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Impacts of sedimentation and dam failure on the macroinvertebrate community in a tropical stream

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ABSTRACT

Impacts of sedimentation and dam failure on the macroinvertebrate community in a tropical stream

Changes in land use due to human activities lead to disturbances related to sedimentation in aquatic ecosystems. Furthermore, the construction of dams in streams raises concerns about their safety, and the rupture of these structures implies significant impacts. Thus, this article assessed the effects of sedimentation and dam failure on the aquatic macroinvertebrate community in a tropical stream and verified its influence on the structural and functional composition of this assemblage of organisms. Water physical-chemical parameters and macroinvertebrate fauna data were obtained from monitoring data for both the pre- and post-rupture period. Macroinvertebrates were identified at the family level and classified according to functional feeding groups. Structural and functional biological indexes were applied, and data were analyzed using comparison tests, correlation matrix, correspondence, and cluster analysis. The results showed that sedimentation resulted in the impoverishment of macroinvertebrate fauna, with the loss of important functional feeding groups, indicating a low environmental quality. Dam failure changed the composition of the fauna, leading to the disappearance of important orders, the appearance of organisms belonging to the order Coleoptera, and the loss of feeding groups with consequent loss of ecological functions. The dam failure was not the only stressor for the studied stream, because it already suffered from small and medium scale disturbances related to sedimentation. However, the rupture of the structure resulted in greater environmental losses, and is considered large scale, implying the need to implement recovery measures in the area.

Key words: benthic invertebrates, functional feeding groups, suspended solids, habitat loss

RESUMO

Impactos da sedimentação e rompimento de barragem na comunidade de macroinvertebrados em um riacho tropical

Mudanças no uso da terra, por atividades humanas, provocam distúrbios relacionados à sedimentação em ambientes aquáticos. Além disso, a construção de barragens em riachos aumenta as preocupações relacionadas à sua segurança e a ruptura dessas estruturas provocam fortes impactos. Dessa forma, o presente artigo avaliou os efeitos da sedimentação e rompimento de barragem na comunidade de macroinvertebrados aquáticos em um riacho tropical e verificou a influência desse evento na composição estrutural e funcional dessa assembleia de organismos. Dado físico-químicos da água e da fauna de macroinvertebrados foram obtidos para os períodos de pré e pós-rompimento da barragem. Os macroinvertebrados foram identificados até o nível de família e classificados de acordo com os grupos funcionais alimentares. Índices biológicos estruturais e funcionais foram aplicados e os dados foram analisados por testes de comparações de médias, matrizes de correlação, análise *de correspondência e de agrupamento. Os resultados demonstraram que a sedimentação resultou em um empobrecimento da fauna de macroinvertebrados, com a perda de importantes grupos funcionais alimentares, indicando uma baixa qualidade ambiental. O rompimento da barragem implicou numa mudança na composição da fauna, com o desaparecimento de importantes ordens e o aparecimento de organismos da ordem Coleoptera, além da perda de grupos alimentares, com consequente perdas de funções ecológicas. O rompimento da barragem não foi o único estressor para o riacho estudado, uma vez que esse já sofria por perturbações de baixa e média escala, relacionadas à sedimentação. No entanto, a ruptura da estrutura resultou em maiores perdas ambientais, sendo considerada de grande escala, implicando na necessidade da implementação de medidas para recuperação da área.*

Palavras chave: *macroinvertebrados bentônicos, grupos funcionais alimentares, sólidos suspensos, perda de hábitat*

INTRODUCTION

Freshwater ecosystems have undergone intense modifications resulting from changes in the structure of river channels, effluent inflow, dams and landscape changes that occur at the basin level, such as deforestation, agriculture and land movements to implement projects and road construction (Herlihy et al., 2005; Li et al., 2013; Pond, 2010; Rodrigues et al., 2016). As a consequence of anthropogenic disturbances, the water quality and biodiversity of freshwater ecosystems are declining globally. Thus, management strategies to ensure the protection of aquatic environments need to focus on keeping such disturbances retained outside them as these environments reflect what is happening on land (Bernhardt & Palmer, 2011).

Soil movement at the basin level increase solids inflow into aquatic ecosystems, in the form of dissolved and suspended particles (Kent & Stelzer, 2007; Wood & Armitage, 1997). In addition, dam construction in streams and rivers is another form of disturbance, leading to a wide range of environmental impacts, highlighting problems related to the safety of these structures. Dam failure results in serious impacts having effects on biological communities (Fernandes et al., 2020; Silva Rotta et al., 2020; Thompson et al., 2020). Brazil has recently suffered two catastrophic disasters related to the rupture of the Brumadinho iron mine dam and the Fundão dam in Minas Gerais State, leading to large scale impacts on communities and the environment (Omachi et al., 2018; Silva Rotta et al., 2020). However, small scale impacts related to the failure of small dams are a growing concern, mainly because it is a frequent problem in developing countries (Pisaniello et al., 2015), and it is the focus of this paper.

Considering all the reported impacts, it can be pointed out that biodiversity is threatened by anthropic activities that cause a deterioration in ecosystems and/or the extinction of local biota, making biodiversity one of the factors used as an impact assessment tool (Serrano Balderas et al., 2016). Biological communities can be applied as biological indicators as they reflect multiple anthropogenic pressures in aquatic ecosystems, and benthic macroinvertebrates are the most commonly used group (Baptista et al., 2013; Callisto et al., 2021). They are an important group in freshwater ecosystems and are sensitive to a range of stresses and environmental conditions, and can be used as a valuable tool (Czerniawska-Kusza, 2005; Taowu et al., 2008), as they are key indicators in determining patterns of degradation in streams (Pond, 2011).

The invertebrate assemblage and their biodiversity are reduced due to habitat degradation in streams (Schröder et al., 2013). Moreover, the increase in sediment levels in the form of suspended and deposited solids in beds has a wide range of effects on aquatic biota (Von Bertrab et al., 2013). Impacts of fine sediments and silting on the macroinvertebrate community have been observed (Callisto et al., 1998; Extence et al., 2013). Thus, richness, community structure, number of tolerant and intolerant groups and the composition of functional feeding groups are useful indicators of environmental quality (Taowu et al., 2008).

Thus, it is evident that this assemblage of organisms can be applied as a valuable tool to assess impacts related to the sediment inflow and the dam failures in streams. Thus, the objective of this article is to assess the effects of sedimentation and dam failure on the aquatic macroinvertebrate community in a tropical stream (Campinha stream) and to verify the influence of these stressors on the structural and functional composition of this assemblage of organisms. The Campininha stream basin (2.65 km^2) has undergone a long degradation process, mainly related to farming, damming the stream for use in livestock and fish farming and soil movement to construct roads and industries. Soil movement caused a high particle inflow into the reservoir and stream, silting up the banks and canal. Furthermore, after an event of heavy rain, the dam broke, leading to implications for the entire aquatic ecosystem. Thus, some hypotheses were formulated concerning this problem: i) the stream does not present high values of diversity (structural and functional) of its macroinvertebrate community due to the various impacts previously experienced, mainly related to sedimentation, both in its lotic and lentic stretch; ii) as stretches with different regimes (lotic and lentic) will be studied, a difference in the structural and functional composition of the macroinvertebrate community is expected, having greater effects on the dammed stretch due to the large inflow and solids retention iii) the rupture of the dam should imply a change in the composition of the macroinvertebrate fauna eliminating sensitive groups and an increase in the dominance of resistant groups and loss of functional groups, with a sharp decrease in richness and diversity.

