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ORIGINAL ARTICLE

Paired catchments with native vegetation as a reference for water quality in streams in forest plantation areas

Microbacias pareadas com vegetação nativa como referência para a qualidade de água em riachos em áreas de plantações florestais

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Abstract

Fast-growing forest plantations can alter catchment hydrological dynamics and stream water quality, for example with turbidity increase after forest harvesting. It is essential that forest management operations be linked to the performance of environmental monitoring, making it possible to identify the magnitude of these changes and contributing to adaptive management aiming to reduce and/or mitigate such effects. The aim of this study was to assess if water quality parameters of native forest are suitable for use as a reference for hydrological monitoring of exotic forest plantations. The study evaluated the water quality values between catchments with *Pinus* plantation and native vegetation, comparing them with limits established in the legal framework (Resolution n° 357/2005). The results show that the values of the water quality parameters of the stream located in the *Pinus* plantation catchment are very similar to those observed in the native forest catchment, both of which are within the limits established by legal framework. Thus, for activities that promote few changes in physical-chemical parameters, such as in the case of forest plantations, it was observed that best water quality standard to be used as reference is the one established in streams under the influence of conserved native vegetation, whose geomorphological characteristics are similar, hence the importance of paired catchments. Therefore, the values observed in native forest catchment can serve as reference for establishing maximum permitted values (MPVs) that are more restrictive and consistent with the local reality of forest plantations.

Keywords: Hydrological monitoring; *Pinus* spp.; Forest management; Forest hydrology.

Resumo

Plantações florestais de rápido crescimento podem alterar a dinâmica hidrológica de microbacias e a composição físico-química da água em seus riachos, por exemplo com o aumento da turbidez após a colheita florestal. É fundamental que as operações de manejo florestal estejam atreladas à realização de monitoramento ambiental permitindo, assim, identificar a magnitude dessas alterações e contribuir para o manejo adaptativo visando diminuir e/ou mitigar tais efeitos. O objetivo deste estudo foi avaliar se os parâmetros de qualidade da água da floresta nativa são adequados para uso como referência no

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monitoramento hidrológico de plantações florestais. O estudo avaliou os parâmetros de qualidade da água entre microbacias com plantações de *Pinus* e de vegetação nativa, comparando-os com limites estabelecidos em uma norma brasileira (Resolução n° 357/2005). Os resultados mostram que os parâmetros de qualidade da água do riacho localizado na microbacia com plantações de *Pinus* são muito semelhantes aos observados no riacho da microbacia de floresta nativa, sendo que ambos se encontram dentro dos limites estabelecidos pela norma brasileira. Assim, para atividades que promovem poucas alterações nos parâmetros físico-químicos, como é o caso de plantações florestais, observou-se que o melhor padrão de qualidade da água a ser utilizado como referência é o estabelecido em riachos sob influência da vegetação nativa conservada, cujas características geomorfológicas sejam semelhantes, destacando a importância das microbacias pareadas. Sendo assim, os valores observados em microbacias com floresta nativa podem servir de referência para o estabelecimento de valores máximos permitidos (VMPs) mais restritivos e coerentes com a realidade local das plantações florestais.

Palavras-chave: Monitoramento hidrológico; *Pinus* spp.; Manejo florestal; Hidrologia florestal.

INTRODUCTION

In Brazil, fast-growing exotic forest plantations for industrial purposes cover an area of approximately nine million hectares, with 6.97 million occupied with forest plantations of *Eucalyptus* spp. and 1.64 million occupied with forest plantations of *Pinus* spp. (Indústria Brasileira de Árvores, 2020). Due to the expansion of the forestry sector, and, consequently, of the area occupied by the exotic forest plantations, environmental monitoring becomes essential to analyze the impacts of this land use on the ecosystems (Ferraz et al., 2021). The monitoring of water resources in areas with exotic forest plantation makes it possible to know and identify the extent of possible effects related to forest management and to propose adjustments and judicious changes to minimize or mitigate the effects of forest operations as recommended by the concept of adaptive management (Deval et al., 2021).

