Austral
ECOLOGY A Journal of ecology in the Southern Hemisphere

Ecological Society of Australia

Austral Ecology (2021) ••, ••–••

Survival, seedlings growth and natural regeneration in areas under ecological restoration in a sandy coastal plain (restinga) of southeastern Brazil

NATHALIE LOUREIRO,*[1,2] TATIANE PEREIRA DE SOUZA,[3]
DANIEL FERREIRA DO NASCIMENTO[4] AND MARCELO TRINDADE NASCIMENTO[1]
[1]*Laboratório de Ciências Ambientais, Centro de Biociências e Biotecnologia, Universidade Estadual do Norte Fluminense Darcy Ribeiro (UENF), Av. Alberto Lamego 2000, Campos dos Goytacazes, 28013-602, (Email: nathalie.loureiro@gmail.com);* [2]*Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, Rio de Janeiro;* [3]*Instituto de Biologia, Universidade Federal Fluminense (UFF), Niterói; and* [4]*Fazenda Saco D'Antas, Prumo Logística S/A, São João da Barra, Brazil*

Abstract Restinga is an ecosystem associated mainly with the Atlantic Forest that can be defined as vegetation of the coastal plain established on sandy soil. This study was carried out in degraded areas of restinga in a Conservation Unit in São João da Barra, Rio de Janeiro, Brazil. In 2012, a restoration project was initiated in the area, with implementation of plantings in hexagonal rings and artificial perches. Seedlings were planted in two contrasting situations: sandbanks (dry areas) and depression zones (areas prone to seasonal flooding). The objective of this study was to evaluate the performance of seedlings planted in both areas and accompany natural regeneration. We hypothesised that species planted and recruited in depressions should have better survival rates and increments in height (H) and diameter at the ground level (DGL) than the ones planted in sandbanks. Monitoring of planted seedlings was carried out in November 2016. Both communities had similar mortality (*c.* 50%). Greater increments in H were found for *Inga laurina* and *Schinus terebinthifolia* in depressions. Higher increments in DGL were observed especially for *I. laurina*, *Inga vera* and *S. terebinthifolia* with good performance in both areas. In general, seedlings planted in depressions showed greater performances, which can be related to higher water and nutrient availability. The most abundant natural regenerant species were *Scoparia dulcis* in sandbanks and *S. terebinthifolia* in depressions. A high number of regenerants was found associated with artificial perches, especially *Cynophalla flexuosa*, which demonstrates that the technique facilitated regeneration in the area.

Key words: Atlantic Forest, ecological restoration, nucleation, regeneration, restinga.

INTRODUCTION

In Brazil, the number of studies focussed on ecological restoration has substantially increased over the last 30 years (Sansevero *et al.* 2018; Guerra *et al.* 2020). Although the Atlantic Forest is the Brazilian biome considered a *hotspot* (Myers *et al.* 2000) with the highest number of studies on restoration (56%, Guerra *et al.* 2020) among biomes in Brazil, some of their associated ecosystems, such as the restingas, still lack research and conservation strategies (Smith *et al.* 2001; Scarano 2002; Wortley *et al.* 2013). The restinga forests are one of the Brazilian vegetation types that exhibits some of the most contrasting characteristics; furthermore, the remaining fragments preserve a large part of the ecosystem processes and services in the Atlantic Forest biome (Marques *et al.* 2015).

Restinga is a vegetational formation with marine influence composed of physiognomic variations from the beach towards the interior the coastal plain (Veloso *et al.* 1991). The different phytophysiognomies found in Brazilian restingas can vary from herbaceous communities to open and closed shrub formations and forest formations, where canopy can reach up to 20 m (Assumpção & Nascimento 1998; Silva 2003; Araujo & Pereira 2009). Many Brazilian restingas suffered processes of deposition and removal of material, caused by marine regressions and transgressions, which generated formations of higher strips of sand, called sandbanks, and of soil removal, the depressions (Martin *et al.* 1997). In these depressions, organic material accumulates quickly which, consequently, leads to changes in soil conditions. Depression areas tend to flood, mainly in restingas of the south and southeast of Brazil

---

*Corresponding author. Present address: Escola Nacional de Botânica Tropical, Rua Pacheco Leão, 2040, Solar da Imperatriz, Horto, Rio de Janeiro 22460-030, Brazil.

Accepted for publication September 2021.

© 2021 Ecological Society of Australia

doi:10.1111/aec.13114

(Sá 2002), with the presence of flooding and/or flooded vegetation formations (Pereira 2003).

Albeit some revegetation actions have been carried out in Brazilian restingas (Sá 2002; Zamith & Scarano 2004, 2006, 2010; Bechara 2006; Fidalgo *et al.* 2009; Correia & Crepaldi 2011; Gerzson *et al.* 2012; Tomazi *et al.* 2012; Tieppo 2015; Da Silva Morais Rodrigues *et al.* 2016; Lorenzo & Campagnaro 2017; Bechara *et al.* 2020), detailed studies on ecological restoration in this community type are still scarce (Correia & Crepaldi 2011), especially in contrasting areas (sandbanks and depressions). There are even fewer studies addressing monitoring of revegetation projects in restinga vegetation. Monitoring is one of the essential steps in the whole process of ecological restoration, not only to evaluate parameters that describe the process (Aronson *et al.* 1995; Block *et al.* 2001; Matthews *et al.* 2009), but also for economic evaluation, introduction of improved methodologies (Brancalion *et al.* 2013) and for providing better recommendations of techniques (Manoliadis 2002; Rodrigues & Gandolfi 2004). Therefore, effective monitoring is absolutely necessary for the success of ambitious restoration programmes, especially in the near future (Perring *et al.* 2018).

On the other hand, natural regeneration has been considered a key factor in restoration of forest ecosystems (Rezende *et al.* 2015) and the main indicator of success in restoration (Holl & Aide 2011; Sansevero & Garbin 2015), although often ignored as a viable option (Chazdon & Uriarte 2016). Nonetheless, the regeneration process depends on seed production (which is affected by the presence and/or distance of forest remnants), seedling establishment and recruitment (Duncan & Chapman 1999; Cubiña & Aide 2001; Yirdaw & Luukkanen 2003; Yadavand & Gupta 2009; Rezende *et al.* 2015). In dry environments, natural regeneration is especially slow as it is also heavily dependent on water availability (Kraaij & Ward 2006; Cardoso *et al.* 2016), nutrient availability (Bardgett & Wardle 2003; Vadigi & Ward 2013) and even resprouting of individuals (Padilla & Pugnaire 2012).

Dispersion processes are an important factor for enabling the regeneration of tropical species (Grombone-Guaratini & Rodrigues 2002; Wang & Smith 2002; Martini & Santos 2007), and their importance has long been recognised (Janzen 1970; Schupp 1995; Howe 1999). Considering that most of restinga species are zoochorous (Oliveira *et al.* 2001; Zamith & Scarano 2004; Scherer *et al.* 2005) and the capacity of restinga communities to shelter a wide variety of animal species – due to its continuous flowering and fruiting throughout the year, providing food sources (Lacerda *et al.* 1993), a good way to attract some potential dispersers such as avifauna and chiropterofauna is the use nucleation techniques. These include applied nucleation, which is the establishment of small patches of shrubs and/or trees to serve as focal areas for recovery (Corbin & Holl 2012) and installation of artificial perches (Holl 1998; Iguatemy *et al.* 2020). Applied nucleation has been used not only for tropical areas (Zahawi & Augspurger 2006; Piiroinen *et al.* 2015; Ramírez-Soto *et al.* 2018), but also in several different ecosystems, such as temperate forests and woodlands (Robinson & Handel 2000; Rey Benayas *et al.* 2015; Saha *et al.* 2016; Aradottir & Halldorsson 2018), salt marshes (Silliman *et al.* 2015), arid shrublands (Hulvey *et al.* 2017) and grasslands (Grygiel *et al.* 2018). In degraded restingas, where environmental conditions are harsh, planted nuclei can recreate a patchy distribution that are expected to expand and connect to each other. In turn, artificial perches are structures made of dry vegetation or woody poles that act as resting and/or shelter points for animals carrying seeds from nearby fragments. The presence of perches facilitates seed arrival, through regurgitation or defecation, and their subsequent germination may lead to the initiation of the restoration process by attracting other animal and plant species and forming larger nuclei of diversity (Holl 1998; Reis *et al.* 2003, 2010; Tres *et al.* 2007; Iguatemy *et al.* 2020) and so intensifies the supply of seed rain (McClanahan & Wolfe 1993) bringing regional diversity to the area under restoration.

Variation in growth response is a consequence of local environmental and/or genetic factors of each species or individual (Botelho *et al.* 1996). Competition with exotic grasses, (Ferreira *et al.* 2010), hydric stress (White 1984) and nutrient shortage (Gullan & Cranston 2007) are some of the factors that affect seedling survival and growth. Therefore, mortality rates and growth in height and diameter are some of the parameters that make it possible to evaluate the development of the process over time. Thus, the objectives of this study were (i) to evaluate and compare the performance of species, planted or from natural regeneration, in sandbanks and in depression zones of a restinga – considering the mortality rate and increments in height and diameter as descriptor parameters and (ii) determine winner species planted and recruited in each of the two areas studied. Our specific questions were (i) Do species' responses (i.e. mortality and growth increments) differ between habitats?, (ii) Are there species that are doing well in both planted areas? and (iii) Is the species composition of regenerating species distinct between habitats? We hypothesised that (i) plants planted and recruited in depressions should have a better performance in general than the ones in sanbanks and (ii) regeneration has different composition between habitats.

doi:10.1111/aec.13114

© 2021 Ecological Society of Australia

MATERIALS AND METHODS

Study area

The 'Natural Heritage Private Reserve' (RPPN) Fazenda Caruara or Caruara Farm (Fig. 1) is the largest private protected area of restinga in Brazil, with 3844.73 ha. It is situated in the Grussaí/Iquipari lagoon complex, at 21°33′44.2″ S and 41°04′32.9″W, located in the municipality of São João da Barra, being one of the last remnants of restinga ecosystem in northern Rio de Janeiro (Assumpção & Nascimento 2000; Farag 2015).

