

Impact of sand mining: A case study of initial growth of forest species for recovery of degraded areas

Impacto de la extracción de arena:
Un estudio de caso del crecimiento inicial de especies forestales para la recuperación
de áreas degradadas

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SUMMARY

The Vale do Ribeira region has a large extension of Brazilian Atlantic Forest, and in most cities, low environmental impact activities predominate, such as sand mining. Sand mining has been trying to adapt their industrial activities to low environmental impact, aiming at the protection of permanent preservation areas (PPAs) of riparian forests. The objective of this work was to conduct a case study focused on monitoring and initial growth of forest species by 18 months. This study was performed in a riparian forest site on the Ribeira de Iguape River, Registro, state of São Paulo, Brazil, in a PPA with extraction of river bed sand. Forest species height, stem diameter and mortality index, and rainfall were evaluated in the period. Non-pioneer species accounted for 42.7 % of the forest, while pioneer species accounted for 53.1 %. These proportions are in accordance with local legislation, which establishes a lower limit of 40 % in planting for both groups. Drought periods and leaf-cutting ants at the beginning of growth stages contributed to a higher mortality index and irregular development of some species, however, even during such adversities, forest species indicated resistance to these conditions. Pioneer species had more important development, with emphasis on *Senna multijuga*, *Alchornea triplinervia*, *Citharexylum myrianthum* and *Trema micranta*, these species must be taken into consideration during the first stages of a project which aims at recovering degraded areas in riparian forests of Atlantic Forest.

Key words: permanent preservation areas, land restoration, Ribeira de Iguape River.

RESUMEN

La región de Vale do Ribeira tiene una gran extensión de selva Atlántica brasileña, y en la mayoría de las ciudades predominan las actividades de bajo impacto ambiental, como la minería de arena de río. La extracción de arena ha estado tratando de adecuar sus actividades con menor impacto ambiental, apuntando a la protección de áreas de preservación permanente (APP). El objetivo fue realizar un estudio de caso con enfoque en el monitoreo y crecimiento inicial de especies forestales hasta 18 meses. Este estudio se realizó en un bosque ribereño del río Ribeira de Iguape, municipalidad de Registro, estado de São Paulo, Brasil, en una APP con extracción de arena de lecho de río. Se evaluó la altura de las especies forestales, el diámetro del tallo, el índice de mortalidad y la precipitación en el período. Las especies no pioneras tuvieron una proporción del 42,7 % del total y las pioneras el 53,1 %; las proporciones están de acuerdo con la ley local. Los períodos de sequía y las hormigas cortadoras de hojas al inicio del crecimiento de las especies contribuyeron para o mayor índice de mortalidad y al desarrollo irregular de algunas especies, sin embargo, incluso las adversidades, las especies forestales indican resistencia en estas condiciones. Las especies pioneras tuvieron mayores desarrollos, con énfasis en *Senna multijuga*, *Alchornea triplinervia*, *Citharexylum myrianthum* y *Trema micranta*. Estas especies deben ser tomadas en consideración al inicio del proyecto de recuperación de área degradada en bosque ribereño de selva atlántica.

Palabras clave: áreas de preservación permanente, restauración de tierras, río Ribeira de Iguape.

INTRODUCTION

The Atlantic Forest is one of the main biomes in Brazil and is highly important for biodiversity, soil and water

conservation (Skorupa *et al.* 2012, Thomazini *et al.* 2015). Among the characteristics of this biome, the forest formation is heterogeneous, extending from tropical to subtropical regions of Brazil (Lima *et al.* 2014). Several authors have

studied forest fragments (Ribeiro *et al.* 2009, Esposito *et al.* 2018), and many forest areas are in extremely degraded conditions, thus, forest recovery should be an instrument to mitigate this situation (Costa *et al.* 2019). Sustainable management practices are instruments that may be used to long-term recovery of these forests, which are mainly focused on planting a community of native species of the Atlantic Forest biome (Hatfield *et al.* 2018, Pastório *et al.* 2020).