MATERIALS AND METHODS

Study area and data collection

The study was conducted at the Campininha stream, located in the municipality of Sorocaba, state of São Paulo – BR (23° 22’ 21’’ S, 47° 28’ 13.2” W). The climate is characterized as a transition between humid subtropical climate (Cfa) and a monsoon-influenced humid subtropical climate (Cwa) according to the Köppen climate classification, with high temperatures (average 24.6 °C) and raining (average 176 mm month) in the summer, and the lowest temperatures (average 19 °C) and rainfall (average 47.6 mm month) in the winter (Bortoleto et al., 2016; Mello et al., 2014). The soils that occur predominantly in the region are dystrophic red-yellow argisoil and dystrophic red latosol (Rossi, 2017). The location map of the basin is presented as Supplementary material (Fig. S1, supplementary material, available at http://www.limnetica.net/en/limnetica). As previously discussed, the Campininha basin had suffered several impacts over time. In 2006, the main use of the watershed was farming, around 70 % of basin area (Pinto, 2018), with damming of the Campininha upstream for animal watering and fish farming. From 2010 onwards, earthmoving began for the construction of a highway and installation of an industry. Thus, the soil was carried into the aquatic system due to the volume of rainfall in the region. This process can be observed by siltation of the reservoir banks and by the color of the water (see Figures S2 and S3, supplementary material, available at http://www.limnetica.net/en/limnetica). In December 2013, after a high rainfall event occurred, the dam ruptured. After rupturing, the degree of siltation was observed in the area where the lake was located. Furthermore, a high quantity of sediment was carried out to the stream (see Figures S3).

Data on water quality and macroinvertebrate assemblages were obtained from monitoring reports between 2010 and 2015. Overall, 21 sampling campaigns were carried out, comprising four annual samplings. Sampling occurred in the wet period (October to March) and dry period (April to September) (Firmiano et al., 2021). The first sampling post-rupture occurred 15 days after the event. The physical-chemical parameters made available in the reports were pH, dissolved oxygen, turbidity and the color of the water (multiparameter probe Oakton model 600, Series Waterproof Portable Meters). Monitoring took place at three points (see Figure S4, supplementary material, available at http://www.limnetica.net/en/limnetica). The P1 was located upstream from the dam (lentic system), without riparian forests, erosion on the banks, and 1.2 ± 0.08 m deep and 15.5 ± 1.7 m width. P2 and P3 were downstream (lotic system), with evidence of silting on the banks and 0.4 ± 0.09 and 0.05 ± 0.09 m deep, and 1.6 ± 0.1 and 2.0 ± 0.2 m width. The P2 had riparian vegetation cover on both banks, and P3 had grass in the right bank. Post-rupture, the P1 was located in the same area, however, with a characteristic of a lotic system (0.25 ± 0.07 m deep and 1.1 ± 0.1 m width), and P2 and P3 had a high degree of siltation on the banks and canal (see Figures S2 and S3, supplementary material, available at http://www.limnetica.net/en/limnetica). The data collected between 2010 to 2013 were called pre-rupture (16 sample campaigns) and between 2014 and 2015 post-rupture (5 campaigns). As only one sampling occurred in 2015 (January), these data are presented together with 2014. The benthic macroinvertebrates were collected by a Surber sampler (0.090 m^2 of area, 210 µm mesh size) concomitantly with the collection of physical-chemical parameters. The final sample consisted of 3 sub-samples carried out

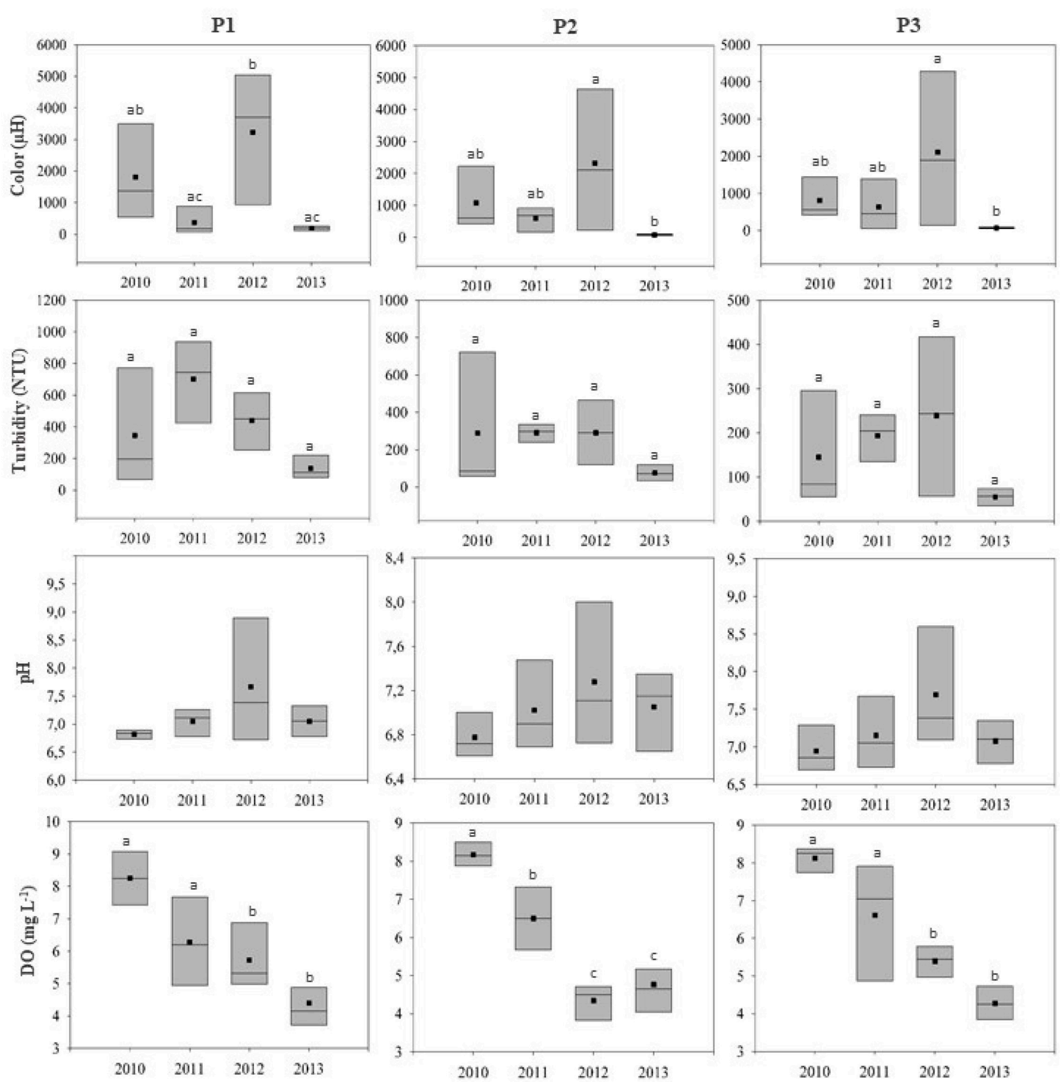

Figure 1. Color of the water, turbidity, pH, and dissolved oxygen to the period before the dam failure (2010 and 2013). Statistically significant differences ($p < 0.05$) are indicated by different letters. *Cor da água, turbidez, pH e oxigênio dissolvido para os períodos anteriores ao rompimento da barragem (2010 e 2013). Diferenças estatísticas (*p < 0.05*) são indicadas por diferentes letras.*

on the banks and in the middle of the stream and dam. The samples were transported, with water from the stream itself, and analyzed with the organisms still alive. The organisms were preserved in 70 % ethanol and identified at the family level, except for Oligochaeta that was identified at the subclass level based on Costa et al. (2001) and Mugnai et al. (2010).