The climate is tropical wet and dry or Aw, according to the Köppen-Geiger climate classification. The average annual temperature (1982–2012) varies from 20 to 30°C, with well-defined seasonality: summer from October to April, with temperatures above 25°C; and winter, from May to September with temperatures around 19°C. The average annual wind speed rate is 7.5 m s^{-1} with predominant directions from E, NE and SE (Amarante *et al.* 2001). The average annual rainfall varies around 1015 mm with higher rainfall between November and January (average of 148 mm in December) and a dry season between May and August (average of 28 mm in July). The coastal plain is approximately 30 km wide, has a river-marine origin and its relief presents small longitudinal elevations represented by parallel, 1–3 meters high, coastal sandbanks that form arches facing the north-south coast (Primo & Ilha 2008). There are four physiognomic units, or zones, in the region (Assumpção & Nascimento 1998, 2000): (i) Beach Grass Formation; (ii) Beach Grass and Shrub Formation; (iii) *Clusia* Formation and (iv) Restinga Forest Formation. According to Daniel Ferreira do Nascimento, RPPN Caruara's manager, flooding events covering the ground, especially in depression zones, occur between 10 and 30 days a year during the peak of the rainy season.

Area history and restoration project

Since the mid-1960s, until it became a conservation unit of 3844.73 ha in 2012, Caruara Farm was used for pasture and sugarcane crops, which led to deforestation of *c.* 1/3 of the area of its restinga. Revegetation at Caruara Farm began in 2012 in the higher sandbanks and in the depression zones. A nucleation technique (Bechara 2006; Corbin & Holl 2012) was used for revegetation and consisted in the establishment of hexagonal rings in linearly distributed groups with 31 seedlings, between 15 and 30 cm tall, planted in each ring, spaced 1.5 m apart, occupying a total area of 47.4 m^2. This technique was developed and tested in restinga ecosystem by Tieppo (2015; Fig. 2). The organisation of the rings was conceived to facilitate the

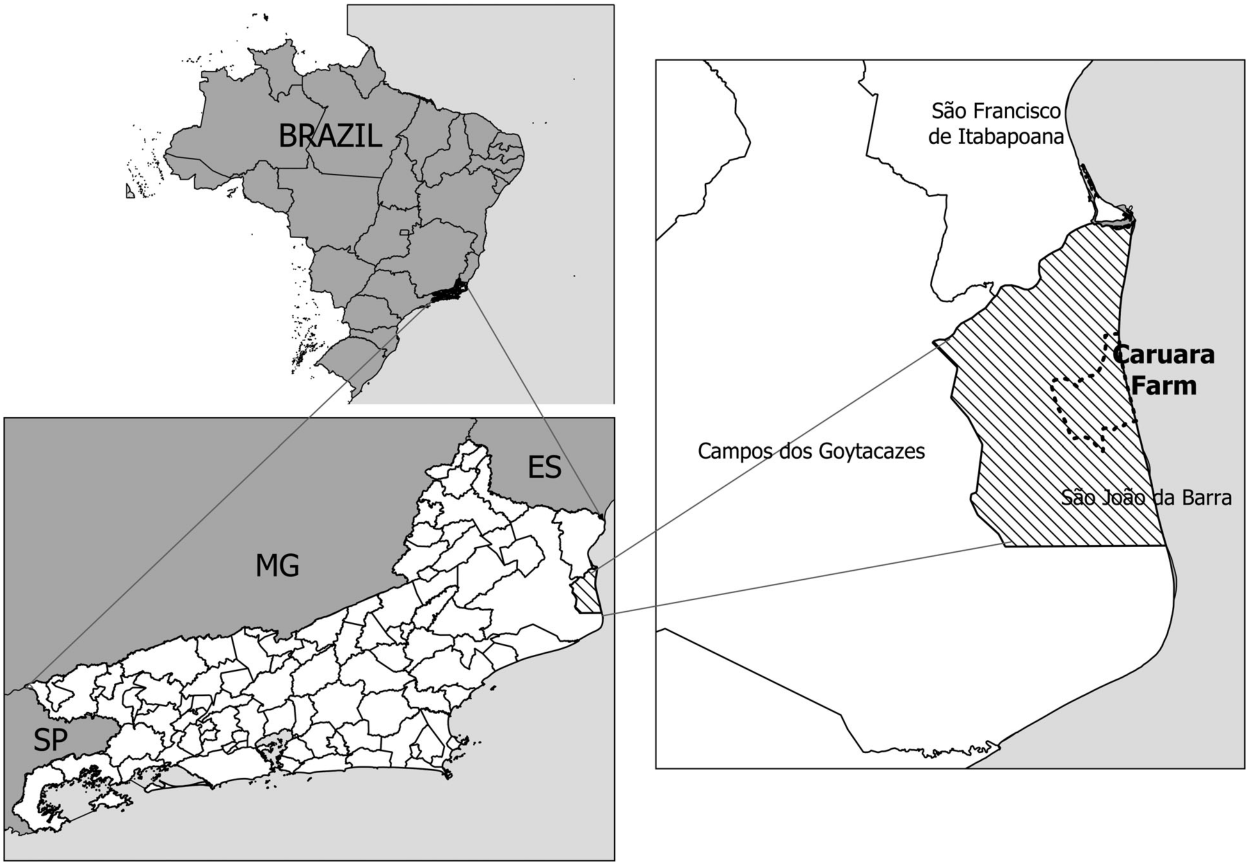

Fig. 1. Localization of RPPN Fazenda Caruara in Rio de Janeiro State (RJ).

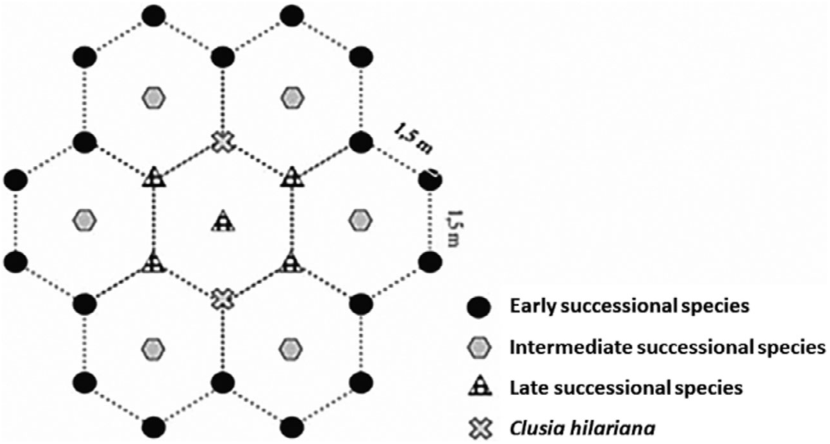

Fig. 2. Representation of a ring used for in the restoration project in Caruara Farm, with the respective successional groups and its position.

establishment of late successional species by providing shading and protection against winds. A hexagonal ring was organised with 18 pioneer species seedlings on the outside followed by six early successional seedlings and five late successional seedlings near the centre. Additionally, the technique included two individuals of *Clusia hilariana* placed in the centre of the ring (Fig. 2). *Clusia hilariana* is considered an important nurse species in the restinga due to the accumulation of litter, humus and nutrients and the provision of shelter and nesting sites for animals, such as lizards, birds and bats under its canopy (Zaluar & Scarano 2000; Liebig *et al.* 2001; Scarano 2002; Dias & Scarano 2007). According to Dr. Leandro Cardoso (ambiental analyst – Caruara Farm unpubl. data, 2020), plant species in the restinga show quite different behaviour in relation to the ecological groups already determined for them for other forest types. Therefore, it is difficult to extract information about ecological groups from the literature, which mainly considers requirement for light, presence in clearings and edges etc., parameters that are difficult to apply or are not applicable in the restinga. Thus, the ecological groups for several species informed in Appendix S1 are mainly based on his personnel field experience and can be subject to disagreements.

From October to December 2012, rings were established in an area of 122 ha. Seedlings of 46 species, mostly zoochoric, belonging to 28 families, were used. The species composition of the rings in each area was not the same but was very similar. Some species were planted only in sandbanks or in depressions, and others were planted in both areas (Appendix S1). Species selection was made using empirical knowledge of the RPPN team responsible for the restoration project, based on their occurrence in each of the habitats. From 2013 to 2016, any seedlings that did not establish was replaced once, but not necessarily by the same species. These individuals were excluded from the growth analyses. Perches were established in November and December 2012 by the Caruara Farm restoration project and randomly distributed between plantations in sandbanks ($n = 13$) and depressions ($n = 12$). Their structure was made of a large branch inserted into the ground reaching a height from 1.6 to 2.5 m, with a perpendicular branch attached near the top. Also, dry branches were placed on the ground leaning on the main branch, to form a shelter. All rings and perches were located at least 200 m from the closest restinga forest remnant.

Sampling

For this study, we randomly selected 30 rings in each area (e.g. sandbanks and depressions) totalling 930 seedlings per habitat. Depression areas were identified by the presence of darker and wetter sand and greater presence of vegetation, especially exotic grasses, while in the sandbank areas the sand was noticeably drier, whiter and with less dense vegetation.

In November/December 2016, the surviving seedlings of the 2012 planting were tagged, identified and measured for diameter at ground level (DGL) with a calliper and total height (*H*) with a measuring tape, extended from ground level to the apex (highest point). Mortality rate included both empty pits and dead seedlings.

Woody individuals from natural regeneration occurring in the selected rings also had their DGL and H measured in May/June 2016 and in November/December 2016 and were tagged and identified. The occurrence of natural regeneration of woody species under artificial perches (1 m radius) was also recorded and evaluated.

