PASSIVE RESTORATION OF MIXED OMBROPHILOUS FOREST A DECADE AFTER FOREST PLANTATION REMOVAL IN THE SOUTH OF BRAZIL

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Abstract

The objective of this study was to evaluate the floristic composition, diversity and ecological characteristics of riparian forest tree species under passive restoration a decade after removing *Pinus* and *Eucalyptus* genus forest plantations and comparing the data to a reference ecosystem. The study was conducted in a Mixed Ombrophilous Forest fragment in the municipality of Ponte Alta, state of Santa Catarina, Brazil. A total of 30 plots of 200 m² were installed, 15 in the area under passive restoration and 15 in the reference ecosystem, covering the arboreal and regenerating strata. In these areas, rarefied richness, Shannon index, Pielou evenness, floristic dissimilarity, ecological group representativeness and the tree species dispersal syndromes were evaluated. The families with the highest specific richness were: Myrtaceae (14 species) in the reference ecosystem, and Lauraceae (eight species) in the area under passive restoration. Considering the ecological indicators used and the use of the reference ecosystem, it can be considered that the passive restoration after a decade in forest succession proved to be efficient for enlarging the riparian forests in the studied area.
Keywords: Riparian forest, environmental monitoring, reference ecosystem.

Resumo

Restauração passiva de Floresta Ombrófila Mista após década da retirada de plantios florestais no sul do Brasil. Objetivou-se avaliar a composição florística, diversidade e características ecológicas das espécies arbóreas de matas ciliares em restauração passiva, após uma década da retirada de plantios florestais dos gêneros *Pinus* e *Eucalyptus*, comparando os dados a um ecossistema de referência. O estudo foi conduzido em um fragmento de Floresta Ombrófila Mista, no município de Ponte Alta, Santa Catarina, Brasil. Foram instaladas 30 parcelas de 200 m², sendo 15 na área em restauração passiva e 15 no ecossistema de referência, abrangendo os estratos arbóreo e regenerante. Nessas áreas, foram avaliados a riqueza rarefeita, índice de Shannon, equabilidade de Pielou, dissimilaridade florística, e representatividade dos grupos ecológicos e das síndromes de dispersão das espécies arbóreas. As famílias com maiores riquezas específica foram: Myrtaceae (14 espécies) no ecossistema de referência e Lauraceae (oito espécies) na área em restauração passiva. Considerando os indicadores ecológicos utilizados e o uso do ecossistema de referência, pode-se considerar que, após uma década em sucessão florestal, a restauração passiva mostrou-se eficiente para a ampliação das matas ciliares na área estudada.
Palavras-chave: Matas ciliares, monitoramento ambiental, ecossistema de referência.

INTRODUCTION

Passive restoration can be described as a technique that recommends a low level of human intervention in the environment, mainly relying on the function of restoring the ecosystem to natural processes and to successional dynamics before suspending or eliminating degradation sources (LETCHER; CHAZDON, 2009; SUDING; HOBBS 2009; REIS *et al*., 2014). It is considered a viable methodological alternative due to its low cost and high efficiency in sites with fast natural regeneration, generally linked to a scenario with a landscape matrix having connectivity (RODRIGUES *et al*., 2015).

The presence of adjacent forest fragments is essential, since even in secondary formation these are responsible for ensuring propagule sources, as well as the presence and quantity of dispersing agents, which consequently promote species recruitment (CIELO-FILHO; SOUZA, 2016). Over time, it is possible to establish functional connectivity and gene flow between the adjacent fragments and the sites to be restored

(LETCHER; CHAZDON, 2009), thereby providing the re-establishment of a series of processes of the system as a whole and generating a diversity of natural flows (SUDING; HOBBS, 2009; REIS *et al*., 2014).

Passive restoration is the most used method for recovering anthropized environments throughout the world (MELI *et al*., 2017). In the Mixed Ombrophilous Forest this methodology is able to reincorporate high species richness in areas previously occupied by forest plantations, spontaneously promoting the return of ecological interactions of plant and animal communities in the ecosystem (FERREIRA *et al*., 2012; FERRACIN *et al*. 2013; SCARIOT *et al*., 2014).

The evaluation of fragments in the secondary stage, called ecological reference, in the same landscape matrix, enables conducting comparative studies with the sites to be restored (RUSCHEL *et al*. 2009; SUGANUMA *et al*., 2013), in addition to making it possible to obtain ecological reference variables, called ecological indicators according to Rodrigues *et al*. (2015). Among the reference variables, we highlight species composition, associated dispersion syndromes, ecological groups, forest structure and species diversity (SCHORN *et al*. 2013; FERRACIN *et al*. 2013; CIELO-FILHO; SOUZA, 2016).

In Brazil, conducting passive restoration along with its guidelines described in Resolution No. 429 of CONAMA (2011) are indicated for riparian forest restoration. On the one hand, Schorn *et al*. (2013) consider that a tested and efficient methodology for restoring riparian forests in the Mixed Ombrophilous Forest as non-existent. On the other hand, pioneering studies guide the use of forest succession (passive restoration) in riparian forests used in the past with silvicultural activities, and show the potential of this methodology (REIS *et al*., 2007; FERREIRA *et al*., 2012; SCARIOT *et al*., 2014).

