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Analysis of the impact of the restoration and conservation actions of the Rio de Janeiro Water Fund on the hydrological regime and ecological environment of the Guandu and Paraiba do Sul river basins.

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Abstract

Population pressure and the use of natural resources in the Rio de Janeiro state, plus the strong demand for water cause increasing changes in land use and coverage that affect water quality and generates a risk for the water security of the population of the state. The Rio de Janeiro Water Fund, an initiative that develops and improves financial and governance mechanisms to contribute to water security, has influenced the actions of nature-based solutions (NbS) in the hydrographic regions of the Guandu River and the Paraíba do Sul River. The study area comprises 7,420 hectares and the objective of the monitoring is to estimate how the effects of NbS (conservation, restoration, and natural regeneration) contribute to the reduction of sediments in water bodies, to the regularization of flow and to the maintenance or improvement of biodiversity compared to an area with natural vegetation, by using a reference-impact monitoring design. The monitoring was structured into three parts: (i) monitoring of land use and coverage and restoration, (ii) hydrological monitoring and (iii) biodiversity monitoring each with their specific methodology for data collection and analysis, considering data consistency and statistic trend tests. In the monitoring focus area, 46 ha were restored, 1785 ha were preserved, and another 356 ha of natural regeneration were identified inside and outside the participating project properties, while approximately 236 ha of native vegetation was lost in this area between 2009 and 2019, with only 16% of this total occurring within the participating project properties, which indicates that the project's contribution was greater in reducing deforestation within participating properties than in directly increasing forest cover by restoration. The analysis shows a trend of significant decrease in rainfall over the years for the reference area only, however data shows a reduction of precipitation for both areas. Regarding flow, despite a slight increase between hydrological years 2018-2019, the reduction in flow is clear. This visual decrease is statistically detectable, according to *the results of the Mann-Kendall test* which indicate a trend of this reduction in both areas, which is also reflected in the also significant trend of decrease in rainfall in the region. Regarding biodiversity, the study shows a total of 303 species of birds registered which represents 37.9% of the species listed for the entire state of Rio de Janeiro, and also an increase of 10% of forest- dependent species.

Keywords: hydrological monitoring, restoration, NbS**,** impact monitoring, water security

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1. Introduction

The state of Rio de Janeiro is the second most important economic center in Brazil, largely urbanized and industrialized, with a total of 16 million inhabitants (75% in urban areas) and the highest population density in the country (IBGE, 2019). Population pressure and the use of natural resources in the state cause increasing changes in land use and coverage that affect water quality. In addition, the strong demand for water and the climatic conditions generates a risk for the water security of the population of the state.

In this context, the Rio de Janeiro Water Fund, an initiative that develops and improves financial and governance mechanisms to contribute to water security, has influenced the actions of nature-based solutions (NbS) (restoration, conservation, and best agricultural practices) in the hydrographic regions of the Guandu River and the Paraíba do Sul River, which together cover 65 million hectares. The Water and Forest Producers (PAF) project, which integrates this water fund, was created in 2008, with pilot action in the municipality of Rio Claro and focused on the restoration and conservation of private rural properties. The PAF area is responsible for supplying the Tocos reservoir, (and it is in one of the priority areas for the protection of water resources according to a study by INEA[2]) which is part of the complex system of supply reservoirs in the metropolitan region of Rio de Janeiro and provides about 80% of the water used by approximately 13 million people (IBGE 2021).

To assess the potential impact of interventions on watershed drainage, in terms of water quality and quantity, as well as to identify patterns, trends and interactions between the different components, monitoring activities were initiated in 2009 in the pilot project implementation area. There is a consensus that areas where nature-based solutions are implemented tend to become areas with characteristics similar to adjacent remains. This is due to the possible reduction of deforestation and fragmentation compared to the pre-project periods, in addition to the return of forest-grade bioindicator birds in the restored areas. In addition, over time, due to the impact of interventions, the flow in the restored areas will tend to behave similarly to a reference area, despite having a more regular reference flow.

The objective of this study is, in addition to characterizing hydrological behavior, changes in the landscape (deforestation, fragmentation, etc.) and biodiversity over time, is to identify whether the restoration and conservation actions of the project are responsible for the changes/improvements of hydrological and biodiversity indicators. More specifically, the study aims to answer the following questions: (i) what were the changes in land use and land cover? (ii) Have the quantity and quality of water improved over time? (iii) was it possible to observe significant changes in weather and/or hydrological patterns? (iv) Can these changes/improvements be directly attributed to restoration and conservation actions in the basin? (v) Were changes observed in ichthyofauna and avifauna?

2. Methods

2.1. Pilot study area of the Water and Forest Producers Project (PAF)

The PAF study area comprises 7,420 hectares and is inserted into the hydrological system of the Guandu River in the municipality of Rio Claro. Located at the head of the upper Piraí River, the study area is concentrated in the drainage area of the Pedras River, the Papudos River and part of the Coutinhos River, in the district of Lídice, in the municipality of Río Claro/RJ (Figure 1). The upper basin of the Piraí River is located between 551 and 1,666 m of altitude and, according

[2] INEA - State Environmental Institute

to the Köppen-Geiger classification, presents the type of climate C – humid subtropical zone, and can vary according to the altitude: Cfa (hot summer), in the valleys and slopes with altitudes below 800 m, corresponding to 2,325 ha (31% of the total surface) and Cfb (temperate summer), dry in the high areas, corresponding to 5,095 ha (69% of the total area) (ALVARES et al., 2013). Approximately 19% of the entire upper Piraí basin is made up of grasslands, about 78% is covered by natural vegetation and the rest is composed of rocky outcrops and urbanized areas (TNC, 2019). [1]

2.2. Monitoring design

The objective of the monitoring is to estimate how the effects of NbS (conservation, restoration, and natural regeneration) contribute to the reduction of sediments in water bodies, to the regularization of flow and to the maintenance or improvement of biodiversity compared to an area with natural vegetation. To establish the monitoring design, the tributary sub-basins of the Piraí River (Coutinhos and Rio das Pedras) were divided into five subunits. The Coutinhos sub-basin was divided into two: the Cachoeira River subunit (S1) and the Coutinhos River subunit (S2). The sub-basin of the Pedras River was divided into three: subunit of the Papudos River (S4), subunit of the Pedras River (S5) and subunit of the Piraí River (S3).

The reference-impact monitoring design (COTTINGHAM et al. 2005) was used, selecting as reference S1, with 6.38 km², which has 99% of its area with preserved vegetation cover and as impact areas the subunits S4 and S5 where the project interventions are carried out. Subunits S4 and S5 are basins where forest restoration and conservation actions are implemented, both with approximately 22 km². The reference and intervention subunits are similar in terms of topography, climate, and other environmental conditions, but vary in area and land use. Subunits S2 and S3 are inter-basins that did not enter this analysis. In addition, we used before-after's monitoring design to assess changes resulting from ownership interventions, comparing the data after activity with the baseline at each site individually.

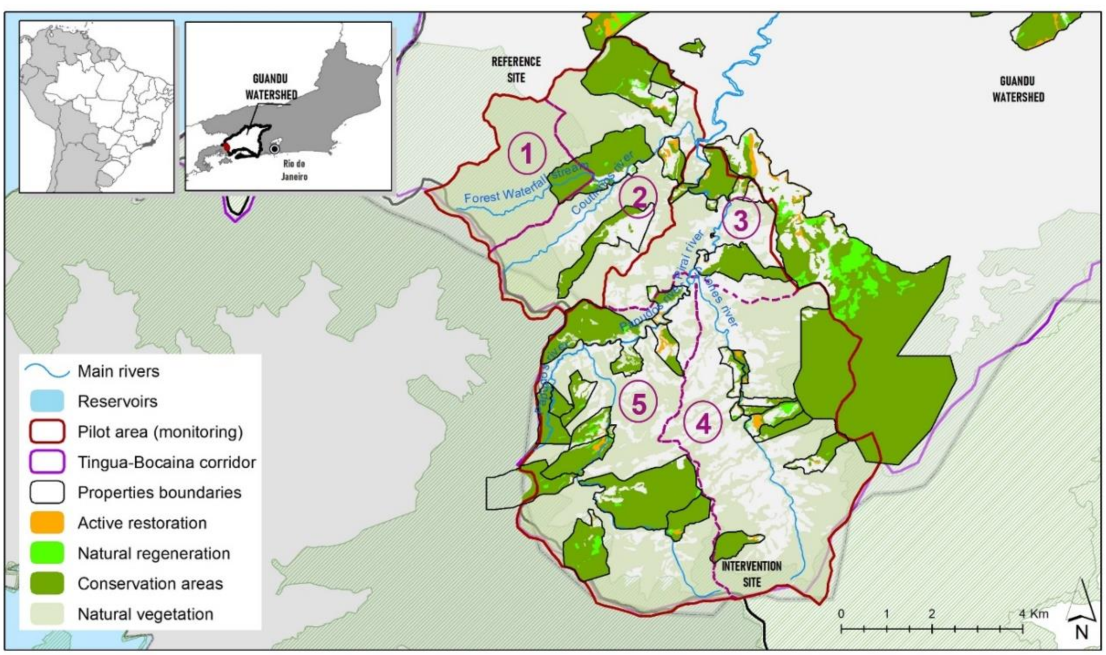


Figure 1. Location of the subunits of the Water and Forest Producers project.

2.3. Monitoring and data collection components

Monitoring was structured into three parts: (i) monitoring of land use and coverage and restoration, (ii) hydrological monitoring and (iii) biodiversity monitoring:

The monitoring of land use and cover and the restoration that was set to be carried out every 5 years was defined, with the purpose of identifying changes in the dynamics of the landscape (deforestation, forest degradation and natural regeneration) from the beginning of the project both in the participating properties of the project and in the non-participants. As well as carrying out an evaluation of the effectiveness of the restoration and conservation (natural regeneration) in the intervention polygons validated by the project.

Hydrological monitoring: it currently has 15 points where 28 automatic and manual sensors are distributed (Figure 2) being: three automatic rain gauges, in which two are in intervention areas (S4 and S5) and one in the reference area (S1); four level sensors paired and synchronized to barometers (atmospheric pressure meters): three in the intervention area (two in S5, one in S4) and one in the reference area (S1). Water quality monitoring consists of two automatic turbidity sensors and two electrical conductivity sensors installed on the main rivers of S4 and S1. All data collected by the automatic sensors is recorded synchronously every 15 minutes and analyzed for consistency and organized into continuous time series. For the analysis, precipitation, and level data from the automatic sensors of the Cachoeira (reference) and Papudos (intervention) stations between 15/11/2013 and 31/12/2021 were used, as well as net discharge data made in sporadic campaigns.

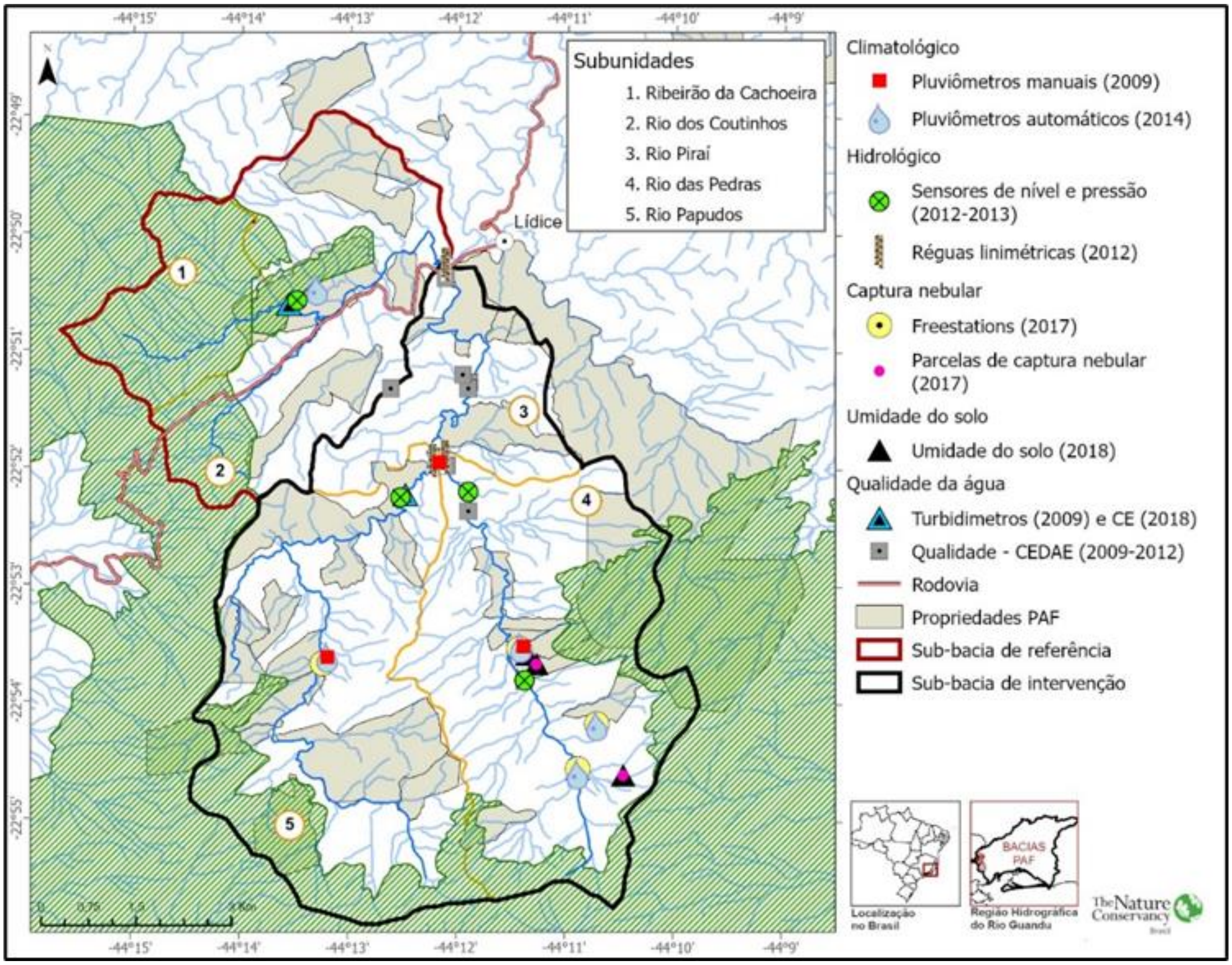


Figure 2. Location of hydroclimatological monitoring sensors of the Water and Forest Producers project.

