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Reference and comparison values for ecological indicators in assessing restoration areas in the Atlantic Forest

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A R T I C L E I N F O

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Reference ecosystems

A B S T R A C T

Information on reference values is one of the great demands in ecological restoration, as they enable evaluating the restoration progress and taking adaptive management measures. Here we aimed to: (i) verify whether ecological indicators are influenced by the area of reference ecosystems (mature fragments); (ii) determine reference and comparison values for comparing the restoration progress; and (iii) check how long restoration forests take to reach naturalness values that are like the reference ecosystems (and can therefore be considered restored). We used the Brazilian Atlantic Forest as an object of study and compiled information about 967 secondary, mature and restoration forests in a wide geographical extension. In total, 14 ecological indicators were assessed in a sampling area of 1,928,024 m^2. We used simple linear regression to analyze the data and descriptive statistics for creating the reference and comparison values. We found that ecological indicators were not related to the area of mature fragments. Thus, they are useful for monitoring reference ecosystems of different sizes, and more attention can be given to the degree of conservation of the ecosystems. We defined intermediate and final reference values from secondary and mature forests, respectively. We also established comparison values for several restoration stages using data of planting, assisted and unassisted restoration areas. At the same time, we applied the concept of naturalness in restoration and obtained a continuum of naturalness, which was very useful for tracking the restoration progress. With the reference and comparison values determined, restoration practitioners can evaluate their restoration areas by comparing their monitoring results with ours. Moreover, by using the naturalness concept we verified that indicators can have different restoration trajectories. Some indicators reached similar naturalness levels as references from the beginning of restoration, but others required between one and two decades to recover. This study is the first to create evaluation criteria for forest restoration based on a large data set, and we hope that similar studies can be developed in other biomes.

1. Introduction

Among the key issues of high interest in ecological restoration is the search for reference information to set goals and measure restoration success (White and Walker, 1997). Mature forest stands are often used as references for ecological restoration and ecological indices derived from such stands provide valuable framework for the evaluation of restoration progress (Brancalion et al., 2015). The reference values (also called evaluation criteria) are objectives to be achieved for each ecological indicator (Brancalion et al., 2015). An ecological indicator, in its turn, is a measure or component, which describe conditions and establish environmental goals, and can be used as a framework for the monitoring and assessment of restoration areas (Heink and Kowarik, 2010). The tree species richness, canopy cover and seedling recruitment are some examples of (plant) ecological indicators used to monitor the recovery of the diversity, structure and function in restoration areas (Ruiz-Jaen and Aide, 2005).

In ecological restoration, differences between the reference conditions and the current situation of the area under restoration are used to evaluate the success of the recovery and to ascertain the need for corrective actions (Moore et al., 1999). A concept that is increasing in importance in some parts of the world, and which basically considers

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this difference between ecosystems is that of naturalness (McRoberts et al., 2012). Naturalness is the similarity of the current state of an ecosystem with its natural state (Winter, 2012). Naturalness can be better described as a continuous variable, where forests and landscapes span a gradient from mainly artificial forests through semi-natural to naturally dynamic forests (Roberge et al., 2008).

At the artificial end, ecosystems are denaturalized or impacted (Angermeier, 2000) and have high hemeroby, which is a measure of the degree of human impact in an ecosystem (Hill et al., 2002). In the context of ecological restoration, naturalness and hemeroby are rarely (or never) used terms, although they represent the observed situations very well. For example, an area that has recently undergone a restoration process by seedling planting has high human intervention, and therefore high hemeroby. With the advancement of ecological restoration, the vegetation of this site should develop and resemble ecosystems with little human intervention (mature ecosystems) (SER – Society for Ecological Restoration International Science Policy Working Group, 2004), meaning that it will have high naturalness, low hemeroby, and can be considered restored.

The way to know what nature produces in the absence of (or minimal) human impacts is based on knowledge of reference values, which are those observed in natural landscapes and mature forests (Winter et al., 2010). In addition, it is also important to know the values of secondary forests and older restoration areas because they can serve as intermediate goals for adaptive management (Brancalion et al., 2015). Thus, in creating the expected reference values for different restoration ages, a continuum of naturalness is obtained in a temporal scale (low naturalness in the areas in initial process of restoration up to maximum naturalness in the reference ecosystems). Knowing this continuum of naturalness enables both a better understanding of the trajectory of the restoration areas and the projection of the age at which they will reach satisfactory values of naturalness.

Our aim in this study was to clarify three points that are currently essential for ecological restoration. First, we verified whether some ecological indicators commonly used to evaluate restoration forests in Brazil and elsewhere are influenced by the total area of the reference ecosystems, considering that different-sized fragments can be used as reference ecosystems for forest restoration. Second, we established reference and comparison values for comparing the restoration progress in Semideciduous Seasonal Forests, Broadleaf Rainforest and Mixed Rainforests in the Brazilian Atlantic Forest. And third, we checked if and when the restoration forests reach naturalness values similar to the reference ecosystems and can therefore be considered restored.

2. Material and methods

2.1. Study areas

In this study we examined a combination of restoration areas and reference ecosystems (described below) totaling 967 stands and 1,928,024 m^2 of sampling area in the Brazilian Atlantic Forest (Fig. 1). The Brazilian Atlantic Forest is one of the most biodiverse and threatened biomes of the planet, being listed as one of the 25 priority biodiversity hotspots for conservation (Myers et al., 2000). The Atlantic Forest covered an area equivalent to 1,315,460 km^2 (Fig. 1a), but its current cover is estimated to be only 11.4–16% (Ribeiro et al., 2009). The original composition of the Brazilian Atlantic Forest was a mosaic of vegetation defined as dense (or broadleaf), open and mixed rainforests, deciduous and semideciduous seasonal forests, altitude grasslands, mangroves and salt marches (SOS Mata Atlântica, 2019).