Data analysis

Species' growth was assessed by the mean annual increment in height (MAIH) and the mean annual increment in diameter at ground level (MAID), which were calculated by the difference between the final value recorded for each parameter and the initial one, divided by time interval between measurements. The Mann–Whitney test was applied to test significant differences between areas. Since there was information only for the mean height of each species planted in 2012, but not for mean diameter, MAIH period was calculated for the 2012–2016, while MAID was calculated only for the interval from May/June and November/December 2016. Individuals with broken apices were not included in MAIH calculation. For individuals with multiple stems, the increment in diameter was based on the thickest one.

doi:10.1111/aec.13114

© 2021 Ecological Society of Australia

Only surviving seedlings from the 2012 planting were used for growth analyses. The mortality rate (M) for the individuals of each species planted in 2012 was calculated after Sheil and May (1996):

$$M = 1 - [(N_0 - N_\mathrm{m})/N_0]^{1/t} \quad (1)$$

where $N_0 =$ number of individuals at time zero; $N_\mathrm{m} =$ number of dead individuals; $t =$ time elapsed between one census and another.

Comparisons between the mean values of height, diameter and percentage of mortality between the two areas were performed using t-test in RStudio 4.0.0 (RStudio Team 2020). We tested normality using the Shapiro–Wilk test and, when data did not have a normal distribution, we applied the Mann–Whitney test. Linear regressions and analysis of covariance (ANCOVA) were also performed using the RStudio program.

RESULTS

Of the initial 46 species planted, 44 were sampled after four years. Of these, a total of 497 seedlings in 35 species were in the sandbanks and 441 seedlings in 39 species were in the depressions. There was no statistical difference in total mortality between the depressions (53%) and sandbanks (46.5%) over the four-year interval ($t = -1.6638$, $P = 0.1029$). The adjusted annual mortality rates from November 2012 to November 2016 were 17.1% and 14.4% for depressions and sandbanks respectively.

The most abundant surviving species (Appendix S2) were *Schinus terebinthifolia* (16.83%), *Guapira pernambucensis* (8.81%), *Maytenus obtusifolia* (7.41%), *Syderoxilon obtusifolia* (7.21%), *Inga laurina* (6.81%, in sandbanks, and *S. terebinthifolia* (19.72%), *I. laurina* (13.60%), *Annona glabra* (10.20%), *Ficus tomentella* (6.80%) and *M. obtusifolia* (6.12%) in depressions.

After four years, seedlings of all species planted in the depressions always had significantly highest mean values of H ($P \leq 0.001$) and DGL ($P = 0.0398$; Fig. 3). Among the species with $n \geq 10$ individuals, *I. laurina* (122.3 cm) and *S. terebinthifolia* (111.2 cm) had the highest mean H values in depressions, while in sandbanks *I. laurina* (75.1 cm) and *G. pernambucensis* (70.1 cm) showed the highest values; the lowest values of H were found for *Sideroxylon obtusifolium* and *Eugenia uniflora* (25.7 and 32.1 cm respectively) in sandbanks and for *Psidium cattleianum* (49.9 cm) in depressions. For DGL, *I. laurina* had the highest mean values in both habitats (3.9 cm in sandbanks and 4.5 in depressions) followed by *Inga vera* (2.7 cm) in sandbanks and *Cordia taguahyensis* (4.4 cm) and *S. terebinthifolia* (4.2 cm) in depressions; *S. obtusifolium* in sandbanks and *M. obtusifolia* in depressions had the lowest mean values (1.2 and 1.7 cm respectively; Appendix S2). Of all individuals sampled, only 7.6% had broken apices.

The highest MAIH values for the 2012–2016 period were generally found in depressions, where the three highest values occurred for *Cecropia pachystachya* (30.6 cm year^{-1}; $n = 7$), *I. laurina* (26.3 cm year^{-1}; $n = 60$) and *S. terebinthifolia* (24.2 cm year^{-1}; $n = 87$; Table 1). In sandbanks, *I. laurina* (14.4 cm year^{-1}; $n = 35$), *G. pernambucensis* (12.5 cm year^{-1}; $n = 44$) and *Clusia hilariana* (12.3 cm year^{-1}; $n = 31$) were the species that had the highest values. The lowest MAIH in over this period was found in sandbanks in *S. obtusifolium* (2.7 cm year^{-1}; $n = 36$; Table 1).

Regarding the increment in DGL, MAID analyses were performed only for seven species whose initial mean diameter values (2012) were known. The highest MAIDs (2012–2016) occurred for *I. laurina* (1.02 cm year^{-1} in depressions and 0.87 cm year^{-1} in sandbanks), *P. cattleianum* (0.93 cm year^{-1} in depressions) and *S. terebinthifolia* (0.93 cm year^{-1} in depressions; Table 1).

Regression analyses and analyses of covariance (ANCOVA) between height and diameter for the most abundant species in each or in both areas showed that there was a linear relationship (proportional growth) for most species in both habitats. For the six

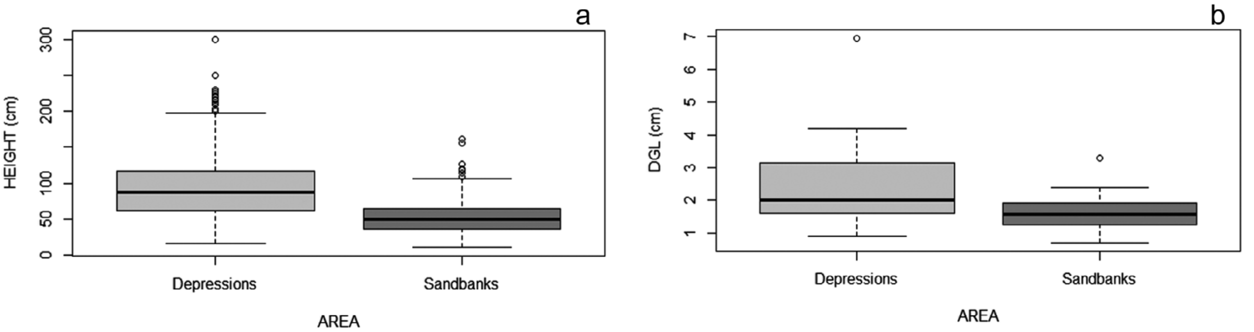

Fig. 3. Comparison of mean height (a) and mean diameter at ground level (b) for individuals planted in 2012 that survived until November 2016 in the RPPN Caraura Farm, São João da Barra, RJ, Brazil. $W = 233.5$, $P \leq 0.001$ (height) and $W = 493$, $P = 0.0398$ (diameter).

© 2021 Ecological Society of Australia

doi:10.1111/aec.13114

Table 1. Mean annual increment in height (MAIH) and in diameter at ground level (MAID) over the four-year period (2012–2016) of most abundant (n ≥ 10) planted species in sandbanks and in depressions in RPPN Fazenda Caruara, São João da Barra, RJ, Brazil

		Sandbanks			Depressions		
Species	H (cm)	*n*	MAIH (cm year^{-1})	MAID (cm year^{-1})	*n*	MAIH (cm year^{-1})	MAID (cm year^{-1})
Annona glabra L.	20	0	NP	NP	44	9.25	ND
Clusia hilariana Schltdl.	19	31	12.25	0.42	13	12.67	0.62
Cordia taguahyensis Vell.	20	0	NP	NP	14	18.57	ND
Eugenia dichroma O.Berg	20	33	4.85	ND	7	10.96	ND
Eugenia uniflora L.	15	12	4.27	ND	0	NP	NP
Ficus tomentella (Miq.) Miq.	20	26	8.12	ND	30	19.51	ND
Guapira pernambucensis(Casar.) Lundell	20	44	12.51	0.37	10	14.30	0.39
Inga laurina (Sw.) Willd.	17	35	14.42	0.87	60	26.32	1.02
Inga vera Willd.	19	15	7.71	0.57	22	19.23	0.89
Maytenus obtusifolia Mart.	18	37	7.67	0.28	27	12.62	0.32
Myrsine parvifolia A.DC.	30	15	4.1	ND	1	10.75	ND
Psidium cattleianum Sabine	15	23	6.42	0.46	10	8.72	0.93
Sapium glandulatum (L.) Morong	20	0	NP	NP	29	19.58	ND
*Schinus terebinthifolia*Raddi	13	84	9.02	0.42	87	24.23	0.93
Sideroxylon obtusifolium (Roem & Schult) T.D.Penn	15	36	2.68	ND	5	9.00	ND
Tapirira guianensis Aubl.	15	3	15.75	ND	14	19.71	ND
Tocoyena bullata (Vell.) Mart.	15	18	11.94	ND	2	13.87	ND

H_o, initial height; ND, no data; NP, not present.

species where intraspecific comparisons were possible, species in the sandbanks generally had a stronger relationship between height and diameter (Fig. 4). *Clusia hilariana* and *G. pernambucensis* did not have a significant relationship between the two measures in depressions, possibly due to a small sample size, since their regression lines behave very similar as in sandbanks. Only two species (*F. tomentella* and *S. obtusifolium*) showed higher growth in DGL than in height, especially in sandbanks. No species invested more in vertical growth (height) than in secondary growth (stem diameter; Fig. 4).

Thirty-three natural regenerants belonging to eight species were found in the rings planted in sandbanks and 53 belonging to 11 species in the depression zone (Table 2). The Jaccard species similarity coefficient between areas was 31.2%, and the diversity of natural regenerant species in sandbanks was similar to that found in depressions (H' sandbanks = 1.64 and H' depressions = 1.65) with the ruderal *Scoparia dulcis* ($n = 15$ individuals) and *S. terebinthifolia* ($n = 27$ individuals) as the most abundant spontaneously regenerating species in depressions and in sandbanks respectively.

In November 2016, the average height values for all regenerating species in sandbanks and depressions were 55.8 and 48.4 cm, respectively, with no significant difference between areas ($t = 1.2415$, $P = 0.218$). However, the average value of diameter was significantly higher ($t = 3.715$, $P \leq 0.001$) in sandbanks (1.76 cm) than in depressions (0.95 cm; Table 3).

Seventeen of the 25 sampled perches (68%), 13 in sandbanks and 12 in depressions, had regenerants. However, the majority (75%) of the regenerants were found under perches situated in depressions. The most common regenerant species in both areas was *C. flexuosa*, present under 14 of the 25 perches (56%), followed by *C. verbenacea*, found at four perches, 3 in the sandbanks and 1 in the depressions (Table 4; Fig. 5).