In fast-growing forest plantations, the management adopted may promote changes in the hydrological dynamics of the catchments, according to the scale and operational practices used (Garlipp & Foekel, 2009; Ferraz et al., 2019). It is essential, therefore, that the forest management practice is tied to the environmental monitoring of streams that can identify the magnitude of these effects (Burt et al., 2008). Forestry operations of soil tillage, application of fertilizers, herbicides and insecticides, construction of roads, and harvest can alter water quality (Neary, 2016), and the main effects observed are the increments of suspended solids, turbidity and electrical conductivity after harvest (Mello et al., 2020). Thus, studies show the importance of monitoring physical-chemical parameters for analysis of the effects of management; for example the monitoring of nitrate and phosphorus for analysis of the effects of fertilization (Binkley et al., 1999) and the monitoring of turbidity and sediment concentration for analysis of the effects of forest harvesting (Câmara & Lima, 1999; Webb et al., 2012; Rodrigues et al., 2019).

The effects of forest management can be observed by comparing the values obtained in the managed area with reference values. In some countries, such as Canada and the United States, it is possible to find guidelines that establish values for surface water quality parameters, by region or ecoregion, aiming at the classification of the river (Canadian Council of Ministers of the Environment, 2016; Environmental Protection Agency, 2000). Water quality standards obtained in the literature have the advantage of being low cost, often available on the internet with easy access, but need to be adapted to the particularities of the region of interest. An alternative is the monitoring of a natural ecosystem as a local reference, which is more expensive, due to the need for periodic and long-term sampling or equipment use, but considering natural conditions, without the need to quantify regional factors (Canadian Council of Ministers of the Environment, 2016). When using a local reference, it is possible to establish a percentile between 5% and 25% of the frequency distribution of the parameter's values to establish the quality criterion (Environmental Protection Agency, 2000). In the European Union, the Directive 2000/60/EC of the European Parliament and of the Council (Jornal Oficial das Comunidades Europeias, 2000) defines elements and quality limits for the classification of the ecological state of the river into excellent, good or reasonable classes. Regarding the physicochemical quality of water, this guideline establishes that an excellent ecological state is one in which the values of physicochemical elements, such as the concentration of nutrients, remain within the values normally associated with undisturbed conditions.

In Brazil there is no guideline for the evaluation of surface water quality, but there is a standard that provides the classification of water bodies and environmental guidelines for their classification, the Resolution of the National Council of the Environment (CONAMA) no. 357/2005 (Brasil, 2005), which aims to improve or maintain the water quality class of a river segment according to the intended preponderant uses. The lack of regional reference values of water quality ultimately encourages the widespread use of this Resolution to assess the impacts of anthropic activity on water resources. Thus, this Resolution provides for the quality of water required for certain predominant uses (Art. 3 CONAMA Resolution 357/2005), but it was not established to be used as a reference in the analysis of environmental impacts. In addition, Brazil has different edaphoclimatic regions with naturally different characteristics, and the use of the same water quality standard for the whole country is not appropriate (Mello et al., 2020). Thus, hydrological monitoring of catchments with natural characteristics close to the catchments of interest is an important option for analyzing the effects of land use on water quality (Neary, 2016).

Studies show differences in the water quality of native vegetation catchments and plantations catchments of *Pinus* spp. (Quinn & Stroud, 2002; Little et al., 2015; Perrando et al., 2020), as well as alterations resulting from the passage of the river through these plantation areas (Guimarães et al., 2010). However, it is also shown that these changes tend not to persist over time, with water quality being similar to native catchments after a few months after a forestry operation (Hopmans & Bren, 2007).

Thus, the aim of this study was to assess if water quality parameters of native forest are suitable for use as a reference for hydrological monitoring of exotic forest plantations.