Data analysis

The ecological indexes of richness, Shannon diversity, Equitability and dominance were applied in the Past program (version 2.17). The density of organisms was calculated from the relationship between the number of organisms and the base area of the sampler (0.09 m^2). In addition, the BMWP (Biological Monitoring Working Party) biotic index, adapted for Brazil by Junqueira and Campos (1998), was applied. The EPT (Ephemeroptera, Plecoptera and Trichoptera) index and indexes related to community composition (percentages of Coleoptera, Gastropoda, Trichoptera, Diptera and Odonata) were also calculated. The composition of organisms according to sensitivity (% Sensitive, % Moderate and % Tolerant) was calculated from the classification of Junqueira and Campos (1998). Organisms with scores of 1-3 were considered tolerant, 4-7 moderate and 8-10 sensitive. Moreover, the macroinvertebrate community was classified according to the functional feeding groups, and the family Chironomidae was classified as collectors-gatherers (Cummins et al., 2005; Damanik-Ambarita et al., 2016; Ramírez & Gutiérrez-Fonseca, 2014).

A Spearman correlation matrix was applied between the environmental variables and the biological indexes, a Correspondence Analysis (CA) was applied to verify the distribution of the applied indexes (CANOCO software, version 4.5), and a Cluster Analysis was performed for the biological indexes applied using Euclidean distance measurements (Past, version 2.17). The difference between the sample periods and sampling points was verified by mixed-design ANOVA. The years were analyzed as a within-effect factor (repeated measures) and the sampling points were analyzed as a between-effect factor (R software, version 3.6.0, 2009). When differences were detected, a post-hoc test (Bonferroni test) was applied. Normality of the data was assessed by the Shapiro-Wilk test and the homogeneity of variances by the Levene test. When the data did not meet the requirements of parametric statistics, data transformations were applied.

RESULTS

Water Physico-chemical data

For the period before the dam failure (2010 to 2013), the P1 was located on the reservoir and P2 and P3 at downstream. For the variable color of the water, no differences were observed between the sampling points ($F_{2\ 1275327} = 0.781$, $p = 0.53$). However, the sampling time presented differences ($F_{3\ 64536751} = 29.95$, $p < 0.0001$), and 2011 and 2013 had a lower color of water compared to 2012 ($p = 0.04$ and 0.02) for P1. For P2 and P3, the color of the water in 2013 decreased compared to 2012 (Fig. 1). There was no significant effect on the interaction between the spatial and temporal variations ($F_{6\ 2912768} = 0.68$, $p = 67$). The turbidity had a high variability, however no statistical differences were detected regarding the sampling points ($F_{2\ 432877} = 3.91$, $p = 0.14$), sampling time ($F_{3\ 559623} = 2.59$, $p = 0.12$), and for the interaction between the two factors ($F_{6\ 232184} = 0.54$, $p = 0.77$, Fig. 1).

For the pH, no differences occurred between the sampling points ($F_{2,\ 0.02} = 0.55$, $p = 0.62$) and time ($F_{3,\ 0.52} = 1.07$, $p = 0.41$), besides the interaction of both factors ($F_{6\ 0.223} = 0.23$, $p = 0.96$). A decrease in dissolved oxygen (DO) was observed over the years ($F_{3,\ 53.65} = 99.7$, $p < 0.0001$). The DO in 2012 and 2013 was lower than 2010 and 2011 ($p < 0.01$) for all sampling points, which were similar ($F_{2,\ 0.42} = 0.69$, $p = 0.57$). In general, no statistically significant differences were found between the dry and rainy seasons and between the sampling points ($p > 0.05$).

Regarding the dam failure event, there was no statistically significant difference for the color of the water, pH, and OD parameters for the periods of pre- and post-rupture ($p > 0.05$). Turbidity decreased in P1 post-rupture, and increased in P2 and P3, although only P1 showed a statistically significant difference between the periods ($p < 0.0001$,

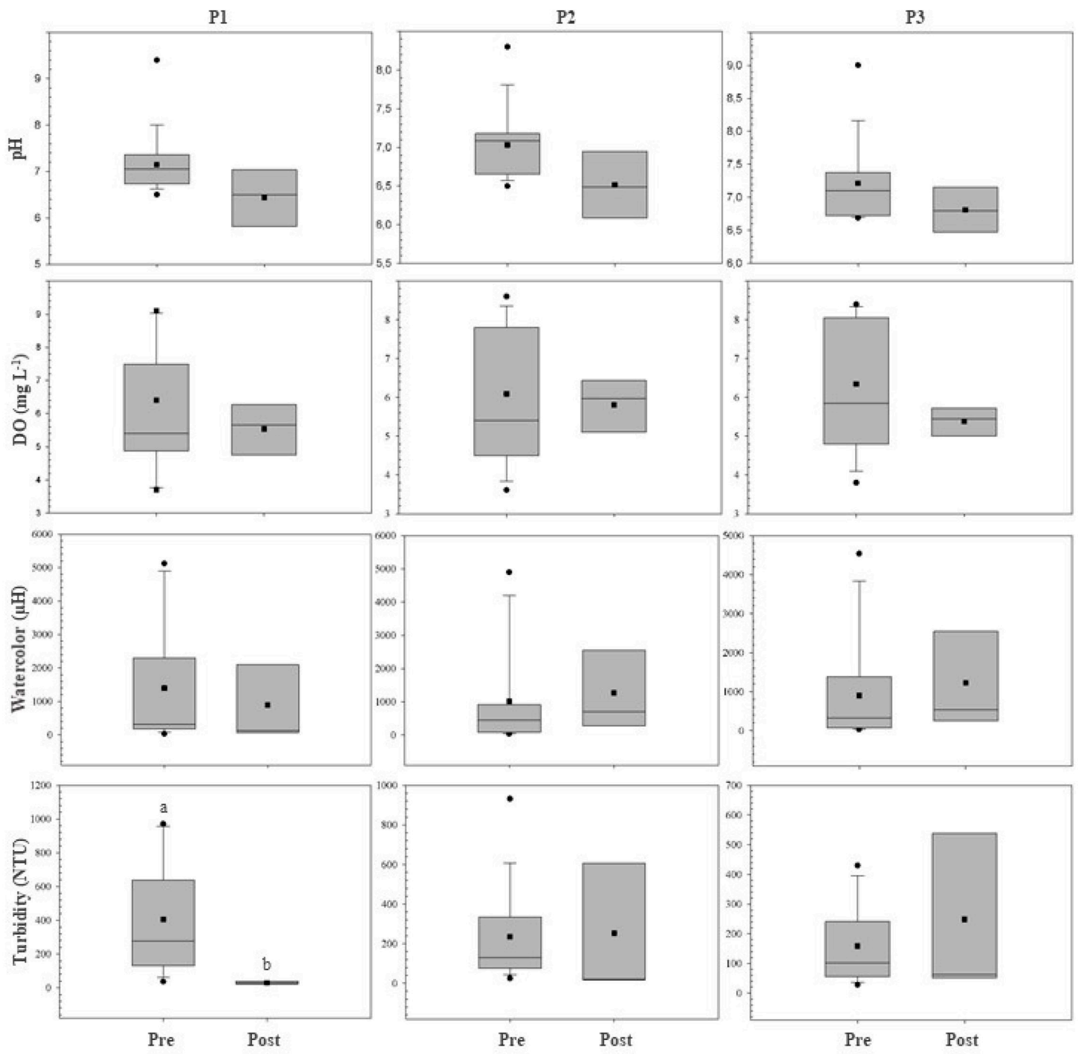

Figure 2. Comparison between the physical-chemical variables between the periods of pre- and post-rupture. Statistically significant differences ($p < 0.05$) are indicated by different letters. *Comparação entre as variáveis físico-químicas entre os períodos de pré e pós ruptura. Diferenças estatísticas (*p *< 0.05) são indicadas por diferentes letras.*

Fig. 2). The S1 and S2 Tables (supplementary material; available at http://www.limnetica.net/en/limnetica) present the water parameters for the pre- and post-rupture periods.