DISCUSSION

Plantation

Our study suggests that the restoration technique used at Caruara Farm seems to be producing good responses related to seedling growth and natural regeneration, although the latter is still dominated by ruderal species. In a Southern Costa Rican tropical

Fig. 4. Linear regressions between height (*H*) and diameter at the ground level (*D*) for the most abundant surviving woody species planted in the RPPN Caruara Farm, São João da Barra, RJ, Brazil. Dep, depressions; Sb, sandbanks.

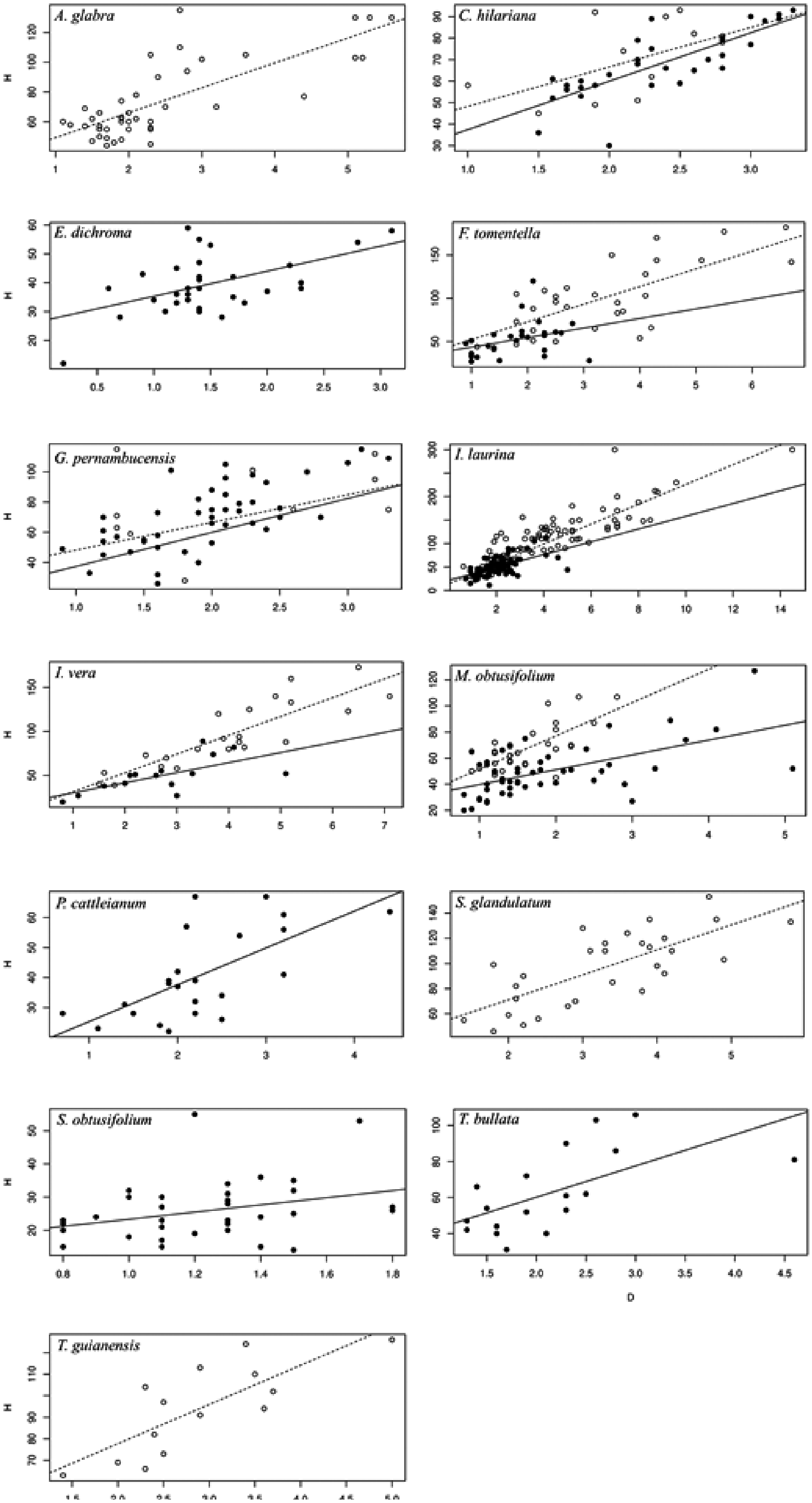
A. glabra
C. hilariana
E. dichroma
F. tomentella
G. pernambucensis
I. laurina
I. vera
M. obtusifolium
P. cattleianum
S. glandulatum
S. obtusifolium
T. bullata
T. guianensis
H
D

Table 2. Number of living and dead regenerants in sandbanks and depressions between May and November 2016 in RPPN Caruara Farm, São João da Barra, RJ, Brazil

	Sandbanks			Depressions		
Species	May/16	Nov/16	Deaths	May/16	Nov/16	Deaths
Andira fraxinifolia Benth.	NP	NP	NA	1	1	0
Chamaecrista ramosa (Vogel) H.S. Irwin & Barneby	5	5	0	1	1	0
Cordia verbenacea D.C.	2	2	0	4	8	0
Cynophalla flexuosa (L.) J. Presl	NP	NP	NA	1	1	0
Eugenia uniflora L.	0	1	0	NP	NP	NA
Guapira pernambucensis (Casar.) Lundell	1	0	1	NP	NP	NA
Indigofera suffruticosa Mill.	1	0	0	0	1	0
Inga laurina (Sw.) Willd.	NP	NP	NA	0	1	0
Inga vera Willd.	NP	NP	NA	2	2	0
Indet 1	NP	NP	NA	1	2	0
Maytenus obtusifolia Mart.	4	3	1	4	6	0
Mimosa arenosa (Willd.) Poir.	NP	NP	NA	0	1	0
Schinus terebinthifolia Radii	NP	NP	NA	22	27	3
Scoparia dulcis L.	13	15	6	NP	NP	NA
Tibouchina clavata (Pers.) Wurdack	NP	NP	NA	0	1	0
Walthria indica L.	1	4	0	NP	NP	NA
Total	27	30	8	36	52	3

NA, not applicable; NP, not present.

Table 3. Mean values of height (*H*), diameter at ground level (DGL) and Mean Monthly Increments in height and diameter at ground level (MMIH and MMID) of regenerant species found in May and November 2016 in sandbanks and in depression zones in RPPN Caruara Farm, São João da Barra, RJ, Brazil

Species	*n*	Mean *H* (cm) May/16	Mean *H* (cm) Nov/16	Mean DGL (cm) May/16	Mean DGL (cm) Nov/16	MMIH (cm month^{-1})	MMID (cm month^{-1})	Individuals with broken apices
Sandbanks								
Chamaecrista ramosa (Vogel) HS Irwin & Barneby	5	58.4	58.2	0.98	1.46	−0.03	0.08	2
Cordia verbenaceae DC.	2	40.5	39	1.35	1.55	−0.25	0.03	2
Indigofera suffruticosa Mill.	1	61	70	2.2	2.1	1.5	−0.02	0
Maytenus obtusifolia Mart.	3	39	43.3	0.93	1.46	0.72	0.09	0
Scoparia dulcis L.	7	67.6	61.33	1.58	1.66	0.31	0.04	4
Whalteria indica L.	1	87	72	4.8	5	−2.5	0.03	1
General mean (all individuals)		56.9	55.58	1.41	1.76	−0.2	0.0	1.5
Depressions								
Andira fraxinifolia Benth.	1	73	80	2.7	3.5	1.17	0.13	0
Cordia verbenaceae DC.	1	65	67	1.2	1.5	0.33	0.05	0
Cynophalla flexuosa (L.) J. Presl.	1	33	46	0.3	0.5	2.17	0.03	0
Indigofera suffruticosa Mill.	1	116	125	1.2	2.3	1.50	0.18	0
Inga vera Willd.	2	59.5	61.5	0.7	0.9	0.33	0.07	0
Maytenus obtusifolia Mart.	4	32	35.5	0.3	0.5	0.58	0.03	2
Schinus terebinthifolia Raddi	14	34.6	40.45	0.5	0.4	0.46	0.03	2
General mean (all individuals)		40.37	48.4	0.67	0.95	0.7	0.0	0.6

forest, Holl *et al.* (2020) compared regular plantations and applied nucleation techniques over a 10-year period; they found similar results in both techniques concerning the enhancing of the recovery of flora. We believe that applied nucleation represents a good technique that can be employed in restinga ecosystems, especially due to the harsh environment presented.

Table 4. Number of perches and number of regenerating individuals (*n*) per species/family observed in the two areas of study in RPPN Caruara Farm, São João da Barra, RJ, Brazil

Area	Observed perches	Observed species/family	*n*
Sandbanks	13	*Cynophalla flexuosa* (L.) J. Presl	12
		Cordia verbenacea D.C.	3 + 1 bush
		Schinus terebinthifolia Raddi	1 + 1 bush
Depressions	12	*C. flexuosa* (L.) J. Presl	47
		S. terebinthifolia Raddi	3
		C. verbenacea D.C.	1
		Eugenia uniflora L.	1
		Scoparia dulcis L.	1
		Asteraceae	1 bush

The number of woody species found in the restoration programme and the species diversity values found for plantations were similar to values found by Assumpção and Nascimento (2000) in a restinga forest in this region (37 species in 900 m^2 and H′ = 2.84). These diversity values (H′) are also in the range reported for other restingas in Southeastern Brazil (H′ = 2.52; Lobão & Kurtz 2000 and 3.73; Assis *et al.* 2004), indicating that the number of species and individuals used in the hexagonal rings is representative of a restinga forest patch.

