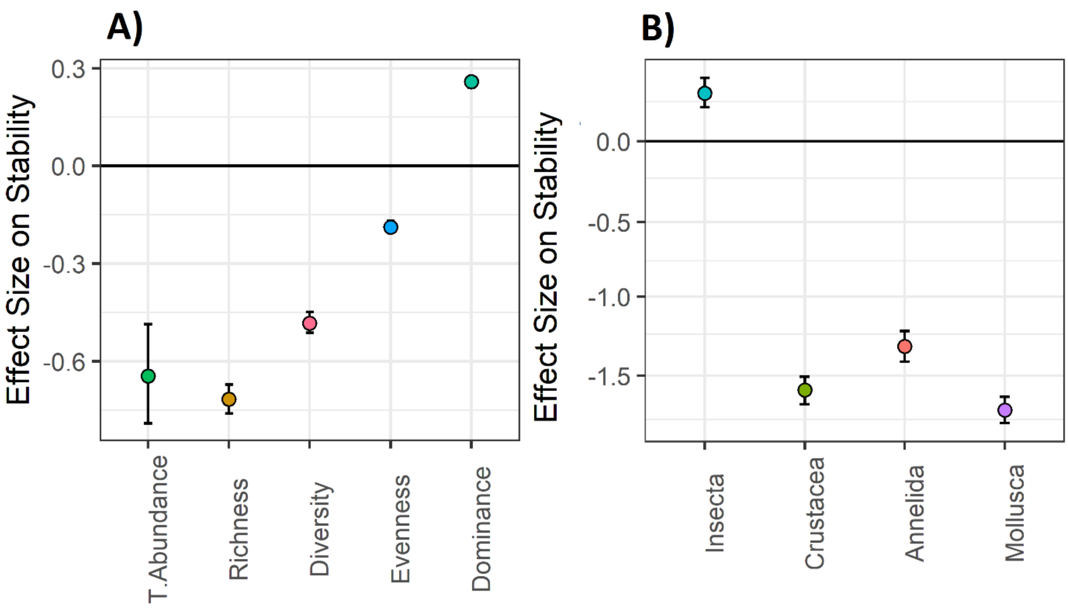


**Figure 5:** Effect of *C. carpio* on temporal stability of abundance, richness, diversity, evenness, and dominance of macroinvertebrates community (A), abundance by philum (B). Positive effects mean an increase in stability, and negative effect mean a destabilizing effect. Source: Authors.