Macroinvertebrate community

The macroinvertebrate assemblage was distributed in 11 orders and 21 families, for the period prior to dam failure, totaling 496 identified organisms. After the rupture, 206 organisms were found, distributed in 6 orders and 14 families, with the disappearance of the orders Ephemeroptera, Plecoptera, Trichoptera and Megaloptera and the subclass Oligochaeta. Consequently, there was a significant increase in the representativeness of the orders Coleoptera (2 % in the pre-rupture period for 38 % post) and Hemiptera (4 % for 10 %) and a decrease in the representativeness of Odonata (52 % for 42 %). The families Hydropsychidae (23 %) (order Trichoptera), Libellulidae (18 %), Gomphidae (13 %) and Coenagrionidae (11 %)

(all belonging to the order Odonata) were the most abundant in the period before the dam failure, occurring with greater frequency in the P1, located in the lentic stretch. Only the family Gomphidae had a greater representation in the points located in the lotic stretch. After the rupture, the family

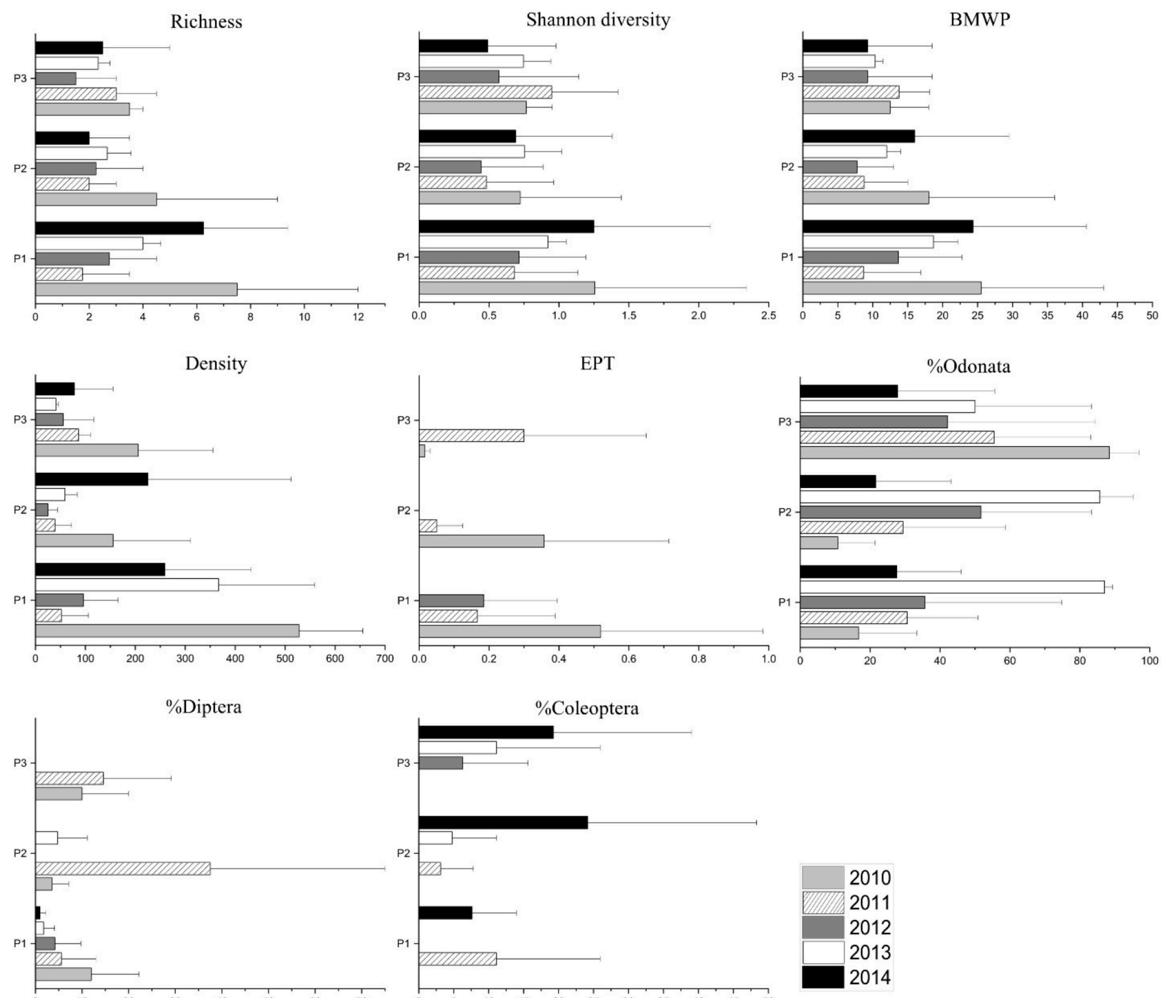

Figure 3. Ecological indexes (mean ± SD) for the period before (2010 to 2013, n = 4) and after the dam rupture (2014, n = 5) for the sampling points. For the pre-rupture period, the P1 was located in the reservoir and post-rupture was in the stream. No differences occurred for richness, BMWP, and EPT. For Shannon diversity differences occurred between the sampling points ($F_{2\ 1.262} = 17.86$, $p = 0.02$) for P1 and P2 ($p = 0.03$) and no time differences were observed. Temporal differences occurred for organism density ($F_{4\ 283317} = 4.88$, $p = 0.01$) and 2010 was different from 2012 and no spatial differences were observed. The percentual of Odonata presented temporal differences ($F_{4\ 15453} = 4.78$, $p = 0.02$) and 2013 differ from 2014. Besides, temporal differences occurred for the percentual of Diptera ($F_{4\ 5740} = 7.75$, $p = 0.001$) and 2011 was different from the other experimental periods. No spatial differences occurred for both parameters. *Índices ecológicos (média ± DP) para o período antes (2010 a 2013, n = 4) e depois (2014, n = 5) da ruptura da barragem para os pontos amostrais. Para o período de pré-rompimento, o P1 estava localizado no reservatório e, após o rompimento, se localizou no riacho. Não houve diferenças para os índices de riqueza, BMWP e EPT. Para a diversidade de Shannon, diferenças ocorreram entre os pontos amostrais ($F_{2\ 1.262} = 17.86$, p = 0.02) para P1 e P2 (p = 0.03) e não foram observadas diferenças temporais. Diferenças temporais ocorreram para a densidade de organismos ($F_{4\ 283317} = 4.88$, p = 0.01), sendo 2010 diferente de 2012, e não foram observadas diferenças espaciais. O percentual de Odonata apresentou diferenças temporais ($F_{4\ 15453} = 4.78$, p = 0.02) com 2013 diferindo de 2014. Além disso, diferenças temporais ocorrerem para o percentual de Diptera ($F_{4\ 5740} = 7.75$, p = 0.001) e 2011 foi diferente dos outros período experimentais. Não ocorreram diferenças espaciais para ambos os parâmetros.*

Hydropsychidae disappeared and the family Dytiscidae (Coleoptera) became the most abundant (28 %), followed by the family Coenagrionidae (25 %). In addition, the families Elmidae and Girinidae (both belonging to the order Coleoptera) were found in the samples. The composition of the macroinvertebrate fauna is presented as supplementary material (Table S3 and Fig. S5, available at http://www.limnetica.net/en/limnetica).