In Brazil, the forest formations located on the banks of rivers, lakes, water springs and hilltops are called riparian forests (Suganuma and Durigan 2014). These forests are included in the category of permanent preservation areas (Nunes *et al.* 2020), and their importance is due to the maintenance of water quality, soil stability, regularization of hydrological alteration and stabilization of riverbanks, avoiding siltation and soil erosion (Holanda *et al.* 2010, Keram *et al.* 2019). The riparian forests are established as forest formations to be conserved or recovered, therefore, to avoid degradation, planning and strategies are priorities for the preservation of riparian zones (Webb and Erskine 2003, Iori *et al.* 2019).

For a successful recovery of riparian lands, the chosen forest species should be adapted for their local environment, including characteristics as drought tolerance, deep root system, vigorous growth, survival in conditions of low fertility and effectiveness in soil cover (Silva *et al.* 2018, Nunes *et al.* 2020). The lack of knowledge of the environmental impacts caused by riparian forest exploitation puts at risk the sustainability of land and water resources in Ribeira de Iguape river basin (Iori *et al.* 2012), and although the agricultural use of permanent preservation areas is prohibited, a part of these areas has been used for agriculture and sand extraction in river beds (Soares-Filho *et al.* 2014, Marçal *et al.* 2017).

The Ribeira de Iguape River is located between southern São Paulo State and eastern Paraná State, comprising approximately 470 km. It is considered the longest river without dams in the state of São Paulo (SIGRB, 2020). The Vale do Ribeira Region has large biodiversity and there is also the estuary-lagoon complex Cananéia-Iguape, a region of rich biological diversity (SOS Mata Atlântica/INPE 2018). Due to its important biodiversity, studies are needed to provide information on the degradation status of protected areas in this fragment of the Atlantic forest (Prado *et al.* 2019, Dalmaso *et al.* 2020). Currently, sand extraction in riverbeds is an industrial process that has been increasing in the Vale do Ribeira Region (SOS Mata Atlântica/INPE 2018), and the industrial activity is called sand mining. The activity is an anthropogenic action that causes drastic disturbances in the ecosystem, and rebuilding a soil profile is one of the main tasks for successful recovery (Bradshaw and Hüttl 2001). The effects and impacts of sand mining on the riparian forest are understudied in Brazilian Atlantic Forest (Boëchat *et al.* 2013) and evaluating the influences of sand extraction from the river bed on the growth of forest species can contribute to the

recovery of a riparian forest (Seitz *et al.* 2019, Qin *et al.* 2020). Sand extraction in the riverbed can alter river flow, inhibiting the growth of forest species. Moreover, during the extraction process, large amounts of water and sand are captured and released, this action, combined with the hydrodynamics of the river, can become critical in periods of flood and increase erosion in soils under riparian forests (Souza *et al.* 2001).

The objective of this work is to evaluate the relationship between the initial growth of forest species and the impact of sand mining in a permanent preservation area in the recovery process, taking into consideration aspects of plant classification and mortality index of forest species. We hope to contribute to the recommendation of best management practices in recovery areas of riparian forest by answering the following questions: Can sand mining influence the initial growth of forest species in degraded areas of riparian forest in the process of recovery? What are the best forest species to be implemented in future projects for the recovery of degraded areas in the Atlantic Forest?

METHODS

Study area. The study was performed in Registro, state of São Paulo, Brazil (24°30'16.85" S, 47°48'18.47" W, 7 m altitude) in a riparian zone in the process of forest recovery. The regional climate is classified as Cfa - humid subtropical (Köppen) with average annual rainfall of 1,700 mm, which is mostly concentrated between December and March (Iori *et al.* 2019).