In restoration areas of Atlantic Forest *strictu sensu*, mortality rates above 10% require immediate corrective actions (Bellotto *et al* 2009). However, the mortality rates (*c.* 50%) found in both habitats (sandbank and depression) are lower or in the range found in other restoration studies in restinga vegetation (Zamith & Scarano 2006; Correia & Crepaldi 2011). Although we expected lower mortality in depressions, the result found may be due to the presence of exotic grasses, which are rarer in sandbanks. Yet, considering all the limiting factors in restingas (drought, salinity, inconstancy of substrate, action of wind and high air temperatures; Reinert *et al.* 1997), at this time, we suggest that managers could focus on a reduced number of species in the plantations, prioritising those that have better performance and survival, to permit the establishment of a vegetation cover, after which, a second species enrichment effort could be initiated with possible better survival results. Species such as *C. pachystachya*, although its low number of observations, seems to have good development in height (see Appendix S2) and could serve as natural perches; however, that species does not provide shade enough to achieve the goal of nucleation and that point should be consider in future plantations.

Our hypothesis that performance in depressions is higher for planted and regenerated individuals was confirmed. Although there was no difference in mortality rates between habitats, increments in height and diameter differed significantly between both areas, with higher values found in depression zones. Although there are only few studies on the role of water table on soil conditions and plant establishment in restinga formations (Scarano *et al.* 1997; Araujo *et al.* 2008; Almeida *et al.* 2011; Magnano *et al.* 2013; Santos-Filho *et al.* 2015), our observed results may be related to better soil conditions, *that is* higher amount of organic matter, water and nutrients in the depressions (Pereira 2003; Araujo *et al.* 2004). The superficial and short-term flooding pattern (up

Fig. 5. Perch established at RPPN Caruara Farm in a depression zone (left). Regenerant of *Cynophalla flexuosa* under perch (right).

© 2021 Ecological Society of Australia

doi:10.1111/aec.13114

to 30 days) observed in the depression zones does not seem to promote the negative effects generally caused by anoxia in the establishment of most plants, as reported for areas with longer flooding duration (Scarano 2006; Zamith & Scarano 2010). This result suggests that species planted in depressions, such as *I. laurina* and *S. terebinthifolia*, seem to be tolerant to short-term flooding and reinforce these species as the right choice for use in restoration efforts in this habitat type. The waterlogging period in Caruara is shorter than other restingas in southeastern and southern Brazil, which, in general, remain flooded during the entire rainy season (Menezes *et al.* 2005; Marques *et al.* 2009; Kurtz *et al.* 2013). Even so, some flood-tolerant species found in longer flooding periods such as *A. glabra*, *Calophyllum brasiliense* and *Sapium glandulatum* (Araujo *et al.* 1998, 2004; Sztutman & Rodrigues 2002; Marques *et al.* 2009) also occur in Caruara plantings and have either good survival rates or performances.

Inga laurina and *S. terebinthifolia* showed the highest MAIH in both habitats and the highest MAID in depressions, corroborating a study by Tieppo and Brancalion (2016). The good performance in the establishment of *I. laurina* and *I. vera* in the studied area seems to be related to their ecological plasticity (Pennington 1997). According to Lorenzi (2002), *I. laurina* has recalcitrant seeds, wind resistant wood and deep roots, qualities that facilitate its establishment and persistence in restinga areas. Both *Inga* species recorded have the capacity for biological fixation of nitrogen (Vitousek & Howarth 1991; Cleveland *et al.* 1999; Galloway *et al.* 2004), and this may have been a factor in the response of these species and also may facilitate colonisation by other plant species and increase biodiversity (Siddique *et al.* 2008). Thus, these species should be prioritised in restoration projects in restinga areas.

The regression analyses showed a positive relationship between height and DGL in almost all species in both areas, with a stronger relationship for individuals in depressions. *Ficus tomentella* and *S. obtusifolium* invested more in diameter growth in the sandbanks, showing different strategy in dry areas. This can explain their survival in the area, since stem biomass growth can guarantee better tolerance to water deficit, wind and/or regrowth, which is certainly the case of *Ficus* spp (Lorenzi 2002) and *S. obtusifolium*, species for which regrowth of stems are well documented (Salis & Crispim 2006). It is noteworthy that in sandbanks, individuals presented lower MAIH and MAID than in depression zones suggesting that species invested more in root development in the drier areas, since light is not a limiting factor in these environments (Melo Jr. & Boeger 2015). This result was expected, since plant growth priority in dry and windy areas is often focussed on radial growth (Sperry & Hacke 2002; Ackerly 2004; Zamith & Scarano 2006). Strong and constant wind in restinga vegetation causes branches to break and other damage to seedlings, directly affecting height growth (Zamith & Scarano 2006). This fact may explain the decrease in height values for several species between censuses. These results reinforce the importance of differentiated restoration planning for sandbanks and depression areas.

Regeneration

Our second hypothesis, that regeneration has different composition between habitats, was also confirmed, since the species similarity index in both habitats was low (31.2%), although diversity were quite the same. On the other hand, the abundances of species in each area were very different, with a strong presence of *S. terebinthifolia* in depressions, which we suppose are seedlings originated from the plantings.

The use of artificial perches as useful nucleation technique for restoration has been reported by several authors for different vegetation types elsewhere, for example Holl (1998) in tropical pastures, Shiels and Walker (2003) for Puerto Rican landslides, Espíndola and Reis (2009) in a Southern Brazilian restinga, Tres and Reis (2009) in riparian forest in Atlantic Forest, Cavallero *et al.* (2013) in post fire areas in Argentina, Vogel *et al.* (2016) in a subtropical agroecosystem, Oliveira *et al.* (2018) in the brazilian Cerrado, Alencar and Guilherme (2020) in Amazon, Iguatemy *et al.* (2020) in Atlantic forest and Freeman *et al.* (2021) in Northeastern Australia.

Cynophalla flexuosa is widely consumed and dispersed by birds, insects and other animals (Zamith & Scarano 2004; Fabricante *et al.* 2009; Silva *et al.* 2013) and occurred with high abundance together with some individuals of another five native species regenerating under perches. The absence of regenerants in the planted rings suggest that the artificial perch technique was efficient and important to accelerate the regeneration of some native zoochoric species in the restoration areas. This result corroborates Dias *et al.* (2014) who found that the use of artificial perches was efficient in increasing the supply of zoochoric restinga forest seeds in abandoned pasture areas and suggest that studies could be done focussing on different structures and heights of perches. Our results also corroborate Guidetti *et al.* (2016) who found that setting-up artificial perches in open areas increases the abundance and richness of seeds and seedlings compared to control sites without perches. These authors consider the use of artificial perches for promoting and/or accelerating vegetation restoration an efficient technique especially in open areas, such as in deforested restinga vegetation,

© 2021 Ecological Society of Australia

where dispersal of seeds by birds is limited by the lack of trees.

Several authors consider that passive regeneration, or reduction in land use and its abandonment, can enable vegetation recovery in tropical forests (Piotto *et al.* 2009; Aronson *et al.* 2011; de Rezende *et al.* 2015; Strassbourg *et al.* 2016; Lewis *et al.* 2019). However, Garbin *et al.* (2018) found that passive regeneration did not play an important role in a restinga area, even 16 years after the end of disturbance by sand mining. Nurse plants, such as *Clusia* sp. and bromeliads, did not occur among the regenerants in their study. Despite the presence of regenerants in plantations, regeneration was not high. On the other hand, regeneration was considerable under artificial perches. Therefore, since only few species are capable of regenerating in bare sand areas (Scarano 2002; Dias *et al.* 2005; Reis-Duarte & Casagrande 2006), active restoration and management, such as installation of artificial perches, seems to be the best technique to promote regeneration in restinga vegetation.

ACKNOWLEDGEMENTS

We thank the RPPN Fazenda Caruara in ensuring access to sites and its local staff for logistic support. We also thank Fábio Scarano, Luis Fernando Tavares de Menezes and Luiz Roberto Zamith Coelho Leal for comments that improved the early version of the manuscript. To John Du Vall Hay for English revision and helpful comments. Marcelo Trindade Nascimento has been supported by *Conselho Nacional de Desenvolvimento Científico e Tecnológico* (CNPq; 305617/2018-4) and *Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro* (FAPERJ E-26/202.855/2018). This study was financed in part by the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil* (CAPES) – Finance Code 001. CAPES also provided master's scholarship to NMLC.

CONFLICT OF INTEREST

I, Nathalie Loureiro, declare that the manuscript has been submitted solely to this journal and is not published, in press, or submitted elsewhere. I confirm that all the research meets the ethical guidelines, including adherence to the legal requirements of the study country. The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

Nathalie Loureiro: Conceptualization (lead); Data curation (lead); Formal analysis (lead); Methodology (equal); Project administration (lead); Resources (equal); Writing-original draft (lead). **Tatiane Pereira de Souza:** Data curation (supporting). **Daniel Ferreira do Nascimento:** Conceptualization (supporting); Resources (supporting). **Marcelo Trindade Nascimento:** Conceptualization (supporting); Funding acquisition (equal); Methodology (equal); Project administration (supporting); Resources (equal); Supervision (lead); Writing-review & editing (lead).

REFERENCES

Ackerly D. D. (2004) Functional traits of chaparral shrubs in relation to seasonal water deficit and disturbance. *Ecol. Monogr.* **74,** 25–44.

Alencar L. & Guilherme E. (2020) Artificial perches for the supply of seeds in a fragmented landscape in southwest Brazilian Amazon. *Braz. J. Bot.* **43,** 1013–23.

Almeida E. B. Jr, Santos-Filho F. S., Araújo E. L. & Zickel C. S. (2011) Structural characterization of the woody plants in restinga of Brazil. *J. Ecol. Nat. Environ.* **3,** 95–103.

Amarante O. A. C., Brower M., Zack J. & Sá A. L. (2001) Atlas do potencial eólico brasileiro. Retrieved October 29, 2019, from http://www.cresesb.cepel.br/publicacoes/download/atlas_eolico/Atlas%20do%20Potencial%20Eolico%20Brasileiro.pdf.

Aradottir A. L. & Halldorsson G. (2018) Colonization of woodland species during restoration: seed or safe site limitation? *Restor. Ecol.* **26,** S73–83.

Araujo D. S. D. & Pereira M. C. A. (2009) Sandy coastal vegetation. In: *Encyclopedia of Life Support Systems (EOLSS), Tropical Biology and Natural Resources*, pp. 173–89. EOLSS Publishers UNESCO-EOLSS, Oxford.

