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Landscape components associated with forestry in the Atlantic rainforest influence the aquatic macroinvertebrate community: a case study in southern Brazil

Componentes da paisagem associados à silvicultura na Mata Atlântica que influenciam a comunidade de macroinvertebrados aquáticos: um estudo de caso no sul do Brasil

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ABSTRACT: Several studies indicate that negative impacts on water quality are minimally related to silviculture. We analyzed the water quality of a stream in a silvicultural region in southern Brazil, considering the relationship between the components of the landscape and biotic quality indexes, merging physical and biological descriptions of the macroinvertebrate community and environment. We selected three points in the Faxinalzinho stream to collect macroinvertebrate samples and to perform perceptual analysis from September to December/2014, applying the Biological Monitoring Working Party (BMWP') and the Rapid Assessment Protocol for Habitat Diversity (RAPHD). Diversity metrics and a Non-metric Multidimensional Scaling (NMDS) were also applied to explore variations in the aquatic community abundance matrix, associating the data to Land Use/Land Cover. A total of 569 individuals was recorded, distributed in 27 taxa. The results showed good water quality in the studied points, mainly when compared to other studies regarding urban rivers. However, we found negative effects in the site with higher silviculture land cover, presenting acceptable water quality (BMWP'= 66) and altered environmental conditions (RAPHD= 51), while the other sites presented excellent water quality (BMWP'= 127–131) and natural environment (RAPHD= 85–91).

Keywords: Bioindicator; Aquatic Insects; Silviculture; Water Quality.

RESUMO: Vários estudos indicam que a silvicultura provoca impactos mínimos nos cursos d'água associados. Nós analisamos a qualidade da água de um córrego em uma região de silvicultura no sul do Brasil, considerando a relação entre os componentes da paisagem e os índices de qualidade biótica, mesclando descrições físicas e biológicas da comunidade de macroinvertebrados e do ambiente. Selecionamos três pontos no córrego Faxinalzinho para coletar amostras de macroinvertebrados e realizar análises perceptivas, de setembro a dezembro/2014, aplicando o índice BMWP' e o Protocolo de Avaliação Rápida para Diversidade de Habitats (PARDH). Métricas de diversidade e um NMDS também foram aplicados para explorar variações no matriz de abundância da comunidade aquática, associando os dados ao uso e cobertura do solo. Foram registrados 569 indivíduos, distribuídos em 27 táxons. Os resultados mostraram boa qualidade da água nos pontos estudados, principalmente quando comparados a outros estudos em rios urbanos. No entanto, encontramos efeitos negativos no local com maior área de silvicultura, apresentando qualidade de água aceitável (BMWP'= 66) e condições ambientais alteradas (RAPHD= 51), enquanto os outros locais apresentaram qualidade da água excelente (BMWP'= 127–131) e ambiente natural (RAPHD= 85–91).

Palavras-chave: Bioindicadores; Insetos Aquáticos; Silvicultura; Qualidade da água.

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INTRODUCTION

Problems related to river water quality in anthropized areas are a major theme regarding water conservation and availability. Several methods have been developed to measure and classify variables to interpret the many intrinsic factors that constitute the rivers, based on physical, chemical, and biological analyses. The presence of riparian forest, for example, besides retaining many substances that can be carried to the water body, provides relevant energy supply, contributing to the increase of ecological niches, which helps in the maintenance of benthic fauna in good quality watercourses (Roy et al., 2003; Moraes et al., 2014).

Although urbanization is one of the most harmful kinds of intervention over watercourses, agriculture and silviculture can also cause significant changes in water quality due to characteristics of these systems, like the input of chemical elements by fertilizing and pest controlling, and by the silting up caused by land use (Hepp et al., 2010; Silveira et al., 2016; Mello et al., 2020). In rural areas, water quality conservation is crucial. The water is used for irrigation, animal desedentation, and occasionally human use due to water supply difficulty outside urban areas (Li et al., 2020).

Many studies have been done using biological methods, particularly aquatic macroinvertebrates, to access water quality (e.g. Hanna et al., 2020; Melo et al., 2020; Restello et al., 2020), since these organisms demonstrate great efficiency and reliability, presenting several sensitive taxa to many types of change, especially regarding anthropic interventions (Baptista, 2008). There are several biological indexes applicable for water quality evaluation and monitoring, such as the Biological Monitoring Working Party scoring system (BMWP) adapted to Brazil (BMWP') (e.g. Junqueira & Campos, 1998).