The study area was pasture until 2009 and was characterized by permanent preservation areas deforestation caused by anthropic action over the years. The sand mining company Pirâmide Extração e Comércio de Areia Ltda. acquired the area in 2010 and started planting forest species in March 2014. The total area of riparian forest has 1.55 ha, from which 0.10 ha was considered in this study, thus, nine plots were delimited, each plot delimited by 2 planting lines of forest species and in each line nine species were planted, with the spacing of 2.5 m x 2.0 m (figure 1).

The monitoring of forest species started in May 2014, two months after the planting of the last recovery stage in the permanent preservation areas and the monitoring occurred until the 18th month.

Plant classification and chemical soil analyses. All forest species were identified (table 1), classified by family, species, successional group and seed dispersal syndrome (Barbosa *et al.* 2017). A total of 143 individuals from 24 different forest species were classified and evaluated over 18 months. Morphological attributes of the forest species were measured, such as species height and stem diameter, assessed by using a measuring tape and a caliper. During measurements, the mortality and pest incidence indexes were evaluated.

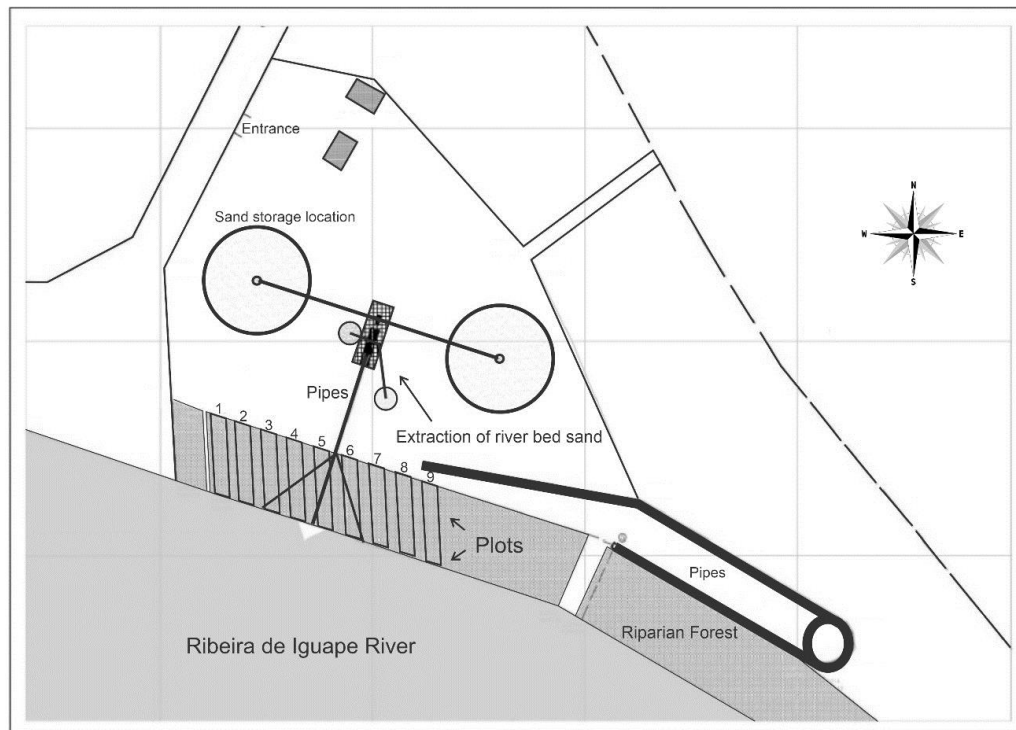


Figure 1. Area of the riparian forest (PPA) with extraction of riverbed sand, plots 1, 2, 3, 4, 5, 6, 7, 8 and 9 were monitored and evaluated until the 18th month.

Ubicación del área del bosque ribereño (APP) con extracción de arena de lecho de río, se monitorearon y evaluaron las parcelas 1, 2, 3, 4, 5, 6, 7, 8 y 9 hasta el mes 18.

