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Commentary

On the relevance of floristic and quantitative studies to the restoration of degraded areas: the case of the Atlantic Forest hotspot

Running title: Insights for restoration in Atlantic Forest

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Abstract: Ecological restoration is an important tool for the conservation of hotspots, and floristic and structural studies can provide theoretical and empirical support for this practice. Our goal was to highlight the relevance of knowledge provided by these studies to the development and success of restoration programs conducted in degraded areas in the Atlantic Forest, a top global hotspot for biodiversity conservation. Through the assessment of articles, books, book chapters, government documents, dissertations and theses, we comment on how floristic and quantitative parameters can provide structure and dynamic information on biological populations existing at restoration sites, allowing for inferences regarding management practices and strategies for the restoration of degraded areas and conservation of biodiversity.

Keywords: anthropic impacts; biodiversity conservation; community data; forest fragments; resilience

1. Introduction

Ecological restoration is the process of aiding in the restoration of an ecosystem that has been degraded, damaged or destroyed [1]. The practice of restoring ecosystems is ancient, with examples of its existence throughout the history of different peoples at various times and regions [2]. The need for improvements of techniques for restoration resulted in the development of a new field of scientific research termed "restoration ecology" [3]. Restoration ecology is the science of the practice of restoration and deals with the concepts, models, methodologies and tools that support the practice of professionals working on the subject [1]. At times, the practitioner and the restoration ecologist are one and the same in a fusion of theory and practice. Thus, ecological restoration has transformed recovery programs from being mere applications of agronomic practices involving plantings of perennial species, which targeted only the reintroduction of trees in a given area, to practices that aim to take on the difficult task of rebuilding the complex interactions in communities [2].

In general, native vegetation areas are resilient, i.e., they have the ability to naturally recover their structural and functional attributes after damage to their environments. However, depending on the type, severity and extent of a disturbance, such resilience may be compromised such that the subsequent natural regeneration process may be considerably slowed or even be completely impaired [4]. To accelerate the return of an ecosystem to a condition as close as possible to the original, it becomes necessary to use restoration practices [5]. In addition to reestablishing highly disturbed communities, restoration allows for the establishment of corridors between fragments, a fundamental activity for the *in situ* conservation of highly disturbed landscapes [6].

The demand for ecological restoration has increased in Brazil. Brazil's impressive natural heritage, with approximately one-third of the world's tropical forest cover [7], puts this country on the top of the list of countries with high species richness of plants and animals [8,9]. The Atlantic Forest in Brazil is a global hotspot for biodiversity conservation [10-12] because of its high species richness and high rate of endemism of vascular flora associated with a diminishing proportion of natural areas due to accelerated exploration and deforestation [13,14]. Despite the fragmentation and its negative consequences for the remaining biota, the forest mosaic of the Atlantic Forest still has one of the highest levels of endemism in the world [10].

When the first Europeans arrived in Brazil in the sixteenth century, the Atlantic Forest was present along nearly the entire coast of Brazil, from Rio Grande do Sul to Rio Grande do Norte states, covering an area equivalent to 1,296,446 square kilometers and approximately 15% of the national territory. Currently, this biome comprises between 11% and 16% of its original area [15] and is distributed across thousands of small fragments, with less than 20% of them under legal protection [7,16]. Nine percent of the area of the Atlantic Forest is included in protected areas, but nearly two-thirds of the area are in units of sustainable use, mostly in categories that admit other land uses, such as grazing, agriculture and urban areas [17]. Considering only conservation units of integral protection, the percentage is much lower: only 1.62% of the Atlantic Forest is protected in this category [15].

Areas of the Atlantic Forest in southeastern Brazil are among those facing the greatest human disturbances along their entire length. In addition to harboring various cities and the most populous metropolitan areas in Brazil, these areas also contain some of Brazil's largest industrial, chemical, oil, and port hubs [18]. Moreover, the Southeast hosts many of the nation's higher education and research institutions. In recent decades, such institutes have been conducting floristic and structural studies on the different vegetation types in the region. In turn, the Pact for the Restoration of the

Atlantic Forest, an ambitious ongoing project, aims to restore 15 million hectares of degraded area by 2050 and to aid in the protection of the remaining fragments [19]. The vast body of existing literature on the Atlantic Forest can provide important knowledge to help optimize the use of data on the composition and structure of forests for ecological restoration.