The BMWP' consists of a scoring ranking, in which the organisms most sensitive to pollution receive high scores, thus, the lower the sum of a water body score, the more polluted it is. Besides, ecosystem physical parameters, such as surrounding land use and occupation, the width of rapids and backwaters, and other natural characteristics of the area, essential for ecological maintenance, can be addressed in water bodies quality analysis (e.g. Callisto et al., 2002; Dala-Corte et al., 2020; Hanna et al., 2020).

Thus, considering that evaluating aquatic macroinvertebrates' community composition allows assessing the current conditions of a stream, we studied this fauna and its relationship to land use and occupation in the Faxinalzinho stream in a stretch under silviculture influence, a kind of anthropic activity that generally is not harmful to water courses' health (Mello et al., 2020), to verify if the water quality from this stream is affected by the silviculture and if there are differences according to the direct influence of surrounding land use and land occupation. The study hypothesizes that although silviculture does not produce damage to aquatic environments such as urbanization and industrialization does, this land use can also modify the aspects of the macroinvertebrates' community and the quality of the water environment.

MATERIAL AND METHODS

Study area

We carried out this study in a silviculture area (Pinus and Eucalyptus plantation) in the Guamirim district (Irati municipality). The vegetation is characterized by presenting several fragments of Mixed Ombrophylous Forest (MOF), commonly called Araucaria forest, due to *Araucaria angustifolia* Bertol. (Kuntze). Historically, the region presents silviculture, as one of the main economic activities for the last decades (Orreda, 2004). Although Irati Municipality belongs to the Iguaçu, Ivaí, and Tibagi basins, the studied region is inserted in the Iguaçu River basin. The evaluated stream has a spring in the studied forest plantation area and is a tributary of the Faxinalzinho river, the so-called Faxinalzinho stream.

We sampled three points in the Faxinalzinho stream, all located within the area of silviculture and forest management: P1 (25°34'30.78"S / 50º49'19.46"W), presenting average width of 4 m and muddy bottom with a large number of vegetal deposits from the silviculture, mostly pine needle; P2: (25º34'49.59"S / 50º48'45.31" W), downstream point with extensive riparian forest in an intermediate stage of succession, with an average width of 7 m characterized by the muddy and sandy bottom; and P3: (25º34'54.06"S / 50º48'28.42"W) characterized by native forest continuation in the surroundings, with an average width of 7 m,

presenting a muddy and sandy bottom, and a distance of approximately 1 km (P1–P2) and 0.5 km (P2–P3) (Figure 1).

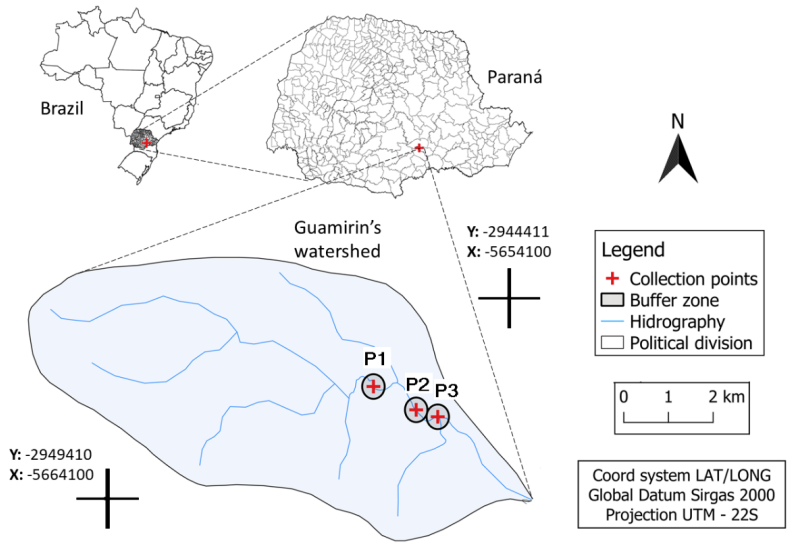

Figure 1: Sampling points (P1, P2, and P3) in the Faxinalzinho stream located in the Guamirim watershed.