For soil analyses, samples were collected in the 0-20 cm-deep layer, at the beginning of the experiment. The chemical attributes of the soil were performed according to the methodology recommended by Brazilian Agricultural Research Corporation (EMBRAPA 2017). The sum of bases had the following order of concentration: $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ (table 2). For the pH value (CaCl_2) in the layer 0-20 cm deep, the soil was slightly acidified (5.4). Overall organic matter was 3.2 %, the riparian soil had a low concentration of nutrients, which was already expected for an area without chemical fertilizers.

Statistical analyses. Sixteen forest species were selected for statistical analyses of height and stem diameter, eight species from the successional group of pioneers: (*Cecropia pachystachya*, *Schinus terebinthifolius*, *Cyatharexylum myrianthum*, *Senna multijuga*, *Alchornea triplinervia*, *Trema micranta*, *Jacaranda caroba*, *Tibouchina mutabilis*) and eight species from the successional group of non-pioneers: (*Ocotea corymbosa*, *Daphnopsis fasciculata*, *Matayba elaeagnoides*, *Clitoria falcata*, *Anadenanthera colubrina*, *Eugenia pyriformes*, *Tabebuia umbellata*, *Ficus guaranitica*). Analyses of variance and Scott-Knott's test ($P < 0.05$) for average comparisons were performed, using the SISVAR 5.6 software (Ferreira 2011).

RESULTS

Diversity of forest species. In total, 143 individuals from 24 different forest species were identified and registered in the study area, among pioneer and non-pioneer species. It is observed that 95.8 % of the total forest individuals are native species of the Atlantic forest (table 3).

The percentage of pioneer species identified were 53.1 % and non-pioneer species were 42.7 % and that of the 143 forest individuals, whereas 113 were classified as zoochorous species, that is 79 %.

Mortality index of forest species. The mortality of forest species was caused by three reasons: Flooding in the area, drought period and attack by leaf-cutting ants (table 4).

For one month, flooding was observed in three plots (6, 7 and 8) due to a work in the pipes of the extraction of riverbed sand. The pipes showed leakage from river water, which was driven by hydraulic pumps to the sand storage location. In this stretch, less development and a higher mortality index of forest species were observed.

The atypical rainfall in the region during the months of monitoring was another factor that contributed to the mortality index of forest species. The area presented months with very high rainfall and above the monthly average and

Table 1. Identification of 24 forest species monitored in the riparian forest area over 18 months.
 Identificación de 24 especies forestales monitoreadas en el área de bosque ribereño durante 18 meses.

Forest species	Family	SG	DS	NI
<i>Alchornea triplinervia</i> (Spreng.) Müll. Arg.	Euphorbiaceae	P	Zoochorous	5
<i>Anadenanthera colubrina</i> (Vell.) Brenan	Fabaceae	NP	Autochorous	14
<i>Cecropia pachystachya</i> Trécul.	Urticaceae	P	Zoochorous	5
<i>Citharexylum myrianthum</i> Cham.	Verbenaceae	P	Zoochorous	11
<i>Clitoria falcata</i> Lam.	Fabaceae	NP	Autochorous	7
<i>Daphnopsis fasciculata</i> (Meisn.) Nevling	Thymelaeaceae	NP	Zoochorous	5
<i>Erythrina falcata</i> Benth.	Fabaceae	NP	Zoochorous	3
<i>Eugenia pyriformes</i> Cambess.	Myrtaceae	NP	Zoochorous	5
<i>Ficus guaranitica</i> Chodat	Moraceae	NP	Zoochorous	5
<i>Gaylussacia brasiliensis</i> (Spreng.) Meisn.	Ericaceae	P	Zoochorous	5
<i>Inga vera</i> subsp. <i>affinis</i> (DC.) T.D.Penn.	Fabaceae	P	Zoochorous	16
<i>Jacaranda caroba</i> (Vell.) DC.	Bignoniaceae	P	Anemochorous	9
<i>Leucaena leucocephala</i> (Lam.) de Wit	Fabaceae	E	Autochorous	2
<i>Matayba elaeagnoides</i> Radlk.	Sapindaceae	NP	Zoochorous	9
<i>Miconia ligustroides</i> (DC.) Naudin	Melastomataceae	NP	Zoochorous	4
<i>Morus nigra</i> L.	Moraceae	E	Zoochorous	1
<i>Ocotea corymbosa</i> (Meisn.) Mez	Lauraceae	NP	Zoochorous	3
<i>Schinus terebinthifolius</i> Raddi.	Anacardiaceae	P	Zoochorous	7
<i>Senna multijuga</i> (Rich.) H. S. Irwin et Barneby	Fabaceae	P	Autochorous	7
<i>Syagrus romanzoffiana</i> Cham.	Arecaceae	NP	Zoochorous	4
<i>Syzygium jambos</i> (L.) Alston	Myrtaceae	E	Zoochorous	3
<i>Tabebuia umbellata</i> (Sond.) Mattos.	Bignoniaceae	NP	Anemochorous	2
<i>Tibouchina mutabilis</i> (Vell.) Cogn.	Melastomataceae	P	Zoochorous	4
<i>Trema micranta</i> (L.) Blume.	Cannabaceae	P	Zoochorous	7