Regarding the functional classification, there was a dominance of predators (65 %) in the lentic and lotic stretches, before the dam failure, ex-

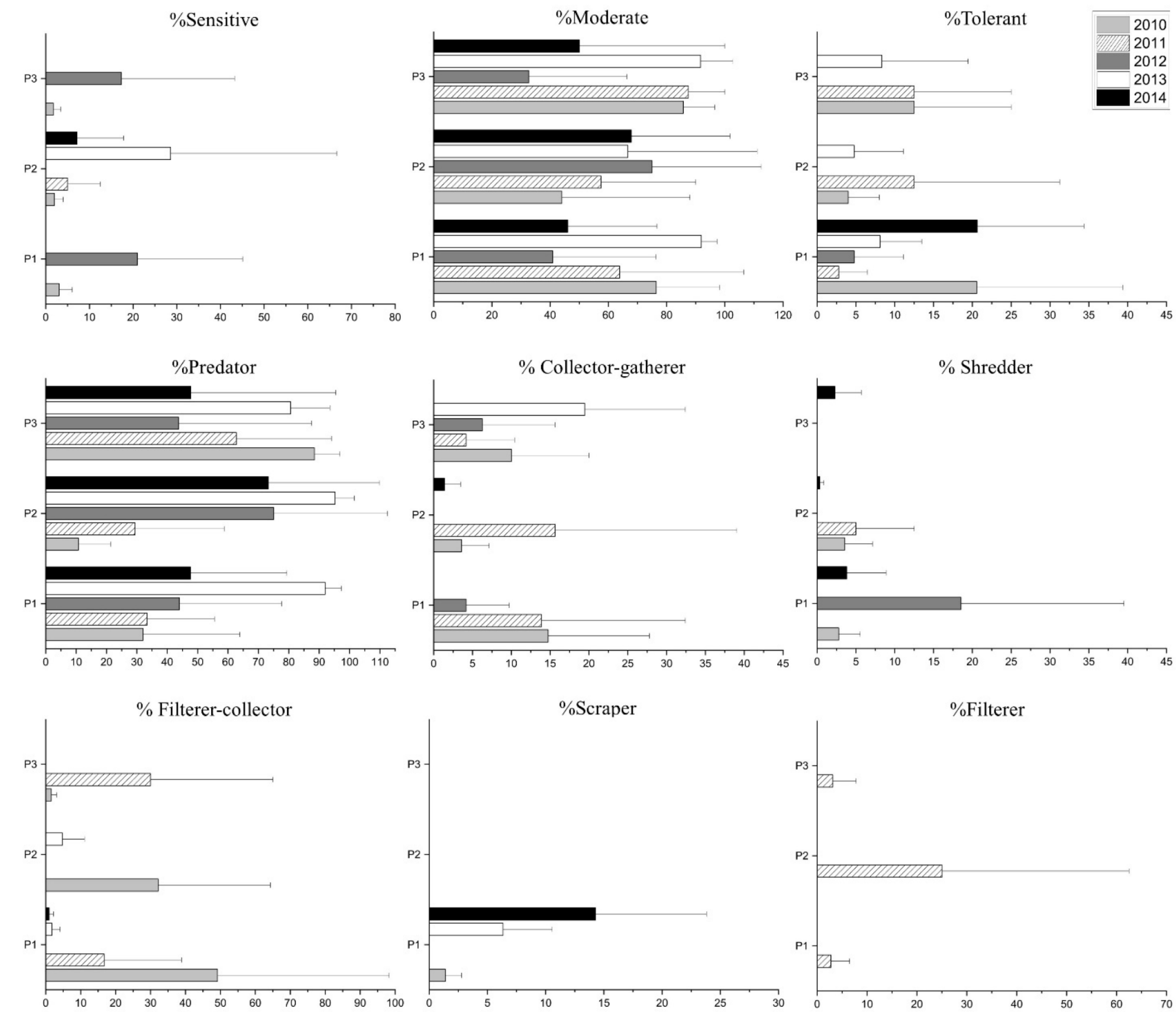

Figure 4. Sensitivity composition and functional response (mean ± SD) for the period before (2010 to 2013, n = 4) and after the dam rupture (2014, n = 5) for the sampling points. For the pre-rupture period, the P1 was located in the reservoir and post-rupture was in the stream. Statistical differences occurred for the percentual of predators between the sampling points ($F_{2\ 515.42} = 25.55$, $p = 0.01$) and P3 was different from P1 and P2, and no temporal differences were observed ($F_{4\ 16827} = 2.54$, $p = 0.09$). No effects were observed for the other functional groups, and % Sensitive, % Moderate, and % Tolerant. *Composição de sensibilidades e respostas funcionais (média ± DP) para o período antes (2010 a 2013, n = 4) e depois (2014, n = 5) da ruptura da barragem para os pontos amostrais. Para o período de pré-rompimento, o P1 estava localizado no reservatório e, após o rompimento, se localizou no riacho. Diferenças estatísticas ocorreram para o percentual de predadores entre os pontos amostrais ($F_{2\ 515.42} = 25.55$, p = 0.01), sendo P3 diferente do P1 e P2, e nenhuma diferença temporal foi observada ($F_{4\ 16827} = 2.54$, p = 0.09). Não foram observados efeitos para os outros grupos funcionais e para % Sensíveis, % Moderados e % Tolerantes.*

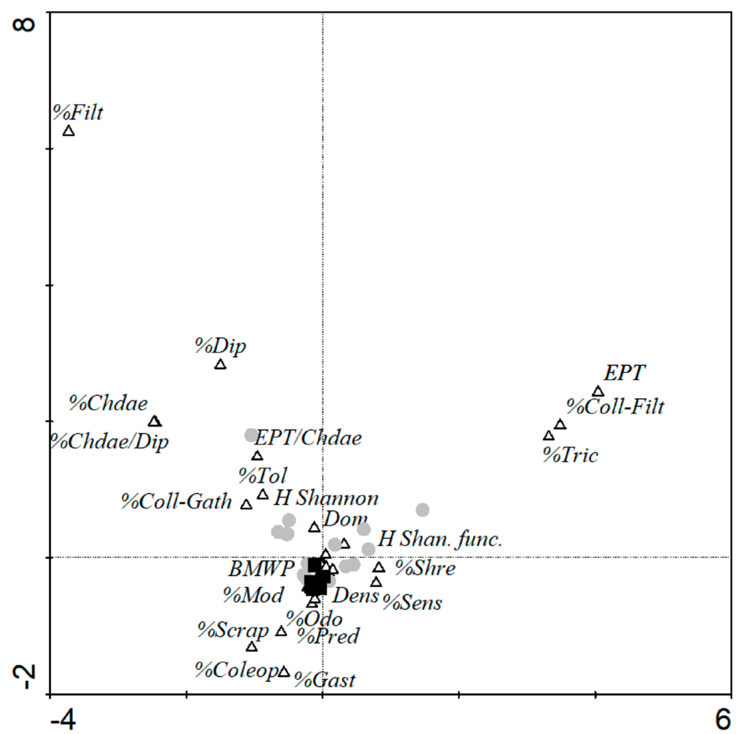

Figure 5. Correspondence analysis with the spatial distribution of the samples and for the indexes to the pre- and post-rupture periods. The first axes explain 22.9 % of the variance and the second axes 19.4 %. Triangles represent the applied indexes, gray circles the sampling points before the dam rupture and black squares the post-rupture sampling points. *Análise de correspondência com a distribuição espacial das amostras e dos índices para o período de pré e pós ruptura. O primeiro eixo explica 22.9 % da variância e o segundo eixo 19.4 %. Triângulos representam os índices aplicados, círculos cinza os pontos amostrais antes da ruptura da barragem e quadrados pretos os pontos amostrais após a ruptura.*

plained by the dominance of Odonata families, followed by the group of collector-filters (23 %), by the presence of the family Hydropsychidae, and collector-gatherers (7 %). The other functional groups had a low representativeness in the sampled community. After rupture, dominance remained among predators (87 %), followed by scrapers (7 %), with the disappearance of the filters. In addition, with the disappearance of the Hydropsychidae family, there was a reduction in the representativeness of the collector-filters (less 1 %) (see Fig. S5, supplementary material, available at http://www.limnetica.net/en/limnetica).