MATERIAL AND METHODS

The study was carried out in two catchments located in the municipality of Telêmaco Borba, state of Paraná, Brazil, at the coordinates 24º02' South Latitude and 50º17' West Longitude, within the Tibagi river basin. The climate in the region is Cfb, according to the Koppen classification, a subtropical climate, with a temperate summer and no defined dry season, the average temperature of the hottest month is 21.8°C and that of the coldest month is 14.7°C, with mean annual precipitation of 1443 mm (Alvares et al., 2013).

The catchment covered with native forest has an area of 34.4 ha, an average slope of 17% and Litholic Neosol soils. This catchment is in the Atlantic Forest biome, in a transition area between Seasonal Semideciduous Forest and Mixed Ombrophilous Forest. The vegetation is in an advanced stage of succession with the presence of typical species, as *Araucaria angustifolia*.

The catchment predominantly covered by commercial exotic forest plantations of *Pinus* spp. has an area of 135.4 ha, an average slope of 16% and Rhodic Hapludox soils. This catchment has forestry operations since 1958, with the plantation of *Pinus* spp. with tree spacing of 3 m x 2 m, for pulp production. In 2010, 17% of the catchment area occupied by pine plantation had 13 years, 59% had 7 years and 24% was harvested (Chiles, 2019).

Water samples were collected manually biweekly in the two catchments from 2004 to 2010, at each weir (Figure 1), totaling 120 and 121 samples for the native forest catchment and the Pinus forest plantation catchment, respectively, the samples were refrigerated and sent to the Laboratory of Applied Ecology of ESALQ/USP to determine the following parameters: nitrate (NO_3^-), phosphorus, pH, turbidity and total suspended solids. NO_3^- concentration was determined by the brucine method; phosphorus concentration was determined by colorimetry (Catani & Bataglia, 1968; Marques, 1961; Vettori, 1969), both analyses using the spectrophotometer (Thermo Genesys 105 UV V15); pH was determined potentiometrically using a pH meter; turbidity levels were determined by the turbidimetric method and using a spectrophotometer (HACH DR 2000); and the concentrations of total suspended solids were obtained by means of an automatic filtration system (47mm polysulfone, Nalgene), drying in the oven (Fanem) and weighing on analytical scale.

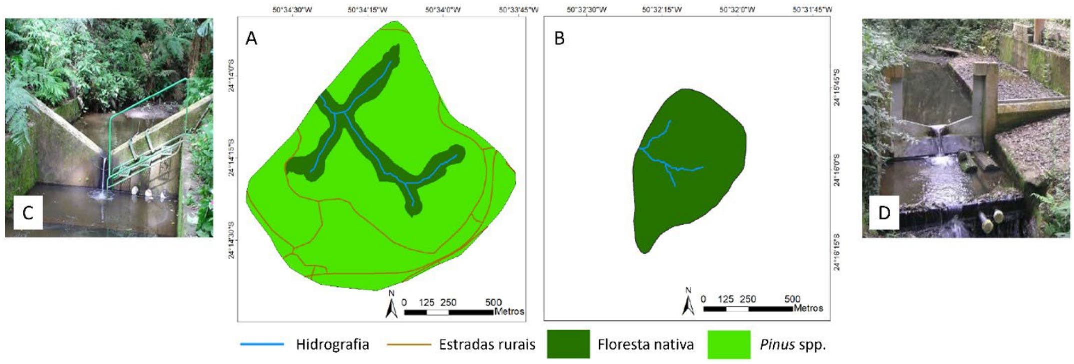

Figure 1: Land use map of the *Pinus* plantation catchment (A) and the native forest catchment (B). Weir photograph of the *Pinus* plantation catchment (C) and the native forest catchment (D) (Adapted from Chiles, 2019)

The probabilistic curve of incompatibilities, which is the analysis of the probability distribution of a variable being equal to or greater than a stipulated value (Cunha & Calijuri, 2010), was performed between the results obtained for each water quality parameter of the catchment with forest plantations and maximum permitted values (MPV) established from the data of the catchment with native forest. The MPV is the maximum limit that a parameter should present to meet a water quality standard, in this case, the values chosen for each parameter were those obtained in more than 95% of the time in the native forest catchment, thus, usually, it is expected to find a lower value.