2.2. Restoration monitoring database

In this study we used information from a monitoring database of areas undergoing restoration in the Brazilian Atlantic Forest to establish comparison values for young forests (up to 7 years of age). In the database the monitoring results of 550 restoring forests in three physiognomies were accessed: Semideciduous Seasonal Forests, Broadleaf Rainforests and Mixed Rainforests (sometimes called Araucaria Forests). Of the 550 forests, 152 are in recovery by seedling planting (about 50 species were planted at each site, mostly regional species) (Fig. 1, blue symbols). These projects were implemented at sites previously used for mechanized agriculture, mainly sugar cane plantations. Therefore, they were non-resilient areas.

The other 398 forests are in recovery by assisted natural regeneration (ANR), which is the induction of natural regeneration with interventions to accelerate ecological restoration (Shono et al., 2007), for example, removing invasive exotic grasses (Fig. 1, green symbols). These ANR areas were previously used for eucalyptus and pine commercial plantations. After the monocultures were extracted the areas were fenced and abandoned for growing vegetation that developed in the understory of the exotic plantations. These were resilient areas, with potential for natural regeneration.

The predefined goals for these restoration projects were a rapidly recovery of the canopy cover in the areas up to two years and the species richness in the older areas (both for planting and ANR areas). All areas were monitored using the same set of ecological indicators listed in Table 1. We point out that these are the indicators that are being used in a monitoring protocol (described below), but they are not necessarily the best ones. Studies like this help to clarify if these are indeed good ecological indicators.

The monitoring and assessment of these 550 restoration forests occurred according to the Monitoring Protocol for Forest Restoration Programs and Projects in the Atlantic Forest (Protocol, 2013). The Monitoring Protocol was created to enable a more efficient evaluation of restoration strategies, identify triggers for corrective actions, compare results between projects, and improve future restoration efforts (Viani et al., 2017). This protocol is part of the Pact for the Restoration of the Atlantic Forest, a program launched in 2009 for articulating several institutions to unite efforts and resources for restoring and preserving the Brazilian Atlantic Forest (Pact for Restoring the Atlantic Forest, 2009).

The projects were monitored and evaluated through non-permanent plots of 60 m^2, 100 m^2, or 120 m^2 randomly distributed. The number of sample plots varied according to the size of the total area of the projects. In projects of 0.5 hectare (ha) or less, 1–4 plots were used; in projects from 0.6 to 1 ha, five plots were used; and in projects > 1-ha five plots were used plus one plot for each additional hectare (e.g., in an 8-ha project, 12 plots were randomly distributed). In total, 4811 plots were allocated, totaling a sampling area of 485,980 m^2, of which 310,160 m^2 in planting areas and 175,820 m^2 in ANR areas.

We identified the species and genera according to the List of Species of the Brazilian Flora (Brazilian Flora, 2016), and the families according to the Angiosperm Phylogeny Group (APG IV, 2016). Moreover, the online List of Species of the Brazilian Flora and National Database of Invasive Exotic Species (Brazilian Flora, 2016; I3N Brazil Database, 2016) databases were used to determine the phytogeographic origin of the species, herein called regionality. We classified the species as to their dispersion mode into zoochoric and non-zoochoric according to Lorenzi (1998, 2009b, 2009a), Souza & Lorenzi (2005) and online databases (IPÊ, 2016; IPEF, 2016; Lopes, 2012). Finally, species were classified as to their successional stage into pioneers and non-pioneers (Gandolfi et al., 1995; IPEF, 2016; Lopes, 2012).

2.3. Survey of reference vegetation

We also conducted a broad search in the scientific literature in order to establish the comparison values (i.e. values based on restoration forests) and reference values (based on secondary and mature forests). We searched for studies developed in the Brazilian Atlantic Forest, in older areas under restoration and in secondary and mature forests. The following criteria were adopted to select the studies: (i) articles