Considering the applied indexes, a tendency to decrease the values of richness and diversity can be observed mainly for 2011 (pre-rupture) and 2014 (post-rupture); however, no temporal differences were detected ($F_{4\ 65.5} = 1.52$ and $p = 0.26$, and $F_{4\ 2.44} = 1.03$ and $p = 0.43$, respectively, Fig. 3). Moreover, 2010 has the highest values of these indexes, including the scores of the BMWP, EPT and density. However, because of the high variability, no temporal differences were observed, except for density ($F_{4\ 283317} = 4.88$ and $p = 0.01$, see Fig. 3). We highlight a disappearance of sensitive groups from 2011 for the P3 and 2012 for the P1 (see Fig. 4). For P2, these organisms were found in all years, focusing on 2013 where they were more dominant compared to other years. Moderately tolerant organisms had a greater dominance in all years and points, while an increase in the representativeness of the Tolerant is observed after the rupture of the dam (2014) for the P1 (Fig. 4).

For the P1, the percentual of Diptera decreased over the years ($F_{4\ 5740} = 9.75$ and $p = 0.001$)

and disappeared in P2 and P3 after the structure was disrupted (2014) (Fig. 3). Thus, the interaction between time and sampling points was significant ($F_{8\ 4133}$ = 3.51 and p = 0.02). On the contrary, there was an appearance of the order Coleoptera for the three points over time, focusing on post-rupture conditions. However, no temporal differences were detected ($F_{4\ 301}$ = 0.90 and p = 0.50). The percentage of Trichoptera had the same behavior as EPT due to the dominance of this order in the composition of the community, as well as the percentage of scrapers behaved similarly to Gastropoda, because this order is the only representative of this feeding group for this study (Fig. 3).

As previously described, there was a dominance of predators for all points in all sampled periods and no temporal differences occurred ($F_{4\ 16134}$ = 2.54 and p = 0.09, see Fig. 4). On the other hand, there were spatial differences ($F_{2\ 515}$ = 25.55 and p = 0.01) and P3 was different from the other sampling points. The collector-gatherers disappeared after the structure rupture (2014) due to the effect observed to the Diptera order. The shredders had a greater representativeness in the P1, before and after the rupture. This feeding group disappeared in the P2 from 2011 onward and was absent in the P3, until the post-rupture period, where they started to be found in both areas. The scrapers were only found in the P1, before and after the rupture (Fig. 4), and the collector-filterer disappeared in the P2 and P3 post-rupture. The filters were identified only in 2011 in all sampling points. Due to the high variability between the sampling throughout the years, no differences were detected for the functional groups (mixed ANOVA p > 0.05, see Fig. 4).

Table S4 (supplementary material available at http://www.limnetica.net/en/limnetica) presents the mean values of the applied indices, in addition to the expected and observed responses for each parameter. It can be observed that some indices showed unexpected responses, highlighting that the values of the richness, diversity, BMWP, % Coleoptera, % Sensitive, % Shredder and % Scraper indices had an unexpected increase for some sampling points. Conversely, the % Diptera, % Chironomidae, Chironomidae/Diptera and % Tolerant indices decreased.

Figure 5 shows the result of the correspondence analysis between the applied indexes and the distribution of the sample points, considering the periods of pre- and post-rupture. The first axis represents 22.9 % of the data variance and the secondary 19.4 % (both axes 42.3 %). When analyzing the figure, a grouping of the post-rupture points can be observed, separated by both axes, indicating great homogeneity of these points. On the contrary, there was a spreading of the post-rupture points. The grouping of the post-rupture points was directly and most strongly influenced by the percentages of Gastropoda, Odonata, Coleoptera and scrapers due to the change in the composition of these orders after the event, and by the BMWP indexes, Shannon diversity, and % Moderate. A grouping of the EPT index and percentage of Trichoptera and the collector-filterer is observed, explained by the dominance of the order Trichoptera in the EPT fauna, in relation to Plecoptera and Ephemeroptera, and by the dominance of the Hydropsychidae family (collectors-filterer). This grouping is inverse from the post-rupture grouped samples due to the disappearance of these organisms after the dam failure. These groups are inverse to the indexes that reflect the most tolerant organisms (% Tol, EPT/Chidae) and those belonging to the order Diptera (% Dip, % Chidae, Chidae/Dip, Col-Cat) (Fig. 5).

Figure 6 shows the cluster analysis of the applied ecological indexes for the periods studied. There is a greater similarity between points 2 and 3 post- and point 3 pre-rupture, considering the BMWP index, which received low scores in all cases, and is classified as having poor quality. P1, in both periods, received higher scores, but it is still classified as having poor quality, highlighting that before the rupture it was in the lotic stretch of stream. There was a high similarity for the EPT index between the post-rupture points due to the total disappearance of this fauna after the incident, with a high similarity with the P3 pre-rupture due to the low occurrence of these organisms in the sampling campaigns. Regarding density, it was observed that the post-rupture P1 distanced itself from the other sampling points, as this point had the highest density of organisms. Initially P1 has a different regime from the others (lentic). Regarding the percentage

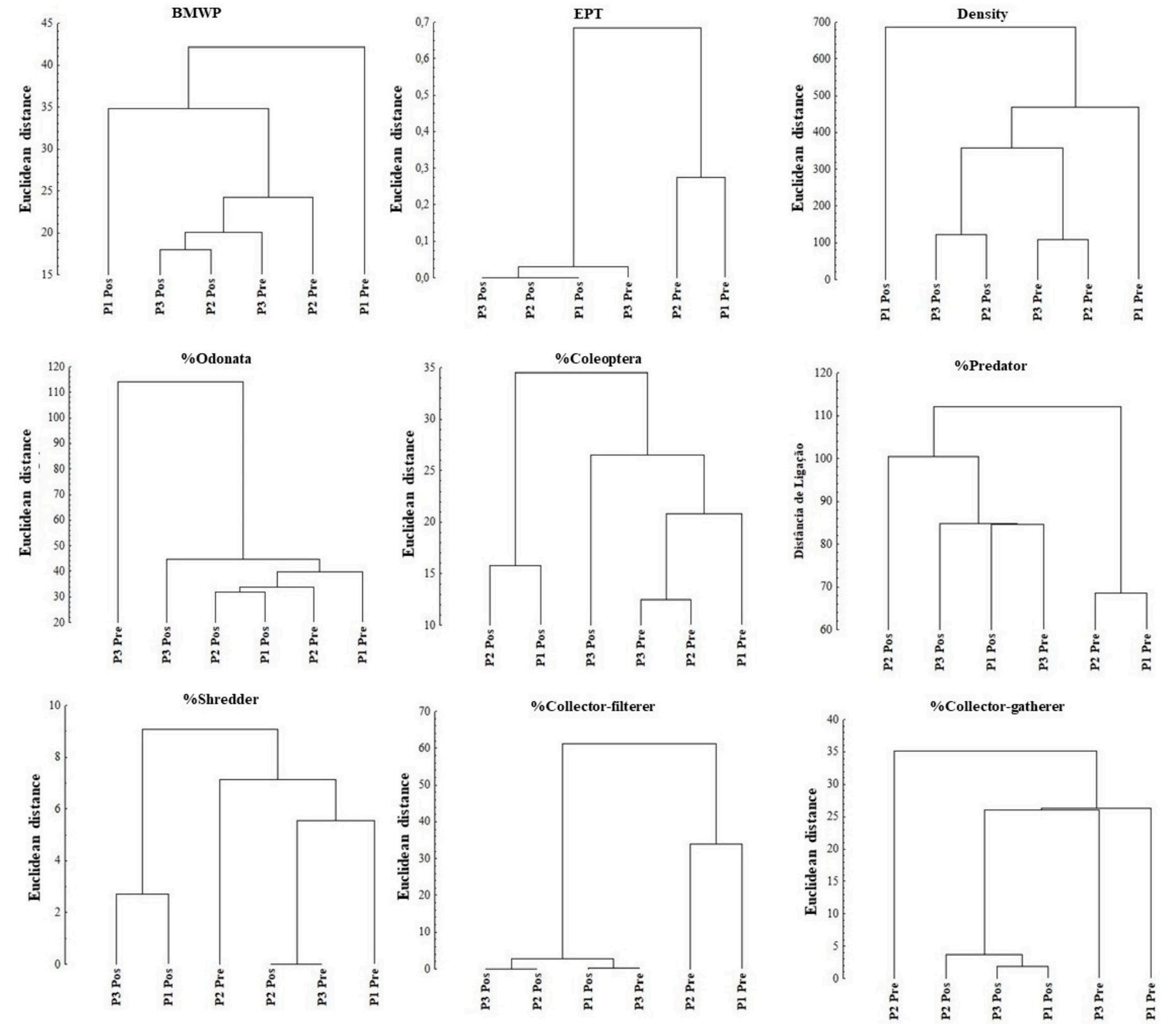

Figure 6. Cluster analysis with Euclidean distance for the main indexes presenting the distribution of the sampling points. *Análise de agrupamento com as distâncias Euclidianas para os principais índices, apresentando a distribuição dos pontos amostrais.*