The objective of this study was to evaluate the floristic composition, diversity and ecological characteristics of riparian forest tree species under passive restoration a decade after removing forest plantations (species of the *Eucalyptus* and *Pinus* genus). Posteriorly, comparing them to a reference ecosystem and answer the following questions: (1) Do the sites under passive restoration in Mixed Ombrophilous Forest present similar tree floristic composition and species diversity to the reference ecosystem? (2) Is there species incorporation of more advanced successional stages in the regenerating stratum of the restoration area in comparison to the arboreal stratum?

MATERIAL AND METHODS

It has a mean altitude of 880 m and a humid subtropical mesothermic Cfb climate (Köppen-Geiger classification), with an average temperature of the hottest months below 22 ºC, and annual precipitation around 1,600 to 1,900 mm (ALVARES *et al*., 2014). The soil is Cambisol Haplic with a clayey texture (EMBRAPA, 2013) and undulated relief to smooth undulation (FERREIRA *et al*., 2012). The study area is composed of two riparian forest environments, namely: sector one (S1) - ecological reference with 176 ha; and sector two (S2) - forest under passive restoration of 88 ha.

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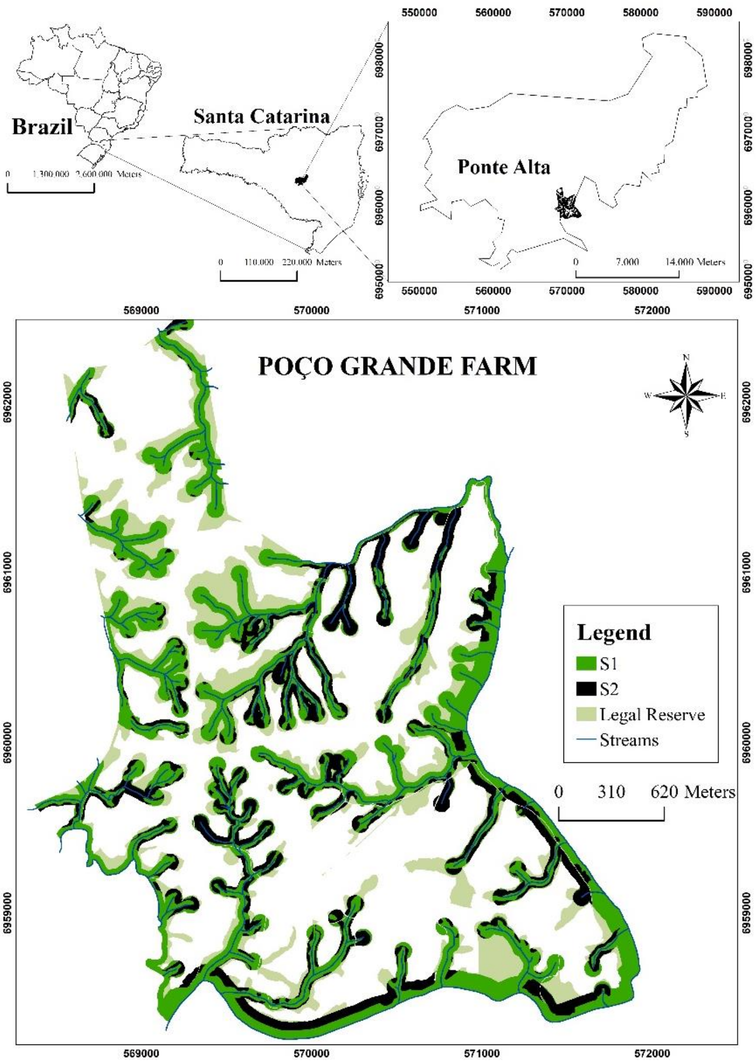

Figure 1. Map of the study area and evaluated sectors (S1 - reference ecosystem and S2 - passive restoration), at the silvicultural Poço Grande Farm, municipality of Ponte Alta, state of Santa Catarina, Brazil.

Figura 1. Mapa da área de estudo e setores avaliados (S1 – ecossistema de referência e S2 – restauração passiva), na fazenda silvícola Poço Grande, município de Ponte Alta, Santa Catarina, Brasil.

Historically, S1 sector areas have undergone selective logging cycles, which has not happened for approximately 40 years. In the S2 sector, native vegetation cover was replaced by plantations with commercial forest species around 1965, mainly *Pinus* and (less expressive) *Eucalyptus*. In order to promote riparian forest expansion, commercial species were mechanically extracted and degradation sources (domestic animals and initial control of invasive species) were eliminated after two cultivation cycles. Since then, the vegetation has been under natural regeneration for at least ten years. Both sites were classified according to vegetation characteristics, land use maps and current and historical aerial photographs. In addition to the riparian forest environments, the property has 103 ha of Legal Reserve in different stages of succession.