Legend: SG = Successional Group; DS = Dispersal Syndrome; P = Pioneer Species; NP = Non-pioneer Species; E = Exotic; NI = Number of Individuals.

Table 2. Chemical property of soil samples from the riparian forest at depth 0-0.20 m.
 Propiedad química de muestras de suelo del bosque ribereño a una profundidad de 0-0,20 m.

pH	OM	P resin	Al ³⁺	H+Al	K ⁺	Ca ²⁺	Mg ²⁺	SB	CEC	BS
CaCl ₂	g dm ⁻³	mg dm ⁻³	-----mmol _c dm ⁻³ -----					--%--		
5.4	32	22	-	31	2.2	22	14	38.2	69	55

Legend: OM = Organic Matter; SB = Sum of Bases; CEC = Cation Exchange Capacity; BS = Base Saturation.

other months of low rainfall, with the forest species *Syagrus romanzoffiana*, being the most sensitive to drought. The mortality index of this species was the highest (50 %), along with *Gaylussacia brasiliensis*; the high mortality index in the latter was caused by leaf-cutting ants.

The attack by ants was one of the main reasons for the increase in mortality of forest species. The species most attacked by ants were from the group of non-pioneer species. Some forest species resisted the attacks by the insects, but some did not resist and died, however, in most of them, the forest species attacked by ants resisted and sprouted, developing satisfactorily throughout the evaluated period.

Table 3. Percentage of native, exotic, pioneer, non-pioneer, zoochorous forest species, and mortality index about the total number of individuals in the riparian forest area over 18 months of monitoring.

Porcentaje de especies forestales nativas, exóticas, pioneras, no pioneras, zoocorosas e índice de mortalidad sobre el número total de individuos en el área de bosque ribereño durante 18 meses de monitoreo.

	Number of individuals	Total percentage (%)
Total of individuals	143	100.0
Native species	137	95.8
Exotic species	6	4.2
Pioneer species	76	53.1
Non-pioneer species	61	42.7
Zoochorous species	113	79.0

Development of pioneer and non-pioneer forest species. In general, the species of riparian forest developed satisfactorily, with good performance in the initial growth, even under some adversities. Some forest species showed a high standard deviation due to a high mortality index or a severe attack by leaf-cutting ants or flooding in the area. However, 16 forest species had similar development and were used for the statistical analysis of the initial growth. The average height and average stem diameter of 8 pioneer forest species and 8 non-pioneer forest species were measured from the 2nd to the 18th month, and therefore the Scott-Knott's test was applied to verify the level of significance of the species (tables 5 and 6).