of Odonata, there is a greater distance from P3 pre-rupture, while in relation to the percentage of Coleoptera, P1 and P2 post-rupture distance themselves from the others, showing high similarity between them. High similarity is observed between P1 and P3 post-rupture concerning the percentage of shredders and P2 and P3 post-, and P1 post- and P3 pre-rupture for the collector-filterer. A high similarity occurred between all points post-rupture in relation to the collector-gatherers and between P1 and P2 pre-rupture regarding predators (Fig. 6).

Relationship between the community and water characteristics

Table 1 shows the correlation between the physico-chemical water parameters and the applied indexes. For the pre-rupture period, pH and water turbidity are the parameters that best correlated with the macroinvertebrate community. The decrease in pH implies an increase in the EPT values and, consequently, in the percentual of Trichoptera, sensitive organisms, scrapers, collector-gatherers and in the density of organisms. Conversely,

Table 1. Spearman correlation matrix between the environmental variables and biological indexes to the pre- and post-rupture periods. The significant values are observed by asterisks. *Matriz de correção de Spearman entre as variáveis ambientais e os índices biológicos, para os períodos de pré e pós rompimento. Os valores significativos são destacados por asteriscos.*

	Pre-rupture				**Post-rupture**			
	DO	**pH**	**Color**	**Turb.**	**DO**	**pH**	**Color**	**Turb.**
Richness	0.08	-0.27	-0.31	**-0.58****	-0.34	-0.05	**-0.16***	-0.16
H Shannon	-0.07	-0.08	-0.36	**-0.53****	-0.11	-0.27	**-0.30***	-0.30
EPT	0.23	**-0.54****	-0.24	-0.03	---	---	---	---
BMWP	0.01	-0.35	**-0.41***	**-0.56****	0.25	-0.33	**-0.86****	-0.24
%Diptera	**0.45***	-0.06	0.30	0.11	---	---	---	---
%Coleoptera	-0.22	**0.46***	-0.22	-0.32	-0.05	-0.31	**-0.80***	-0.51
%Trichoptera	0.23	**-0.54****	-0.24	-0.03	---	---	---	---
%Odonata	-0.15	-0.30	-0.37	**-0.43***	-0.36	-0.10	**-0.83***	-0.30
%Sensitive	0.09	**-0.67****	-0.24	-0.18	0.24	-0.38	-0.27	-0.09
%Moderate	-0.25	0.03	-0.40*	**-0.49***	-0.67	0.36	-0.55	-0.02
Richness FFG	0.11	-0.22	-0.35	**-0.46***	-0.63	0.21	-0.70	-0.04
Eq FFG	**-0.30***	0.16	-0.28	**-0.24***	-0.31	0.11	-0.42	-0.07
% Predators	-0.35	-0.17	-0.40	**-0.55****	-0.25	0.08	-0.39	-0.05
% Scrapers	0.26	**-0.40***	-0.19	-0.03	-0.58	0.25	-0.50	-0.08
% Collector-gathers	0.04	**0.40***	-0.04	-0.27	-0.16	---	-0.25	0.08
% Collector-filterer	0.07	**-0.58****	-0.16	-0.10	---	---	---	---
Density	0.14	**-0.53****	-0.28	**-0.48***	-0.48	0.06	**-0.80***	-0.22

FFG – Functional Feeding Grouping; Eq – Equitability
* = $p < 0.05$; ** = $p < 0.01$

the decrease in pH implies a reduction in the proportion of Coleoptera. Increases in turbidity have a negative effect on richness, diversity, BMWP scores, density of organisms, and percentage of moderate organisms, Odonata, and predators. After the dam rupture, only the color of the water had a significant relationship with the applied indexes ($p < 0.05$). Increases in the color of water decreased the BMWP index values, the density of organisms, and the percentages of Coleoptera and Odonata. Moreover, a weak and inverse relationship occurred with richness and diversity.

DISCUSSION

The Campininha stream underwent cycles of increase and decrease in the color of the water and was characterized since the beginning of the sampling campaigns, as having high values of turbidity. Both parameters were found to be above what is recommended by the Brazilian law for turbidity and color of the water. Only the P1 post-rupture met the resolution for the turbidity values and the pH and DO values are within the established by legislation (CONAMA, 2005). These results are associated with the activities developed in the stream basin, which involved intense soil movements, for the installation of an industry and the implementation of roads. These activities caused a large influx of dissolved and particulate material into the dam reservoir and stream, as described above. It is noteworthy that the Campinha stream is located in a region of sub-tropical climate, with hot and rainy summers. This period allows the release and carrying of soil particles into the interior of the aquatic systems due to the intense rain regime (average 176 mm month) (Bortoleto et al., 2016; Mello et al., 2014).

The rupture of the dam resulted in a great disturbance in the stream, mainly due to carrying all the material deposited in the reservoir to downstream stretches. This process was confirmed by changes in the color of the water and turbidity variables between the pre- and post-rupture periods. The P1, which was located in the stretch of the dam before the rupture, showed a sharp decline mainly in the turbidity resulting from carrying the solids downstream. On the contrary, the downstream points were heavily impacted and showed an increase in these variables, highlighting that they already had high values before the accident.

Small dam failure is a current problem around the world, and the rupture occurs mainly due to structural failures associated with flow variations, rain peaks, or landslide events (Dam et al., 2012; Pisaniello et al., 2015). When a dam breaks, the entire aquatic environment is altered, this is the case of the present study. The collapse of the dam changed the composition of the aquatic invertebrate fauna, and led to the disappearance of important orders. Effects close to, but not related to the dam failure, were found by Burdon et al. (2013) who observed a strong effect threshold between sediment deposits and changes in the compositions of macroinvertebrate fauna, which went from a community dominated by Ephemeroptera and Trichoptera to one characterized by non-insect invertebrates, including microcrustaceans, mollusks and worms. Through modeling, the authors observed that the deposited sediment significantly affected the variability of feeding and habitat, with consequent effects on aquatic invertebrates (Burdon et al., 2013). Thus, it is highlighted that significant increase in suspended solids can have lethal effects on the aquatic biota (Miserendino et al., 2012). Moreover, before the dam rupture, the order Odonata had the higher dominance in the macroinvertebrate fauna. Silva et al. (2021) found a positive relationship between the occurrence of taxon from Libellulidae and Gomphidae families with areas of exposed soil, pasture, and high electrical conductivity and dissolved solids in tropical streams.

The disappearance of the Oligochaeta subclass, as well as the decrease in the percentage of Chironomidae, was an unexpected effect, because these groups are considered resistant to environmental disturbances (Beyene et al., 2009; Hodkinson & Jackson, 2005; Junqueira & Campos, 1998). Furthermore, chironomids can be found in areas ranging from low to high anthropogenic disturbance (Martins et al., 2021). The dam rupture generated a transport of the sediment to the downstream stretches and may have buried these organisms, implying their disappearance (Jones et al., 2012). A similar situation was observed by Miserendino et al. (2012) studying the effects of volcanic ash in streams. Severe impacts occurred for species of Chironomidae, in addition to Trichoptera, Coleoptera, Plecoptera and Ephemeroptera that was associated with burial of these organisms. This was confirmed by the encounter of these fossilized groups in sediments constituted by ash. For tropical areas, Firmiano et al. (2021) observed that the macroinvertebrate traits associated with fine sediments were organisms with spherical body shapes, and adults with aquatic stage and long lives. This may explain the increase in the proportion of the orders Coleoptera and Hemiptera, and the subclass Hirudinea, post-rupture. It is noteworthy that in the first sampling campaign, in January 2014 (15 days post-rupture), no organisms were found in any sampling point. The recovery of the macroinvertebrate fauna and reappearance in the samplings occurred in the subsequent campaigns.