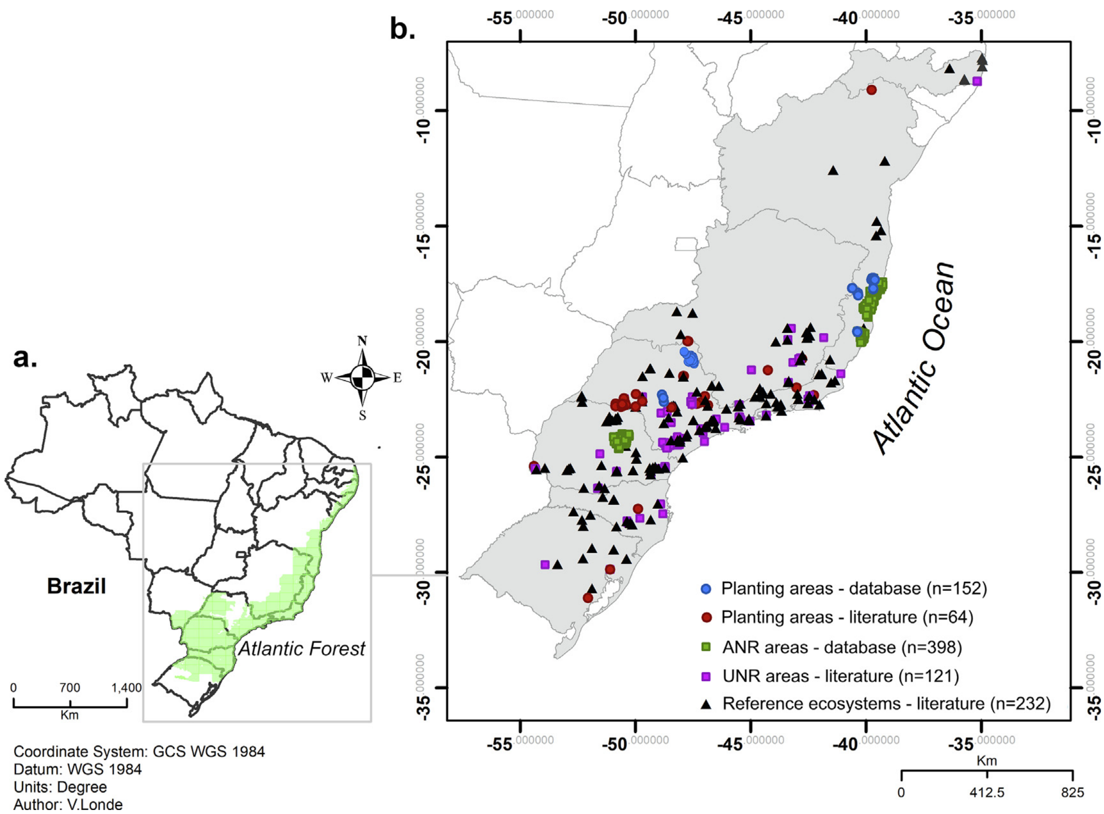


Fig. 1. Geographic range of the Brazilian Atlantic Forest (a) and location of the 967 study areas (b). Information on areas comes from a database of monitoring of restoration areas (blue and green symbols) and queries in the literature (red, purple and black symbols). The sampling area totals 1,928,024 m^2 — the largest monitoring database we know of. The numbers in parentheses are the study totals in each category. ANR = assisted natural regeneration; UNR = unassisted natural regeneration.

Table 1
Ecological indicators used to monitor and assess restoration areas/projects registered in the Pact for the Restoration of the Brazilian Atlantic Forest. Based on the Monitoring Protocol (Protocol, 2013).

Ecological indicator	Description
Aggressive exotic grasses (%)	Soil cover by exotic and/or invasive grasses[†]
Canopy coverage (%)	Soil cover by tree crowns
Mean height (m)	Height of planted or regenerating individuals
Basal area (m^2/ha)	Estimated from planted or regenerating individuals with DBH[‡] > 4.77 cm
Tree density (ind./ha)	
Tree species richness (n)	
Regional tree species (%)	Proportion of species of planted or regenerating individuals with DBH > 4.77 cm
Zoochoric tree species (%)	
Non-pioneer tree species (%)	
Density of regenerating species (ind./ha)	Regenerating (non-planted) individuals with DBH ≤ 4.77 cm
Regenerating species richness (n)	
Regional regenerating species (%)	Proportion of species based on regenerating individuals with DBH ≤ 4.77 cm
Zoochoric regenerating species (%)	
Non-pioneer regenerating species (%)	

[†] This indicator was estimated in three plots of $2 \times 2\,m^2$ within the plots of 60, 100 or 120 m^2.
[‡] Diameter at the breast height (130 cm above soil).

published in a journal indexed with peer review; (ii) executed in the physiognomies Semideciduous Seasonal Forest or Broadleaf Rainforest or Mixed Rainforest; (iii) clear indication of the geographical coordinates, or elements for locating the study site; (iv) information on the total area of the fragment and details of the sampling procedures; and (v) use of the same ecological indicators used in assessments of forests in restoration by the Pact (Table 1).

We initially performed searches in the main Brazilian scientific journals that publish the desired themes. Key terms such as 'Atlantic Forest' and 'restoration', 'floristic', 'phytosociology', in English and Portuguese were used to obtain more accurate results. In journals that did not have search engines, each published volume was investigated. In addition to the Brazilian journals, searches were made in databases such as Google Scholar. (The list of journals and number of articles consulted can be found in the Supplementary material 1).

We then extracted the geographic location of the study areas (municipality and coordinates), and information on the forest physiognomy, the total area of the fragments (ha), the sampled area (m^2), the fragment age (in years, when applied), the tree stratum (DBH > 4.77 cm or > 1.30 m height), and the regenerating stratum (DBH ≤ 4.77 cm or ≤ 1.30 m) from each publication. Many studies did not classify species as to regionality, successional group or dispersal syndrome. In these cases, species were classified based on the literature (Gandolfi et al., 1995; IPÊ, 2016; IPEF, 2016; Lopes, 2012; Lorenzi, 2009a, 2009b, 1998) and from our experience.

2.4. Relationship between reference ecosystems and ecological indicators

One of the factors that determine the choice and use of a given reference ecosystem is its total size/area (White and Walker, 1997), which can influence the obtained results and the data comparison. We investigated which ecological indicators were influenced by the total area of the reference ecosystems. As some mature fragments were very large (e.g. 48,000 ha), and restoration areas are unlikely to be of this size, mature fragments of up to 500 ha were used in the analyzes. This cut in size corresponds to five times the size of the largest restoration area of our database (i.e. 104 ha). We initially checked the basic assumptions of the dependent variables and then applied simple linear regressions to test relationships between the fragment area (independent variable) and each ecological indicator (dependent variable). The percentage units were turned into logit (Warton and Hui, 2011), and the fragment areas into square root for better adjustment of the data. We considered as good indicators the descriptors that did not have significant relation with the fragment area ($\alpha > 0.05$) or have low coefficient of determination (R^2).

2.5. Defining comparison and reference values

We call comparison values the ones calculated for the ecological indicators in restoration forests with different ages (from one month up to ± 60 years); and intermediate and final reference values those calculated for secondary and mature forests, respectively. Secondary forests were considered to have been abandoned for at least 80 years, and mature forests as those described in the original studies as primary, mature or old-growth and in good condition, usually located in protected areas. The reference ecosystems were used as the natural state to measure naturalness (Winter, 2012) of forests in process of restoration (i.e., the degree of similarity to references).