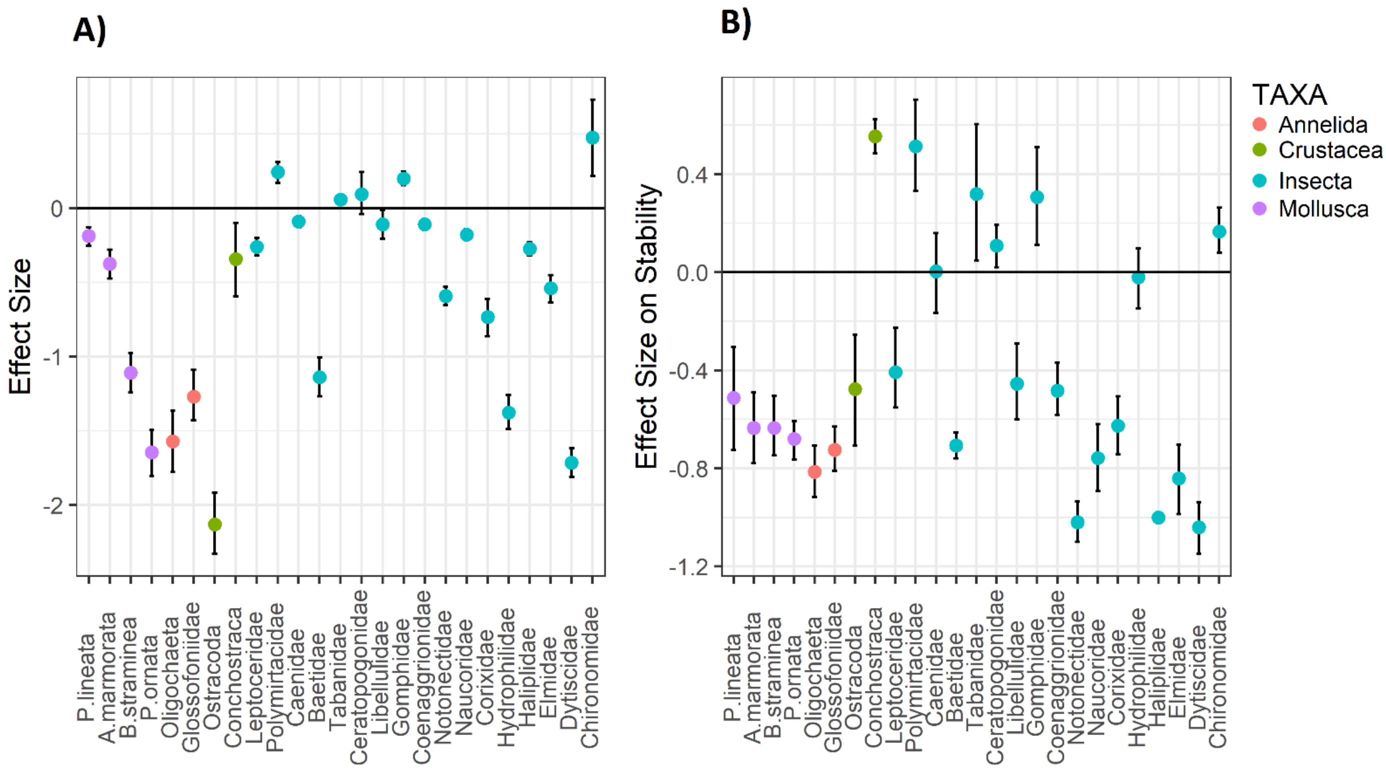


**Figure 6:** Effect of *C. carpio* on abundance (A) and temporal stability (B) of family or species found by group. Positive effects mean an increase in abundance (A) and stability (B), and negative effect mean a decrease in abundance (A) or destabilizing effect (B). Source: Authors.

## 4. Discussion

Our results show that the introduction of fish, such as *C. carpio*, may bring strong changes the in macroinvertebrates community dynamic. We found a significant decrease in mollusks, annelids and crustacean abundance, as well in species richness, evenness and Shannon diversity after carp introduction, and just a marginal effect of this fish species in total macroinvertebrates abundance. However, according to the Model Average results, common carp exert the strongest effect in total macroinvertebrates, and when we removed chironomids from total abundance, since only part of their life cycle takes place in the water, we found a significant effect of common carp in total macroinvertebrates. Besides, common carp destabilized the abundance, and diversity index (richness, Shannon diversity and evenness) of total macroinvertebrates, and exerted a stabilizing effect in groups dominance. Still, carp increased the variability in mollusks, annelids and crustacean abundance, and stabilized insect abundance.

Common carp are known for their impact in sediment resuspension, which increases phytoplankton productivity by releasing nutrients (Vilizzi et al. 2015; Rahman 2015; Zambrano & Hinojosa 1999; Zambrano et al. 1998; Badiou & Goldsborough 2015). However, the effect of common carp on organic matter only occurred in interaction with precipitation, and we observed an increase in organic matter variability among sampling points. The movement of wind in a shallow lake, like Panati Lake, can additionally influence the disruption of sediment and the fluctuations in organic matter. Even though we did not find a direct effect of common carp in organic matter, the disturbance caused by fish's sediment mixing may have ' negatively impacted the Oligochaeta group. Oligochaeta are a highly abundant group in the aquatic environments of the

Brazilian semiarid region (Abílio et al. 2007; Paiva et al. 2023). They live buried in the sediment and do not have dispersal mechanisms. The high variability in organic matter among sampling points after common carp introduction could indicate increased mortality of benthic organism due to bioturbation or consumption. Despite the lack of specific common carp diet data, research suggests that oligochaetes are included in their diet, as a significant portion of common carp's diet consists of detritus (Dadebo et al. 2015).

Nevertheless, we observed that *C. carpio* had direct effects on the macroinvertebrate community (reducing abundance, richness, and diversity), which are independent of organic matter, and related to food preference by benthic organisms. Common carp is a benthivorous fish, that prefers insects and benthic macroinvertebrates when they are available (Rahman et al. 2008; Rahman et al. 2010; Dadebo et al. 2015). Therefore, the strong decline in Ostracoda, Conchostraca and Oligochaeta, as well as gastropods abundance shows the direct impact of *C. carpio*. Despite common carp also consuming chironomids (García-Berthou 2001), our current study did not detect any effect of carp in chironomids. Chironomids have multiple reproductive cycles throughout the year (Melo et al. 2022), and a significant portion of their life cycle occurs outside of the aquatic environment (Abílio et al. 2007), which may restrict the short-term impact of fish in chironomid abundance.

On the other hand, common carp had a positive effect on the alkalinity and hardness of Panati Lake. Alkalinity was also identified as a factor that negatively impacted macroinvertebrate richness and diversity. High organic matter can contribute to decreased pH and alkalinity, related to $CO_2$ release during decomposition (Rahman et al. 2008). However, pH values of Panati lake typically exceed 8, and have high concentrations of calcium bicarbonate in the water, as indicated by elevated alkalinity and total hardness values. High alkalinities contribute to a significant abundance of gastropods in the environment, given that these organisms are commonly found in high densities in alkaline habitats (Abílio et al. 2006). According to Abílio (2002), there is a higher species richness of mollusks in water bodies of the semiarid region of Paraíba when the water is alkaline. In the case of Panati lake, which is characterized as slightly alkaline, four gastropod species were more abundant: *Pomacea lineata, Biomphalaria straminea, Aplexa marmorata and Plesiophysa ornata*. Besides the gastropod abundance in alkaline habitats, we observe a sharp decline in gastropod abundance after common carp introduction. Nevertheless, the elevation in alkalinity could have adverse effects on sensitive species, leading to a reduction in the abundance and diversity of other macroinvertebrate groups (Tamiru 2019).