Regarding the changes in the functional feeding groups, it is highlighted that the shredders are underrepresented in the samples for all years. This can be explained, at least in parts, by the absence of riparian vegetation that provides a fragmentary structure to support this group of organisms in P1 and P3. The shredders use coarse particulate organic matter (CPOM > 1mm), such as leaf waste, as a food resource (Vannote et al., 1980). According to the ratio proposed by Cummins et al. (2005) between the number of scrapers and the sum of collectors and shredders, the environment was classified as heterotrophic. This classification is justified by the absence of food resources for scrapers (algae), explained by the high values of turbidity and color of the water. The P1 post-rupture showed autotrophic characteristics reinforcing this finding, as it presented the lowest turbidity averages. Changes in the percentage of shredders and scrapers were described as indicators of environmental degradation by Helson and Williams (2013). These authors observed a low percentage of these groups in degraded environments, with a decrease in this percentage according to the disturbance gradient, i.e., the more impacted the environment, the smaller the number of these two groups.

When studying a sedimentation gradient in a stream, Buendia et al. (2013) found that certain feeding groups, such as those that use deposited materials as a resource, were favored. Conversely, the filters were the most sensitive, while the other groups did not show marked changes in their frequency along the gradient of fine sediment (Buendia et al., 2013). Similar results were observed in this study for the filters that had a low occurrence throughout the sample periods in the pre-rupture campaigns. In this period, the stream was already suffering from impacts caused by the silting, as previously discussed. For the post-rupture period, filters disappeared from the Campininha stream.

Contrary to what was described by Buendia et al. (2013), the collector-gatherers were not favored by sedimentation in the present study. The collector filter from the transport material, or collect from the sediment, fine (50-1000 μm) and ultrafine (0.5-50 μm) particulate organic matter. They are expected to be co-dominant together with the shredders in upstream regions (Vannote et al., 1980). The hypothesis raised here for the low representativeness of the collector-gather is the burial, as previously discussed. The collector-filterers had a high representativeness for the P1 in 2010, with its occurrence decreasing in all points over time, caused by the sedimentation impacts, disappearing after the rupture in all points, probably due to the loss of habitat, burial, and the low quality of particulate material. Many aspects of fluvial ecosystems are altered as a result of the increase in the load of fine sediments, including changes in the habitats available to invertebrates, mainly due to changes in the size of substrate particles and changes in the macrophyte community (Jones et al., 2012).

Predators were the dominant functional feeding group at all points and periods. Considering the River Continuum Concept, such a dominance is not expected, as predators, in theory, have low dominance in the community, and their composition does not change according to the order of streams and rivers (Vannote et al., 1980). Damanik-Ambarita et al. (2016) found similar results for a reservoir in a tropical river with the dominance of predators (45 %), followed by collectors (33 %), shredders (12 %) and scrapers (10 %). However, for the lotic stretch of the studied environment, dominance remained among the collectors (40 %), followed by predators (31.6 %) and scrapers (22.1 %) in rivers with elevations below 250m, and at higher elevations the dominance also remained among collectors (60.3 %) followed by scrapers (19.8 %) with predators having a lower proportion in the community (15.6 %).

The application of the BMWP index makes it possible to verify that regardless of the event of environmental disturbance (dam failure), the environment was already degraded, due to the impacts of sedimentation in the stream, which resulted in an impoverishment of the fauna of macroinvertebrates. The decrease in the percentage of tolerant organisms, observed in P2 and P3 post-rupture, was an unexpected effect. This effect was attributed to the burial of organisms of the Chironomidae and oligochaeta family, as described above. This behavior was observed by Villamarín et al. (2013), who also found a decrease in the % Tolerant when comparing impacted areas and control. Chronic sedimentation events can limit the colonization of available substrates and interfere with the feeding and reproduction of organisms, regardless of resistance organisms (Pond, 2011).

Water pH is an important limnological parameters, and in general, it can be seen in the present study that the decrease in pH favored the organisms of the order Trichoptera. Sensitive organisms were also favored, as well as the group of scrapers and collector-gatherers. In addition, slightly acidic characteristics seem to favor the increase in the density of organisms, due to the increase in density after the dam failure at points 1 and 3 and maintenance of values for the P2 (see Table 1 and S1). The increase in turbidity implied a decrease in the BMWP scores due to the reduction in the richness of sensitive families. This finding is strengthened by the correlation between turbidity and % Moderate. The increase in turbidity can have effects on the proportion of predators and Odonata, which can be related to the decrease in prey density, as observed by the inverse relationship between turbidity and density. Buendia et al. (2013) found a direct relationship between the increase in the content of fine sediment and the decrease in the richness and density of organisms, as well as Sharma and Rawat (2009) who also found an inverse relationship between the density of macroinvertebrates, and the turbidity and total solids dissolved.

After the rupture of the structure, the color had a greater influence on the fauna, causing negative effects to the diversity and density of organisms. The lower scores of the BMWP index are strongly correlated to the color of the water, showing that the impacts of the dissolved solids intensified after the rupture, decreasing the environmental quality of the stream. The increase in color also had negative effects on the composition of the order Odonata, for the same reasons given for the effects of turbidity. The same effects occurred for organisms of the order Coleoptera, which also includes predators, which may have been affected by the effects discussed above. These findings are confirmed by the observation of the highest proportion of larvae of the Girinidae and Dysticidae families, both composed of predators, in P1, which presented the lowest color of water values for the post-rupture period.

Biomonitoring in Brazil, as well as in other tropical and subtropical regions, is still scarce. Thus, little information about biological communities and their responses to different environmental impacts is available. (Buss et al., 2014; Oliveira et al., 2011). Thus, this article shows the importance of biomonitoring programs for a better understanding of the impacts of installing small dams in streams. Furthermore, the results show that the disruption of the dam altered the composition of the macroinvertebrate fauna, leading to a loss of important groups, and consequently environmental functions.

CONCLUSIONS

The Campininha stream has undergone several environmental impacts over time, including damming, for farming, suppression of riparian vegetation and more recently by siltation and dam rupture, which increased the level of environmental degradation. Among the hypotheses raised in this work, it is noteworthy that it was confirmed that the stream did not present high values of diversity and other indexes applied, such as EPT, BMWP, proportions of specific groups, confirming the assumption that the sedimentation process had an effect in the composition of macroinvertebrate fauna and functional groups. It is noteworthy the low representativeness of the shredders and collector-gathers, as well as the absence of filters that are sensitive to sedimentation and an unexpected dominance of predators. Thus, there is a loss of functions in the aquatic environment, which can negatively influence the flow of matter and energy within the trophic levels, resulting in impacts for other biological communities.

The hypothesis that there would be a difference in the composition of the community between the lentic and lotic stretches has not been confirmed. This was attributed to the high impact of silting in both stretches, implying an impoverishment of their fauna. Considering the hypothesis related to the dam failure, the change in the composition of the macroinvertebrate fauna was confirmed, with the disappearance of important orders and functional groups, which did not reappear even after a year of monitoring after the rupture. Thus, it is emphasized the need to implement intervention measures in the area and recovery of the degraded environment, considering not only issues related to the rupture of the structure, but measures at the basin level that also minimize the effects of silting, pointed out here as harmful to the environment.

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