Up to month 2, the eight pioneer species showed no significant difference, probably because of their initial fast-growth. After month 2, the species *Senna multijuga*, *Alchornea triplinervia* and *Trema micranta* had superior growth regarding the other species. Species such as *Cyathoxylum myrianthum* also developed more in the months 14 and 18.

By contrast, non-pioneer species had higher heterogeneity in development up to month 2, both for average height and for average stem diameter. From month 8, the species followed a more homogeneous tendency and had low variation in average height and average stem diameter. There was no significant difference among forest species because these species were adapted in the riparian forest area, therefore, pioneer species with fast growth already offered shade conditions for non-pioneer species to develop under suitable settings.

Pioneer and non-pioneer species had the highest mortality index. For example: *Inga vera*, *Daphnopsis fasciculata*, *Clitoria falcata* and *Gaylussacia brasiliensis* were the fo-

Table 4. Mortality index (%) for pioneer and non-pioneer forest species and the cause of mortality in the riparian forest area over 18 months of monitoring.

Lista de especies forestales pioneras y no pioneras que presentaron índice de mortalidad (%) y causa de mortalidad en el área de bosque ribereño durante 18 meses de monitoreo.

Forest species	Successional group	Number of individuals	Dead individuals	Mortality (%)	Cause of mortality
<i>Syagrus romanzoffiana</i>	NP	4	2	50.0	Drought
<i>Trema micranta</i>	P	7	1	14.3	Flooding
<i>Jacaranda caroba</i>	P	9	2	22.2	Flooding
<i>Inga vera</i>	P	16	3	18.8	Leaf-cutting ants
<i>Daphnopsis fasciculata</i>	NP	5	1	20.0	Leaf-cutting ants
<i>Matayba elaeagnoides</i>	NP	9	1	11.1	Flooding
<i>Clitoria falcata</i>	NP	7	2	28.6	Leaf-cutting ants
<i>Anadenanthera colubrina</i>	NP	14	4	28.6	Flooding
<i>Gaylussacia brasiliensis</i>	P	4	2	50.0	Leaf-cutting ants

Legend: P = Pioneer Species; NP = Non-pioneer Species.

Table 5. Average height and average stem diameter of eight pioneer forest species in the riparian forest area over 18 months of monitoring.

Altura promedio y diámetro promedio del tallo de ocho especies forestales pioneras en el área de bosque ribereño durante 18 meses de monitoreo.

Months	2	8	14	18	2	8	14	18
Species	Average height (cm)				Average stem diameter (mm)			
<i>Cecropia pachystachya</i>	66.4ns	86.0a	121.4a	192.0a	7.8ns	18ns	32.4a	42.6a
<i>Schinus terebinthifolius</i>	75.7ns	86.7a	114.6a	174.0a	7.0ns	14ns	28.2a	39.2a
<i>Cyatharexylum myrianthum</i>	80.4ns	82.3a	174.3b	222.8b	7.1ns	18ns	46.6b	59.6b
<i>Senna multijuga</i>	88.9ns	138.4b	230.7b	315.6b	10ns	34ns	66.9b	83.3b
<i>Alchornea triplinervia</i>	76.6ns	149.8b	219.8b	235.6b	9.6ns	33ns	69.8b	75.6b
<i>Trema micranta</i>	70.3ns	117.2b	136.0a	220.5b	7.5ns	24ns	48.8b	55.9b
<i>Jacaranda caroba</i>	52.0ns	60.8a	95.7a	116.5a	5.0ns	12ns	26.9a	30.3a
<i>Tibouchina mutabilis</i>	54.0ns	82.0a	104.0a	133.5a	6.3ns	17a	21.0a	28.5a

Average means followed by the same letter in the column are not significantly different by Scott-Knott's test ($P < 0.05$); ns = Not Significant.

Table 6. Average height and average stem diameter of eight non-pioneer forest species in the riparian forest area over 18 months of monitoring.