Araujo D. S. D., Pereira M. C. A. & Peixoto A. L. (2008) Campos nativos at the Linhares forest reserve, Espírito Santo, Brazil. In: *The Atlantic Coastal Forest of Northeastern Brazil* (ed W. Thomas) pp. 365–88. The New York Botanical Garden, New York.

Araujo D. S. D., Pereira M. C. A. & Pimentel M. C. P. (2004) Flora e estrutura de comunidades na Restinga de Jurabatiba – síntese dos conhecimentos com enfoque especial para a formação aberta de Clusia. In: *Pesquisas de longa duração na Restinga de Jurabatiba: ecologia, história natural e conservação* (eds C. F. D. Rocha, F. A. Esteves & F. R. Scarano) pp. 59–76. RIMa, São Carlos.

Araujo D. S. D., Scarano F. R., Sá C. F. *et al.* (1998) Comunidades Vegetais do Parque Nacional da Restinga de Jurubatiba. In: *Ecologia das Lagoas Costeiras do Parque Nacional da Restinga de Jurubatiba e do Município de Macaé, RJ* (ed F. A. Esteves) pp. 39–62. Universidade Federal do Rio de Janeiro, Rio de Janeiro.

Aronson J., Durigan G. & Brancalion P. H. S. (2011) *Conceitos e definições correlatos à ciência e a prática da restauração ecológica*, Vol. **44** pp. 1–38. Instituto Florestal Série Registros, São Paulo.

Aronson, J., Floret, C., Le Floc'h, E., OValle, C. & Pontanier, R. (1995) Restauration et rehabilitation des ecosystems degrades en zones arides et semi-arides. Le vocabulaire et lês concepts. In: *L'homme peut-il refaire ce qu'il a défait?* (eds R. Pontanier, A. M'hiri, N. Akrimi, J. Aronson & E. Le Floc'h) pp. 11–29. John Libbey Eurotext, Paris.

© 2021 Ecological Society of Australia

doi:10.1111/aec.13114

Assis A. M., Pereira O. J. & Thomaz L. D. (2004) Fitossociologia de uma floresta de restinga no Parque Estadual Paulo César Vinha, Setiba, município de Guarapari. *Rev. Bras. Bot.* **27,** 349–61.

Assumpção J. & Nascimento M. T. (1998) Fitofisionomia de uma restinga no extremo norte do litoral fluminense: um novo elemento no mosaico? In: *IV Simpósio de Ecossistemas Brasileiros*, Vol. **3** (org ACIESP) pp. 15–164. Águas de Lindóia, São Paulo.

Assumpção J. & Nascimento M. T. (2000) Estrutura e composição florística de quatro formações vegetais de restinga no complexo lagunar de Grussaí/Iquipari, São João da Barra, RJ, Brasil. *Acta Bot. Bras.* **14,** 301–15.

Bardgett R. D. & Wardle D. A. (2003) Herbivore mediated linkages between aboveground and belowground communities. *Ecology* **84,** 2258–68.

Bechara F. C. (2006) Unidades Demonstrativas de Restauração Ecológica através de Técnicas Nucleadoras: Floresta Estacional Semidecidual, Cerrado e Restinga. Doctoral dissertation. Universidade de São Paulo, Piracicaba, SP, Brazil.

Bechara F. C., Salvador L. Z., Ventura R. A. *et al.* (2020) Vegetation and seed bank of an open-scrub bush restinga formation in the Southeastern coast of Brazil. *Rev. Biol. Trop.* **68,** 541–50.

Bellotto A., Viani R. A. G., Nave A. G. & Gandolfi S. (2009). Monitoramento das áreas restauradas como ferramenta para avaliação da efetividade das ações de restauração e para redefinição metodológica. In: *Pacto pela restauração da mata atlântica: referencial dos conceitos e ações de restauração florestal* (eds R. R. Rodrigues, P.H.S. Brancalion & I. Isernhagen) pp. 130–46. LERF/ESALQ, São Paulo.

Block W. M., Franklin A. B., Ward J. R., Ganey J. L. & White G. C. (2001) Design and implementation of monitoring studies to evaluate the success of ecological restoration on wildlife. *Restor. Ecol.* **9,** 292–303.

Botelho S. A., Daviede A. C. & Faria J. M. R. (1996) Desenvolvimento inicial de seis espécies florestais nativas em dois sítios, na região sul de minas gerais. *Rev. Cerne* **2,** 4–13.

Brancalion P. H. S., Viani R. A. G., Rodrigues R. R. & Gandolfi S. (2013) Avaliação e monitoramento de áreas em processo de restauração. In: *Restauração Ecológica De Ecossistemas Degradados* (ed S. V. Martins) pp. 262–93. Viçosa.Editora UFV.

Cardoso A. W., Medina-Vega J. A., Malhi Y. *et al.* (2016) Winners and losers: tropical forest tree seedling survival across a West African forest – savanna transition. *Ecol. Evol.* **6,** 3417–29.

Cavallero L., Raffaele E. & Aizen M. A. (2013) Birds as mediators of passive restoration during early post-fire recovery. *Biol. Cons.* **158,** 342–50.

Chazdon R. L. & Uriarte M. (2016) Natural regeneration in the context of large-scale forest and landscape restoration in the tropics. *Biotropica* **48,** 709–15.

Cleveland C. C., Townsend A., Schimel D. *et al.* (1999) Global patterns of terrestrial biological nitrogen (N2) fixation in natural ecosystems. *Glob. Biogeochem. Cycles* **13,** 623–45.

Corbin J. D. & Holl K. D. (2012) Applied nucleation as a forest restoration strategy. *Forest. Ecol. Manag.* **265,** 37–46.

Correia G. G. S. & Crepaldi M. O. S. (2011) Taxas de crescimento e mortalidade de espécies em áreas em restauração, Parque Estadual de Itaúnas, ES, *Congresso Brasileiro de Reflorestamento Ambiental*, Sesc Centro de Turismo de Guarapari Guarapari, ES, 23–26 October.

Cubiña A. & Aide T. M. (2001) The effect of distance from forest edge on seed rain and soil seed bank in a Tropical pasture. *Biotropica* **33,** 26–267.

Da Silva Morais Rodrigues, L. G., Rodrigues, F. M. & Melo Viroli, S. L. (2016) Techniques of forest restoration in restingas. *J. Bioenergy Food Sci.* **3,** 28–35.

De Rezende C. L., Uezu A., Scarano F. R. & Araujo D. S. D. (2015) Atlantic forest spontaneous regeneration at landscape scale. *Biodivers. Conserv.* **24,** 2255–72.

Dias A. T. C. & Scarano F. R. (2007) Clusia as nurse plant. In: *Clusia a Woody Neotropical Genus of Remarkable Plasticity and Diversity* (ed U. Lüttge) pp. 55–71. Springer, Berlin; New York.

Dias A. T. C., Zaluar H. L. T., Ganade G. & Sacarano F. R. (2005) Canopy composition influencing plant patch dynamics in a Brazilian sandy coastal plain. *J. Trop. Ecol.* **21,** 343–7.

Dias C. R., Umetsu F. & Breier T. B. (2014) Contribution of artificial perches to seed dispersal and its application to forest restoration. *Ciência Florestal* **24,** 501–7.

Duncan R. S. & Chapman C. A. (1999) Seed dispersal and potential forest succession in abandoned agriculture in tropical Africa. *Ecol. Appl.* **9,** 908–1008.

Espíndola M. B. & Reis A. (2009) A eficiência de poleiros artificiais na restauração ambiental de restinga no Parque Estadual do Rio Vermelho, Florianópolis, SC. In: *Perspectivas Sistêmicas Para a Conservação e Restauração Ambiental: do Pontual ao Contexto* (eds D. R. Três & A. Reis) pp. 217–26. Herbário Barbosa Rodrigues, Itajaí.

Fabricante J. R., Andrade L. A. & Oliveira L. S. B. (2009) Fenologia de *Capparis flexuosa* L. (Capparaceae) no Cariri Paraibano. *Rev. Bras. Ciênc. Agrár.* **4,** 133–9.

Farag P. R. C. (2015) Implantação da RPPN Fazenda Caruara. In: *O Tempo e a restinga*, 1st edn (eds M. G. M. Freire, V. Mussi-Dias, G. M. B. Siqueira & D. F. Nascimento) p. 349. M.G.M. Freire, Campos dos Goytacazes.

Ferreira W. C., Botelho S. A., Davide A. C., Faria J. M. R. & Ferreira D. F. (2010) Regeneração natural como indicador de recuperação de área degradada a jusante da usina hidrelétrica de Camargos. *Rev. Árvore* **34,** 651–60.

Fidalgo A. O., Alcântara R. P. & Caldiron G. T. (2009) Parâmetros de crescimento na avaliação de uma floresta implantada em uma restinga degradada pela mineração. *R. Bras. Bioci.* **7,** 382–6.

Freeman A. N. D., Freebody K., Montenero M., Moran C., Shoo L. P. & Catterall C. P. (2021) Enhancing bird-mediated seed dispersal to increase rainforest regeneration in disused pasture – a restoration experiment. *For. Ecol. Manage.* **479,** 118536.

Galloway J. N., Dentener F. J., Capone D. G. *et al.* (2004) Nitrogen cycles: past, present and future. *Biogeochemistry* **70,** 153–226.

Garbin M. L., Misaki F., Ferreira P. F. *et al.* (2018) Long-term regeneration of a tropical plant community after sand mining. *Ecol. Evol.* **8,** 55712–23.

Gerzson N. D., Fuentes E. V., Hessel M. & Hernández M. I. M. (2012) *Efetividade de medidas complementares de restauração em vegetação de restinga* p. 59. Universidade Federal de Santa Catarina, Florianópolis.

Grombone-Guarantini M. T. & Rodrigues R. R. (2002) Seed bank and seed rain in a seasonal semi-deciduous forest in south-eastern Brazil. *J. Trop. Ecol.* **18,** 759–74.

doi:10.1111/aec.13114

© 2021 Ecological Society of Australia

Grygiel C. E., Norland J. E. & Biondini M. E. (2018) Precision prairie reconstruction (ppr): 15 years of data. *Ecol. Restor.* **36,** 276–83.