Biodiversity monitoring includes monitoring of avifauna and ichthyofauna. It was planned to carry out the bird survey every 5 years, and so far 4 campaigns were carried out (2010, 2013, 2017 and 2020). The monitoring has 10 points of observation, active listening, and capture (fog network) for records of physical parameters of individuals and indicators of abundance, richness, and conservation status of species. There are points located in areas of forest remnant (S1 and S4), restoration areas (S1, S4 and S5), open areas near villas and on roads dominated by pastures (S4 and S5). Regarding the monitoring of ichthyofauna, 3 campaigns were carried out (2009, 2010 and 2016) in 14 points distributed in all subunits to inventory and assign ichthyofauna conservation index in the region of interest. The sampled river sections were selected to include areas of preserved forest, areas under the influence of agroforestry activities, and areas close to the limits of the city's urban area. The parameters monitored were relative abundance, richness, pH, conductivity, water temperature, current, type and amount of vegetation, type of aquatic substrate and type of landscape (Figure 3).

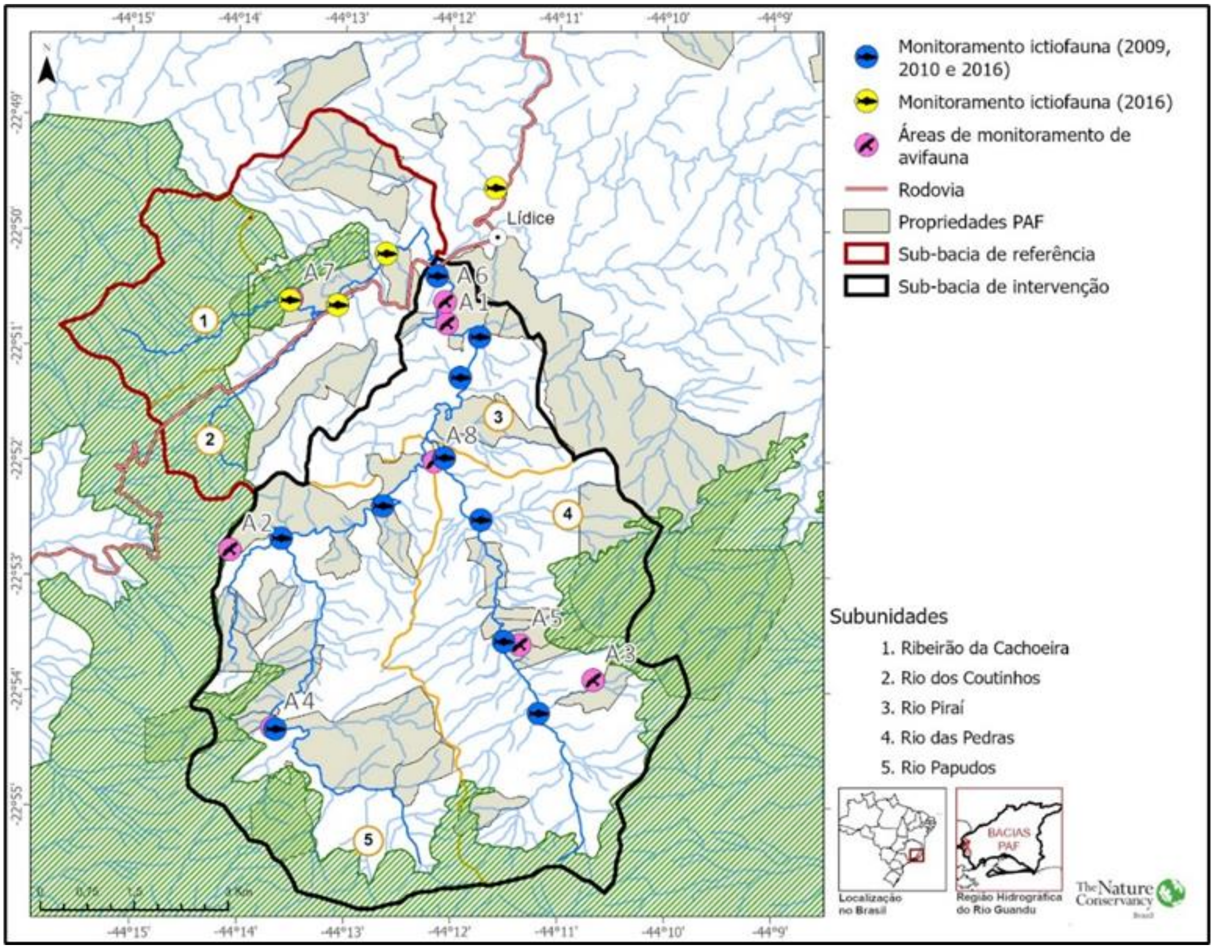


Figure 3. Location of the biodiversity monitoring points of the Water and Forest Producers project.

2.4. Data analysis approach

The data **on the monitoring of restoration and changes in the landscape** were related to the baseline (period between 2005 and 2009), when the project had not yet begun, being considered as an intervention period between 2009 and 2020. For the evaluation of land use and land cover in the properties participating in the project, restoration and conservation data validated in the field in 2020 by a consulting company contracted by the Pro-Water Management Association in the Paraíba do Sul River Basin - AGEVAP, as well as historical series of remote sensing data from the Mapbiomas project (https://mapbiomas.org/pt) - spatial resolution of 30m - to identify changes in landscape dynamics (deforestation, forest degradation and natural regeneration) both in the properties participating in the project and in non-participants throughout the municipality. For monitoring in the field of restoration, 50 plots were assigned in the reference area and 47 plots in the restoration area, where the following indicators were collected: (i) number of larger individuals, (ii) number of smaller individuals, (iii) coverage of competing herbaceous, (iv) species of shrubs and trees, (v) presence of strata, (vi) degradation factors, vii) the average height of vegetation, as well as the analysis of landscape characteristics.

For the analysis of the data **obtained with hydrological monitoring**, they were grouped into 3 data sets: rainfall, fluviometric and water quality. Data analysis sought to understand the relationships between weather patterns, watershed hydrological response, and the effects of restoration and conservation, especially during the dry season. The hydrological year was defined as the period between 01/08 of a given year and 31/7 of the following year, depending on the seasonality of rainfall. The data collected by automatic sensors every 15 minutes were analyzed for their consistency and organized into continuous time series. Finally evaluated using features such as graphs, tables and tests. Statistical tests considered a significance level of 5% and analyses were performed using the 'R/Rstudio' software.

- To determine the normality of the precipitation data, the Shapiro-Wilk test was performed, in addition to descriptive statistics (mean, median, standard deviation, coefficient of variation, maximum and minimum values), in addition to a homogeneity test to verify if the reference and intervention areas are comparable to each other. Finally, the Mann-Kendal test was used (MANN, 1945; KENDALL, 1975) to detect trends in the series.
- To evaluate the fluviometric data, first the pressure data collected by the automatic sensor every 15 minutes were compensated barometrically, that is, the piezometric values were converted into height of the water column. The series of levels were then corrected according to the difference between talvegue elevation and sensor position based on cross-profile field studies. With the net discharge point data measured in the field, the rating curves were adjusted to relate the level and flow, allowing the flow values (m^3/s) to be inferred for the entire historical series. Hydrograms and permanence curves were generated in order to observe the behavior of the series and in relation to the statistical variables such as mean, median, maximum and minimum. Flow data were normalized by area (specific flows), allowing comparison of flows between different subunits. To compare the hydrological behavior of the basin over time (before and after) the Mann-Kendall statistical test was performed and to verify the behavioral trends between the reference and impact stations. The reference flow indicators of $Q_{05,}$ $Q_{50,}$ Q_{90} and Q_{95} were also analyzed, and comparisons of the excess curves and series were analyzed.
- Regarding water quality monitoring, despite temporary turbidity (mV) data and collected water samples, it was not possible to establish a rating curve for total suspended solids x turbidity curve because the turbidimeter presented defects in the same water sample collection period, and it was not possible to make a temporal relationship of the data collected by the sensor.

Regarding the biodiversity, for the ichthyofauna, and with the aim of characterizing the environmental quality according to the fish community of each locality, the interannual temporal variation of the richness of fish species in the total of species was evaluated and two indices were defined based on the bioindication potential established for each fish species found in the Pedras river basin with two indexes: (i) **index 1** represents the average value of the bioindications classification of the fish community present in each sampled locality, calculated by the sum of the classification values of each species present divided by the species richness values at the site; (ii) **index 2** is calculated by the sum of the product between the relative abundance and the classification of each species. This index is equivalent to the average of the values of the bioindication ranking weighted by the relative abundance of each species. In relation to bird monitoring, the abundance, diversity, and apparent richness were evaluated**,** which refers to the total number of species detected in each of the ten sampled areas. In addition, the percentage of classes of forest dependence of the registered avifauna was evaluated, as well as the endemic species or with some degree of vulnerability and their impact on the restored areas.

3. Results

3.1. Achieve monitoring of restoration and landscape changes

3.1.1. Changes in land use and occupation in monitoring subunits

The actions of the project restored about **243 ha** and preserved more than **4100 ha** throughout the municipality of Rio Claro. Of these totals, in the monitoring focus area, 46 ha were restored, **1785 ha were preserved, and another 356 ha** of natural regeneration were identified inside and outside the participating project properties, while approximately 236 ha of native vegetation was lost in this area between 2009 and 2019, with only 16% of this total occurring within the participating project properties (Figure 4). Of the total area of native vegetation lost, 75% was transformed into grasslands, 21% became degraded forests, and 4% became some form of infrastructure.

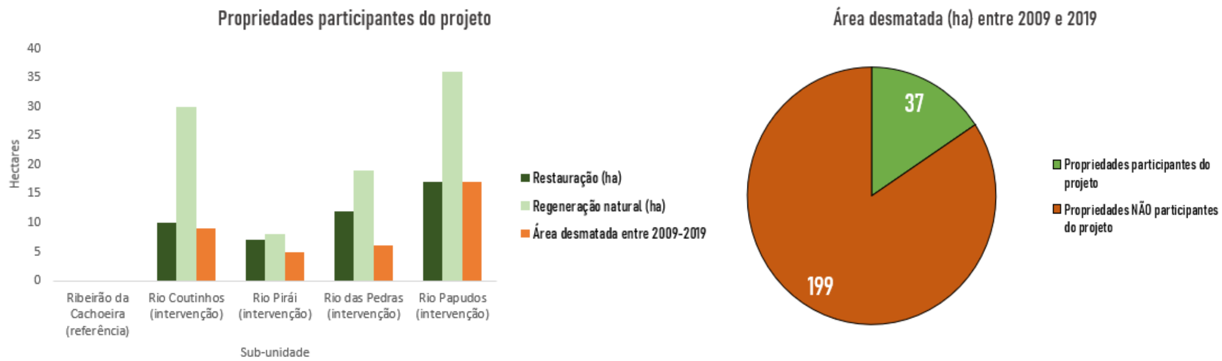


Figure 4. Restored hectares, natural regeneration and deforestation in the Properties participating in the Project.

In the properties participating in the project, 92 hectares of natural regeneration and about 37 hectares were detected deforested (respectively 4.23% and 1.68% of the area within the project). These data show that, in relative numbers, the area with natural regeneration was similar inside and outside the project properties, but deforestation was much higher on the properties that did not participate in the project. Thus, for each hectare of forest lost in the participating properties, 3.76 hectares of forest were restored, while in the non-participating properties this proportion was 1 hectare lost for only 1.32 hectares of restored forest (Figure 5).

These results are aligned with a study conducted by Fiorini et al (2019) in which the authors indicate that the project's contribution was greater in reducing deforestation within participating properties than in directly increasing forest cover by restoration. Unsurprisingly, the reference subunit, which is an RPPN (Private Reserve of Natural Heritage), showed no change in its natural coverage.

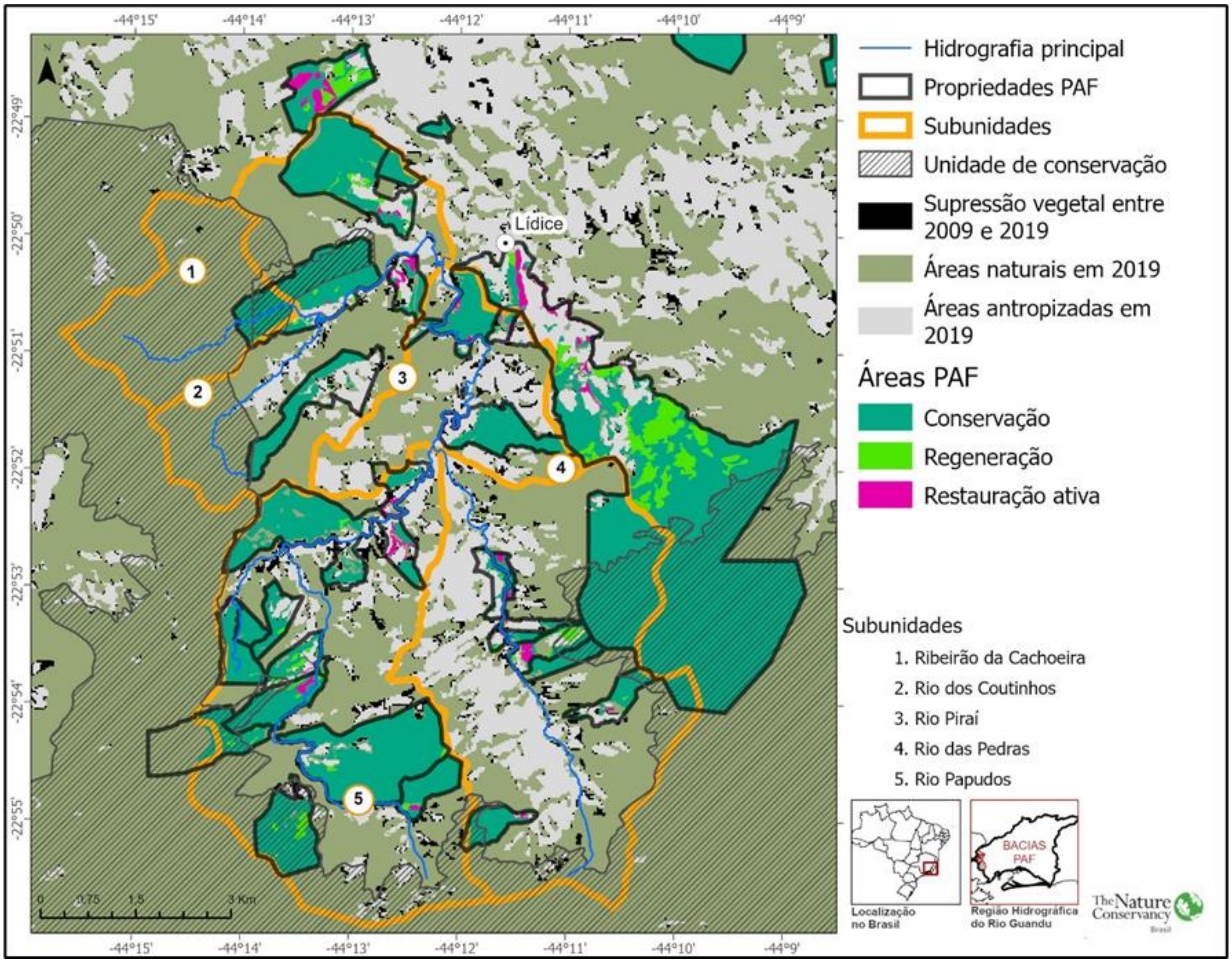


Figure 5. Areas of intervention in the monitoring subunits.