Land use

A 500 meters buffer was established to analyze the land use around the selected points. This radius size was determined to avoid sampled points overlapping (specifically P2 and P3 – Figure 1), preventing spatial autocorrelation between the sampled water quality parameters (Frieden et al., 2014). Another important criterion for determining the radius was the landscape scale that influences the macroinvertebrate community since environmental changes 500 m away can compromise the aquatic community (Yirigui et al., 2019).

An image from Google Earth was selected using the Quickmapservice package in the Qgis 3.4 (Qgis Development Team, 2020). This image has three bands – red (R), green (G), and blue (B) – and a spatial resolution of 4.5 m and 8 bits. The multi-resolution segmentation (Baatz & Schape, 2000) was used with segment algorithm value 15.10 and the Full Lambda Schedule value 96.40 for merge. Consequently, land use classes were defined: I. Araucaria forest, represented by the Mixed Rain Forest or Araucaria Forest; II Agriculture and field, represented by the cultivation of fields of commercial species / shrub-herbaceous vegetation; III. Exposed soil, represented by agricultural areas or landslides; IV. Buildings, represented by areas with a low density of a built area; and V. Silviculture, a monoculture of commercial species, in general, *Pinus* spp. For each class, samples were collected to train the Support Vector Machine - SVM algorithm (Singh et al., 2013; Thanh Noi & Kappas, 2017), which was performed using the Kernel trick with a radial hyperplane.

Macroinvertebrate collection and analysis.

We sampled the macroinvertebrates using a D-frame net (300µm mesh), totalizing three collections in each section of the stream for 4 consecutive months (September – December / 2014) denominated C1, C2, C3, and C4. We transferred the material to transparent plastic bags with 80% alcohol. In the laboratory, we identified the organisms to the family taxonomic level (Mugnai et al., 2010), required for BMWP' index application.

The Shannon-Wiener diversity index (H'), Pielou Equitability (J'), and the relative percentages of Chironomidae (% Chironomidae) and Ephemeroptera, Plecoptera, and Trichoptera (% EPT) were calculated. The used indexes to analyze the water quality were the BMWP' modified by Loyola (2000) and the Rapid Assessment Protocol for Habitat (RAPHD) (Callisto et al., 2002). To compare if there were differences in macroinvertebrate community as a function of the individual's abundance, a Permutational Multivariate Analysis of Variance (PERMANOVA) test (Anderson, 2008) was applied, with 999 permutations of residues in the complete model, and Bray-Curtis distance (Legendre & Legendre, 2012). A non-metric multidimensional scaling (NMDS) was also applied to analyze the formation of

clusters related to the sampled points based on the macroinvertebrate community. The relative abundance matrices of the community were transformed, and then the Bray-Curtis distance (Legendre & Legendre, 2012) was used, and the matrix distance was subjected to the multidimensional scaling NMDS non-metric analysis (Kruskal, 1964a, 1964b). This analysis was performed in R software 3.6.3 (R Development Core Team, 2018) using vegan package version 2.5-3 (Oksanen et al., 2018).

RESULTS AND DISCUSSION

High accuracy was obtained in the classification using SVM. However, supporting statistics do not apply to the case since manual adjustments were made to the classes. The purpose is not to test the classifier's capacity but to represent the landscape with the greatest possible likelihood. Despite being in a rural area, the landscape presents a degree of heterogeneity and, consequently, high fragmentation (Figure 2).