The introduction of common carp has led to a decline in stability, indicated by decreases in total abundance and diversity indexes. This decline is particularly evident in certain groups, specifically benthic macroinvertebrates like Gastropods and Annelida, which are both prey and competitors of the common carp. As a result, the impact of common carp on these species is quite strong. However, we also observe a decrease in variability (stability) in certain plankton-related groups, such as some Insects and Crustaceans (Conchostraca). This demonstrates that common carp primarily act as benthivores, impacting species associated with sediment, agreeing with the literature (Rahman et al. 2008; Rahman et al. 2010; Miller & Crowl 2006; Dadebo et al. 2015). Overall, our findings suggest that the negative effect of common carp on species abundance contributes to reduced stability in those species or groups. Additionally, the decrease in species richness and diversity may also contribute to the overall reduction in stability.

By feeding on more than one trophic level omnivores tend to stabilize communities (Holyoak & Sachdev 1998; Fagan 1997). However, despite being an omnivore and consuming multiple trophic levels, the common carp's direct consumption of benthic macroinvertebrates and its indirect effects through sediment disturbance appear to exert a significant impact. This interaction was responsible for the decline in both abundance and diversity and led to the destabilization of the community. Although they can stabilize, the effects of omnivores can be complex and dependent on environmental conditions, predator and prey identity, and strength of interaction (Morin & Lawler 1996; Lawler & Morin 1993). Therefore, the destabilizing effect of omnivorous may also be common.

Environments characterized by high diversity and richness exhibit greater stability and resilience in the face of environmental disturbances (Tilman & Downing 1994; de Mazancourt et al. 2013; Tilman et al. 2014). However, the studied environment experiences significant seasonal fluctuations and prolonged drought periods, therefore, the natural disturbance is inherent (Maltchick & Florín 2002) and potentially contribute to the observed low richness and diversity before common carp introduction. Furthermore, due to the environmental instability, we did not observe a high diversity with the presence of a stable dominant species, which can also play a role in community stability (Grime 1998). The presence of dominant species in stable environments can mitigate the impacts on the community, since they tend to have greater temporal stability, that in some environments can drive the community stability (Steiner et al. 2005; Roscher et al. 2011). However, we found a state of high equitability before to the introduction of common carp. Therefore, when anthropogenic influences, such as species introductions, occur in unstable environments with low dominance, the consequences can be severe, leading to substantial impacts on biological communities, such as a strong decrease in species richness and diversity and an increase in dominance due the severe species elimination, as we found. Additionally, further reductions in diversity can decrease the community's resilience.

Common carp are well-known for their strong impact on sediment resuspension, changes in water quality, decrease in macrophyte biomass and richness, which can indirectly affect macroinvertebrates by depriving them of places to settle, besides the direct consumption on macroinvertebrates can lead to reductions in species abundance (Badiou & Goldsborough 2015; Vilizzi et al. 2015; Bajer et al. 2016; Zambrano & Hinojosa 1999; Zambrano et al. 1998; Fletcher et al. 1985; Barthelmes & Brämick 2003; Miller & Crowl 2006). In our study, we observed a significant effect of common carp on macroinvertebrates, resulting in substantial decreases in abundance, species richness, and diversity of benthic species or groups, such as gastropods and annelids. Benthic invertebrates play a crucial role in the food chain by consuming detritus and algae, and they serve as a food resource for fish while also participating in nutrient cycling. Any disturbance in macroinvertebrate communities can have negative implications for native fish communities and the overall functioning of the ecosystem, as well as the services it provides. Although our study has limitations, it is widely known that the impacts of common carp, particularly benthivorous species, should not be underestimated, especially in shallow lakes facing challenging conditions like prolonged dry periods and eutrophication.

Despite the limitations of the work, such as the absence of biomass data of common carp, we show the negative impact of common carp on benthic macroinvertebrates abundance, diversity and community stability that can potentially affect the ecosystems services. The removal of benthivorous fish, even native species, has been suggested as an alternative to mitigate the effects of eutrophication (Meijer et al. 1990; Araújo et al. 2016; Dantas et al. 2018). In tropical shallow lakes that experience significant hydrological fluctuations, the introduction of benthivorous species like common carp can be highly detrimental. We recommend avoiding the introduction of carp in shallow lakes of semiarid areas. However, if the *C. carpio* are already established in the environment, as the common carp effects are dependent on biomass (Badiou & Goldsborough 2015; Zambrano et al. 1998), maintaining their populations at low biomass may reduce the negative impact on biological communities and water quality, as well as being an important fishery resource.

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