For the study, 15 plots of 10 x 20 m (200 m²) were installed in each sector, and randomly distributed. Among them, ten comprised the arboreal stratum sample of each sector [individuals with circumference at breast height (CBH), measured at 1.30 m above ground level, ≥ 15.7 cm]. The regenerating stratum was evaluated in the other plots (individuals of tree species with height ≥ 10 and < 150 cm). In addition to the angiosperm and gymnosperm species, pteridophytes, which are commonly sampled in this phytophysiognomy, were included in both strata. We carried out species identification based on herbarium exsiccates, specialized literature and by consulting specialists, and the spelling of the scientific names is based on the List of species of Brazilian flora (FLORA DO BRASIL 2020; FLORA DO BRASIL, 2018). For young plants, the identifications were based on dendrological characteristics and on comparisons with a survey made on the same property by

Ferreira *et al*. (2012). The collections with reproductive structures were deposited in the Lages Herbarium of the State University of Santa Catarina (*LUSC*) and the non-reproductive collections (young plants) were stored in the Forest Ecology Laboratory of the State University of Santa Catarina.

To describe the ecological indicators, the species were classified into ecological groups (EG) according to Budowski (1965), and dispersion syndromes (DS) according to Van der Pijl (1972), through field observations, diaspore characteristics and consultations, especially by Reitz *et al*. (1978) and Giehl *et al*. (2007). Relative participation of species and individuals in the EG and DS was analyzed by the proportion test ($p \leq 0.05$) between sectors for each EG or DS in relation to the total sampled. The diversity in the strata of each sector was subsequently evaluated by the Shannon index (H'), evenness by the Pielou index (J'), and a comparison of the Shannon index was performed by the Hutcheson t-test.

The sample intensity was verified by the values obtained in the average curve of species accumulation using the permutational method as based on the species/area ratio. Standardized wealth estimation was determined using a rarefaction curve, allowing a comparison of wealth among the evaluated sectors.

We evaluated the existence of floristic-structural patterns by the Non-Metric Multidimensional Scaling (NMDS) method and by the Bray-Curtis index, followed by the STandardized REsidual Sum of Squares (STRESS) analysis value. Significant differences in the floristic-structural composition of the sectors for each stratum were subsequently verified using Permutational Multivariate Analysis of Variation (PERMANOVA). The R statistical program was used for these analyses (R DEVELOPMENT CORE TEAM, 2016).

RESULTS

A total of 89 species were sampled, constituents of the arboreal and regenerating strata belonging to 60 genera and 35 botanical families (Table 1). It was not possible to identify two individuals of the S1 sector tree stratum in this study.

Table 1. Floristic survey of the arboreal (ARB) and regenerating (REG) stratum, followed by abundance, sectors of reference ecosystem (S1) and passive restoration (S2), registered in the Herbarium Lages of the State University of Santa Catarina (RH), ecological group (EG), and dispersion syndrome (DS), sampled in riparian forests, Mixed Ombrophilous Forest, municipality of Ponte Alta, state of Santa Catarina, Southern Brazil.

Tabela 1. Florística do estrato arbóreo (ARB) e regenerante (REG), seguida da abundância, setores de referência ecológica (S1) e restauração passiva (S2), registro no Herbário Lages da Universidade do Estado de Santa Catarina (RH), grupo ecológico (GE) e síndrome de dispersão (SD), amostrada em matas ciliares, Floresta Ombrófila Mista, município de Ponte Alta, Santa Catarina, Brasil.

Family	Species	ARB		REG		RH	EG	DS
		S1	S2	S1	S2			
Anacardiaceae	*Schinus terebinthifolius* Raddi	2	-	-	1	8205	Is	Zoo
Annonaceae	*Annona rugulosa* (Schltdl.) H.Rainer	-	-	-	1	-	Is	Zoo
Aquifoliaceae	*Ilex dumosa* Reissek	-	-	-	1	-	Is	Zoo
	Ilex microdonta Reissek	-	-	-	2	-	Is	Zoo
	Ilex paraguariensis A. St. Hill.	8	4	74	18	8204	Pi	Zoo
	Ilex theezans Mart. ex Reissek	1	1	1	-	-	Is	Zoo
Araucariaceae	*Araucaria angustifolia* (Bertol.) Kuntze	1	-	1	2	8209	Pi	Zoo
Asteraceae	*Baccharis semiserrata* DC.	-	-	-	9	-	Pi	Ane
	Baccharis sp.	-	-	-	1	-	Pi	Ane
	Baccharis uncinella DC.	-	-	-	2	-	Pi	Ane
	Piptocarpha angustifolia Dusén ex Malme	6	34	-	4	8157	Pi	Ane
	Symphyopappus compressus (Gardner) B.L.Rob.	-	1	-	-	8176	Pi	Ane
	Vernonanthura discolor (Spreng.) H.Rob.	12	9	2	10	8203	Pi	Ane
Bignoniaceae	*Jacaranda puberula* Cham.	-	4	-	2	2678	Pi	Aut