3.1.2. Restoration monitoring results

In the reference area, a total of 205 species distributed in 46 botanical families were identified, the main one being *Cupania oblongifolia* (Cambotá) and *Tibouchina pulchra* (Manacá da Serra) representing 10% and 7% of the identified species, respectively. Of these, 1 species is considered regionally exotic, only 13 species are shrub size and 3 species (*Myracrodruon urundeuva*, *Euterpe edulis*, *Cariniana estrellensis)* were identified as endangered according to the red list of species for Brazil. Table 1 shows the results of the indicators evaluated for the restoration area.

Table 1: Results of indicators in the reference area

Site	Variable	Expected result	Observed result	Achieved target	Adaptive management
Reference site - AP 07 68 ha 50 sampling sites	Grass cover	Maximum of 40% of the area	12,40%	YES	-
	Density of shrub-tree individuals	Minimum of 2500 individuals/ha	5720	YES	-
	Density of shrub-tree individuals > 1.5m height	Minimum of 2500 individuals/ha	3833	YES	-
	Density of shrub-tree individuals between 0.5-1.5m height	Minimum of 2500 individuals/ha	1886	NO	Enrichment with seedlings of secondary and/or climax species
	Average height of shrub-tree individuals	2,5m	7,7	YES	-
	Shrub-tree richness	40 sp	126	YES	-
	Degradation factors	Absence of evidence of degradation factors (e.g., fire, garbage, cattle, etc.)	None	YES	-

Source: TNC

Except for the density of individuals of shrubs and trees between 0.5 m and 1.5 m in height, all other parameters are in accordance with the expected values. Notably, many of these plots were allocated near the edge of the fragments, so they may not represent the actual diversity that the fragment presents, especially in relation to late secondary species and climax. The presence of excessive lianas was observed in 20% of the plots evaluated. Such a situation, common at the edges, may be interfering with the quality of some parameters.

In the intervention subunit there were actions of total sowing/enrichment and conduction of natural regeneration. For the area where natural regeneration was taking place, 2971 individuals were identified, distributed in 41 families and 219 species, among which 8 are regional exotic species, 17 species are shrub size and 3 species threatened with extinction. Table 2 shows the results of the indicators evaluated for the area with natural regeneration conduction.

Table 2: Results of indicators in the field of intervention - natural regeneration

Site	Variable	Target	Reference area results	Observed result	Achieved target (compared to the reference)	Adaptive management
Natural regeneration AP 02 43 ha 47 sampling sites	Grass cover	Maximum of 40% of the area	12,40%	46,90%	NO	Manual mowing and crowning
	Density of shrub-tree individuals > 1.5m height	Minimum of 2500 individuals/ha	3833	2077	NO	Densification with fast-growing species
	Density of shrub-tree individuals between 0.5-1.5m height	Minimum of 2500 individuals/ha	1886	1058	NO	Enrichment with secondary and/or climax species
	Average height of shrub-tree individuals	2,5m	7,7	4,34	NO	Fertilization with nitrogen source
	Shrub-tree richness	40 sp	126	132	YES	-
	Degradation factors	Absence of evidence of degradation factors (e.g., fire, garbage, cattle, etc.)	None	Cattle presence	NO	Fence maintenance

Source: TNC

Only values of richness of tree species were found, average height of individuals as expected. In addition, it was observed that degradation agents are still present in the area, such as a breaking fence and, consequently, the entry of livestock. Therefore, it is considered a priority to eliminate the degradation factor (livestock), in addition to the control of invasive grass and the density of individuals of shrubs and trees.

For the area where there was enrichment, 2459 individuals were identified, distributed in 27 families and 108 species, among which 2 are regional exotic species, 10 species are shrub species by size and 1 species in danger of extinction. Table 3 shows the results of the indicators evaluated for the area with enrichment

Table 3: Results of indicators in the field of intervention - enrichment

Site	Variable	Target	Reference area results	Observed result	Achieved target (compared to the reference)	Adaptive management
Enrichment AP 03 22 ha 26 sampling sites	Grass cover	Maximum of 40% of the area	12,40%	52,60%	NO	Manual mowing and crowning
	Density of shrub-tree individuals > 1.5m height	Minimum of 2500 individuals/ha	3833	1935	NO	Densification with fast-growing species
	Density of shrub-tree individuals between 0.5-1.5m height	Minimum of 2500 individuals/há	1886	1247	NO	Enrichment with secondary and/or climax species
	Average height of shrub-tree individuals	2,5m	7,7	1,9	NO	Fertilization with nitrogen source
	Shrub-tree richness	40 sp	126	57	NO	Enrichment with trees
	Degradation factors	Absence of evidence of degradation factors (e.g. fire, garbage, cattle, etc.)	None	None	YES	

Source: TNC

Only species richness values were found as expected. However, although it is a block whose method was the enrichment of species, no evidence was found of the use of enrichment techniques, such as the introduction of species from the final stages of succession, especially species with greater interaction with fauna. Along with this, a large number of shrubs (45% of individuals) were found, which can impair the structural formation of the forest. Thus, in addition to the control of invasive grass, it is considered a priority to carry out densification with individuals of tree species.

Finally, in the area where the total planting was carried out, as in the parcel of Figure 6, 2547 individuals were identified, distributed in 38 families and 211 species, among which 7 are regional exotic species, 18 species are shrub species by type and 1 species threatened with extinction.

Figure 6. Comparison of a restoration area on a grass plot whose technique used was total planting - years 2011 and 2020

Table 4 shows the results of the indicators evaluated for the area with enrichment

Table 4: Results of the indicators in the intervention area - total planting

Site	Variable	Target	Reference area results	Observed result	Achieved target (compared to the reference)	Adaptive management
Active planting AP 05 68 ha 50 sampling sites	Grass cover	Maximum of 40% of the area	12,40%	70,00%	NO	Manual mowing and crowning
	Density of shrub-tree individuals > 1.5m height	Minimum of 2500 individuals/ha	3833	1308	NO	Densification with fast-growing species
	Density of shrub-tree individuals between 0.5-1.5m height	Minimum of 2500 individuals/ha	1886	1239	NO	Enrichment with secondary and/or climax species
	Average height of shrub-tree individuals	2,5m	7,7	2,6	NO	Fertilization with nitrogen source
	Shrub-tree richness	40 sp	126	113	NO	Enrichment with trees
	Degradation factors	Absence of evidence of degradation factors (e.g. fire, garbage, cattle, etc.)	None	None	YES	

Source: TNC

Values of species richness, average height of individuals according to the expected values were found. In general, in the portions of the total planting treatment, a considerable average of diversity of species used was observed, but with a poor distribution of the same in terms of equability. Thus, in addition to the control of invasive grass, it is considered a priority to densify with fast-growing species punctually in places with low density. As a conditioning action, the enrichment of non-pioneer species is indicated, in addition to fertilization with nitrogen source.

Considering all the blocks sampled, individuals distributed in 64 families of 374 different species were identified. It was observed that the grass cover and density of larger and smaller individuals were the parameters that least achieved the desired objectives, especially since it was a monitoring after only 2 years of restoration actions. Other techniques used such as nucleation and FAS were also monitored. For details, see the specific tracking report.

In terms of species richness, the method of conducting natural regeneration stood out the most compared to the reference area. (Figure 7).

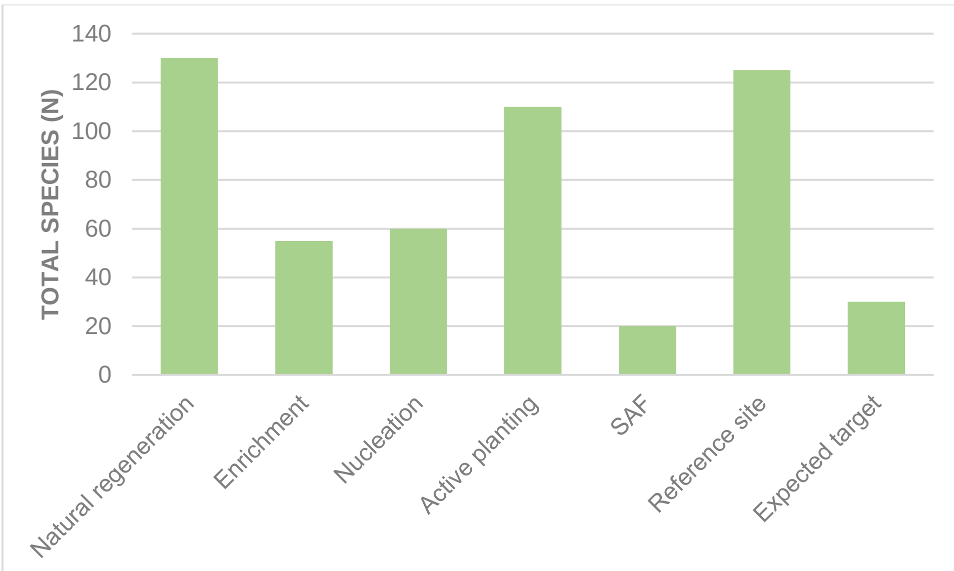


Figure 7. Richness (total number per block) of larger tree-shrub species (greater than 1.5 m in height) in the different restoration methods used (conduction = natural regeneration conduction).

Regarding the density parameter of the shrub-tree individuals, with respect to the smallest group (0.5 m to 1.5 m in height), none of the methods compared with the values identified in the reference area (Figure 8). Most plots contain high grass cover (recent monitoring) considered invasive, which impairs the recruitment of regenerating tree shrubs.

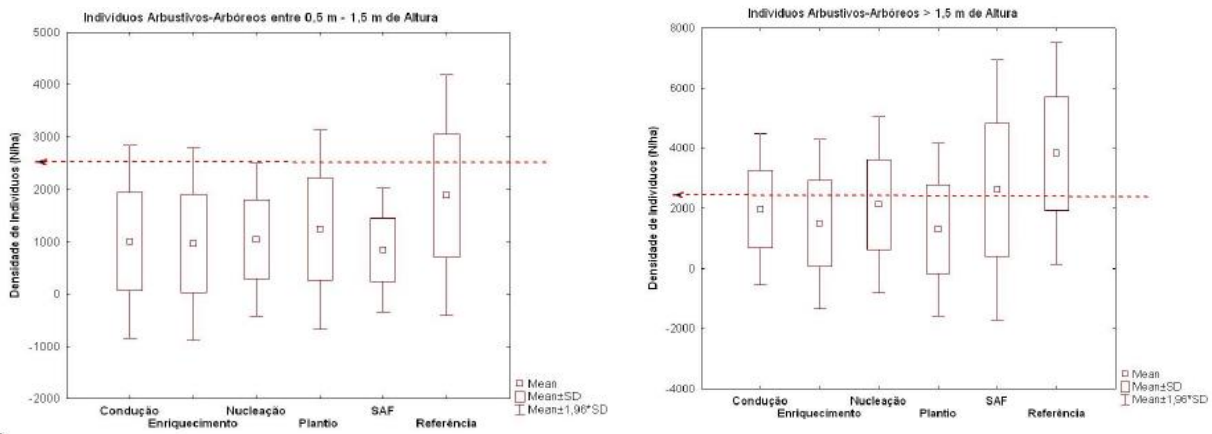


Figure 8. Means and their respective standard deviations from the density of smaller and larger individuals in the different restoration methods employed. The red dash indicates the expected default value (driving = natural regeneration driving).

In many plots it was noticed that the soil was very degraded with signs of erosion and compaction due to the history of the area (mainly pasture areas) and the relief (the areas are steep and suffered leaching and erosion). In addition, fires and livestock were detected as the main degradation factors. In the case of cattle, traces of the presence of these animals were found in many plots. Thus, it can be observed that in some plot's fences must be made and in others they were loose or in poor condition, which allowed the access of the animals.

3.2. Results of hydrological monitoring

3.2.1. Precipitation

Precipitation analysis sought to understand temporal and spatial variability, precipitation trends, and how these behaviors can influence water availability in the basin, as precipitation is among the highly relevant climate variables. From the data series of the stations, descriptive statistics were calculated defined as monthly historical averages to assess the seasonality of precipitation (Figure 9).

The average monthly rainfall was characterized by a large variation throughout the year, the highest concentration of rainfall occurred in the summer in November and January, representing 15% to 20% of the total annual rainfall in all regions. On the other hand, in spring and winter most months presented between 1% and 5% of the total rainfall in the year, a result consistent with tropical regions. For this phenomenon, these regions are classified as having two well-defined seasons: the dry season (from April to September) and the rainy season (from October to March). This analysis is consistent with the "Situation Report - Hydrographic Region II - Guandu, 2011/2012", of the Pro-Water Management Association of the Paraíba do Sul River Basin - AGEVAP, which indicates that the maximum period of precipitation in the Guandu Hydrographic Region goes from November to March and the minimum, from June to October. In the stations of Rio das Pedras and Papudos the month with the highest monthly average was in January, while in the riverside waterfall station the highest average was recorded in February.