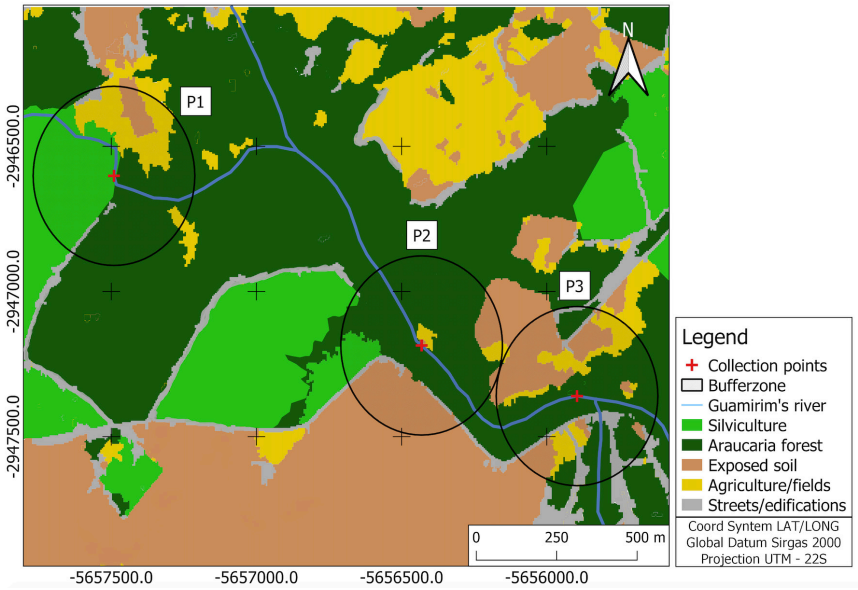

Figure 2: Classification of landscape elements and delimitation of buffers around the collection points in the Faxinalzinho stream.

Analyzing the area proportion for each class (Table 3), Points 1 and 2 presented a higher percentage of Pinus plantation with 38.7% and 16.9% of occupation, followed by Araucaria Forest with 35.2% and 49.5%, respectively. Although P2 presents silviculture influence, the most predominant land use and land cover are due to natural vegetation. At Point 3, the class with the highest percentage is Araucaria Forest with 38%, followed by exposed soil, with 35.3% of land occupation, probably an area used for agriculture, during the research period.

Table 1. Area and class percentage of occupation for each 500m buffer from three sections of the Faxinalzinho stream.

Classes	Point 1		Point 2		Point 3	
Silviculture	101,422 **m²**	38.7%	45,375 **m²**	16.9%	0 **m²**	0%
Araucaria Forest	98,202 **m²**	35.2%	132,750 **m²**	49.5%	102,175 **m²**	38%
Exposed soil	5,450 **m²**	2.1%	79,325 **m²**	28.8%	94,775 **m²**	35.3%
Agriculture/field	50,525 **m²**	19.3%	7,175 **m²**	2.7%	50,500 **m²**	18.8%
Streets/edification	6,225 **m²**	2.4%	5,475 **m²**	2.0%	20,100 **m²**	7.5%

We sampled a total of 569 individuals, distributed into 27 families (class, for Hirudinea) comprised of 9 orders (Table 1). The taxa with the highest values of total abundance were Aeglidae at points 2 and 3, followed by Leptoplhebiidae (Ephemeroptera), corroborating data from Santestevan (2004) and Raio et al. (2011), who observed this family as one of the most abundant in Paraná State watercourses. The construction of such knowledge is fundamental since the lack of consistent knowledge regarding aquatic invertebrates of watercourses in Paraná state (mainly low-order rivers

in small municipalities, see Crisigiovanni et al., 2020) is an impediment to further applied researches, such as preventing data use in an important and large-scale analysis like the one performed by Dala-Corte et al. (2020).

Table 2. Aquatic macroinvertebrate families and the number of individuals sampled in the Faxinalzinho stream (Irati-PR).

Taxa			P1	P 2	P 3	Total
Mollusca						
	Gastropoda					
		Lymnaeidae	3	17	44	64
		Ancylidae	24	9	20	53
Annelida						
		Hirudinea			1	1
Arthropoda						
	Ephemeroptera					
		Polymirtacydae		2		2
		Leptoyphidae		1		1
		Baetidae	14	14	12	40
		Caenidae		1	1	2
		Leptophlebiidae	12	35	42	89
	Odonata					
		Gomphidae			2	2
		Coenagrionidae		3	2	5
		Libellulidae		1		1
		Calopterigidae			3	3
	Plecoptera					
		Perlidae		1	1	2
		Gripopterygidae		6		6
	Trichoptera					
		Leptoceridae	3	1	6	10
		Hidropsychidae	1	3	2	6
		Sericostomatidae			3	
	Hemiptera					
		Mesoveliidae	3	1		4
		Belostomatidae			2	2
		Veliidae	5	31		36
		Gerridae	2	2		4
	Coleoptera					
		Elmidae		10	17	27
		Psephenidae	2	6	43	51
	Diptera					
		Chironomidae	2	3	2	7
		Tipulidae		3	1	4
	Decapoda					
		Aeglidae	19	45	79	143
		Trichodactylidae		1		1
Total			**90**	**196**	**283**	**569**

Chironomidae were not abundant, presenting relative abundance between 0.7 to 2.2%, indicating good water quality. Although some members of this group can colonize preserved environments (Molineri et al., 2020; Santos et al., 2020), this group is frequently related to water pollution, showing tolerant species and higher abundance in human-impacted environments (Marques et al., 1999; Nicacio & Juen, 2015; Arimoro et al., 2018; Restello et al., 2020; Rosa et al., 2021).