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Stedille. L. I. B *et.al.*
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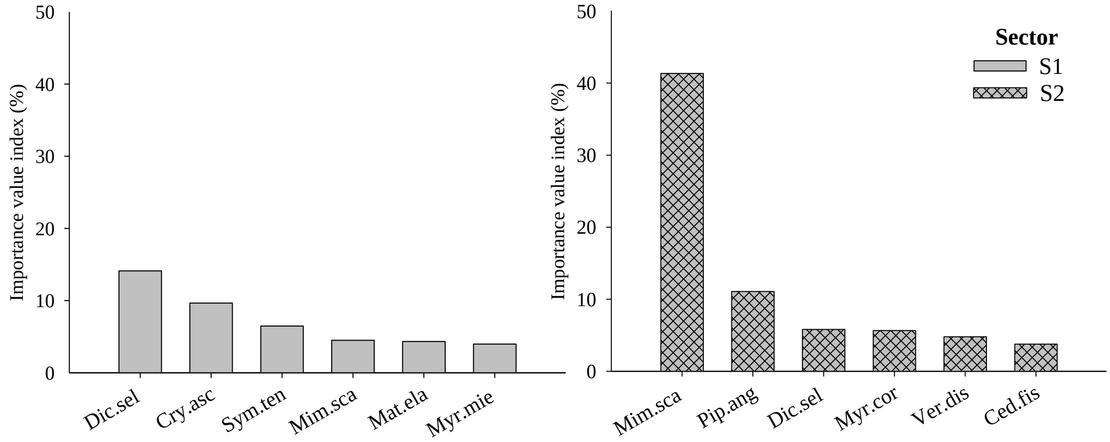
Canellaceae	*Cinnamodendron dinisii* Schwacke	-	-	1	1	-	Pi	Zoo
Cannabaceae	*Celtis iguanaea* (Jacq.) Sarg.	-	-	1	-	-	Is	Zoo
Cardiopteridaceae	*Citronella gongonha* (Mart.) R.A. Howard	-	-	3	-	-	Is	Zoo
Clethraceae	*Clethra scabra* Pers.	4	1	1	54	8202	Pi	Aut
Cunoniaceae	*Lamanonia ternata* Vell.	-	-	1	-	-	Is	Ane
	Weinmannia paulliniifolia Pohl ex Ser.	-	-	1	-	-	Is	Aut
Cyatheaceae	*Alsophila setosa* Kaulf.	2	1	-	-	8201	Cli	Ane
Dicksoniaceae	*Dicksonia sellowiana* Hook.	53	6	45	17	8208	Cl	Ane
Erytroxylaceae	*Erythroxylum deciduum* A.St.-Hil.	-	-	-	1	-	Is	Zoo
Euphorbiaceae	*Gymnanthes klotzschiana* Müll. Arg.	3	1	19	7	2689	Is	Aut
	Sapium glandulosum (L.) Morong	-	-	-	1	-	Is	Zoo
Fabaceae	*Dalbergia frutescens* (Vell.) Britton	1	-	28	1	-	Is	Ane
	Inga lentiscifolia Benth.	10	-	26	2	8199	Is	Zoo
	Machaerium paraguariense Hassl.	-	-	1	-	-	Is	Ane
	Mimosa scabrella Benth.	20	92	-	56	8156	Pi	Aut
	Muellera campestris (Mart. ex Benth.) M.J. Silva & A.M.G. Azevedo	-	-	2	-	-	Is	Ane
Lauraceae	*Cinnamomum amoenum* (Nees) Kosterm.	-	1	2	18	8196	Is	Zoo
	Cinnamomum glaziovii (Mez) Kosterm	-	1	-	-	8194	Cl	Zoo
	Cryptocarya aschersoniana Mez	13	-	5	-	8195	Ls	Zoo
	Ocotea puberula (Rich.) Nees	1	7	-	9	8165	Pi	Zoo
	Ocotea pulchella (Nees & Mart.) Mez	2	-	3	10	8164	Pi	Zoo
	Nectandra grandiflora Nees	-	-	-	3	-	Ls	Zoo
	Nectandra lanceolata Nees	4	1	-	-	-	Is	Zoo
	Nectandra megapotamica (Spreng.) Mez	-	-	2	1	2680	Is	Zoo
	Persea major (Meisn.) L.E.Kopp	-	-	2	2	-	Cl	Zoo
Malvaceae	*Luehea divaricata* Mart. & Zucc.	-	-	1	-	-	Is	Ane
Melastomataceae	*Miconia* sp.	-	-	1	-	-	Is	Zoo
Meliaceae	*Cedrela fissilis* Vell.	2	4	1	-	2681	Is	Ane
Myrtaceae	*Blepharocalyx salicifolius* (Kunth) O. Berg	-	-	5	-	-	Is	Zoo
	Calyptranthes concinna DC.	3	-	-	49	-	Is	Zoo
	Campomanesia rhombea O.Berg	-	-	13	-	-	Is	Zoo
	Campomanesia xanthocarpa Mart. ex O. Berg	1	-	3	-	2683	Is	Zoo
	Eugenia burkartiana (D.Legrand) D. Legrand	-	-	33	-	-	Ls	Zoo
	Eugenia pluriflora DC.	-	-	23	-	-	Is	Zoo
	Eugenia subterminalis DC.	1	-	-	-	8189	Is	Zoo
	Myrcia hatschbachii D.Legrand	1	-	-	-	-	Is	Zoo
	Myrcia oblongata DC.	-	-	1	-	-	Is	Zoo
	Myrcia palustris DC.	1	-	-	-	-	Is	Zoo
	Myrcia splendens (Sw.) DC.	1	2	11	2	8190	Is	Zoo
	Myrceugenia miersiana (Gardner) D. Legrand & Kausel	5	-	-	-	8192	Is	Zoo
	Myrceugenia myrcioides (Cambess.) O.Berg	11	-	89	-	8191	Cl	Zoo
	Myrciaria delicatula (DC.) O.Berg	-	-	6	-	-	Is	Zoo