Initially we divided the areas by physiognomy (Semideciduous Seasonal Forest, Broadleaf Rainforest, and Mixed Rainforest). Then, the restoration areas were grouped into age classes and restoration method: (i) seedling planting (implemented in non-resilient sites); (ii) assisted natural regeneration (ANR) (in our case, this kind of restoration occurred after cutting and abandoning pine and eucalyptus commercial plantations); and (iii) unassisted natural regeneration (UNR) (also called passive restoration because the site is fenced to cease the stressors and natural regeneration occurs without further intervention (Morrison and Lindell, 2011)).

To obtain the comparison values (those based on restoration areas of different ages), we calculated the median and the semi-amplitude of the confidence interval (SACI) for each one of the 14 ecological indicators by age and restoration method in the three physiognomies (n = 42). The same approach was used to calculate the intermediate reference values (based on secondary forests) and final reference values (based on mature forests) for each ecological indicator.

Dispersion diagrams were subsequently built by plotting the median and SACI of the calculated values of the indicators on the Y axis and the age of the restoring forests on the X axis. This way we could check from which age of restoration the forest hemeroby decreased and the naturalness increased, attaining similar values to the references; in other words, we could verify when the comparison values of the restoration forests overlapped the reference values of the reference ecosystems.

In addition, we checked whether the naturalness (represented by the medians) significantly increased over time. To do so, the data were submitted to simple linear regressions, in which the restoration time was the independent variable and the ecological indicators were the dependent variables. We did this for every indicator in each physiognomy and restoration method. The data normality was tested by Shapiro-Wilk tests and the homogeneity of variances by Levene tests. Some variables were turned into log when needed. All statistical analyzes were performed in SPSS Statistics 23 software.

3. Results

3.1. Data collection from the literature

We analyzed 1673 scientific articles in total and extracted information from 211 of them. These articles represented 417 study areas (Fig. 1, red, purple and black symbols). These areas totaled 1,442,044 m^2 of sampling area. Planting forests (n = 64) totaled 127,852 m^2 of sampling area, unassisted natural regeneration areas (n = 121) totaled 207,822 m^2, secondary forests (n = 33) totaled 79,535 m^2 and mature forests (n = 199) totaled 1,026,835 m^2.

More studies were carried out on Semideciduous Forests (38.85%) and Broadleaf Rainforests (38.37%) than on Mixed Rainforests (22.78%). In addition, a small amount of data on Broadleaf and Mixed Rainforest areas recovering by planting were registered. A variable amount of information for each age, restoration method and ecological indicators were found. In general, few studies have evaluated the cover of aggressive grasses and canopy cover in older forests.

3.2. Relationship between reference ecosystems and ecological indicators

We disregarded grass cover and the proportions of regional tree and regenerating species in this analysis due to insufficient information gathered from the literature. Thus, 11 ecological indicators were analyzed in reference ecosystems, of which basal area was the only one with a significant relation with the fragment area, yet with a very low coefficient of determination (Supplementary material 2). Hence, all ecological indicators analyzed are good enough to be used in evaluating reference ecosystems, since they were not influenced by the fragment areas.

3.3. Comparison and reference values for the Atlantic Forest

We generally noticed similar results between the intermediate and final reference ecosystems for all the evaluated indicators, since their confidence intervals overlapped in all cases (Fig. 2). Restoration forests of up to 15 years old had problems with the occurrence of aggressive grasses in the understory. In the first year after implementing the restoration actions we noticed low grass cover, especially when the planting restoration method was used. However, the grass cover significantly increased after two years (Supplementary material 3). Only a few areas of Semideciduous Forest (0–3 years and 5–6 years) showed grass cover naturalness (similarity of the restoration areas with the reference ecosystems) compatible with the reference value (Fig. 2. a1).

Canopy cover tended to increase in all three phytophysiognomies over time (Fig. 2. b1–3, Supplementary material 3). Canopy cover naturalness attained the confidence interval of the reference values after three years of restoration, but only the oldest recovering forests (12, 22, 50 and 55-year-old) had median values like the references. Basal area and height are restored more slowly, since at least 10 years were necessary for these indicators to recover (Fig. 2c, d). We observed a significant increase in these indicators in the three phytophysiognomies throughout the restoration (Supplementary material 3).

In general, planting forests had similar tree density to the intermediate and final reference ecosystems since the first year (Fig. 2e). Restoration forests based on natural regeneration (assisted and unassisted) obviously required more time to recover tree density (around 20 years), but then they exceeded the reference ecosystems.

Reference values of tree species richness in Seasonal Semideciduous Forests and Mixed Rainforests was 60–90 species, and most of the planting forests had naturalness values like the references since the first years (Fig. 2. f1 and f3). When the ANR and UNR restoration methods have been used, only forests over thirteen years old reached tree species richness naturalness like the reference ecosystems. In the Broadleaf Rainforest, the reference values for tree species richness was quite high (138 species), but the restoration areas also reached similar naturalness (Fig. 2. f2). As expected, we observed a significant increase in species richness in natural regeneration areas with advancement of ecological restoration (Supplementary material 3).

In the three phytophysiognomies, the proportion of regional tree species remained around 100% since the first year in both restoration methods (Fig. 2. g1–g3). The proportions of zoochoric and non-pioneer tree species also remained within the confidence interval of the reference values, increasing with advancement of the restoration (Fig. 2. h, i, Supplementary material 3).