Guerra A., Reis L. K., Borges F. L. G. *et al.* (2020) Ecological restoration in Brazilian biomes: identifying advances and gaps. *For. Ecol. Manage.* **458,** 117802.

Guidetti B. Y., Amico G. C., Dardanelli S. & Rodriguez-Cabal M. A. (2016) Artificial perches promote vegetation restoration. *Plant Ecol.* **217,** 935–42.

Gullan P. J. & Cranston P. S. (2007) *Os Insetos: Um Resumo de Entomologia* p. 456. Roca, São Paulo.

Holl K. D. (1998) The roll of bird perching structures in accelerating tropical forest recovery. *Restor. Ecol.* **6,** 253–61.

Holl K. D. & Aide T. M. (2011) When and where to actively restore ecosystems? *For. Ecol. Manage.* **261,** 1558–63.

Holl K. D., Reid J. L., Cole R. J., Oviedo-Brenes F., Rosales J. A. & Zahawi R. A. (2020) Applied nucleation facilitates tropical forest recovery: lessons learned from a 15-year study. *J. Appl. Ecol.* **00,** 1–13.

Howe H. (1999) Seed dispersal by birds and mammals: implications for seedling demography. In: *Reproductive Ecology of Tropical Forest Plants. Man and the Biosphere Series*, Vol. **7** (eds K. S. Bawa & M. Hadley) pp. 191–218. UNESCO, Paris, and Parthenon Publishing Group, Carnforth, UK.

Hulvey K. B., Leger E. A., Porensky L. M. *et al.* (2017) Restoration islands: a tool for efficiently restoring dryland ecosystems? *Restor. Ecol.* **25,** S124–34.

Iguatemy M. A., Vilarinhos J. A., Oda G. A. A., Conde M. M. S. & Zaú A. S. (2020) Artificial perches: ecological and functional aspects of its contribution in the Atlantic forest. *Floresta Ambiente* **27,** e20180301.

Janzen D. (1970) Herbivores and the number of tree species in tropical forest. *Am. Nat.* **104,** 501–28.

Kraaij T. & Ward D. (2006) Effects of rain, nitrogen, fire and grazing on tree recruitment and early survival in bush-encroached savanna. *S. Afr. Plant Ecol.* **186,** 235–46.

Kurtz B. C., Gomes J. C. & Scarano F. R. (2013) Structure and phytogeographic relationships of swamp forests of Southeast Brazil. *Acta Bot. Bras.* **27,** 647–60.

Lacerda L. D., Araujo D. S. D. & Maciel N. C. (1993) Dry coastal ecosystems of the tropical Brazilian coast. In: *Ecosystems of the World 2B: Dry Coastal Ecosystems Africa, America, Asia and Oceania* (ed E. Van der Maarel) pp. 477–93. Elsevier, Amsterdam.

Lewis S. L., Wheeler C. E., Mitchard E. T. A. & Koch A. (2019) Regenerate natural forests to store carbon. *Nature* **568,** 25–8.

Liebig M., Scarano F. R., De Mattos E. A., Zaluar H. L. T. & Luttge U. (2001) Ecophysiological and floristic implications of sex expression in the dioecious neotropical CAM tree Clusia hilariana Schltdl. *Trees Struct. Funct.* **15,** 278–88.

Lobão A. Q. & Kurtz B. (2000) Fitossociologia de um trecho de mata de restinga na Praia Gordas, município de Armação de Búzios, RJ. In: *Proceedings of V Simpósio de Ecossistemas Brasileiros*, Vol. **3** (org ACIESP-SP) pp. 66–75. Watanabe, S., Vitória.

Lorenzi H. (2002) *Árvores Brasileiras: Manual de Identificação e Cultivo de Plantas Arbóreas do Brasil,* 4th ed. Instituto Plantarum, São Paulo.

Lorenzo L. & Campagnaro V. H. (2017) Litterfall production as a function of planting seedlings system in a two years forest restoration area in the Coastal-Plain of Caraguatatuba, São Paulo, Brazil. *Rev. Árvore* **41,** e410319.

Magnago L. F. S., Martins S. V., Schaefer C. E. G. R. & Neri A. V. (2013) Structure and diversity of restingas along a flood gradient in southeastern Brazil. *Acta Bot. Bras.* **27,** 801–9.

Manoliadis O. G. (2002) Development of ecological indicators – a methodological framework using compromise programming. *Ecol. Ind.* **2,** 169–76.

Martin L., Suguio K., Dominguez J. M. L. & Flexor J. M. (1997) *Geologia do quaternário costeiro do litoral norte do Rio de Janeiro e do Espírito Santo*, p. 112. CPRM/FAPESP, Belo Horizonte.

Marques M. C. M., Burslem D. F. R. P., Britez R. M. & Silva S. M. (2009) Dynamics and diversity of flooded and unflooded forests in a Brazilian Atlantic rain forest: a 16-year study. *Plant. Ecol. Div.* **2,** 57–64.

Marques M. C. M., Silva S. M. & Liebsch D. (2015) Coastal plain forests in southern and southeastern Brazil: ecological drivers, floristic patterns and conservation status. *Braz. J. Bot.* **38,** 1–18.

Martinelli G. & Moraes M. A. (2013). *Livro Vermelho da Flora do Brasil*, 1st ed. 1100 p. Andrea Jakobsson: Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, Rio de Janeiro.

Martini A. M. Z. & Santos F. A. M. (2007) Effects of distinct types of disturbance on seed rain in the Atlantic forest of NE Brazil. *Plant Ecol.* **190,** 81–95.

Matthews J. W., Peralta A. L., Flanagan D. N. *et al.* (2009) Relative influence of landscape vs. local factors on plant community assembly in restored wetlands. *Ecol. Appl.* **19,** 2108–23.

McClanahan T. R. & Wolfe R. W. (1993) Accelerating forest succession in a fragmented landscape: the role of birds and perches. *Conserv. Biol.* **7,** 279–88.

Melo Jr J. C. F. & Boeger M. R. T. (2015) Leaf traits and plastic potential of plant species in a light-edaphic gradient from restinga in southern Brazil. *Acta Biol. Colomb.* **21,** 51–62.

Menezes L. T., Peixoto A. L. & Araujo D. S. D. (2005) *História natural da Marambaia.*, p. 288. EDUR, Seropédica.

Myers N., Mittermeier R., Mittermeier C., Da Fonseca G. A. & Kent J. (2000) Biodiversity hotspots for conservation priorities. *Nature.* **403,** 853–58.

Oliveira A. K. M., Bocchese R. A., Pereira K. R. F. & Carvalho T. D. (2018) Seed deposition by birds on artificial perches on diferent distances from a gallery forest in the Cerrado area. *Floresta* **48,** 363–72.

Oliveira R. J., Mantovani W. & Melo M. M. R. F. (2001) Estrutura do componente arbustivo-arbóreo da floresta atlântica de encosta, Peruíbe, SP. *Acta Bot. Bras.* **15,** 391–412.

Padilla F. M. & Pugnaire F. I. (2012) Sucesión y restauración en ambientes semiáridos. *Ecossistemas* **13,** 55–8.

Pennington T. D. (1997) *The Genus Inga: Botany* p. 844. Royal Botanical Garden, London.

Pereira O. J. (2003) Restinga: origem, estrutura e diversidade. In: *Desafios da botânica brasileira no novo milênio: inventário, sistematização e conservação da biodiversidade vegetal* (eds M. G. Jardim, M. N. C. Bastos & J. U. M. Santos) pp. 177–9. Museu Paraense Emílio Goeldi, Belém.

Perring M. P., Erickson T. E. & Brancalion P. H. S. (2018) Rocketing restoration: enabling the upscaling of ecological restoration in the Anthropocene. *Restor. Ecol.* **26,** 1017–23.

Piiroinen T., Nyeko P. & Roininen H. (2015) Natural establishment of indigenous trees under planted nuclei: a study from a clear-felled pine plantation in an afrotropical rain forest. *For. Ecol. Manage.* **345,** 21–8.

Piotto D., Montagnini F., Thomas W., Ashton M. & Oliver C. (2009) Forest recovery after swidden cultivation across a 40-year chronosequence in the Atlantic forest of southern Bahia, Brazil. *Plant Ecol.* **205,** 261–72.

Primo O. S. & Ilha A. S. (2008) *Estudo técnico para criação do parque estadual para proteção das restingas de Grussaí e Iquipari e da Lagoa Salgada*. Superintendência de Biodiversidade Secretaria de Estado do Ambiente – SEA e Instituto Estadual de Florestas IEF/RJ.

Ramírez-Soto A., Lucio-Palacio C. R., Rodríguez-Mesa R. *et al.* (2018) Restoration of tropical montane cloud forests: a six-prong strategy. *Restor. Ecol.* **26,** 206–11.

Reinert F., Roberts A., Wilson J. M., Ribas L., Cardinot G. & Griffiths H. (1997) Gradation in nutrient composition and photosynthetic pathways across the restinga vegetation of Brazil. *Bot. Acta* **110,** 135–42.

Reis A., Bechara F. C., Espindola M. B., Vieira N. K. & Souza L. L. (2003) Restauração de áreas degradadas: a nucleação como base para incrementar os processos sucessionais. *Nat. Conserv.* **1,** 28–36, 85–92.

Reis A., Bechara F. C. & Tres D. R. (2010) Nucleation in tropical ecological restoration. *Sci. Agricola* **67,** 244–50.

Reis-Duarte R. M. & Casagrande J. C. (2006) A interação solo-planta na recuperação de áreas degradadas. In: *Manual para recuperação de áreas degradadas do Estado de São Paulo: Matas Ciliares do Interior Paulista* (ed L. M. Barbosa) pp. 52–69. Instituto de Botânica, São Paulo.

Rey Benayas J. M., Martínez-Baroja L., Pérez-Camacho L., Villar-Salvador P. & Holl K. D. (2015) Predation and aridity slow down the spread of 21-year-old planted woodland islets in restored Mediterranean farmland. *New For.* **46,** 841–53.