Also, no observation was seen for Oligochaeta, which in abundance might reveal the presence of organic matter enrichment in the aquatic ecosystem and low water quality (Frizzera & Alves, 2012; Clemente et al., 2019; Hartmann et al., 2019). This group plays an important role in the processes of decomposition and cycling of organic materials in freshwater environments (Gorni et al., 2018). Relative abundance of Gastropoda was higher at P1 (30%), followed by P3 (22.61%) and P2 (13.26%), showing a higher degree of disturbance associated with a higher percentage of silviculture area (P1),

as found by Silva et al. (2017), that observed the increase in Gastropoda relative abundance according to increasing disturbance.

Regarding the %EPT index, the values showed a small decrease along with the sample points (Table 2), however, Plecoptera was sampled only in P2 and P3, which may show unfavorable conditions for these taxa in the first point (P1) since stoneflies are quite sensitive to anthropic changes (e.g. Schimitt et al., 2019; Restello et al., 2020). In addition, Polymitarcyidae and Leptohyphidae were found only at P2, which can reinforce the good quality in this point. These families are classified as the sensitive group to different environmental impacts and have been recognized as essential indicators of biological health in aquatic systems due to their sensitivity to disturbance (Companhia Ambiental do Estado de São Paulo, 2013; Gargiulo et al., 2016; Silva et al., 2017), despite some *Campsurus* are found in anthropically altered sites (e.g. Kuhlmannet al., 2020).

Individuals from Hydropsychidae are selective in choosing the substrate and are found in clean waters or less impacted sites, indicating the sensibility of this group in degraded water bodies (Queiroz et al., 2018; Clemente et al., 2019). It therefore could inform that the presence of these organisms in the Faxinalzinho stream might also indicate good environmental quality. In this study, we found this family in the three points with low differences between them. Therefore, %EPT must be used with parsimony, since some taxa do not fully fit in the established score, moreover, the watercourse characteristics are fundamental for the EPT assemblage composition (e.g. Amaral et al., 2019; Schimitt et al., 2019).

Table 3. The number of taxa, individuals, and biotic indexes calculated for each collection point.

	Point 1	***Point 2***	***Point 3***
Number of taxa	12	22	19
number of individuals	90	196	283
Shannon Wiener (H')	2,043	2,382	1,906
Pielou (J')	0,6431	0,4923	0,4484
%Chironomidae	2.2%	1.5%	0.7%
%EPT	33.3%	32.7%	23.6%
BMWP'	66 [A]	131[B]	127[B]
RAPHD	51[E]	91[F]	85[F]

Legend: A. acceptable, B. excellent, C. questionable quality, D. clean water, E. altered, F. natural.

Despite Shannon-Wiener (H') and Pielou (J') diversity indexes were similar, P2 showed the greatest diversity (H'= 2.350), as it had a higher number of taxa and fewer individuals than P3. Ferreira et al. (2021) also found a higher diversity of macroinvertebrates in a point with a predominance of natural vegetation (forest). Hartmann et al. (2019) found a very low Shannon-Wiener index value for macroinvertebrates at a point with indication of severe pollution in a river in Paraná state, with a range between 0.31 (severely polluted) to 0.78 (moderately polluted). The diversity index (H') is a frequent tool to evaluate the conditions of an aquatic ecosystem based on biological components (Patang et al., 2018). The equitability index, which measures the distribution of individuals between taxa, has shown to be higher at P1 with equitability of 0.65, in contrast to 0.49 and 0.45 at P2 and P3, respectively. The discrepancy found in equitability values must also be linked to the low number of individuals found in P1. According to Ferronato et al. (2021), parameters such as richness, Shannon-Wiener, and equitability are indicators of the development and colonization of macroinvertebrates organisms. Despite the influence of silviculture seen in lower taxa richness and individuals at P1, the results found in this research reveal that these three points present conditions for the development and colonization by benthic organisms.