In the Semideciduous Forests, the regenerating density and

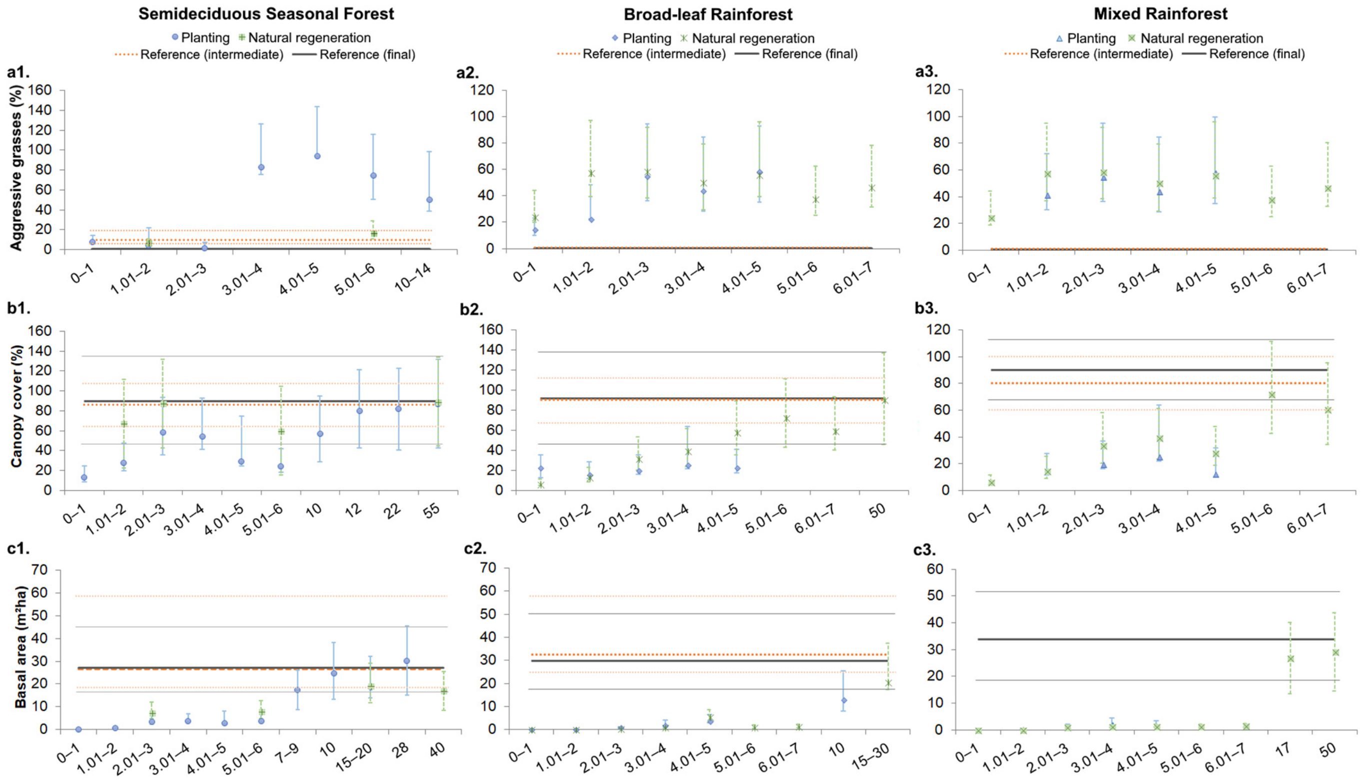


Fig. 2. Final (black horizontal lines) and intermediate (orange horizontal lines) reference values and comparison values (blue and green† symbols) for each ecological indicator. Naturalness continuity in three phytophysiognomies of the Atlantic Forest is also evidenced: of low naturalness in the 0–1-year-old areas until maximum naturalness in the final references. The thinner horizontal lines and the vertical bars represent the semi-amplitude of the confidence interval (SAIC) around the median. †Green symbols combine assisted (< 7-year-old) and unassisted (≥7-year-old) natural regeneration areas.

regenerating species richness took at least a decade to recover (Fig. 2. j1, k1). On the other hand, the regenerating density did not reach appropriate values in the Broadleaf Rainforest and Mixed Rainforest, even after two decades (Fig. 2. j2–3). Conversely, the regenerating species richness recovered more rapidly in the Broadleaf Rainforest and Mixed Rainforest, especially in the natural regeneration areas (Fig. 2. k2–3). The planting areas in the Semideciduous Seasonal Forest and the natural regeneration areas in the Broadleaf and Mixed Rainforests showed a significant increase in the regenerating species richness over time (Supplementary material 3).