The probabilistic curve of incompatibilities analysis was also performed for the water quality parameters of both catchments and the standards defined in the Brazilian legislation for water bodies in Class 2 of CONAMA resolution. It is emphasized that the studied streams have no classification; however, the class adopted as a reference is in accordance with Article 42 of Resolution No. 357/2005, which establishes that in the absence of classification, fresh waters must be included in Class 2.

The concentrations of nitrate, phosphorus and total suspended solids, pH and turbidity were compared between the two catchments for the study period by Wilcoxon-Mann-Whitney nonparametric statistical test in PAST software.

RESULTS AND DISCUSSION

When analyzing the probabilistic curve of occurrence of incompatibilities (Figure 2) between the values found in the catchment with forest plantations and the maximum permitted values (MPVs) obtained in the catchment with native forest, it was observed that nitrate concentrations and turbidity of the forest plantation exceed the values of the native forest in less than 5% of the time. The values of phosphorus, pH and suspended solids in the catchment with forest plantation have 7.4%, 17.2% and 15.1%, respectively, of probability of exceeding the values of the catchment with native forest.

When comparing the parameters of the two catchments to the Brazilian standard for nitrate, it was observed that the probability of exceeding the MPVs for class 2 of Resolution No. 357/2005 were null in both catchments (Figure 3). Regarding phosphorus, the probability of exceeding the standard was less than 1% for the catchment with native forest and approximately 3% for the catchment with forest plantation.

Regarding pH, the probability of exceeding the upper limit established by the resolution was null, and the probability of having pH values lower than the lower limit was approximately 1% for both catchments. Turbidity showed null probability of exceeding 100 NTU for the catchment with native forest, and the probability was approximately 2% for the catchment with forest plantation.