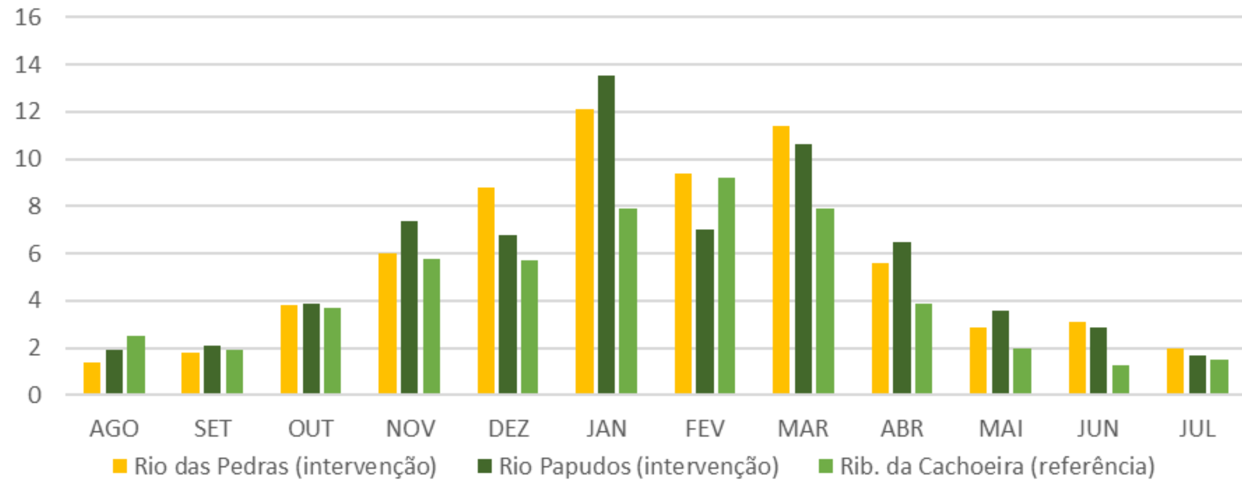
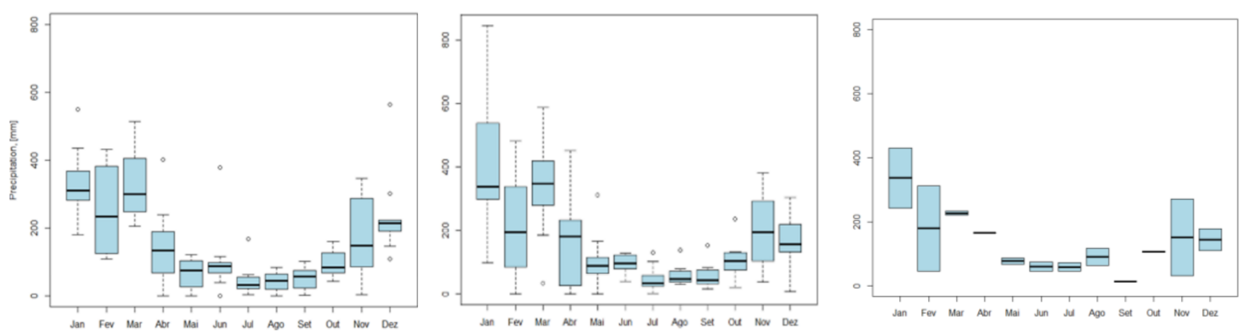


Figure 9. Historical monthly average of the precipitation period from 2009 to 2021.

The records show that the median trend of the monthly distribution of rainfall in the three seasons is very similar, despite the variation in quartiles for the different seasons in the same month (Figure 10). This variation may be associated with the difference between the total number of records in each of the stations for the different hydrological years and the lack of data in some periods.



Intervention Subunit - Papudos River | **- Subunity of Intervention - Rio das Pedras** | **Subunidad of reference - Ribeirão da Cachoeira**

Figure 10. Distribution of monthly rainfall in the period from 2012 to 2021 for the stations Rio Papudos and Rio das Pedras and from 2014 to 2021 for Ribeirão da Cachoeira.

The maximum precipitation values for the three monitored stations were observed between December and March. In the station of the subunit of the river of stones the highest historical record of daily rainfall of 177 mm was recorded, followed by Papudos that reports a rainfall of 174.6 mm and Cascada with 165.2 mm. The region is characterized by very intense rainfall, of the total of days with record rainfall, 6.9%, 6.6% and 3.6% corresponded to heavy or extreme rains in the stations of the Pedras River, Papudos River and Cachoeira stream, respectively. This variability in rainfall intensity within the project region produces flood occurrences that are reported by residents and known locally as "guava flooding" as it is the fruit harvest season. This phenomenon may be associated with the mountainous relief of the region and the location of weather stations, making it difficult to interpret the likelihood of precipitation occurring in the region.

Thus, with the results of the Shapiro-Wilk test, the nonnormality of the data was confirmed, pointing out *that every year the p-value values* are less than 0.005 and the W values less than 1, which is a measure of the correction of the normal quantile-quantile graph, so when it is closer to one, the sample is more normal (Table 5). It is characteristic to show that the response of the hydrographic basins has a strong dependence on climatic phenomena, such as the movements of air masses coming from the coast, cloud forests, as well as the orographic dynamics of the region, which in this case is highly declivous etc.

Table 5: Statistics for each hydrological year of precipitation and p-value data to determine the data distribution (mean (mm), coefficient of variation (%), W value of the Shapiro Wilk test and respective p-values) *rejects H0 - data is not normal.

Hydrological year	- Intervention 1 - River of Stones				Intervention 2 - Papudos River				Reference - RPPN Rib. of the Waterfall			
	Average	CV	Shapiro-Wilk		Average	CV	Shapiro-Wilk		Average	CV	Shapiro-Wilk	
	millimet er	%	In	p-value	millimeter	%	In	p-value	millimeter	%	In	p-value
2008-2009	5,4	2,6	0,428	< 2.2e-16 *								
2009-2010	8,6	2,3	0,498	< 2.2e-16 *	8,5	2,3	0,487	< 2.2e-16 *				
2010-2011	6,3	2,2	0,509	< 2.2e-16 *	6,0	2,2	0,517	< 2.2e-16 *				
2011-2012	4,5	2,2	0,539	< 2.2e-16 *	4,2	2,1	0,542	< 2.2e-16 *				
2012-2013	6,5	2,7	0,399	< 2.2e-16 *	7,0	2,3	0,482	< 2.2e-16 *				
2013-2014	4,3	2,6	0,445	< 2.2e-16 *	4,7	2,5	0,465	< 2.2e-16 *				
2014-2015	4,3	3,0	0,357	< 2.2e-16 *	2,4	2,8	0,421	< 2.2e-16 *	3,0	3,0	0,361	< 2.2e-16 *
2015-2016	6,7	2,5	0,449	< 2.2e-16 *	6,1	2,3	0,498	< 2.2e-16 *	4,5	2,3	0,496	< 2.2e-16 *
2016-2017	5,3	2,4	0,485	< 2.2e-16 *	5,6	2,5	0,451	< 2.2e-16 *	4,7	2,1	0,544	< 2.2e-16 *
2017-2018	4,2	3,6	0,306	< 2.2e-16 *	6,6	2,6	0,445	< 2.2e-16 *	5,5	2,5	0,435	< 2.2e-16 *
2018-2019	7,3	2,5	0,451	< 2.2e-16 *	8,6	2,3	0,483	< 2.2e-16 *	4,5	2,4	0,477	< 2.2e-16 *
2019-2020	6,5	2,1	0,537	< 2.2e-16 *	1,7	3,1	0,344	< 2.2e-16 *	3,6	2,3	0,471	< 2.2e-16 *

To define the existence of trends in precipitation data in the region, *the Mann-Kendall test was applied*. This is a nonparametric test that makes no distinction as to the distribution of the data, but it is useful for analyzing the difference in signals between the previous and subsequent data, and if there is a trend, the values will constantly increase or decrease, indicating an increase or decrease variation in the precipitation pattern over time. The trend analyses of the daily precipitation data obtained between 2008 and 2020 were carried out in the case of the Rio das Pedras stations, from 2011 to 2020 for Rio Papudos and from 2016 to 2018 and for Ribeirão Cachoeira for the period from 2017 to 2019.

Trends by hydrological year for each season were considered, with the purpose of comparing the slope (*Tau)* year by year (Table 6). Until 2014 no significant trend was observed, but *it is observed that Tau* varies and may have a trend of decrease in rainfall during the year, only in the years 2011 to 2013 has a positive trend, precisely years that did not have climatic abnormality.

Table 6. Mann Kendall trend test results (Z value (tau) and p-value) for daily precipitation data in each season during the full data years (95% confidence interval).

Hydrological year	Intervention 1 - Rio das were carried out stone analysis		Intervention 2 - Papudos River		Reference - RPPN Rib. of the Waterfall	
	Tau	*P-value of 2 faces*	Tau	*P-value of 2 faces*	Tau	*P-value of 2 faces*
2008-2009	I	I	n.a.	n.a.	n.a.	n.a.
2009-2010	-0.0721	0.059087	I	I	n.a.	n.a.
2010-2011	-0.0671	0.076859	I	I	n.a.	n.a.
2011-2012	0.00518	0.89367	0.0281	0.46329	n.a.	n.a.
2012-2013	0.0702	0.069494	0.0658	0.076556	n.a.	n.a.
2013-2014	I	I	-0.0594	0.12326	n.a.	n.a.
2014-2015	-0.112	0.071792	-0.179	0.0072475*	I	I
2015-2016	-0.0396	0.31766	-0.0135	0.74738	I	I
2016-2017	-0.00976	0.81127	-0.013	0.73338	-0.109	0.0035512*
2017-2018	-0.0996	0.012545*	-0.0858	0.0042752*	-0.0268	0.47676
2018-2019	0.137	0.00099826*	-0.0988	0.0090632*	I	I
2019-2020	-0.285	0.005483	-0.0793	0.026911	-0.0158	0.047981
2020-2021	I	I	I	I	I	I

*I - incomplete data series for analysis
*n.a - no data available for the period

When analyzing the entire series, the Papudos station shows a trend of significant decrease in rainfall over the years (Table 7), since the Rio das Pedras station does not show a significant trend. For the Ribeirão subunit of Cachoeira, there was difficulty in performing the test in the complete series due to data failures. For this reason, this subunit was not considered in the series trend analysis.

Table 7. Results of the mann kendall trend test for the data series of the Papudos and Rio das Pedras stations.

Area	Tau	P-value of 2 faces
- Talk:River of Stones	0,00168	0.80518
Intervention - Papudos River	-0,0032	6.2038e-06*

*Shows a significant trend (*p-value* < o = 0.025)

3.2.2. Evaluation of the amount of water.

To evaluate the fluviometric data, the pressure data collected by the automatic sensor every 15 minutes were first barometrically compensated, that is, the piezometric values were converted into water column height in meters. The series of levels were then corrected according to the difference between talvegue elevation and sensor position based on cross-profile field studies. With the net discharge point data measured in the field, the rating curves were adjusted to relate the level and flow, allowing the flow values (m^3/s) to be inferred for the entire historical series. Considering the availability of data, the estimated flow was made for the stations of the Papudos River (intervention area) and the Cachoeira River (reference area), and not for the Pedras River subunit. It is emphasized that the rating curves used for the flow estimates were constructed based on field flow measurements between July 2019 and July 2020, along with hydrograms by hydrological year (Appendix 1), which were used to represent the entire historical period of the data (Figure 10).

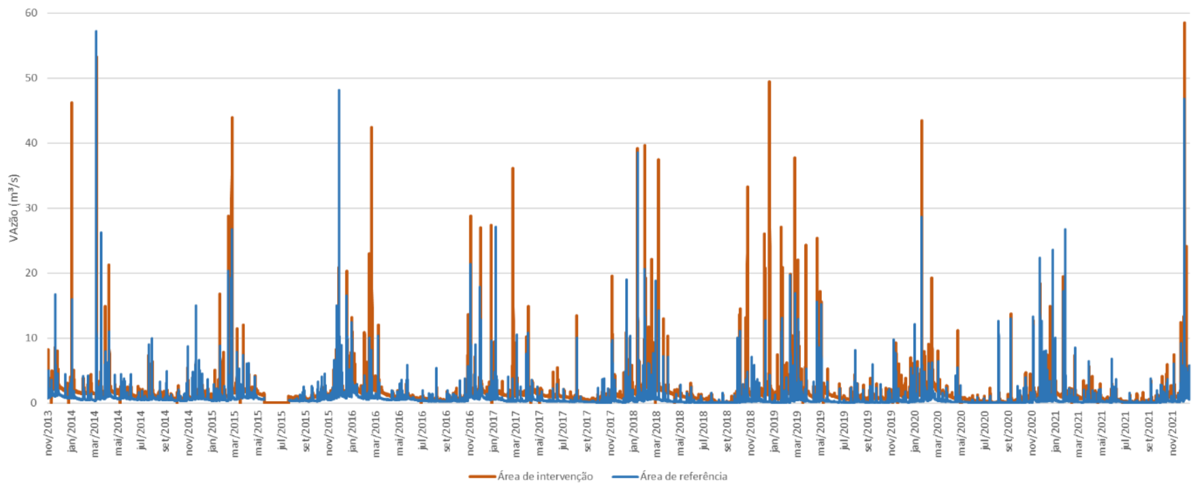


Figure 10. Estimated flow rate (m^3/s) for intervention stations (Papudos River) and reference period (Sambaíba) Nov/2013 to Dec/2021.

The flows with extreme peaks in the subunit of the Papudos River are linked to the high rate of circularity of this area (0.97), which contributes to the concentration of water that leads to rapid flooding, and to its greater area of contribution. The channel of the intervention subunit of the Papudos River is also more confined and steeper. In a counterpoint, in the reference zone, the flows have less variability, with relatively lower peaks in rainy periods, because the moderate circularity index of this subunit (0.53) favors the flow process, in addition to the fact that the bed is less dynamic.