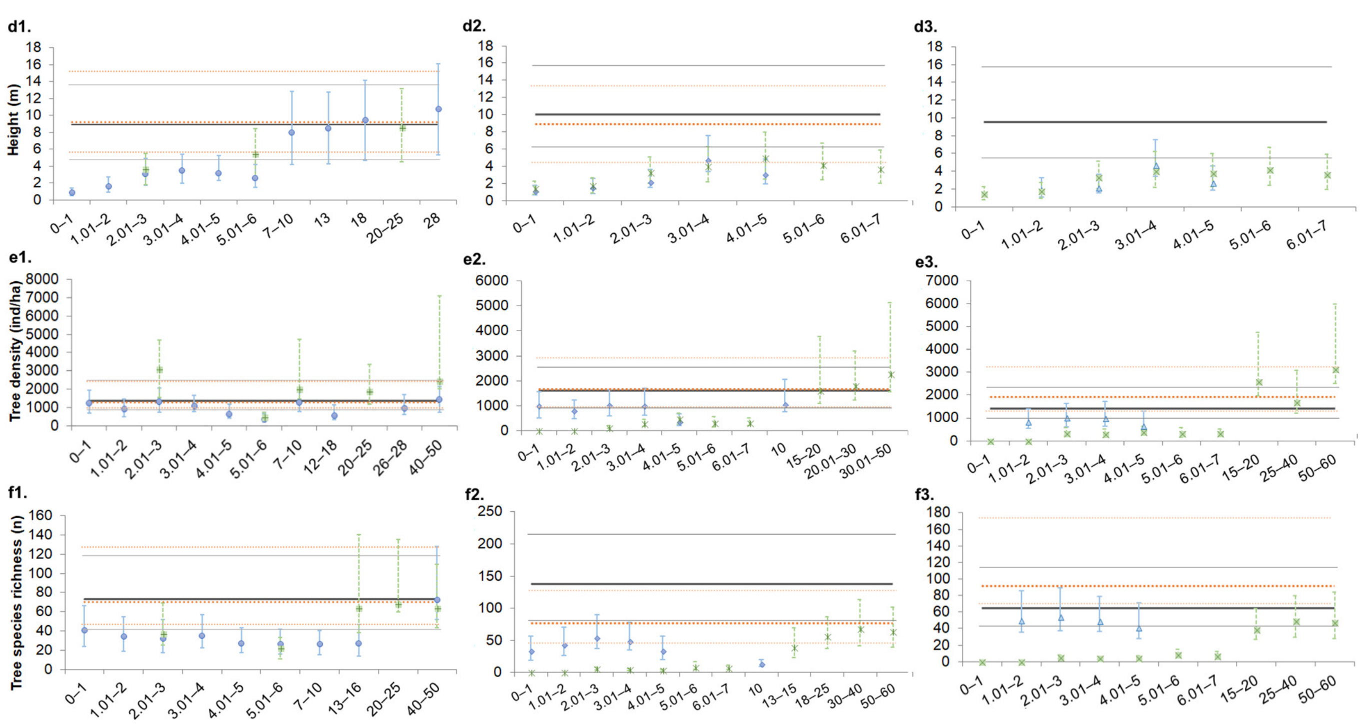


Fig. 2. (*continued*)

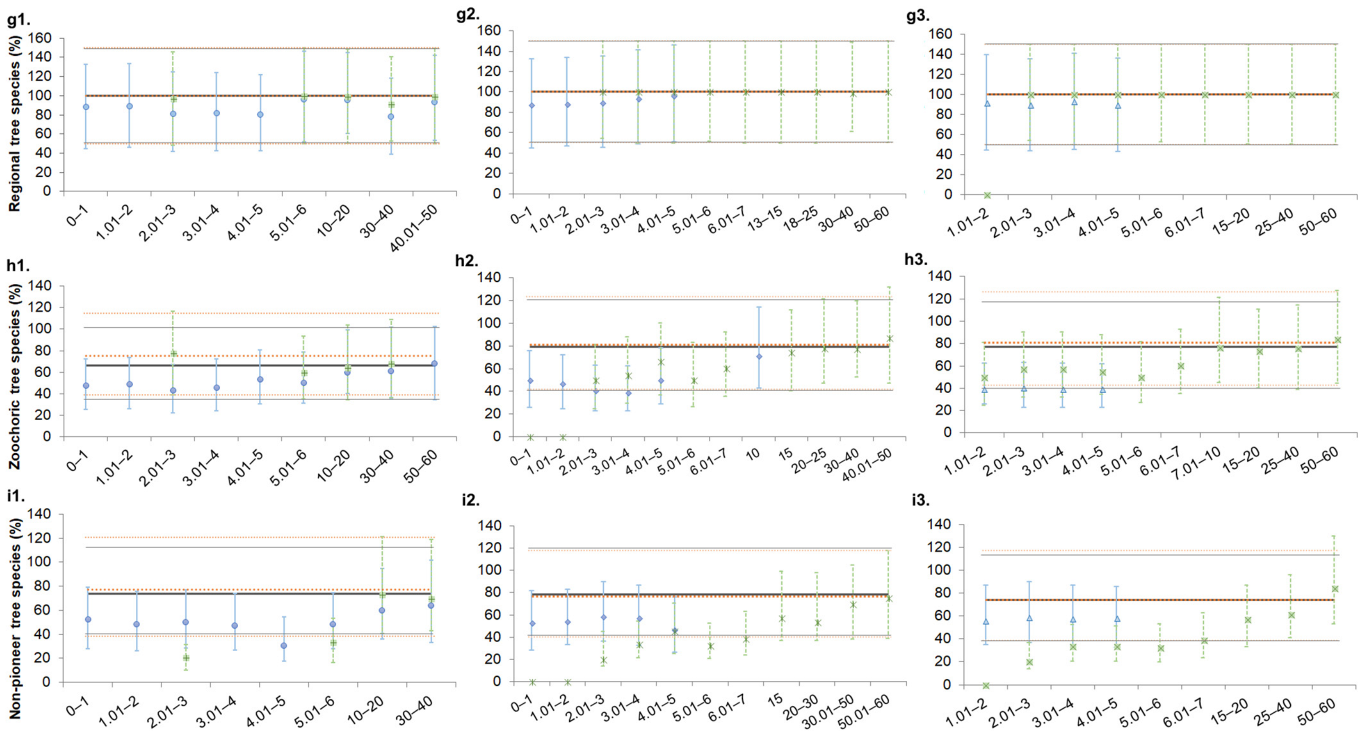
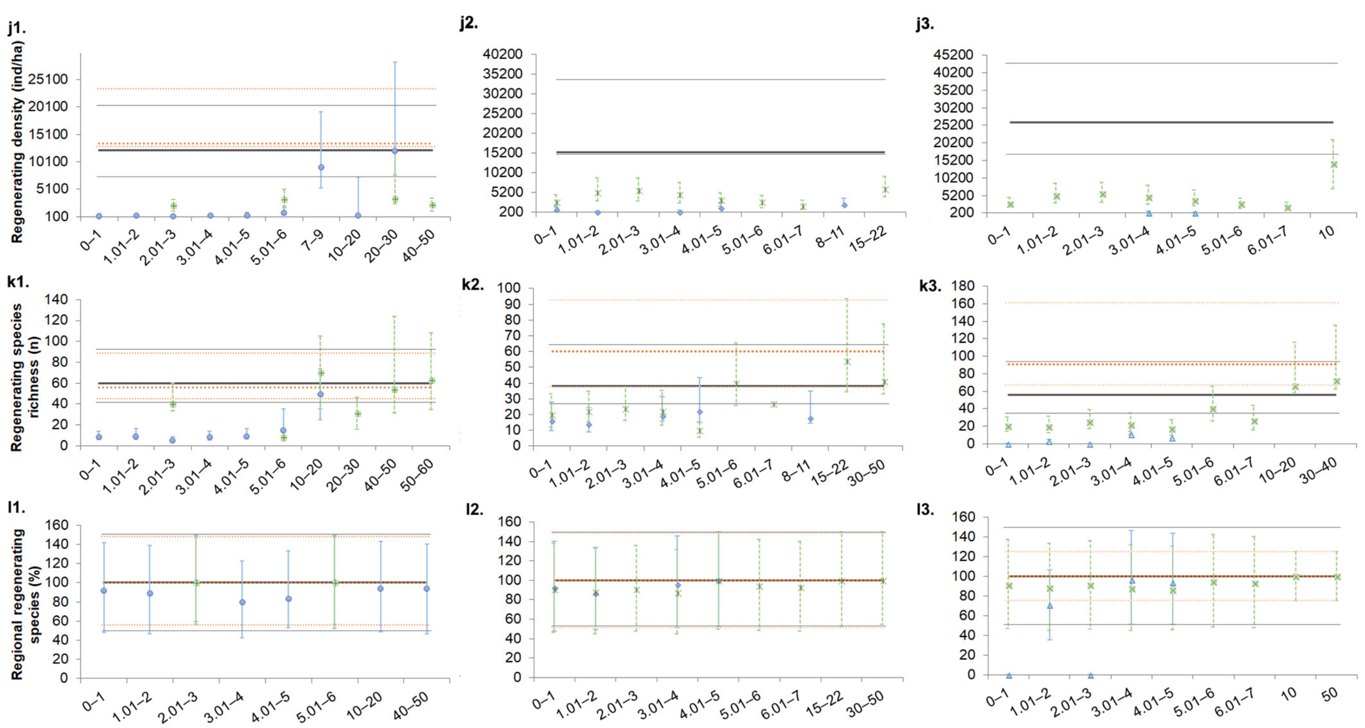