Considering the BMWP' index, P1 had a sum equal to 66, P2 had 131 points, and P3 had a value equal to 127. According to the criteria of Paraná (2014) for the classification of these scores, P2 and P3 presented "excellent" water quality with "spotless waters". However, P1 is classified as having "acceptable" water quality with "moderate pollution effects" due to the results presented here. Bagatini et al. (2012) also found values classified as excellent water quality in a river in the north region of Paraná using the BMWP index. RAPHD index results were similar to those found for BMWP' (Table 3), suggesting the worst water quality at P1, and improving at P2 and P3. Both results are coherent to the presence and abundance of certain groups, which are described in the literature as pollution tolerant (Chironomidae, Oligochaeta) with low or no observation. Also, families seen in clean water in other studies were found in the point (P2) with the highest BMWP' and RAPHD scores

(Polymitarcyidae and Leptohyphidae). It, therefore, shows that the indexes go in the same direction as the observed organisms between the points.

The macroinvertebrate community composition is affected by environmental and spatial variables, thus presenting temporal changes mainly due to precipitation and temperature changes (Silveira et al., 2006; Pires et al., 2020; Santos, et al., 2020). In our study, PERMANOVA showed a significant difference between samplings ($F_{1,11}$ = 2.26, p = 0.013). In the community composition ordered by NMDS, we observed the formation of distinct groups related to each sampled point's community structure (Figure 3). The NMDS showed a stress of 13.6 and R^2 = 0.88 to the Shepard diagram for 11 iterations. These results can be considered a non-assortment distribution indicating that the composition of the community in each collection point is not random. We can also observe that for the samples C1, C3, and C4 the points are relatively close to each other, indicating a difference in C2 between P1 and P2, and P1 and P3.

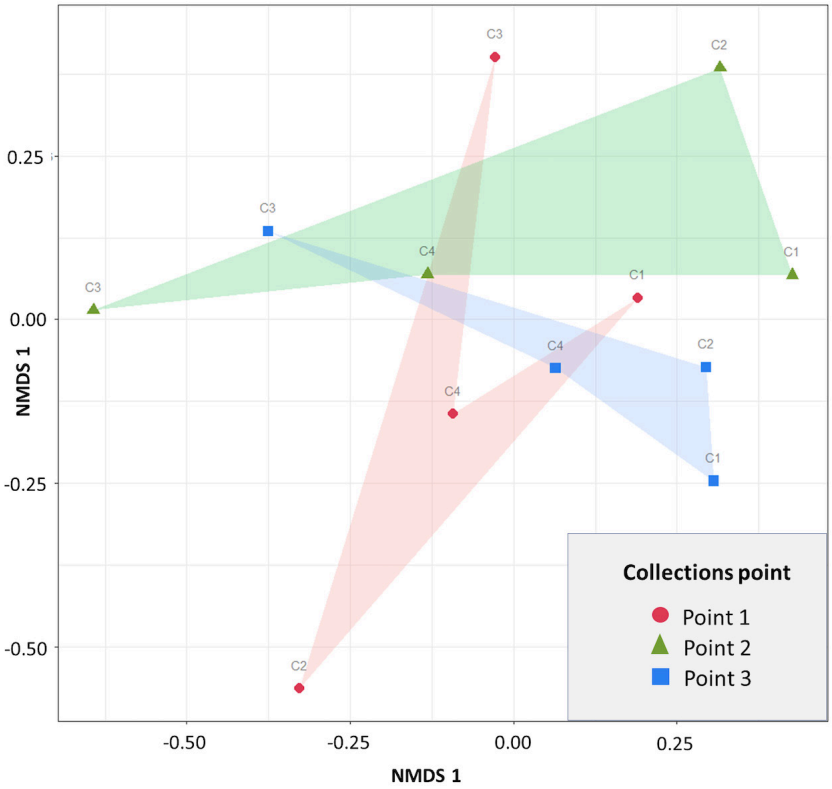

Figure 3: Non-metric Multidimensional Scaling (NMDS) applied to the abundance matrix of the macroinvertebrate community of the Faxinalzinho stream. Legend: The acronyms C1, C2, C3, and C4 represent the dates of the four collections performed for each point.