Table 8 presents a summary of the flow characteristics in the intervention and reference subunits. In the intervention area of the Papudos River, the average flow of the period analyzed in the intervention area of the Papudos River ranged between 0.94 and 1.87 m^3/s, with an overall average of 1.39 m^3/s. For the reference subunit in the Cachoeira River, the average flow of the analyzed period ranged between 0.40 and 1.03 m^3/s, with an overall average of 0.62 m^3/s, and from the hydrological year 2017-2018 the values were below this average, which indicates a trend of decrease in flow.

Table 8. Summary of descriptive statistics of flow data for the intervention area and reference by hydrological year.

Hydrological year	Media (m³/s)		Sample standard deviation (m³/s)		Medium (m³/s)		Coefficient of variation (m³/s)		Maximum (m³/s)		number of daily data recorded	
	R	I	R	I	R	I	R	I	R	I	R	I
2013-2014*	1,03	1,87	0,74	0,83	0,86	1,7	0,71	0,44	8,52	8,55	258	259
2014-2015**	0,84	1,38	0,63	0,88	0,66	1,21	0,75	0,64	4,44	8,76	303	303
2015-2016	0,90	1,50	0,69	0,93	0,69	1,23	0,76	0,62	5,47	7,24	361	362
2016-2017	0,64	1,41	0,60	0,89	0,44	1,26	0,94	0,63	6,37	7,47	364	365
2017-2018	0,47	1,47	0,61	1,25	0,27	1,07	1,31	0,85	5,63	13,96	365	364
2018-2019	0,41	1,46	0,46	1,34	0,24	1,18	1,12	0,92	2,88	11,14	364	364
2019-2020	0,43	1,29	0,55	1,04	0,25	1,04	1,26	0,81	4,94	11,51	364	360
2020-2021	0,40	0,94	0,55	0,74	0,25	0,78	1,37	0,78	5,20	5,31	365	364

*Incomplete hydrological year - monitoring begins in November/2013. R= reference site; I= intervention site
**Year in which no data were collected in July/August.

Hydrograms were generated in order to observe the behavior of the series, and in general, the hydrograms year by year show the variation in the flow throughout the year and interannual in each subunit but does not allow a direct comparison between the subunits analyzed; for this it is necessary to consider the specific flow. The specific flow rate (Figure 10) takes into account the total drainage area of the subunits and allows to compare different basins in terms of water production per unit of land. In this case we can see that the reference station naturally has higher water production per km².

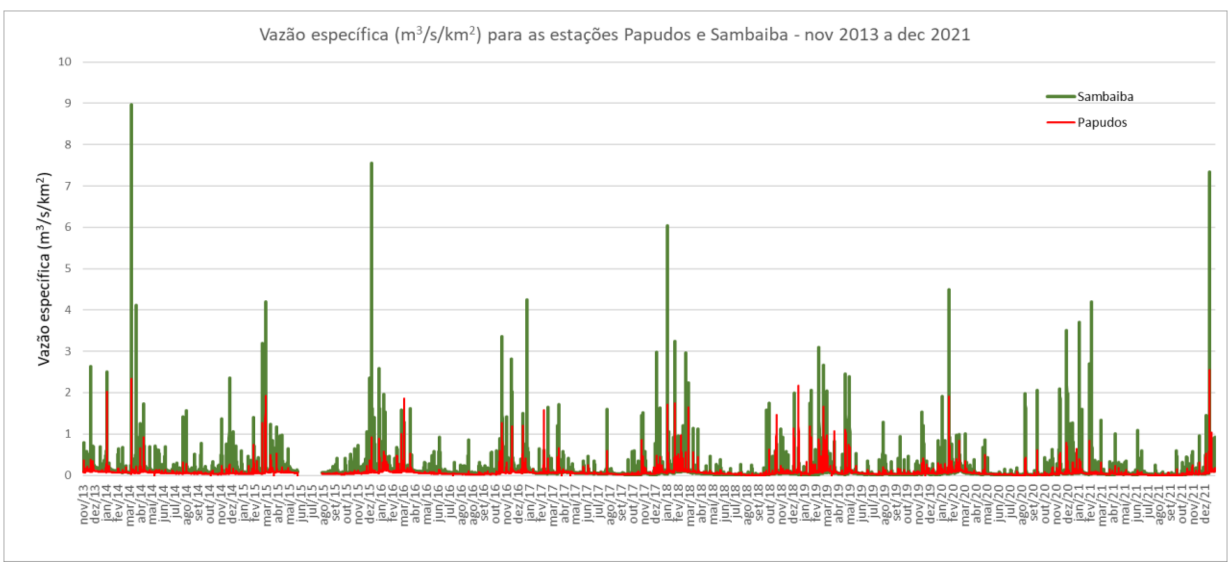


Figure 10. Specific flow ($m^3/s/km^2$) for Papudos and Sambaiba stations from Nov 2013 to Dec2021.

To compare the flow of the intervention and reference areas, the indicators of mean reference flow (Q_{50}), the flow rate with probability of exceeding 95% (Q_{95}) and the flow rate equaled or exceeded by 5% (Q_{05}) were analyzed. Figure 11 shows the comparison between these indicators for the specific flow during the hydrological years for the two areas, observing a reduction of all indicators. The reference basin shows a sharper descent probably explained by the size of the basin and the one that is located on another slope with less influence of the air mass coming from the coast. In addition, it is possible that the observations and flow changes observed after 2018 may also be a product of the sensor change in the intervention area, since from 2018 the sensor was lost and had to be relocated and may influence data collection.

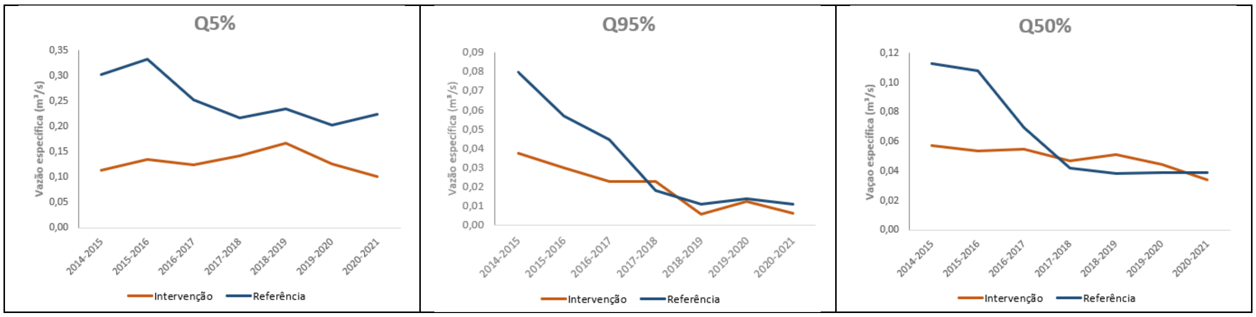


Figure 11. Reference flows Q_{95}, Q_{50} and Q_{05} compared between the intervention station (blue) and the reference station (orange).

Table 10 presents the indicators of the reference flows Q_{05}, Q_{50}, Q_{90} and Q_{95} for the period 2013-2021, estimated from the complete database, with data recorded every 15 minutes. It is possible to state that the average flow rate (Q_{50}) is very similar for the two stations varying only by 0.02 m^3/s (20 liters). The flow rate with a probability of exceeding 90% (Q_{90}), has a difference of only 2 liters, and in the indicator of maximum flows (Q_{05}) it is possible to verify a difference that reaches 133 liters (0.3m^3 / s), having to be analyzed more carefully, especially since the key curve of the reference subunit was constructed with few maximum flow data that could be only an extrapolation artifact of the equation. This observed limitation should be correct soon with the continuity of monitoring.

Table 10. Summary of the descriptive statistics of the average data of specific flow for the areas of intervention and reference in the period 2013-2020.

Season	Average specific flow rate (m^3/s. Km^2)	Maximum (m^3/s)	Q_{50} specific (m^3/s. Km^2)	Q_{90} specific (m^3/s. Km^2)	Q_{95} specific (m^3/s. Km^2)	Specific Q05 (m^3/s. Km^2)	number of data recorded
Papudos River - intervention	0,061	2,33	0,040	0,020	0,009	0,122	277.869
Ribeirão da Cachoeira - reference	0,097	8,96	0,060	0,018	0,013	0,255	278.866

The excess/permanence curves indicate the probability of occurrence of a given flow over time (Appendix 2) in the historical series and are presented separately by periods and seasons in Figure 12. Theresults of the exploratory analysis based on permanence curves, data distribution and reference flow indicators show that there is a decrease in flows from both areas. Figure 12a shows that the permanence curves between 2013 and 2017 present a well-defined separation between the specific flow data series that identify a higher flow reference area.

For the years 2017 to 2019 (Figure 12b) it is possible to observe that the permanence curves tend to behave similarly, reducing the space between them, the exception of the year 2018-2019, where, Papudos (area of intervention) presents very different low values, which can be explained by the loss of sensor level in January 2018 and the use of complementary data of the level of the electroconductivity sensor,   in the same location, but shows differences in the installation of the computer. The same goes for between 2018 and 2021 where curves behave similarly and only differ at extremes with higher high flows in Sambaíba and higher flow ends in Papudos. This shows that despite having a reduction in flow, the station in the reference area (Sambaíba), still has more regularized flows in the dry season in all cases.

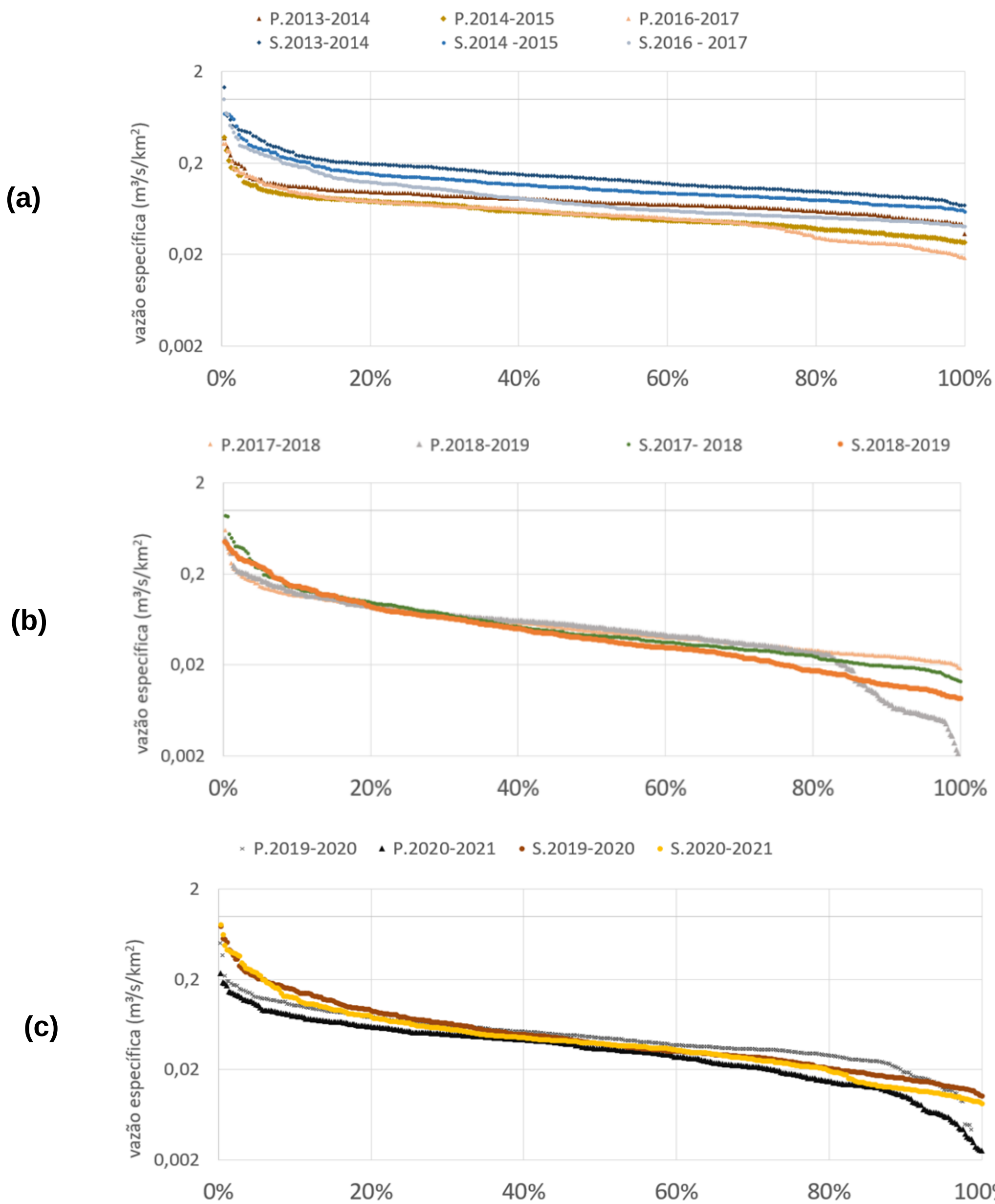


Figure 12. Probability of exceeding the specific flow ($m^3/s/km^2$) for the intervention stations - Papudos (P) and reference - Simbaíba (S), for each hydrological year monitored.

However, it is possible to verify an approximation of the flow behavior (Figure 13) of the intervention station compared to the reference station over the years. Before 2017 the variability of the flow recorded at the intervention site was greater than at the reference site, after 2017 it is possible to notice a similar behavior of the two seasons, with a possibly more pronounced decrease in flow in the reference area because it is a smaller basin with greater need for evapotranspiration and less rainfall. By observing the production of water as a whole and without the low flow, it is possible to observe that the reference station maintains a greater regularization of the flow, producing a stable amount of water in the river even at the time of the drought.