To provide data support for our discussion on the applicability of the selected floristic and community structural studies to the restoration of degraded areas, we searched for restoration studies undertaken in the Atlantic Forest of southeastern Brazil by consulting books, scientific articles, reports, government documents, and theses. We employed the "tree literature search" strategy [20], which states that upon encountering an interesting article on a given topic, pursuing the references therein can lead to other informative articles that on the same topic. We did not aim to provide a full revision on the theme, but instead we opted to use historical perspectives as a background and consider the general literature and current challenges related to this subject. Thus, we addressed (i) how floristic and community data could be used as a basis for restoration, (ii) the main restoration methods used in the Atlantic Forest, (iii) the risk of biological invasion in restoration models, and (iv) the relevance of monitoring areas of natural ecosystems or areas where restoration is occurring.

2. Floristic and community structural data as a basis for restoration

Ecological restoration can be considered in two different ways. According to the classical paradigm, the aim of restoration is to return a degraded community to a condition as close as possible to the original [21]. According to the contemporary paradigm, restoration should provide the reestablishment of ecological processes rather than focusing solely on achieving a single, predetermined goal [22]. Whatever the view adopted, the practice of restoration requires detailed knowledge of a restoration area's vegetation [23]. In fact, ecological restoration projects depends on the presence of high regional species diversity, involving not only the trees but also other forms of plant life, the different faunal groups and their interactions [2,4].

In the Atlantic Forest domain, there are large floristic and structural variations, as climate, latitude, altitude, topography and other environmental factors vary within the domain [24], both at broad and small scales or even within a single fragment [25,26]. Therefore, the restoration of an area should be preceded by floristic and/or community structural surveys in the greatest possible number of nearby forest fragments that are expected to belong to the same vegetation type and cover various conservation degrees [27]. Based on these surveys, it is possible to determine the following: the condition of the ecosystem that restoration can be expected to achieve, the main relationships of species with each other and with the environment, the identification of rare taxa or taxa of wide distribution, and the ability of the landscape to supply the area to be restored with new propagules. In this way, a plan of action can be developed that is consistent with the local parameters and based on the appropriate choice of plant species that comprise the initial community, which can increase its probability of success [28,29].

It is important that floristic and/or structural inventories be performed not only over particular areas but also over time. Information about the dynamics of Atlantic Forest remnants, whether altered or intact, is still scarce; such data have been produced only since the 1980s [30,31]. Knowledge of the dynamics of these forest formations, along with associated information about their composition and structure, can enable inferences to be made about management strategies, biodiversity conservation, and restoration strategies for other degraded areas [32].

Surveys carried out to support restoration efforts should include not only the trees in a given area but all plant life forms present in the area, such as shrubs, herbs, lianas and epiphytes, which represent much of the species richness of tropical forests [33], enhance the provision of resources for wildlife [34], and perform other functions in the communities. Despite the recognized ecological importance of non-tree components of communities, relatively few quantitative surveys have focused on this group [35-37].

A review of more than 30 years of ecological restoration in the Brazilian Atlantic Forest shows that many past experiences did not result in self-perpetuating forests, for different reasons [38]. According to this research paper, the first restoration projects started in 1862, but became more pronounced after the 1970s, and intent to protect water and soil resources rather than forest biodiversity: the prevalence of exotic versus native plants, aiming to recreate a forest physiognomy, ignored ecological processes responsible for forest maintenance.

The projects proposed in the 1980s were based on floristic and phytosociological data from a single community from the set of remaining forests in a region and, based on the classic paradigm, aimed to promote the emergence of a mature forest identical to the original in structure and species composition [39]. From this phase on, the planting of native species became widespread. The ecological or successional groups, which are based on the existence of different species with common requirements for their development, have been the point of interest for the association of tropical tree species in the restoration projects. However, these first models did not take the plant species richness in each successional group into consideration. Thus, one of the critical points detected was the low diversity in areas already restored even after decades from planting, which is intrinsically related to the low number of shade-tolerant species [27].

Currently, most projects aim to construct self-sustaining communities and no longer see restoration as a deterministic process. The goals of restoration projects changed, new techniques were developed based on the available ecological theory and monitoring furnished new insights on the best practices in restoration [38,40]. In spite of this, to ignore the several life forms and genetic bases of a high-diversity Atlantic Forest [41] may result in an artificial homogenization of the restored environment, with unpredictable consequences for the dynamics of these areas and for the success of the restoration projects, especially at regions where the natural remnants are too fragmented [27].

Despite the scientific efforts undertaken to enhance knowledge of Atlantic Forest flora, some regions still lack data, and new species from different plant families are described every year [42]. Thus, restoration projects should include inventories of regional flora as a means of recording and increasing the number of known species and the genetic basis of their populations in the restoration regions; these data should be made available for use in conservation programs.