Fig. 2. (*continued*)

We verified that the proportions of regional, zoochoric and non-pioneer regenerating species had naturalness values like the references since the first year of restoration (Fig. 2l, m, n). The proportion of these three groups in Broadleaf and Mixed Rainforests significantly increased with restoration time in natural regeneration areas, while the proportion of non-pioneer species in the regeneration tended to grow over time in the Semideciduous Forest (Supplementary material 3).

4. Discussion

The definition of reference values is currently one of the most important topics in ecological restoration and our study defines the reference values for the three phytophysiognomies of the Atlantic Forest which have been receiving the greatest restoration efforts in Brazil. In addition, we also defined the comparison values and considered a series of ecological indicators calculated from almost two million square meters of sampling area. Some studies have been published for this



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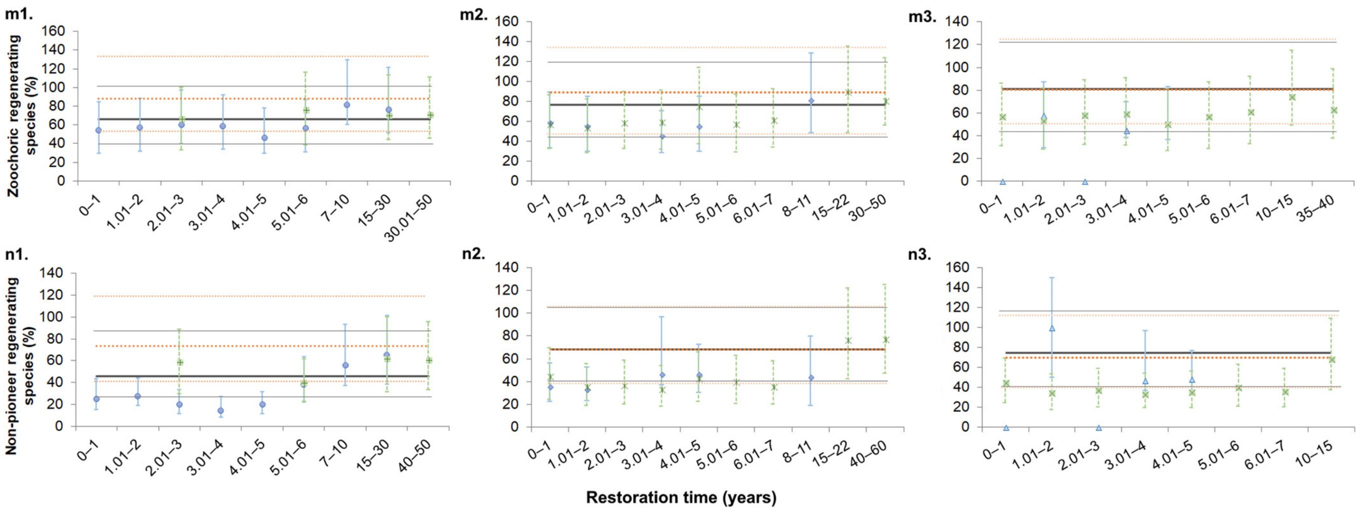

Fig. 2. (*continued*)

purpose regarding the Atlantic Forest (Durigan et al., 2016; Suganuma et al., 2013; Suganuma and Durigan, 2015), but their results are limited to riparian forests and consider a small number of indicators based on a small number of reference ecosystems.