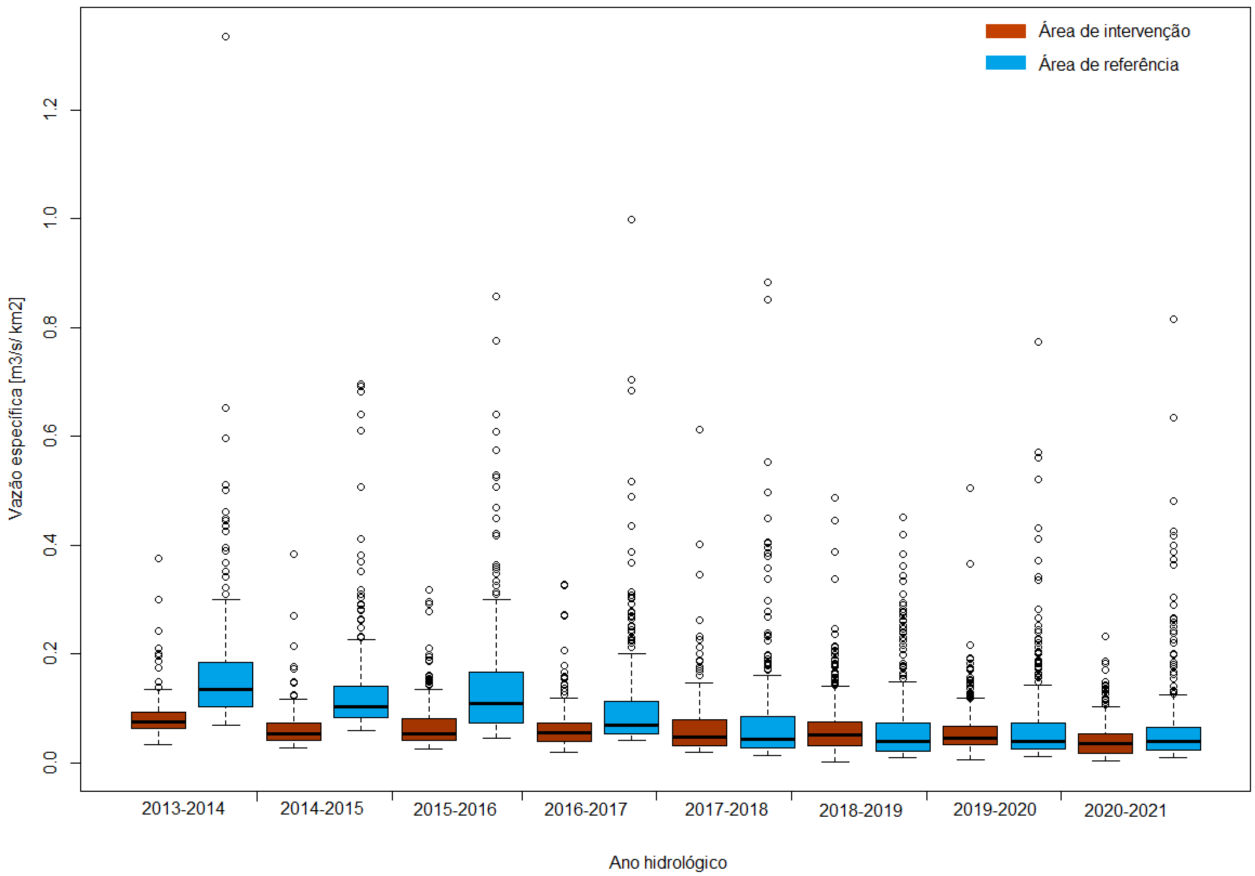


Figure 13. Specific flow behavior (m³/s) for reference stations and intervention by hydrological year. The axis represents the median; the box, the quartiles; the bars represent the non-atypical range, and the filtered circles represent the outliers.

Despite a slight increase in flow between hydrological years 2018-2019, the reduction in flow is clear. This visual decrease is statistically detectable, according to *the results of the Mann-Kendall test* (Table 11), which indicate a trend of this reduction in both areas, which is also reflected in the also significant trend of decrease in rainfall in the region.

Table 11. Mann Kendall trend test results for flow data series for reference and intervention areas

Area	Tau	P-value of 2 faces
Reference - Sambaíba	-0,39	=< 2.22e-16*
Intervention - Papudos River	-0,199	=< 2.22e-16*

*shows a significant trend (*p-value* < or = 0.05)

3.3. Biodiversity

3.3.1. Ichthyofauna - environmental quality based on the fish community

A total of 5,215 specimens were collected (969 in 2009, 1215 in 2010 and 1635 in 2016) representing 30 native species of 12 families and 5 orders respectively and one exotic species. Of this total, 20 species were collected in 2009, 24 in 2010 and 26 in 2016. The 5 most abundant species accounted for 75% of the catches and were present in the 3 sampling intervals. Eighteen species occurred in the 3 years sampled, four species occurred in 2 years, and eight species were only collected in one of the 3 sampling events. Six species were represented by three or fewer specimens throughout the sample period, considered *rare, such as Hemipsilichthys gobio* (Lütken 1874). Ten species are endemic to the Paraíba do Sul basin and 2 are endemic at the regional level.

Two species found in the study area are included in the red book of endangered species in Brazil (ICMBio 2018), with *Hemipsilichthys gobio* listed as endangered and Brycon *opalinus* (Cuvier 1819) as vulnerable. *Brycon opalinus*, known as "pirapitinga", was captured in the lower course of the Pedras River in 2010 and 2016, and visually detected at the Ribeirão Waterfall in the Fazenda Sambaiba rppn area (reference area) in the drainage of the Coutinhos River in 2016. Pirapitinga is vulnerable due to commercial exploitation and environmental degradation, and its distribution is restricted to the preserved tributaries of the headwaters of the Paraíba do Sul and Doce rivers (GOMIERO & BRAGA, 2007; ICMBio, 2016).

Species richness was scarce among the drains sampled in the intervention areas. Figure 14 shows the temporal pattern of variation in species richness between the 3 events in the sample. There was a noticeable difference between the lower drains and the headwaters. In the Piraí River the species richness varied between 10-16 species, in the lower rivers of Pedras and Lower Papudos the richness varied between 8-14 and 9-13 respectively, while in the region of the headwaters the richness varied between 4-6 for the upper Rio das Pedras and 3-7 for the Alto Papudos. At the sampling point within the simbaíba RPPN (reference area) there were 9 species.

The non-native species *Oreochromis niloticus* was recorded at two points in the main channel of the Upper Pyrenees. Known as Nile tilapia, it is a species of invasive cycla, native to Africa, widely grown in tanks and net cages in Brazil, and was probably introduced by fish farming leaks. The introduction and establishment of the population of this invasive species in the main channel of the Alto Piraí are widely associated with areas of intense human occupation and land use.

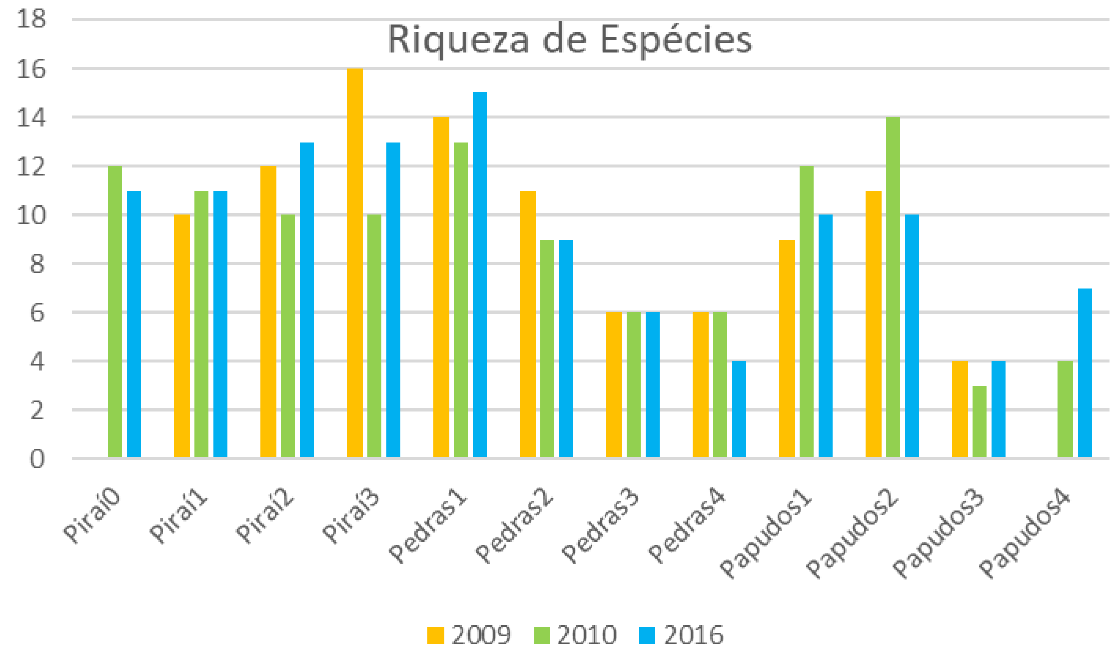


Figure 14. Year-on-year temporal variation in fish species richness.

Index 1: = average value of the bioindication ranking of the fish farming community of each locality

In all sampling periods, the highest values of Index 1 were consistently recorded in the upper stretch of the Pedras River basin and in the headwaters of the Papudos River, while the lowest values were recorded in the vicinity of the city of Lídice, showing the correlation between the species composition of the fish community and the levels of environmental degradation (Figure 15).

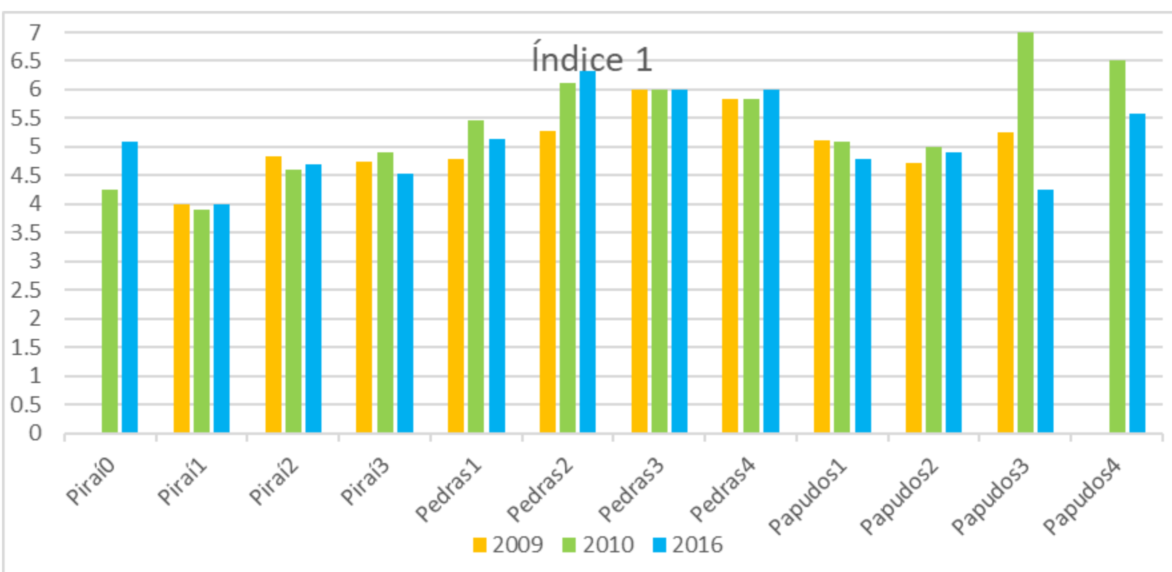


Figure 15. Temporal evolution of the quality of the aquatic environments of the Pedras River basin based on the average bioindication ranking of current species, index 1.

The relative stability in the number of species over time was reflected in the maintenance of the general pattern of distribution of index 1 values among the sampling stations. This pattern indicates that the composition of fish communities has remained stable over time and that the composition of fish communities adequately reflects the characteristic environment structure of each sampled site. The exception to the rule was recorded in the upper section of the Papudos River Sub-basin (Papudos3 and Papudosstations4), with greater variations over time. In this passage, the reduced number of species and the occurrence of recent housing construction and renovation activities may have influenced the responses of the fish community.

Index 2: = mean classification values of bioindications weighted by the relative abundance of each species

This index reflects short-term variations in the abundance of individuals of each species (Figure 16). In general, there was a tendency to increase the values of index 2 in the stretch of the Pedras River located upstream of the Pedras River (intervention area).

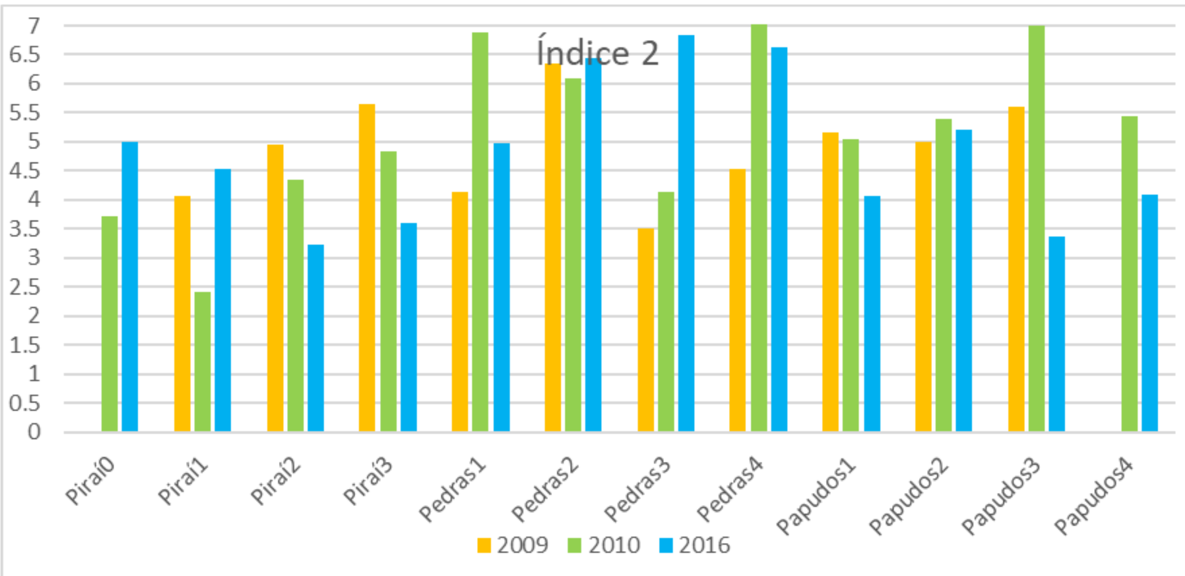


Figure 16. Temporal evolution of the quality of the aquatic environments of the Pedras River basin based on the average ranking of bioindication of the species present, index 2.