3. Main restoration methods applied in the Atlantic Forest

The first actions toward restoring degraded areas in the Atlantic Forest utilized conventional methods of planting trees, culminating in random arrangements of exotic and native tree species of rapid and/or slow growth [43]. Most of these plantations were carried out without clear ecological criteria in the choice of species and disregarded all other life forms, thus ultimately failing to turn the sites into self-sustaining forests [38].

Since the 1980s, restoration methodologies have incorporated more ecological concepts and paradigms [2,4], e.g., seeking initiation or acceleration of the process of ecological succession [44]. The most widely used models of restoration are random planting, successional model planting, planting seeds, natural regeneration, balancing common and rare species, and regeneration in islands [45]. The choice of restoration strategy depends on the characteristics of the vegetation at the site to be restored and nearby forests, particularly their conservation condition. At this stage, floristic and phytosociological surveys are essential to support the decisions of management in degraded areas, where there are usually numerous exotic species competing with native species. With information on the community structure of fragments available, it is possible to plan strategies to address the need for the enrichment of stretches where species of final successional stages are at risk of local extinction, either as a result of low resilience, genetic erosion, or the absence of pollinator/disperser fauna [2].

Table 1. Non-exhaustive list of studies highlighting techniques or measures used for the restoration of degraded environments in the Atlantic Forest and what they specifically addressed.

Author(s)	Methods of addressing restoration
[43]	State that the first techniques used to restore areas were the random planting of exotic and native species without ecological criteria for the choice and combination of species.
[46]	Claim that the method of direct seeding is also useful as a means of restoring degraded environments because seed dispersal in rain forests is the main mechanism for their natural regeneration.
[47]	Consider the successional model because it favors rapid soil coverage and ensures the self-renewal of a forest.
[2,4]	Incorporate concepts and paradigms of forest ecology to supplement restoration methodologies. Emphasize the importance of managing and maintaining restoration areas through mowing, crowning, and care for both invasive species and ants.
[48]	Claim that the most well-known and frequently used models in restoration are random planting, successional model planting, planting seeds, natural regeneration, and regeneration in islands. Promote planting associated with forestry practices, the use of seed banks, and natural succession.
[49]	Emphasize the formation of ecological corridors through the recovery of areas that are strategic for gene flow between forest fragments.
[50]	Advocate the management and induction of ecological processes.
[51]	Claim that seed rain is a key element for the dynamics of ecosystems.
[52]	Highlight the importance of mixing native species at different successional stages.
[39,46,53]	Highlight the use and the importance of floristic and phytosociological data in projects to restore degraded areas.
[54]	Evaluates the possibility of natural restoration of the region or the planting of native seedlings.
[23,55]	State that the planting of native trees is the most widely adopted practice for the restoration of degraded tropical landscapes.
[15]	State that typical models of forest restoration predominantly emphasize the planting of tree species following the models of ecological succession.
[6,53,56]	Suggest nucleation techniques: the transposition of soil, the transposition of brushwood, natural and artificial perches, seed rain, and planting seedlings.
[44]	States that the reestablishment of an area depends on the presence of high regional diversity of species involving not only the trees but also other plant life forms, different faunal groups and their interactions.
[53]	Underscores the importance of assessing the potential for natural regeneration by seed banks or seed rain.

Some studies (e.g., [45]) have highlighted the importance of using floristic and phytosociological studies to supplement knowledge of the area to be restored and focus mainly on the specific characteristics of each environment. With regard to the techniques that aim to restore certain areas, seven studies suggest the use of the ecological succession model; 10 suggest a direct planting of seedlings, two suggest the use of seed banks or seed rain, two suggest passive restoration, three suggest the adoption of nucleation techniques, one suggests the formation of ecological corridors to facilitate gene flow species by dispersion, and one highlights the use of the technique of direct seeding (Table 1). In addition, the success of the techniques used depends on the management and maintenance of the areas in question [2,4].

4. The risk of biological invasion in restoration models

Concerns regarding biological invasion into agroforestry systems, especially with respect to the less complex systems, arise from the wrong choice of exotic species. For example, reviewing the arrangements of the silvopastoral systems most commonly utilized in Brazil, [57] noted that among the most used species, the african acacia (*Acacia mangium* Willd.), american pines (*Pinus* spp.), *Leucaena leucocephala* (Lam.) De Wit, mulberry (*Morus alba* L.) and australian cedar (*Toona ciliata* M. Roem.) are widely reported in the literature as major weeds in neotropical regions and are already listed as invasive species in Brazil (see also [58]).