Picramniaceae	*Picramnia parvifolia* Engl.	-	-	2	-	-	Is	Zoo
Pinaceae	*Pinus taeda* L.	-	2	-	3	8187	Pi	Ane
Primulaceae	*Myrsine coriacea* (Sw.) R. Br. ex Roem. & Schult.	11	14	1	21	8206	Pi	Zoo
	Myrsine umbellata Mart.	-	-	2	-	-	Is	Zoo
Proteaceae	*Roupala montana* Aubl.	-	1	1	-	-	Is	Ane
Rosaceae	*Prunus myrtifolia* (L.) Urb.	-	-	3	22	2697	Is	Zoo
Rubiaceae	*Coutarea hexandra* (Jacq.) K. Schum.	-	-	2	-	-	Is	Ane
Rutaceae	*Zanthoxylum rhoifolium* Lam.	-	-	1	-	-	Is	Zoo
Salicaceae	*Banara tomentosa* Clos	-	-	6	-	-	Ls	Zoo
	Casearia decandra Jacq.	2	1	51	1	8186	Is	Zoo
	Casearia obliqua Spreng.	1	-	8	-	-	Is	Zoo
Sapindaceae	*Allophylus edulis* (A.St.-Hil. *et al*.) Hieron. ex Niederl.	3	-	45	2	2699	Is	Zoo
	Allophylus guaraniticus (A. St.-Hil.) Radlk.	-	-	71	-	-	Ls	Zoo
	Cupania vernalis Cambess	3	-	-	-	8184	Ls	Zoo
	Matayba elaeagnoides Radlk.	11	3	81	28	8185	Is	Zoo
Solanaceae	*Aureliana fasciculata* (Vell.) Sendtn.	1	3	-	-	8183	Pi	Zoo
	Cestrum corymbosum Schltdl.	-	1	-	-	8210	Pi	Zoo
	Solanum sp.	-	-	1	-	-	Pi	Zoo
	Solanum pseudoquina A. St.Hill	-	2	-	-	8182	Pi	Zoo
	Solanum lacerdae Dusén	-	-	-	2	-	Pi	Zoo
	Solanum mauritianum Scop.	-	-	-	3	-	Is	Zoo
	Solanum variabile Mart.	1	4	-	23	2685	Is	Zoo
Styracaceae	*Styrax leprosus* Hook. & Arn.	1	-	14	7	8180	Is	Zoo
Symplocaceae	*Symplocos tenuifolia* Brand	43	1	-	-	8181	Is	Zoo
	Symplocos uniflora (Pohl) Benth.	-	-	1	-	-	Is	Zoo
Winteraceae	*Drimys brasiliensis* Miers	2	-	-	-	2687	Ls	Zoo

In which: Pi: pioneer; Is: initial secondary; Ls: late secondary; Cl: climax; Ane: anemochoric; Aut: autochoric; Zoo: zoochoric.

Figure 2 shows the species of highest importance value that compose the tree stratum for each sampled area.



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In which: S1: reference ecosystem; S2: passive restoration; Dic.sel: *Dicksonia sellowiana*; Cry.asc: *Cryptocarya aschersoniana*; Sym.ten: *Symplocos tenuifolia*; Mim.sca: *Mimosa scabrella*; Mat.ela: *Matayba elaeagnoides*; Myr.mie: *Myrceugenia miersiana*; Pip.ang: *Piptocarpha angustifolia*; Myr.cor: *Myrsine coriacea*; Ver.dis: *Vernonanthura discolor*; Ced.fis: *Cedrela fissilis.*

Figure 2. Importance value of the main representative species of the arboreal stratum in descending order for both evaluated sectors in a riparian Mixed Ombrophilous Forest, municipality of Ponte Alta, state of Santa Catarina, Southern Brazil.

Figura 2. Valor de importância das principais espécies representantes do estrato arbóreo em ordem decrescente para os dois setores avaliados, em uma mata ciliar da Floresta Ombrófila Mista, Ponte Alta, Santa Catarina, Brasil.

The comparisons of the ecological indicators between sectors and the sample intensity are presented in Table 2. The sample adequacy was achieved with adherence to the criterion proposed by Cain and Castro (1959) for both sectors and in both strata, where the increase of 10% in sample area did not surpass the inclusion of 10% of new species. Sample intensity values are presented in Table 2.