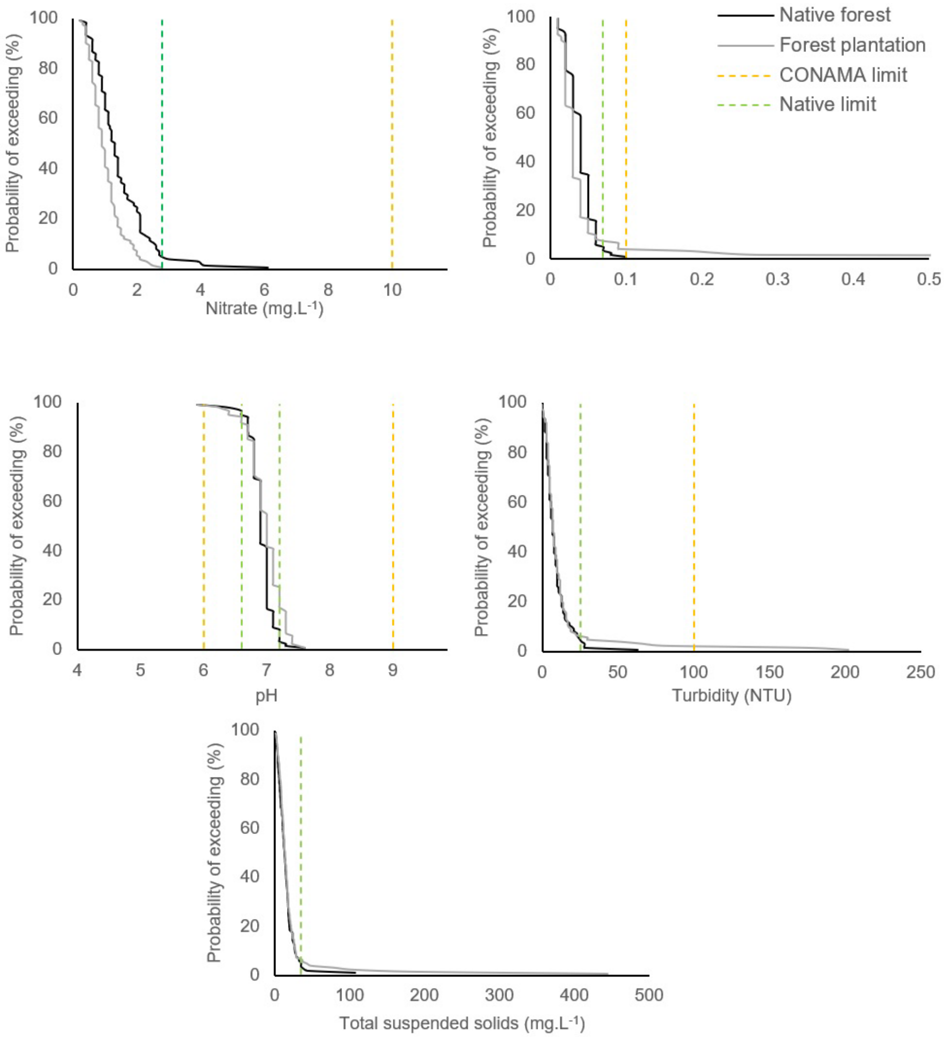

Figure 2: Probabilistic curve of incompatibilities of the parameters nitrate, phosphorus, pH, turbidity and total suspended solids of the *Pinus* plantation and the native forest catchments, from 2004 to 2010.

The parameters analyzed showed probability of less than 5% of exceeding the limits established in CONAMA for Class 2, which demonstrates that the two catchments meet the quality requirements of this class.

Although Resolution No. 357/2005 does not establish limits for total suspended solids, this is an important parameter, as it may indicate soil erosion processes in the catchment as a result of inadequate forest management (Webb et al., 2012). In the present study, the maximum value for total suspended solids was 107 mg.L^{-1} for the catchment with native forest and 445 mg.L^{-1} for the catchment with forest plantation. However, it was observed that in 95% of the time the values shown by the catchments are lower than 35 mg.L^{-1} and 43 mg.L^{-1}, in the native forest and in the forest plantation, respectively. Thus, there is a low probability of occurrence of high values of concentration of total suspended solids, which indicates that these values are associated with isolated events, probably with heavy precipitation events. Values below 50 mg.L^{-1} for the concentration of total suspended solids have also been observed in studies that evaluated the effects of mechanized harvesting in fast-growing forest plantations (Câmara & Lima, 1999; Vital et al., 1999; Rodrigues et al., 2019).

The concentrations of total suspended solids and turbidity for the catchments with native forest and *Pinus* plantation showed no significant difference, although these parameters are described as the main ones affected by the forest plantations (Mello et al., 2020), demonstrating that the study catchment has good management practices. Nitrate and phosphorus were significantly higher in the native forest ($p < 0.01$), despite having low values, this result is the opposite of what was expected since studies show a greater concentration of these nutrients in *Pinus* plantations, compared with native catchments (Little et al., 2015); the greater their occupation in the catchment (Hughes & Quinn, 2019). The pH was significantly higher in the forest plantation (Figure 3), the increase in pH in the stream has already been observed after passing through a *Pinus* plantation (Guimarães et al., 2010), however, the value satisfies the need for maintenance of the aquatic ecosystem, between 6.0 and 9.0 (Qiao et al., 2016).