Robinson G. R. & Handel S. N. (2000) Directing spatial patterns of recruitment during an experimental urban woodland reclamation. *Ecol. Appl.* **10,** 174–88.

Rodrigues R. R. & Gandolfi S. (2004) Conceitos, tendências e ações para a recuperação de florestas ciliares. In: *Matas Ciliares Conservação e Recuperação* (eds R. R. Rodrigues & H. F. Leitão-Filho) pp. 235–47. Universidade de São Paulo, Piracicaba.

RStudio Team (2020) *RStudio: Integrated Development Environment for R*. RStudio, PBC, Boston.

Sá C. F. C. (2002) Regeneration of a stretch of restinga forest of the State Ecological Reserve Jacarepiá, Saquarema, State Rio de Janeiro: II – shrub strata. *Rodriguésia* **53,** 5–23.

Saha S., Kuehne C. & Bauhus J. (2016) Lessons learned from oak cluster planting trials in central Europe. *Can. J. For. Res.* **47,** 139–48.

Salis S. M. & Crispim S. M. A. (2006) *Densidades de Árvores Listadas como Ameaçadas de Extinção na Bacia do Alto Paraguai. Technical Communication*, Vol. **54**. Embrapa, Corumbá.

Sansevero J. B. B., Alonso J. M., Booth M. C. *et al.* (2018) On the teaching of ecological restoration in Brazil: an analysis of postgraduate courses. *Restor. Ecol.* **26,** 997–1004.

Sansevero J. B. B. & Garbin M. L. (2015) Restoration success of tropical forests: the search for indicators. In: *Sustainability Indicators in Practice* (eds A. Latawiec & D. Agol) pp.146–59. De Gruyter Open Ltd., Warsaw.

Santos-Filho F. S., Almeida E. B. Jr, Soares C. J. R. S. & Zickel C. S. (2015) Flora and woody vegetation structure in an insular area of restinga in Brazil. *Int. J. Ecol. Environ. Sci.* **41,** 147–60.

Scarano F. R. (2002) Structure, function and floristic relationships of plant communities in stressful habitats marginal to the Brazilian Atlantic rain forest. *Ann. Bot.* **90,** 517–24.

Scarano F. R. (2006) Plant community structure and function in a swamp forest within the Atlantic rain forest complex: a synthesis. *Rodriguesia* **57,** 491–502.

Scarano F. R., Ribeiro K. T., de Moraes L. F. D. & de Lima H. C. (1997) Plant establishment on flooded and unflooded patches of a freshwater swamp forest in southeastern Brazil. *J. Trop. Ecol.* **13,** 793–803.

Scherer A., Silva F. M. & Baptista L. R. M. (2005) Florística e estrutura do componente arbóreo de matas de restinga arenosa no Parque de Itapuã, RS, Brasil. *Acta Bot. Bras.* **19**(4)**,** 717–26.

Schupp E. (1995) Seed-seedling conflicts, habitat choice, and patterns of plants recruitment. *Am. J. Bot.* **82,** 399–409.

Sheil D. & May R. (1996) Mortality and recruitment rate evaluations in heterogeneous tropical forests. *J. Ecol.* **84,** 91–100.

Shiels A. B. & Walker L. R. (2003) Bird perches increase forest seeds on Puerto Rican landslides. *Restor. Ecol.* **11,** 457–65.

Siddique I., Engel V. L., Parrota J. A. *et al.* (2008) Dominance of legumie trees alters nutrient relations in mixed species forest restoration plantings within seven years. *Biogeochemistry* **88,** 89–101.

Silliman B. R., Schrack E., He Q. *et al.* (2015) Facilitation shifts paradigms and can amplify coastal restoration efforts. *Proc. Natl. Acad. Sci. USA.* **112,** 14295–300.

Silva S. M. (2003) Diagnóstico das restingas do Brasil. In: Fundação Bio Rio (ed.). Workshop Avaliação e Ações Prioritárias Para a Conservação da Biodiversidade da Zona Costeira, Ilhéus. Available from URL: http://brazilrounds.anp.gov.br/arquivos/Round7/arquivos_r7/PERFURACAO_R7/refere/Restingas.pdf

Silva A. C. C., Prata A. P. N., Mello A. A. & Santos A. C. A. S. (2013) Síndromes de dispersão de Angiospermas em uma Unidade de Conservação na Caatinga, SE, Brasil. *Hoehnea* **40,** 601–9.

Smith T. B., Kark S., Schneider C. J., Wayne R. K. & Moritz C. (2001) Biodiversity hotspots and beyond: the need for preserving environmental transitions. *Trends Ecol. Evol.* **16,** 431.

Sperry J. S. & Hacke U. G. (2002) Desert shrub water relations with respect to soil characteristics and plant functional type. *Funct. Ecol.* **16,** 367–78.

Strassburg B. B. N., Barros F. S. M., Crouzeilles R. *et al.* (2016) The role of natural regeneration to ecosystem services provision and habitat availability: a case study in the Brazilian Atlantic Forest. *Biotropica* **48,** 890–9.

Sztutman M. & Rodrigues R. R. (2002) O mosaico vegetacional numa área de floresta contínua da planície litorânea, Parque Estadual da Campina do Encantado, Pariquera-Açu, SP. *Rev. Bras. Bot.* **25,** 161–76.

Tieppo F. M. M. (2015) Testing the applied nucleation approach for restoring a naturally patchy coastal Restingas shrubland, Rio de Janeiro State, Brazil. Mastership dissertation. Institut des sciences et industries du vivant et de l'environnement. Paris, France.

© 2021 Ecological Society of Australia

Tieppo F. M. M. & Brancalion P. H. S. (2016). Identificando "espécies-estrutura" em técnica de nucleação aplicada para restauração de restingas. In: *IV Congresso Brasileiro de Reflorestamento Ambiental*. Rio de Janeiro. Resumo. Rio de Janeiro, RJ, 19–21 October.

Tomazi A. L., Fuente E. V., Hessel M. & Hernández M. I. M. (2012) *Diversidade de formas de vida vegetal como indicador do status de regeneração de uma restinga arbustivo-arbórea em processo restaurativo* p. 125. Universidade Federal de Santa Catarina, Florianópolis.

Tres D. R. & Reis A. (2009) Seed rain of a riparian forest under ecological restoration process within a farma producing *Pinus Taeda* L., Rio Negrinho, Santa Catarina. In: *Perspectivas sistêmicas para a conservação e restauração ambiental: do pontual ao contexto* (eds D. R. Três & A. Reis) pp. 217–26. Herbário Barbosa Rodrigues, Itajaí.

Tres D. R., Sant'anna, C. S., Basso S., Langa R., Ribas J. R. & Reis A. (2007) Poleiros artificiais e transposição de solo para a restauração nucleadora em áreas ciliares. *Rev. Bras. Biocienc.* **5,** 312–4.

Vadigi S. & Ward D. (2013) Shade, nutrients, and grass competition are important for tree sapling establishment in a humid savanna. *Ecosphere* **4,** art142.

Veloso H. P., Rangel Filho A. L. R. & Lima J. C. A. (1991) *Classificação da Vegetação Brasileira, adaptada a um sistema universal*, p. 112. IBGE, Rio de Janeiro.

Vitousek P. M. & Howarth R. W. (1991) Nitrogen limitation on land and in the sea: how can it occur?. *Biogeochemistry*. **13,** 87–115.

Vogel H. F., Spotswood E., Campos J. B. & Bechara F. C. (2016) Annual changes in a bird assembly on artificial perches: implications for ecological restoration in a subtropical agroecosystem. *Biota Neotrop.* **16,** e0069.

Wang B. C. & Smith T. B. (2002) Closing the seed dispersal loop. *Trends Ecol. Evol.* **17,** 379–85.

White T. C. R. (1984) The abundance of invertebrate herbivores in relation to the availability of nitrogen in stressed food plants. *Oecologia* **63,** 90–105.

Wortley L., Hero J. M., Howes M., Ortley L., Hero J. M. & Howes M. (2013) Evaluating ecological restoration success: a review of the literature. *Restor. Ecol.* **21,** 537–43.

Yadavand A. S. & Gupta S. K. (2009) Natural regeneration of tree species in a tropical dry deciduous thorn forest in Rajasthan, India. *Natl. Inst. Ecol.* **20,** 14.

Yirdaw E. & Luukkanen O. (2003) Indigenous woody species diversity in *Eucaliptus globulus* Labill plantations in the Ethiopian highlands. *Biodivers. Conserv.* **12,** 567–82.

Zahawi R. A. & Augspurger C. K. (2006) Tropical forest restoration: tree islands as recruitment foci in degraded lands of Honduras. *Ecol. Appl.* **16,** 464–78.

Zaluar H. L. T. & Scarano F. R. (2000) Facilitação em restingas de moitas: um século de busca por espécies focais. In: *Ecologia de restingas e lagoas costeiras* (eds F. A. Esteves & L. D. Lacerda) pp. 3–23. NUPEM, UFRJ, Rio de Janeiro.

Zamith L. R. & Scarano F. R. (2004) Produção de mudas de espécies das Restingas do município do Rio de Janeiro, RJ, Brasil. *Acta Bot. Bras.* **18,** 161–76.

Zamith L. R. & Scarano F. R. (2006) Restoration of a restinga sandy coastal plain in Brazil: survival and growth of planted woody species. *Restor. Ecol.* **14,** 87–94.

Zamith L. R. & Scarano F. R. (2010) Restoration of a coastal swamp forest in southeast Brazil. *Wetl. Ecol. Manage.* **18,** 435–48.

SUPPORTING INFORMATION

Additional supporting information may/can be found online in the supporting information tab for this article.

Appendix S1. Species used in the reforestation of RPPN Fazenda Caruara, São João da Barra, RJ (Martinelli & Moraes 2013).

Appendix S2. Mean values of height (*H*) and diameter at ground level (DGL) ± 1 standard deviation (SD) and number of individuals of each species observed in November 2016.

© 2021 Ecological Society of Australia

doi:10.1111/aec.13114