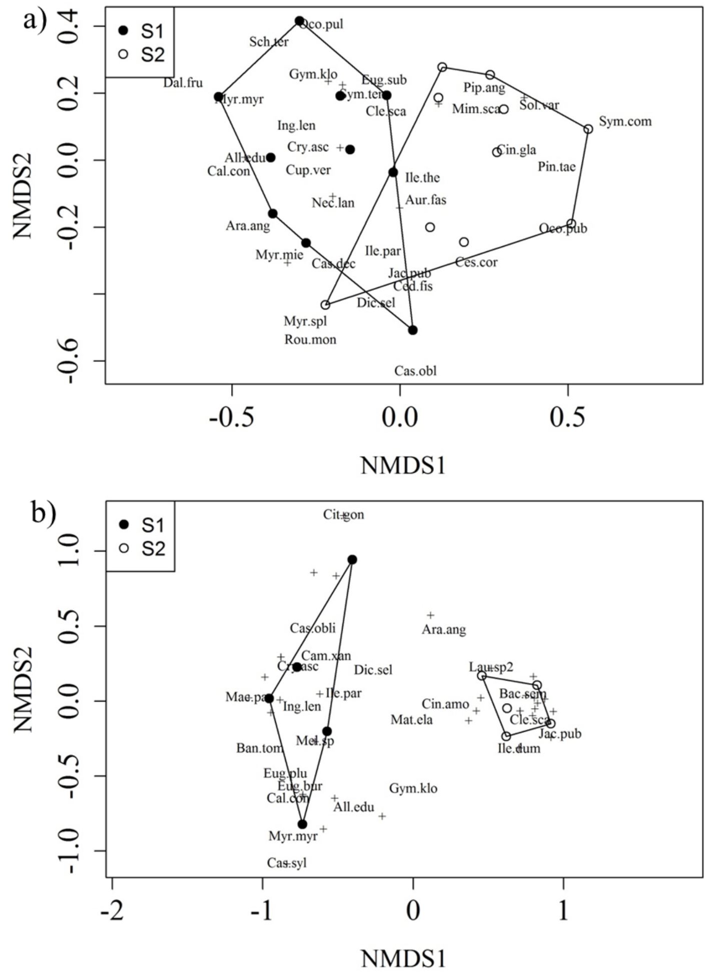
Table 2. Ecological indicators of a riparian Mixed Ombrophilous Forest, municipality of Ponte Alta, state of Santa Catarina, Southern Brazil.

Tabela 2. Indicadores ecológicos de uma mata ciliar, Floresta Ombrófila Mista, município de Ponte Alta, Santa Catarina, Brasil.

Ecological indicators	**S1**	**S2**	***p***
Species richness (Abundance of individuals) ARB	39 (250)	28 (202)	
Species richness (Abundance of individuals) REG	50 (698)	38 (399)	
Rarefied richness of ARB ± standard error*	37.64 ± 1.08	28.00 ± 0.00	
Rarefied richness of REG ± standard error*	35.66 ± 2.66	34.63 ± 2.10	
Shannon Index (nats ind^{-1}) ARB	2.86	2.09	<0.01[1]
Shannon Index (nats ind^{-1}) REG	2.99	2.91	ns[1]
Pielou Evenness - J’ ARB	0.78	0.63	
Pielou Evenness - J’ REG	0.76	0.80	
Ecological Group - individuals (% in relation to the total per sector) (the rest not significant) [2]			
Stratum ARB, **pioneer**	66 (26.6%)	174 (86.1%)	<0.01[2]
Stratum REG, **pioneer**	84 (11.2%)	204 (58.3%)	<0.01[2]
Stratum ARB, **initial secondary**	98 (39.5%)	20 (9.9%)	<0.01[2]
Stratum REG, **initial secondary**	412 (55.2%)	124 (35.4%)	<0.01[2]
Stratum ARB, **late secondary**	18 (7.3%)	0	<0.01[2]
Stratum REG, **late secondary**	115 (15.4%)	19 (5.4%)	<0.01[2]
Stratum ARB, **climax**	66 (26.6%)	8 (4.0%)	<0.01[2]
Stratum REG, **climax**	136 (18.2%)	3 (0.9%)	<0.01[2]
Ecological group – species (% in relation to the total per sector) (the rest not significant) [2]			
Stratum REG, **pioneer**	8 (16.0%)	16 (42.1%)	0.010[2]
Dispersion Syndrome - individuals (% in relation to the total per sector) (the rest not significant) [2]			
Stratum ARB, **zoochoric**	145 (58.5%)	46 (22.8%)	<0.01[2]
Stratum REG, **zoochoric**	642 (85.9%)	184 (52.6%)	<0.01[2]
Stratum ARB, **autochoric**	27 (10.9%)	98 (48.5%)	<0.01[2]
Stratum REG, **autochoric**	21 (2.8%)	119 (34.0%)	<0.01[2]
Dispersion Syndrome - species (% in relation to the total per sector) (the rest not significant) [2]			
Stratum REG, **zoochoric**	37 (74.0%)	26 (68.4%)	<0.01[2]
SAMPLE INTENSITY			
% ARB species with the addition of 10% of sample area	*3.61*	*5.46*	
% REG species with the addition of 10% of sample area	*5.60*	*5.34*	

In which: S1: reference ecosystem; S2: passive restoration; ARB: arboreal stratum; REG: regenerating stratum; *p:* test significance; ns: not significant; *: abundance limit for construction of the rarefaction curve of 205 individuals; [1]: Hutcheson t-test; [2]: test of proportions.

The floristic-structural dissimilarity was high among the sector plots, with significant floristic-structural distance and ratified by PERMANOVA ($p < 0.01$). Interpretation of results by NMDS is possible because STRESS values are less than 0.2.