Altura promedio y diámetro promedio del tallo de ocho especies forestales no pioneras en el área de bosque ribereño durante 18 meses de monitoreo.

Months	2	8	14	18	2	8	14	18
Species	Average height (cm)				Average stem diameter (mm)			
<i>Ocotea corymbosa</i>	63.3a	73.3ns	112ns	150ns	6.1a	8.3a	19.9a	33.0a
<i>Daphnopsis fasciculata</i>	114b	133ns	180ns	204ns	13.6b	26.0c	50.4b	56.4b
<i>Matayba elaeagnoides</i>	74.6a	83.1ns	105ns	149ns	7.9a	13.5a	24.6a	29.5a
<i>Clitoria falcata</i>	91.2b	103ns	141ns	174ns	9.9b	17.4a	35.1a	46.2b
<i>Anadenanthera colubrina</i>	78.9a	100ns	172ns	190ns	7.1a	12.7a	24.9a	30.3a
<i>Eugenia pyriformes</i>	129b	132ns	173ns	135ns	10.9b	15.9a	23.0a	29.6a
<i>Tabebuia umbellata</i>	57.0a	100ns	159ns	216ns	5.7a	11.3a	27.0a	29.6a
<i>Ficus guaranitica</i>	40.3a	83.7ns	173ns	243ns	6.5a	19.3b	45.3b	54.0b

Average means followed by the same letter in the column are not significantly different by Scott-Knott's test ($P < 0.05$); ns = Not Significant.

rest species with the maximum attack by leaf-cutting ants. Even under attack by leaf-cutting ants, *Clitoria falcata* had one of the largest stem diameters at month 18. There was no statistical difference in the months 14 and 18 for average height, although *Daphnopsis fasciculata* and *Ficus guaranitica* had the highest mean for average stem diameter these months for the non-pioneers group. Moreover, *Daphnopsis fasciculata* was one of the species that had an attack by leaf-cutting ants at the beginning of development, which proves the high regenerative capacity of this forest species.

DISCUSSION

The percentage of pioneer and non-pioneer species were 53.1 % and 42.7 %, respectively. These values are in the percentage range found by other authors in reforestation studies in the Atlantic forest (Souza *et al.* 2012, Machado *et al.* 2013). Moura and Montavani (2017) found 42 % of non-pioneer species in areas of regeneration of the Atlantic forest and according to the São Paulo state legislation, SMA 32/2014, the total proportion of species from

the same successional group must not exceed 60 % (São Paulo 2014). In the area of this study, neither group exceeded this percentage. The biodiversity of forest species and the species distribution of both successional groups (pioneer and non-pioneer) are essential for the success of forest restoration projects in areas of the Atlantic Forest (Esposito *et al.* 2018).

The importance of zoochorous species needs to be highlighted, which is mainly linked to the enrichment of the region flora, increasing the presence of seed-dispersing animals (Reznik *et al.* 2012, Colmanetti *et al.* 2016). In degraded or recovering land, the planting of zoochorous species is particularly important due to the seed spread of forest species by wild animals when the forest is in an advanced stage of ecological succession (Sangsupan *et al.* 2018). In month 18 of monitoring, the presence of birds was observed because of the first fruiting of *Schinus terebinthifolius*. Table 5 shows that of the three pioneer forest species showing the fastest growth (height and stem diameter means), two species (*Alchornea triplinervia* and *Trema micranta*) have common morphophysiological characteristics, as they have seed dispersion syndrome classified as zoochorous. Zama *et al.* (2012) also observed that zoochorous forest species were important for advancing in the recovery of degraded areas and influenced the success of the Atlantic Forest.