The results, therefore, indicate that there are differences in the ecological aspects between the three sampling points, where the metrics (H', BMWP') and the abundance of specific groups reveal the worst water quality at P1. The macroinvertebrate community is one of the main components of lotic systems that best provide information about the degree of biotic integrity (Bagatini et al., 2012), where the reduction of the biodiversity and changes in the functional structure of the community might reveal environmental impacts on the aquatic ecosystem. In this study, we found differences in biological indexes for the evaluation of water quality and ecological parameters between the studied sites. Higher values of richness and abundance coupled with BMWP' and RAPHD demonstrate the improvement of water quality at P2 and P3.

The hypothesis that silviculture influences the water quality, and the community of aquatic macroinvertebrates have been verified and accepted. Despite that P2 presents a low percentage of silviculture, the higher percentage of natural forest may favor the quality in this point. The substitution of natural forests for other land uses is the main source of watercourses integrity reduction; however, it is often directly associated with the lack of riparian vegetation conservation (Collier et al., 2019; Dala-Corte et al., 2020; Melo et al., 2020; Hanna et al., 2020; Restello et al., 2020). In this way, some

studies show that silviculture can be less harmful to watercourses than other anthropogenic interventions (see Mello et al., 2020) if the riparian forest is properly maintained (see Borges et al., 2021). The BMWP' results in this study are similar to those found in agricultural regions (e.g. Zequi et al., 2019). The lowest values found here are similar to the highest value found near headwater in an urban watercourse from the same municipality (Crisigiovanni et al., 2020). The %Chironomidae was very lower than found in agriculture-associated sites (Zequi et al., 2019), but similar to that found in protected sites (e.g. Restello et al., 2020), reinforcing the generally good condition of the stream.

The results of biotic indices and RAPHD may be linked to the difference in the sampled scenarios. It is possible to evidence the contrast between the width of riparian vegetation of the margins, where the first point presents a small portion of riparian forest concerning P2 and P3, besides being directly associated with sloping Pinus plantation. This data is important to show that water quality can be reestablished downstream by the forest/riparian forest recomposition, although some water quality parameters do not present a prompt return to natural conditions (Collier et al., 2019; Crisigiovanni et al., 2020).

Several studies point out that the impacts caused by water quality by forest plantations are low due to improved management practices (Mello et al., 2020). Despite the current limits of riparian vegetation maintenance are considered ineffective for water quality protection (Valera et al., 2019), there are minimum criteria that must be followed for proper planting and management, supported by legal regulations for the location of planting areas close to water bodies to guarantee acceptable levels of water integrity.

CONCLUSIONS

The work's focus was to carry out a survey and characterization of benthic macroinvertebrates to determine the water quality of the Faxinalzinho stream to relate it empirically to land use and occupation in a silviculture region. From an analysis of the macroinvertebrates community, it was possible to characterize the water quality of the Faxinalzinho stream in the Guamirim district, Irati municipality. In this way, the relationship between land use and occupation and the water quality values found by the evaluation of macroinvertebrates showed reasonable values for biotic indices and RAPHD, mainly compared to the quality of rivers in the region, both in urban and rural areas (e.g. Crisigiovanni et al., 2020).

The hypothesis of the work was accepted that the water quality in the region of intense silviculture land might negatively impact the water quality and influence the aquatic macroinvertebrates community composition, abundance, and richness, as demonstrated at P1 with lower taxa richness and abundance. In addition, the indexes results showed a better quality at P2, which was the only point with the presence of sensitive groups, located in the site with a higher area and percentage of native vegetation. It reinforces that in preserved areas, sensitive groups of macroinvertebrates can be found.

Few studies compare different land use and water quality in the region southeastern Paraná, which makes comparisons difficult and encourages the realization of more in-depth and comprehensive research of the quality of aquatic ecosystems in forest management areas and other scenarios so that a broader view and more substantiated data becomes possible.

This study, therefore, provides an ecological study applied for analysis of water quality in a stream in southern Paraná, Brazil. The results found in this research confirm that although reduced, silviculture decreases the water quality. Still, we reinforce that the used methodology in this study produced a satisfactory evaluation of water quality in the Faxinalzinho stream, and might be replicated in other studies.

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