In which: S1: reference ecosystem; S2: passive restoration; All.edu: *Allophylus edulis*; Ara.ang: *Araucaria angustifolia*; Aur.fas: *Aureliana fasciculata*; Bac.sem: *Baccharis semiserrata;* Ban.tom: *Banara tomentosa*; Cal.con: *Calyptranthes concinna*; Cam.xan: *Campomanesia xanthocarpa*; Cas.dec: *Casearia decandra*; Cas.obl: *Casearia obliqua*; Ced.fis: *Cedrela fissilis*; Ces.cor: *Cestrum corymbosum*; Cin.amo: *Cinnamomum amoenum*; Cin.gla: *Cinnamomum glaziovii*; Cle.sca: *Clethra scabra*; Cry.asc: *Cryptocarya aschersoniana*; Cup.ver: *Cupania vernalis*; Dal.fru: *Dalbergia frutescens*; Dic.sel: *Dicksonia sellowiana*; Eug.bur: *Eugenia burkartiana*; Eug.plu: *Eugenia pluriflora;* Eug.sub: *Eugenia subterminalis*; Gym.klo: *Gymnanthes klotzschiana*; Ile.dum: *Ilex dumosa*; Ile.par: *Ilex paraguariensis*; Ile.the: *Ilex theezans*; Ing.len: *Inga lentiscifolia*; Jac.pub: *Jacaranda puberula*; Mac.par: *Machaerium paraguariense*; Mat.ela: *Matayba elaeagnoides*; Mel.sp: *Miconia* sp.; Mim.sca: *Mimosa scabrella*; Myr.mie: *Myrceugenia miersiana*; Myr.myr: *Myrceugenia myrcioides*; Myr.spl: *Myrcia splendens*; Nec.lan: *Nectandra lanceolata*; Oco.pub: *Ocotea puberula*; Oco.pul: *Ocotea pulchella*; Pin.tae: *Pinus taeda*; Pip.ang: *Piptocarpha angustifolia*; Rou.mon: *Roupala montana*; Sch.ter: *Schinus terebinthifolius*; Sol.var: *Solanum variabile*; Sym.com: *Symphyopappus compressus*; Sym.ten: *Symplocos tenuifolia.*

Figure 3. Non-metric Multidimensional Scaling (NMDS) for plots and sampled species; (a) arboreal stratum and (b) regeneration stratum, sectors S1 and S2.

Figura 3. Escalonamento Multidimensional Não Métrico (NMDS) para parcelas e espécies amostradas; (a) estrato arbóreo e (b) estrato regenerante, setores S1 e S2.

DISCUSSION

In the reference ecosystem (S1), Myrtaceae stood out as the richest family with 14 species; a fact quite common in surveys carried out in Mixed Ombrophilous Forests, mainly in mature secondary forests (SIMINSKI *et al*., 2011; VIBRANS *et al*., 2011; FERREIRA *et al*., 2012). In the S2 sector, Myrtaceae was not a very expressive family, with the general species *Myrcia splendens* (Sw.) DC. as its only representative. The most representative botanical family in this sector was Lauraceae, which is also commonly sampled in this phytophysiognomy (REITZ *et al*., 1978; VIBRANS *et al*., 2011).

Due to the fact that Myrtaceae is characterized as a family with exclusive zoochoric dispersion syndrome (GRESSLER *et al*., 2006), a possible failure in the arrival of propagules, in the recruitment of species and/or in the establishment of individuals of this family for sector S2 were first suggested. However, the study by Scariot *et al*. (2014) corroborates the results obtained in this study, in which Myrtaceae was not an expressive family. No species of the family were sampled after two decades of passive restoration in an area previously used for forest plantations. Thus, we consider that the species incorporation of this family in the forest is gradual and the short period in forest succession (a decade) is not enough to allow greater participation of the family. We emphasize that other factors may be influencing this process, such as the absence of ecological corridors, as well as dispersing agents, landscape connectivity, or abiotic characteristics of the site.

Among the evaluated species, *Pinus taeda* deserves to be highlighted, and can be considered a threat to biodiversity due to its invasive nature in open areas of Mixed Ombrophilous Forest (EMER; FONSECA, 2011). This was the only species of the arboreal composition that presents invasive character and only occurred in the S2 sector. This highlights the importance of monitoring the restoration process, which enables indicating the need for intervention and managing the environment. In this case, it acts as an eliminator of a future source of propagules in the environment when these individuals reach the reproductive stage.

Throughout the successional process, there is a tendency of an increase in the proportion of more demanding individuals in environmental conditions, mainly propitiated by the lower light incidence. Thus, the greatest abundance of pioneer individuals, as observed in S2 (Table 2), has the function of preparing the environment for climatic species, since pioneer species naturally have an early senescence, playing the role of facilitator in the successional process (REIS *et al*., 2007). With the natural death of pioneer species individuals and the consequent decrease of density, they become less frequent starting from 15 years of the forest (RUSCHEL *et al.*, 2009; SIMINSKI *et al.*, 2011).

In addition to abundance, the S2 sector obtained the highest proportion of pioneer species. This fact was expected among the evaluated sectors, since the pioneer tree species constituted the first forest stratum of the environment to be restored at the beginning of the forest succession process.

The large number of pioneer species observed in the regenerating stratum in S1 (eight species), and S2 (16 species), evidences the difficulty in the substitution process. Or, more likely, a short period of time for forming a modified microenvironment suitable for occupation, by demanding species, as promoted by the occupation of the arboreal stratum (RODRIGUES *et al*., 2015). We also consider that there is environmental heterogeneity in the forest (with the opening of clearings being possible), mainly caused by the death of individuals, which makes the light arrival to the forest soil more intense and enables pioneer species present in the soil seed bank to germinate (MACIEL *et al*., 2004).