Unlike Index 1, there is greater temporal variability in this index. While Index 1 indicates that the composition of the fish community at the Pedras3 station maintained its original characteristics, Index 2 indicates that changes in the riverbed provided conditions for increased fish populations associated with low anthropic impact environments. This significant change in index 2 values demonstrates the ability of ichthyofauna to respond positively to natural events in regions with low anthropic impact. Even with marked natural disturbances and radical changes in bed structure, there was no significant change in the ichthyofauna, demonstrating the resilience and tolerance of this fauna to extreme weather events.

3.3.2. Avifauna - monitoring results

In addition to the detections obtained in the monitoring of avifauna in 2010, 2013 and 2017, a total of 303 species of birds registered in Río Claro were identified. This total represents 37.9% of the species listed for the entire state of Rio de Janeiro, 34% of the birds known in the Atlantic Forest and 15.78% of the bird species in Brazil. Due to the size of the area included in the monitoring of Rio Claro, this area can be considered as a region of very high relevance for the diversity of avifauna. Of the total species identified, 69 are endemic to the Atlantic Forest and 22 are classified as threatened, to some extent, at the international, national or regional level. Of the threatened species, three species were found in two monitored restoration areas (A5 - Carlinhos and A6 - Jubinha). One of them, commonly known as araponga, *Procnias nudicollis* considered threatened by both the IUCN international list and the national MMA list. This species was detected in all sampled forest remnant areas and in one restoration area (A6, Jubinha), a good indication of the ecological role of restored areas for biodiversity use in the landscape.

Also, 12 species of hummingbirds were identified. Although they are not the only birds capable of pollinating plants, hummingbirds are the most specialized in this bird-flower relationship (ANDERSON et al., 2016). The various species of hummingbirds also have different functions and interactions with different plants. Their varied beak sizes and shapes reflect the diversity in foraging strategies and interaction with flora. The sampling area with the greatest diversity of hummingbirds was the restoration area A5 (Carlinhos). This area had the presence of the most generalist species and less sensitive to environmental modification, such as the violet-eared hummingbird (*Colibri serrirostris*) and the black-tuned hummingbird (*Anthracothorax nigricollis*), as well as specialized and more sensitive species, such as the white-red tail (P*haethornis ruber*) and the white tail of the cracked (*Phaethornis eurynome*).

In 2020, two forest remnant areas (A2 and A3) and restoration area a5 had the highest number of species detected. Area A7a (RPPN Sambaíba), also a forest remnant located in the reference subunit, contrary to expectations, presented a low apparent species richness. This result observed in A7a is possibly due to rain and fog that occurred on the day of sampling. Sampling points A1 and A6 showed similar richness, while restoration areas a7, A8 and Open also had low richness (Figure 17).

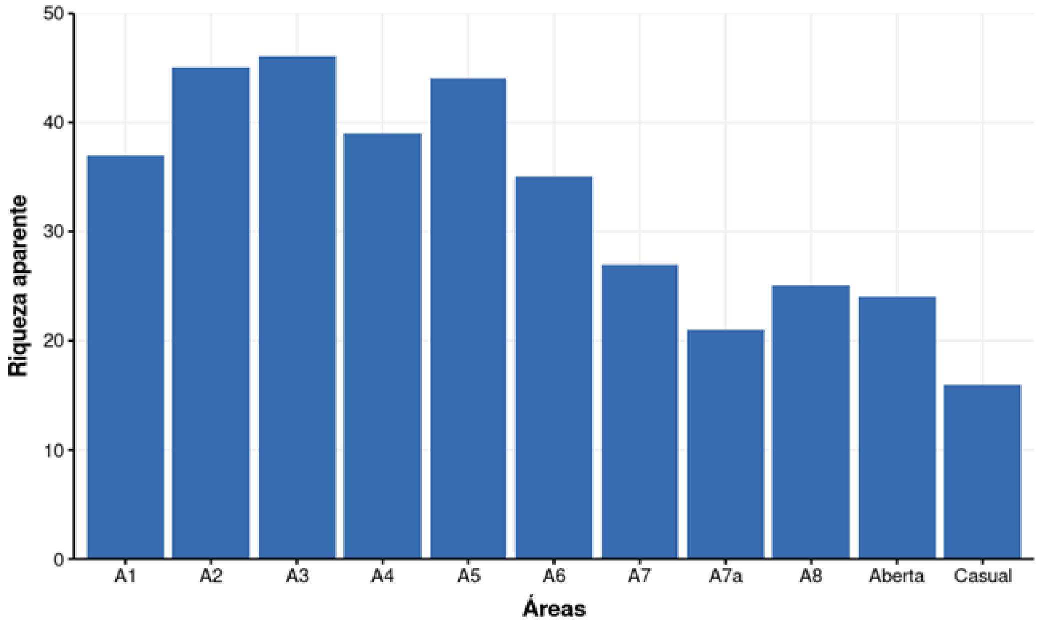


Figure 17. Total species detected (apparent richness) in each of the ten areas sampled by the listening point method and/or fog nets during the fourth avifauna monitoring campaign in Lídice, Río Claro (RJ), in 2020. The figure also shows the total number of species detected during the chance observations, only as supplementary information.

More important than the species richness in each area is the composition (combination of abundance, richness, and species identity) of the avifauna detected in each area, which was used to estimate the similarity between these areas. Through this analysis, two main groups were identified:

1) the group of restoration areas, which covers the restoration areas A8, A7 and A6 with the "Open" area and with the remaining forest A1, which has an important edge effect.

2) the forest area group, consisting of four of the five forest remnant areas included in the study, plus the A5 forest restoration area. Zone A5 is the one that reflects the greatest success of the restoration, resembling more the areas of forest remnants than the other restoration areas or open areas. As a notable differential, A5 is the restoration with the largest area and is surrounded by forest remnants, thus avoiding the edge effect with open areas.

Compared to previous monitoring (2010, 2013 and 2017), in 2020 there was a proportional increase of more than 10% of the species characteristic of forest environments, considering the records made in all sample areas of Rio Claro (Figure 18).

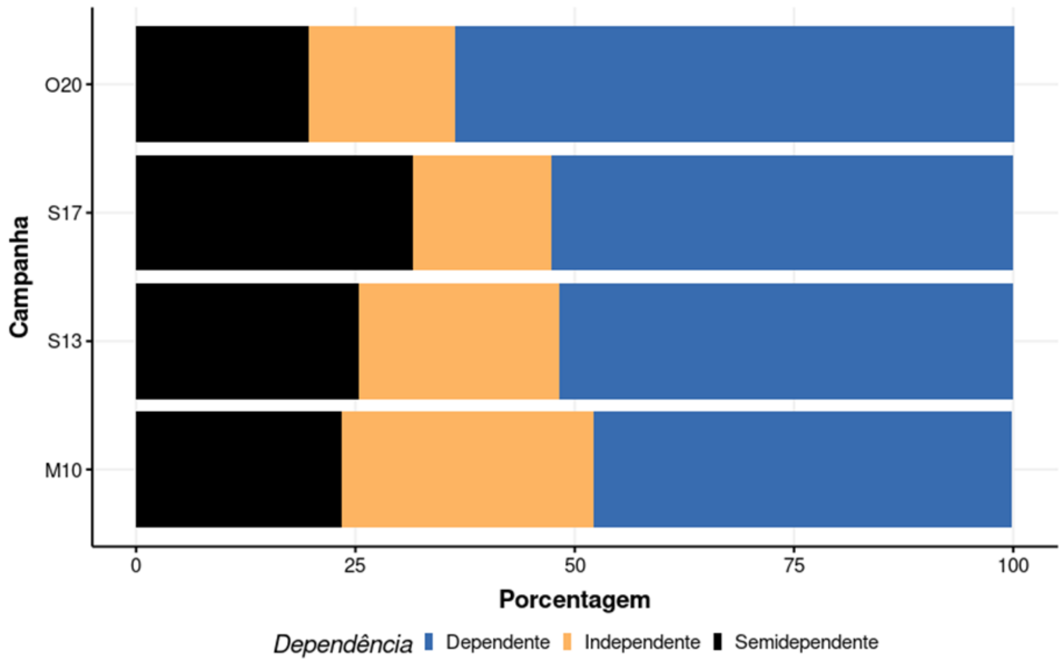


Figure 18. Percentage of classes of forest dependence of avifauna recorded in the four monitoring campaigns of the Water and Forest Producers Project (PAF), in Lídice, Río Claro/RJ. Legend: M10 - National Museum; S13 - SAVE 2013; S17 - SAVE 2017; O20 - OAMA 2020.

On the other hand, there was a reduction in semi-forest-dependent species and little change in the proportion of species that are independent of these environments in local avifauna. Specifically, the restoration areas A5, A6 and A7 follow the local trend, with around 56 to 59% of species totally dependent on forests and between 25 and 29% of species semi-dependent on these environments. The open areas (A8 and Open), on the other hand, have a large part of their avifauna independent of the forest, and other semi-dependent areas, as expected. The remnants, finally, have avifauna composed of mostly forest species.

4. Discussion and conclusion

It is emphasized that the rating curves used for flow estimates were constructed based on field flow measurements between July 2019 and July 2021 (Appendix 3) and were used to represent the entire historical periodof the data (Figure 19) and divided for the dry and rainy periods, which allows an analysis of the maintenance or regulation of water. Although a slight increase in flow has been observed in specific hydrological years (2017-2018 and 2018-2019) there is a significant trend of flow reduction considering the entire historical period monitored. Decreased flow may be correlated primarily with changes in weather patterns, also identified with a tendency to reduce.

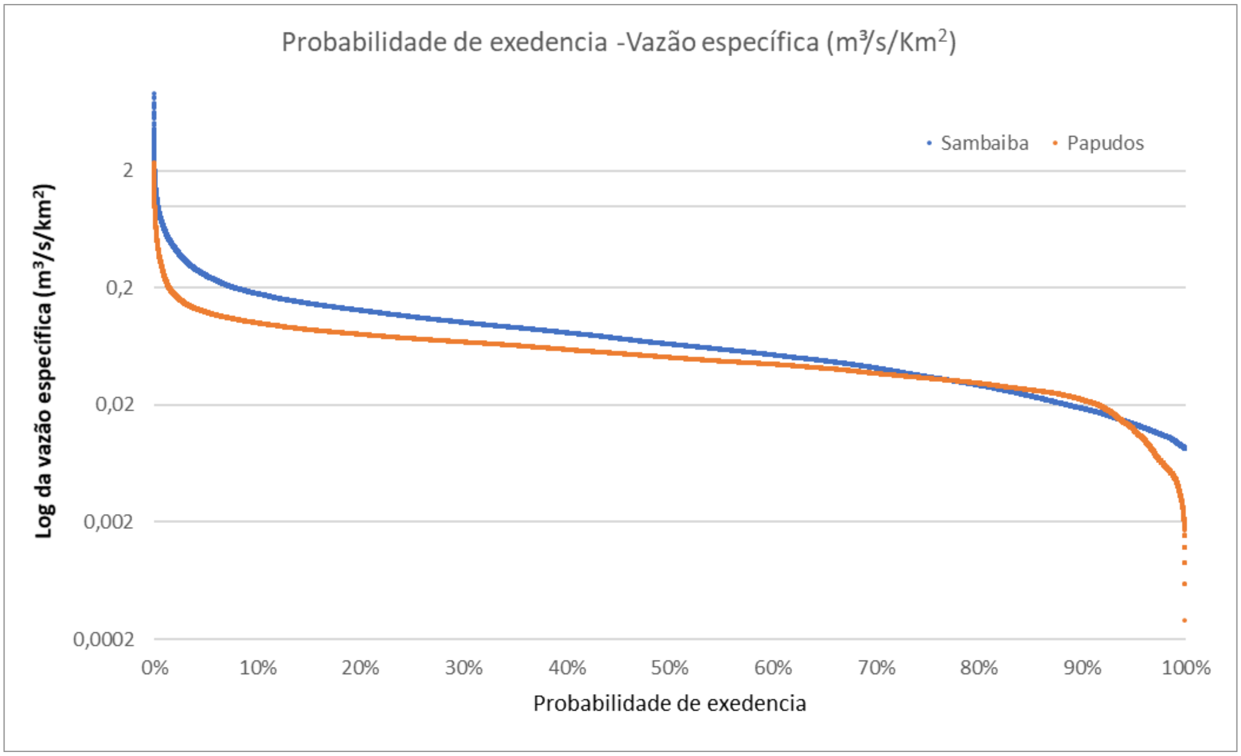


Figure 19. Specific flow rate (m³/s/km²) for Reference and Intervention sites

As expected, the reference subunit has a more regular specific flow than in the intervention subunit, however, due to this flow reduction, from 2017, the hydrological behavior of the intervention basin begins to match the behavior of the reference basin. However, at first there are still no elements to estimate the potential contribution of interventions directly on erosive processes, sediment intake and the regularization of the water flow itself, even with the relative increase in vegetation cover especially by natural regeneration.

It is also necessary to consider the variations associated with the size and format of the subunits. Although the analyses use specific flows (comparable by area), soil shape, slope and type influence hydrological responses, causing different concentration times for the same rainfall intensity between the intervention subunits and the reference subunits. These variations are reinforced by differences in the percentage of forest cover. The reference area is a naturally stable area that results in long natural infiltration processes. The areas of intervention, despite having a lot of forest cover, present a human dynamics of land use that favors surface runoff. It was observed from the beginning of the PAF, a certain loss of forest, although to a much lesser degree than the gain of native vegetation. After the start of the project, deforestation, and fragmentation in the intervention subunits, especially in the participating properties, are lower than those observed before the start of the project, reflecting a change in the behaviour and socio-economic indicators of the basin.

The absence of hydrological data from periods prior to recovery actions makes it difficult to associate the analyzed flow patterns with the restoration actions themselves. Importantly, it is likely that the use of *the BACI (Before-After Control-Impact) methodology* would have contributed to a better understanding of the effect of restoration and conservation actions. This methodology, however, would require that the data had been collected at the stations before the actions of the restoration actions (STEWART-OATEN et al., 1986; SMITH, 2013). However, due to the availability of resources, the acquisition and installation of the entire structure required for monitoring ended up happening gradually and not simultaneously at all stations. With the continuity of monitoring in an appropriate manner, combining measurements from automatic sensors with intensive field flow measurements in periods of drought and flooding, together with meteorological measurements, over time it will be possible to identify if this pattern will be maintained and if it is a consequence of the restoration and conservation activities of vegetation in the basin.