In addition to providing information for defining reference values, the literature review also enabled us to evaluate which phytophysiognomies and ecological indicators have been less considered in studies in Brazil. The studies were generally less directed to the Mixed Rainforest, perhaps because its extension is smaller than the other two analyzed phytophysiognomies (Ribeiro et al., 2009). Moreover, for some ecological indicators such as canopy cover and vegetation height, it was more difficult to obtain information on secondary and mature forests. Both are indicators which have been the most used to monitor areas under restoration, and since they are easy and quick to measure in the field, we suggest that future studies use and disclose the information for improving the established reference values.

We found that the ecological indicators had no significant relation with the area of the mature fragments. This allows us to infer that the described indicators can be used in mature forests of different sizes, so that we can direct our attention to other relevant factors such as the conservation state of the fragments. As a final reference, for example, it is important to choose well conserved areas with no recent history of disturbance, continuous canopy, lianas in equilibrium and an absence of exotic grasses (Brancalion et al., 2015). In addition, the nature of the edges and the distribution and isolation degree of the fragments should also be considered (White and Walker, 1997).

With regard the reference ecosystems, a relevant question that emerges is whether we should compare the results of monitoring restoration areas with mature or secondary forests (Brancalion et al., 2015). In our study, we found that intermediate and final reference values were similar for all ecological indicators, which indicates that the secondary forests analyzed (between 80 and 120 years) already are very similar to mature forests. Thus, we conclude that both mature and secondary forests can be used in choosing reference ecosystems, since we did not find a significant difference between them. As an intermediate restoration goal, it may be best to use older restoration areas to compare data (for instance, 30 or 40-year-old forests). In addition, other studies may use our results to compare their baseline information.

Some ecological indicators presented naturalness values like the references from the beginning of the restoration (e.g., the proportion of regional, zoochoric and non-pioneer species); a sign that they already are restored at the beginning of the restoration projects. However, the other indicators varied in the age at which the values of naturalness were reached (from a few years to one or two decades). Overall, the elapsed time from implementing the projects is one of the main factors affecting the restoration's success (Crouzeilles et al., 2016). Therefore, depending on the goals of the restoration project (e.g., to restore the species richness up to 10 years), some adaptive management interventions should be implemented to accelerate the recovery of slow ecological indicators.

Among the analyzed ecological indicators, coverage by aggressive grasses was probably the most critical indicator. Except for some Semideciduous Seasonal Forests, adequate naturalness values were not achieved even with a decade of restoration. This shows that recovering this indicator can take a long time or it may not even recover depending on the context where the restoration area is located (e.g., small fragments with great edge effect). The high proportion of grasses can also present evidence that restoration projects have not been adequately managed. In addition, it is an indirect evidence of slow recovery of canopy cover (ascertained in this study), which is an indicator that is expected to recover rapidly in order to increase the shading and to hinder the establishment of aggressive grasses (Protocol, 2013).

Another indicator that did not reach similar naturalness values to the references was the density of regenerating plants. In general, forests under natural regeneration showed higher results, but still below the references. The regenerating plants are the representatives of the future floristic composition and the dynamics of the vegetal communities (Ribbens et al., 1994), and a low density of regenerating species can cause problems during the restoration. For example, there may not be enough individuals to colonize new open gaps. Small fragments can also be more threatened because the fragment size can affect animal dispersers and seedling establishment (Andresen, 2003).

In relation to the functional groups of the tree stratum, we also noticed that the proportions of regional, zoochoric and non-pioneer species recovered from the first years after restoration. This suggests that adequate proportions of these groups have been used in plantings and that they are also present in natural regeneration areas. Adequate values of these groups are important indicators of the progression of the ecological succession, the participation of local species and attraction of the fauna, which contributes to the diversity of species and accelerates regenerating the native vegetation (Wunderle, 1997).

The richness of tree species was another indicator which, in the planting areas, presented similarity to the references from the beginning of the projects. This result indicates that efforts have been made so that naturally diverse areas are restored using a large set of species, which is more efficient for the permanent restoration of forests (Rodrigues et al., 2009). However, at least 20 years may be necessary for the recovery of species richness in assisted and unassisted natural regeneration areas. This coincides with recovery in the richness of animal species in abandoned tropical areas (Dunn, 2004), evidencing a strong relationship between flora and fauna.

5. Conclusions

We verified that the ecological indicators which have been routinely used for monitoring and assessing restoration forests are also adequate to monitor reference ecosystems of different sizes because they were not related to the area of the mature fragments. Thus, more attention can be given to other factors, such as the degree of conservation and the format of the reference ecosystems.

We were able to define the reference and comparison values first hand for several ecological indicators used for monitoring and assessing restoration forests. This is a great demand for ecological restoration and can be used to compare monitoring results. We point out that by presenting these results we are not saying that all restoration forests should achieve these values, especially the final reference ones. Other alternative states can be achieved depending on the objectives of the restoration project.

Using naturalness to evaluate the restoration areas was very useful. Contrary to the term 'success', which is categoric and sometimes subjective, naturalness is given in continuous and comparable values. We suggest that future studies should employ this concept and help improve it for wide use in ecological restoration. Using naturalness, we verified that some ecological indicators had similar values to the reference ecosystems from the beginning of the restoration actions and other indicators took from one to two decades to reach similar naturalness values to the references. Although we used naturalness in a broad scale, it can also be employed locally.

CRediT authorship contribution statement

Vinícius Londe: Conceptualization, Methodology, Validation, Formal analysis, Data curation, Writing - original draft. **Fabiano Turini Farah:** Validation, Investigation, Writing - review & editing. **Ricardo Ribeiro Rodrigues:** Conceptualization, Validation, Writing - review & editing, Supervision. **Fernando Roberto Martins:** Conceptualization, Methodology, Validation, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2019.105928.

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