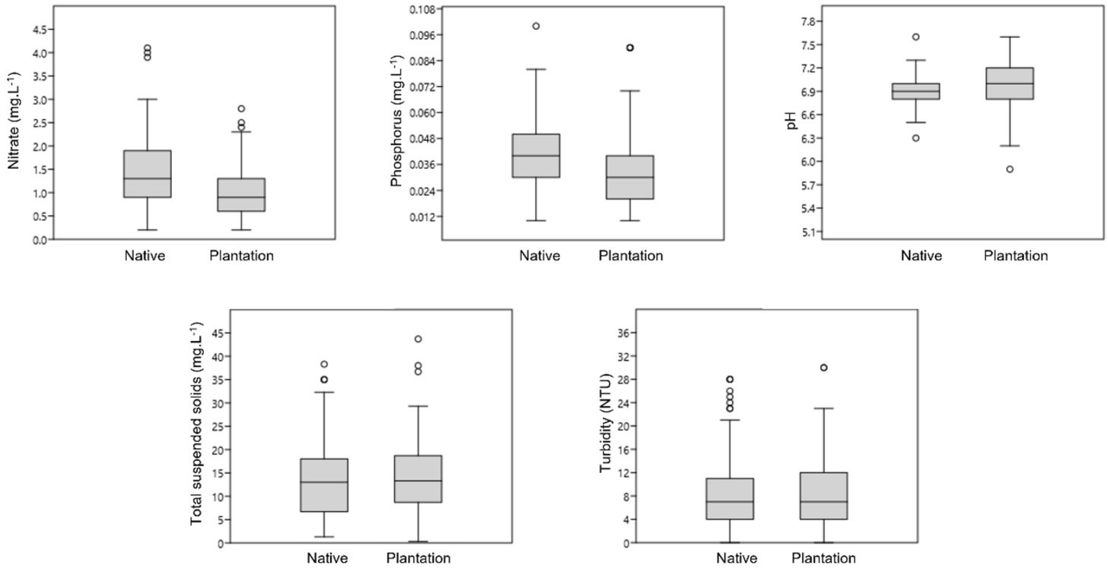

Figure 3: Concentrations of nitrate, phosphorus, pH, turbidity and total suspended solids of the native forest catchment (n = 120) and the *Pinus* plantation catchment (n = 121), for the period from 2004 to 2010.

In general, the results show that the values of the water quality parameters of the streams located in *Pinus* plantation are similar to those observed in the native forest, both of which are below the limits established by CONAMA. Thus, the limits of classification of water bodies in Resolution No. 357/2005 may not be suitable for use as a reference when the goal is to understand the effects of forest management on water resources since this is not the aim of this Resolution. Thus, it is possible to note the need to establish standards for monitoring the effects of forest management on water quality of catchments.

In activities that promote few changes in the physical-chemical water parameters, as is the case of forest plantation; the most appropriate standards to reference water quality would be those obtained in streams of catchments with native vegetation in a good state of conservation and with similar characteristics. Among these similar characteristics, the following stand out: climate, morphology and geology (Andréassian, 2004; Brown et al., 2005). Catchments with native forest tend to have higher water quality compared to other land uses (Vandijk & Keenan, 2007), so they can be used to establish maximum permitted values (MPVs) that are more restrictive and consistent with local reality. In addition, with the history of water quality of the catchment itself, it is possible to identify changes resulting from forest management (Câmara & Lima, 1999; Vital et al., 1999; Rodrigues et al., 2019). Therefore, it is important to conduct medium/long-term hydrological monitoring in paired catchments with forest plantation and native vegetation, using the latter as a reference, in order to build consistent historical series to understand the effects of forest management on water quality.

CONCLUSIONS

The analyzed *Pinus* plantation showed values of the physical-chemical water parameters similar to or lower than those found in the native forest, demonstrating an adequate forest management. The probability of exceeding the limits established in the standard was less than 5% for all parameters analyzed in both catchments. Thus, it is understood that the evaluation of forest management in forest plantations should be carried out through continuous and long-term monitoring of paired catchments with forest plantations and native vegetation, taking the latter as a regional reference of water quality.

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