Monitoring of aquatic biodiversity based on the occurrence of ichthyofauna is used as a biological indicator, emphasizing species that demand high-quality water. The objective is that, based on the knowledge of the occurrence and abundance of species over time, we have a "thermometer" to evaluate the quality of the aquatic environment in the basin, while developing conservation and restoration actions in the region through the PAF. The presence of an endangered species indicates that preserved stretches of the Pedras River serve as a natural refuge for threatened ichthyofauna and reinforces the importance of the conservation of this river. In addition, the registration of additional species in the last field campaign, not previously caught in the area, despite the use of a standardized sampling effort, demonstrates the importance of continuous studies in freshwater systems, in order to increase knowledge about the distribution and impact of human activity on the fish assemblies present. remnants of Atlantic Forest. As data from longer time series accumulate, it will be possible to deepen analyses of the relationships between hydrological monitoring and monitoring of aquatic biodiversity.

On the other hand, the high concentration of thermotolerant coliforms detected by the monitoring carried out by CEDAE, in disagreement with the standards allowed by conama, indicates that, for the maintenance of water quality, if these levels persist today, health factors must also be considered both in terms of monitoring and intervention.

Considering that the main cause of decline in bird populations in the world is habitat loss and fragmentation, the project's restoration and conservation interventions are of great importance to avifauna. The Atlantic Forest now has only about 12% (SOS MATA ATLÂNTICA, 2020) of its area covered by original habitats and the population of many wild species is in decline. At least 233 (26%) species of birds in the Atlantic Forest are classified as internationally or nationally threatened (MOREIRA-LIMA, 2013). Among the species listed during the monitoring, the presence of 21 of these species was identified, that is, 10% of the total in a relatively very small area. The actions of conservation of the remaining natural habitats in the area and the restoration of the native forest are therefore of great importance for the maintenance of these species that need protection measures. In addition, the increase in species characteristic of forest environments in 2020 compared to previous monitoring (2010, 2013 and 2017) indicate that habitat restoration actions have the potential, when well planned and executed, to connect fragmented landscapes, increase the viability area of species that depend on specific habitats and reduce the processes of population decline and extinction of species.

In general, the results of this monitoring do not yet allow to identify significant improvements in hydrological terms, although there has been a specific increase in flow in the last three years, followed by a significant decrease in both rainfall and flow. To do this, a longer historical data series will be required. On the other hand, although a certain forest loss has still been detected in the participating properties of the PAF, the comparison with non-participating areas indicates that one of the most important results of the project has been forest conservation and restoration, which in turn has benefited the avifauna and ichthyofauna of the region. The data obtained have allowed a better understanding of the dynamics of the drains, to support discussions on the shortcomings, successes and possible changes in the action plan and budget of the project as well as the search for strategic alliances in order to continue and even expand the actions of the project.

5. References

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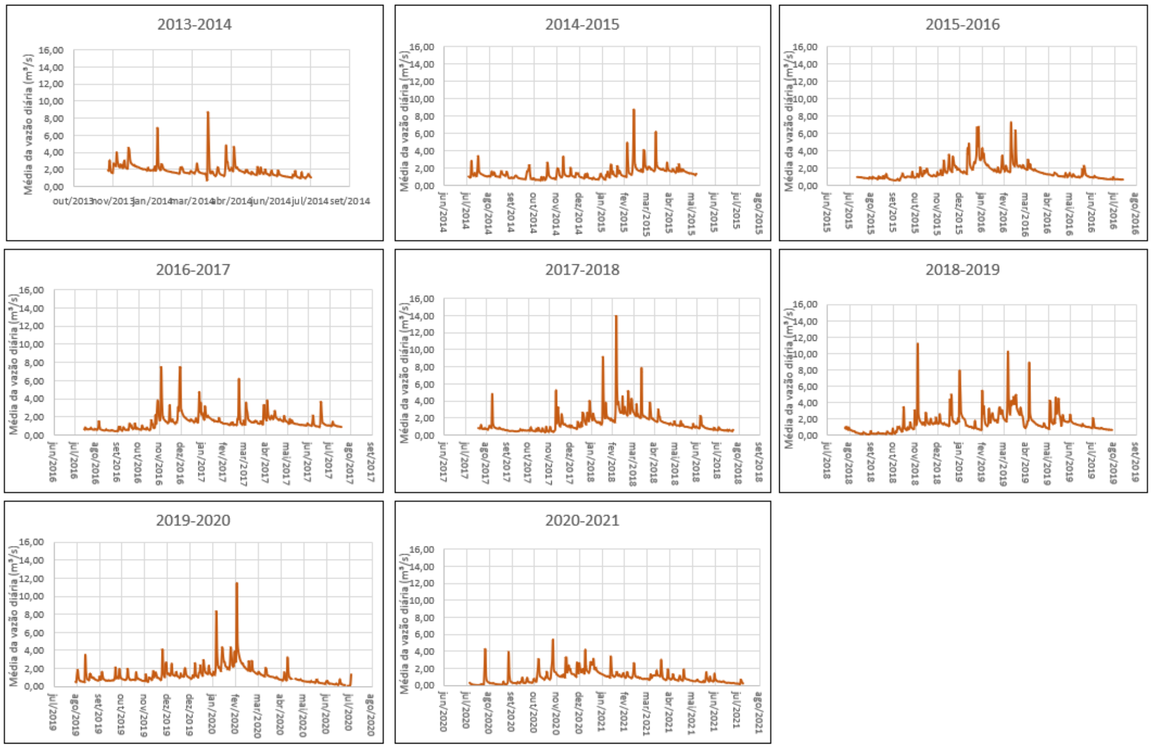
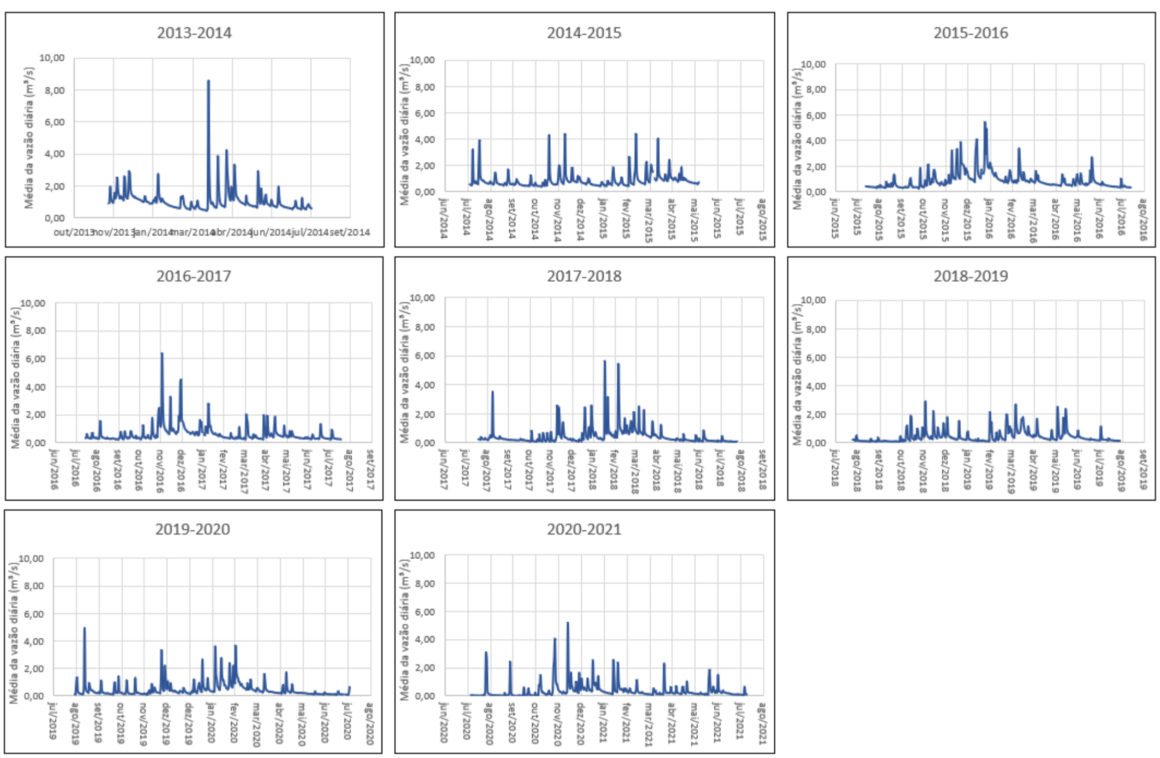
APPENDIX

1. HYDROGRAMS BY HYDROLOGICAL YEAR

HIDROGRAMAS - área de intervenção (Papudos)

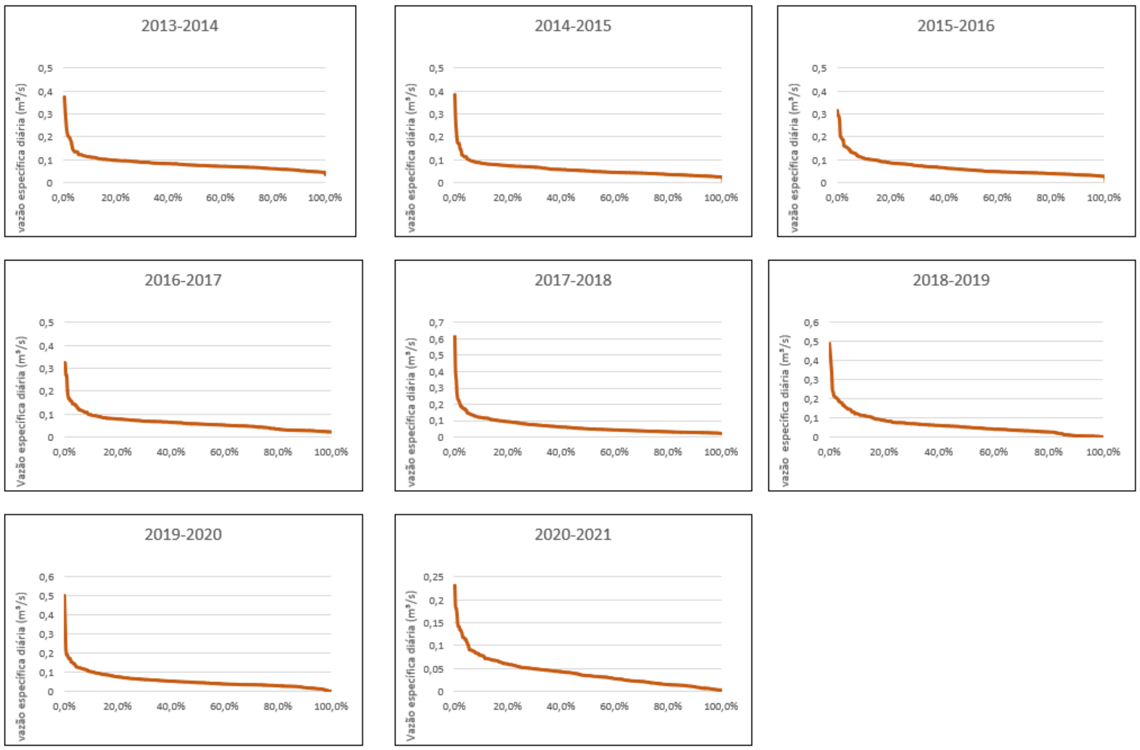


HIDROGRAMAS - área de referência (Sambaíba RPPN)

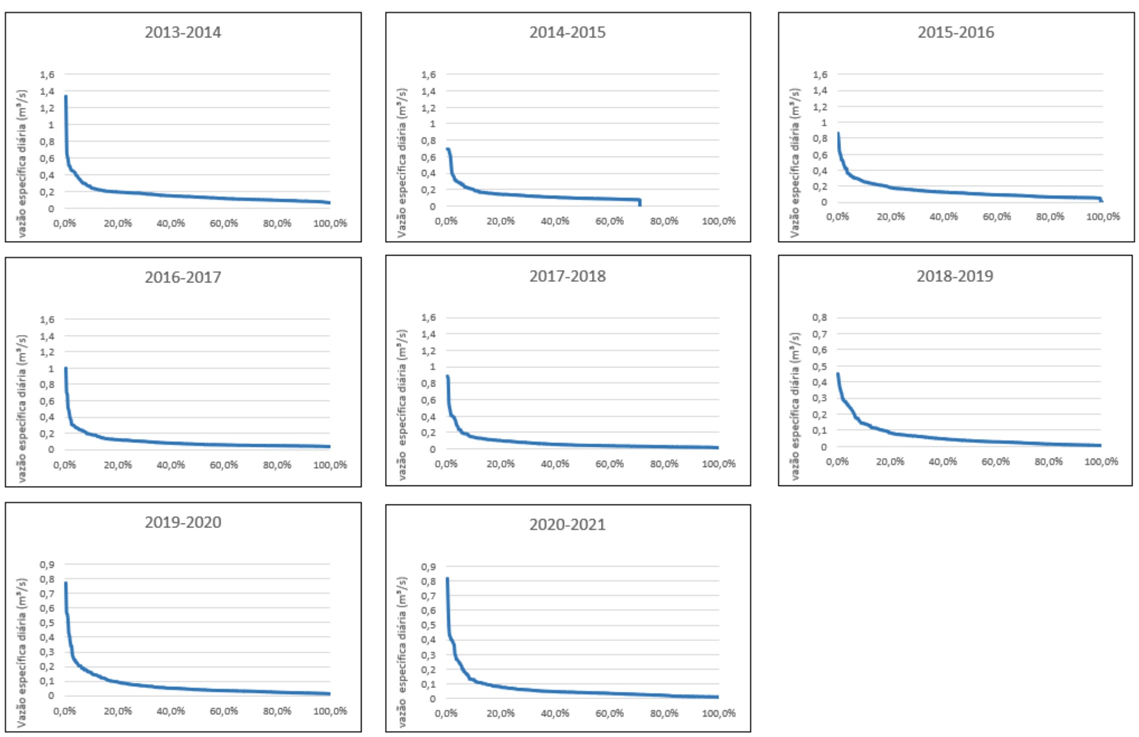


2. EXCESS/PERMANENCE CURVES

CURVAS DE PERMANÊNCIA - área de intervenção (Papudos)



CURVAS DE PERMANÊNCIA - área de referência (Sambaíba RPPN)



3. RATING CURVES – LEVEL X DISCHARGE