There were more species with zoochoric dispersion syndrome in the S2 sector, 15 species for the arboreal stratum (55.6%) and 26 species for the regenerating stratum (68.4%), compared to the other syndromes evaluated. According to Giehl *et al*. (2007), zoochory is the main dispersion form for Mixed Ombrophilous Forest; a fact reinforced by the obtained results. The sites under passive restoration have a close relationship with zoochoric species, meaning there is a great dependence of animals on this phytophysiognomy (FERREIRA *et al*., 2012; FERRACIN *et al*. 2013; SCARIOT *et al*., 2014; CIELO-FILHO; SOUZA, 2016).

The Shannon Index (H') indicated considerable species diversity, with values varying from 2.09 to 2.99 nats ind-1. These values are consistent with the variation found by Vibrans *et al*. (2011) for the Mixed Ombrophilous Forest of Santa Catarina, in environments under different successional stages (H' ranging from 2.85 to 2.90 nats ind^{-1}). Dalla Rosa *et al*. (2015) found values similar to those of the present study for a fragment with influence of forest plantations in the southern plateau of Santa Catarina. However, the highest values found by these authors refer to the arboreal stratum (H' = 3.2 nats ind^{-1}), while the highest values in the present study were found for the regenerating stratum. This may indicate the possibility of maintaining or even increasing the diversity in the future (RUSCHEL *et al*., 2009; RODRIGUES *et al*., 2015).

There was an increase in the values of H', J' and standardized richness of the adult stratum for the regeneranting in the S2 sector with the incorporation of species in more advanced stages in the regenerating stratum, thereby answering the second question of this study.

We considered that there is a possible presence of ecological dominance (J'= 0.69) in the adult stratum (Table 2) caused by the abundance of the *Mimosa scabrella* pioneer species. Occupation by this species was expected, since it is commonly found in high density in the initial phase of secondary Mixed Ombrophilous Forest formations (FERREIRA *et al*., 2017). As it is a species capable of promoting ecological facilitation or nucleation in restoring environments (REIS *et al*., 2014), *M. scabrella* was the species with the highest importance value in an evaluation performed by Ferreira *et al.* (2012), three years after the riparian forests began to expand.

Populations of *M. scabrella* tend to reduce the number of individuals gradually over time, from 13 to 20 years of forest (SCARIOT *et al*., 2014). Therefore, it is assumed that in the S2 sector (in forest succession since 2005), total substitution of the species has not yet occurred, occupying a large portion of the importance value of the S2 sector adult stratum, as observed in Figure 2. According to Ruschel *et al*. (2009), the decline or rise of the populations occur in the communities according to the forest's successional stage, meaning after the replacement of the initial species that currently compose the canopy of the forest under restoration, there will possibly be incorporation of species individuals of more advanced successional stages.

The NMDS ordering showed differences in the floristic-structural composition between the S1 and S2 sectors, with several species characterizing the arboreal stratum (Figure 3A), and the regenerating stratum (Figure 3B). The study developed by Scariot *et al*. (2014) corroborates this research, as it also revealed low floristic similarity among the evaluated fragments, including in sites under passive restoration and conserved environments. Fragments such as riparian forests in more advanced successional stages as well as the Legal Reserve are important propagule sources. However, for large areas, such as this farm (Figure 1), the arrival of propagules may occur differently, including from non-sampled areas such as areas outside the farm, which could partially explain the floristic distance found between the sectors.

In general, significant differences for the tree stratum were observed for most of the evaluated ecological indicators, showing that there are differences between the successional stages of the environments. Regarding the regenerating stratum and despite significant floristic-structural differences, similarities were observed in the ecological indicators such as standardized richness, H' and J', which suggests resilience of the area under restoration (S2) in detriment to possible connectivity with S1. Furthermore, it is assumed that natural regeneration presents heterogeneous behavior in the forest due to biotic and abiotic factors (SCARIOT *et al*. 2014; REIS *et al*., 2014).

According to Suding and Hobbs (2009), the gradual enrichment of ecosystems under restoration is done by new animal and plant species entering, which depends on a series of internal factors (competition, predation and facilitation) and external factors (flows in the landscape and regional set of species). These factors can result in different communities in terms of composition and structure, meaning that it is not intended for two environments to be identical, but rather that they are diverse enough that they can perpetuate themselves, allowing restoration to be part of a continuous dynamic process (REIS *et al*., 2014). Therefore, a decade after forest plantations being removed, the tree composition presents differences which are evidenced by the succession time. Regarding species diversity, there are similar values between the sector and the reference area, and the area under passive forest restoration process.

CONCLUSIONS

- After a decade in succession, the passive restoration showed to be efficient for enlarging the riparian forest located in the Mixed Ombrophilous Forest, with values of tree richness, diversity, evenness, number of individuals from later succession and zoochoric stages being maintained and incorporated from the arboreal to the regenerating stratum.
- The regenerating stratum of the forest under passive restoration, and the reference ecosystem did not show differences at diversity levels of tree species. This indicate that the evaluated restoration process allows environments in restoration to reach a level of composition and structure similar to the reference ecosystem over time.

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