The non-pioneer forest species had a more heterogeneous behavior, probably because the riparian forest was not in satisfactory conditions for the development of non-pioneer species since the pioneer species were also in an initial growth stage. Shadow is a key component for the growth of non-pioneer species (Piñarodrigues *et al.* 1997), nonetheless it was not achievable in the studied area as both groups were planted at the same time. Moreover, these species were classified in the same group (non-pioneer), however, initial secondary species, late-stage species and climax species are in this group, hence it was naturally more heterogeneous than the group of pioneer species (Pontes *et al.* 2019).

For the chemical analysis of soil, the values were in the slightly acidic range. Thomazini *et al.* (2015) found pH values (CaCl_2) between 4.6 and 4.7 in Atlantic forest areas in Brazil, and other authors also identified pH in the acidic range, showing that Atlantic forest soils are naturally acidic (Pinheiro *et al.* 2004, Marques *et al.* 2015). The importance of soil pH is associated with plants absorption of nutrients from the soil solution and with its significance as indicator of soil chemical conditions, as it can influence the chemical disposition of various nutrients in plant development, changing nutrient availability for the plant (Brandão and Lima 2002).

Higher concentrations of Ca^{2+} and Mg^{2+} compared to K^+ are also reported by Souza *et al.* (2001) in the Atlantic Forest in the state of Minas Gerais, Brazil. In the soil-plant system, K^+ is one of the most leached nutrients, not being part of any organic compound, therefore, among the main nutrients, it is the one with the biggest leaching loss

(Marques *et al.* 2015, Zanon *et al.* 2020). Although Ca^{2+} and Mg^{2+} have structural functions in plant tissues, Ca^{2+} is found in a higher rate in the sum of bases due to the low mobility of this nutrient, furthermore, Ca^{2+} is the main element of the cell wall, including leaf, bole and roots; therefore, the fall of these parts of the species contributes to the supply and cycling of this nutrient.

Three factors were the causes of the mortality of species in the riparian forest, and the flooding of three plots (6, 7, and 8) was the one with the highest index. Keram *et al.* (2019) studied the hydrological dynamics of the river and the implications for reforestation of riparian forest, and they observed that the survival of forest species in wetlands varies according to the species. In our study, mortality occurred mainly in non-pioneer species (table 4). This group has a slower growth compared to pioneer species, being more demanding in water and nutrients (Esposito *et al.* 2018), however, excess water was very harmful. The physiological factor of this group presents morphoclimatic characteristics more susceptible than those presented by pioneer species (Brandão *et al.* 2017); besides, non-pioneer species were implanted in larger proportion, which contributed to the higher proportion in the mortality index of forest species.

The attack by leaf-cutting ants was another serious mortality problem in the riparian forest, however, in general, the forest species had an efficient regeneration. Xavier *et al.* (2019) also had problems with leaf-cutting ants in forest planting, the authors suggested the introduction of forest species diversity to minimize the impacts of ants in highly degraded ecosystems. However, several authors have found positive effects of ants for the transport of nutrients in forest soil (Madureira *et al.* 2013, Almeida *et al.* 2019), thus the extermination of ants is not the best option to eliminate the problem (Alvarez-Loayza and Terborgh 2011), rather a solution may be to carry out effective management with biological control (Roos *et al.* 2011), as some species of ants, even the leaf-cutting, have a fundamental role in improving soil fertility (Farji-Brener and Werenkraut 2017).

CONCLUSIONS

Sand mining in the river bed has altered the initial growth of forest species in riparian forest areas of the Atlantic Forest, however, the effects were mitigated by the implementation of adequate proportions of non-pioneer and pioneer forest species (42.7 % and 53.1 %). Furthermore, forest species had a low mortality index due to drought and flooding tolerance and regeneration by leaf-cutting ants.

The forest species with the highest average height and average stem diameter during initial growth were: *Senna multijuga*, *Alchornea triplinervia*, *Citharexylum myrianthum* and *Trema micranta*. All pioneer species, therefore, are the most suitable to be implemented at initiation of a project to recovery of degraded area in riparian forest of Atlantic Forest.

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