Although the current forest legislation highlights the use of native species, there are restoration practices based on exotic species that require special care because they involve a risk of biological invasion. By definition, an invasive species is one living outside its natural range and that is able to colonize, establish and spread in ecosystems where it would not be found naturally [59]. To be considered invasive, a species must cross successive biological stages of (1) transport, (2) introduction, (3) establishment at the new location, (4) reproduction at the new location and (5) dissemination (perpetuation) to other areas beyond the place of introduction where the species has not occurred naturally [59]. The success of the invasion depends on the interaction among the intrinsic adaptations of species, ecological attributes of the community, efficiency of natural enemies, availability of adequate resources and environmental conditions [60].

Exotic species can invade habitats with few resources after a disturbance that increases the availability of resources, such as clear-cutting, fire or soil disturbance, and eutrophication [60,61]. Some environments, especially those with more resources (e.g., areas with rich soils or with high luminosity), are more susceptible to invasion and, in turn, tend to be more successful when there is a large alien propagule pressure that is able to provide feedback populations [62]. In most cases, the environment in the restoration process provides increased resources, especially in terms of nutrition (through the addition of chemical or natural fertilizers), which greatly facilitates the establishment of exotic species.

Some restoration techniques involving the use of exotic plant species fall within the context of “agroforestry systems”, plantations where woody perennial species and systems are used in conjunction with agricultural crops in the same land management unit [63]. Agroforestry systems vary widely in complexity, from the simplest, involving consortia of agricultural species (e.g., pastures) with trees without concern for the successional status of the area, to the most complex, involving greater native species richness and successional dynamics based on secondary forests [64,65]. It is expected that the greater the complexity of agroforestry in an area, the lower the likelihood of success of an invasive species due to the strong competition for the native resources and the natural sequence of processes in areas of increasing complexity [61].

In their extensive review on the use of alien species in restoration, [62] highlighted the need to understand the ecological role that each introduced species has played on ecosystems to seek to reduce the controversy around its intentional use in the restoration, as not all alien species become invasive in areas where they have been introduced [66]. Thus, the use of exotic species in areas where restoration is ongoing should not be seen as an impediment to the restoration because, especially in highly degraded environments, restoration with the exclusive use of native species may not be successful.

5. The importance of monitoring

The efficiency of a project in restoring degraded areas can be assessed through recovery indicators [38]. Using these indicators, one can define whether a project must undergo further interference or even be redirected to accelerate the process of succession and restoration of the functions of the implanted vegetation [56].

An effective ecological indicator to monitor areas of natural ecosystems or areas where restoration is occurring must meet the basic requirements of any indicator (easy measurement and possible modification throughout the process) and (1) must be sensitive to factors that modify the ecosystem; (2) respond to the factors that influence the ecosystem in predictable ways; (3) allow predictions to be made regarding the effects of degradation or agents on the beneficial effects of management practices that may be applied; (4) be integrative, i.e., represent, as much as possible, other variables that may be difficult to measure; and (5) have low variability in responses [67].

The evaluation and monitoring of areas in the process of restoration covers aspects broader than just the physiognomic assessment required by regulatory agencies and by certification bodies. Indicators of restoration must assess not only the visual recovery of the landscape but also the reconstruction of ecological processes and maintainers of plant dynamics to ensure that restored areas are sustainable over time and fulfill their role in the conservation of local biodiversity [2].

In general, the main variables used to evaluate areas in the restoration process can be divided into three distinct categories: (1) diversity, (2) vegetation structure and (3) ecological processes [68]. These categories are basically the same criteria listed in the National Council for Environmental Issues (CONAMA) Resolutions for characterizing the regeneration stages of vegetation in the Atlantic Forest. For example, CONAMA Resolution 392/2007, which addresses the "definition of primary and secondary vegetation regeneration of Atlantic Forest in the state of Minas Gerais", specifies evaluation indicators divided into the following categories: (1) diversity: richness (number) and species identity; (2) structure: stratification defined (canopy and understory), amplitude of diameter distribution, density and biomass (basal area) of the stand; and (3) ecological processes: defining successional ecological groups and the presence of other biomarkers (litter, epiphytes, vines etc.). Additionally, the use of species diversity indices (for example, the Shannon, Simpson and Pielou indices) and phytosociological indices (cover value and importance value) are valid for assessing the progress of restoration.

For the evaluation and monitoring of restoration projects, variables appropriate to the different stages of the process are necessary to define indicators that restoration actions deployed in a given area are actually promoting their recovery [52]. Recommended indicators are those that measure the gradual and growing occupation of the area by individuals of native species, the coverage that is being promoted in the area, and changes in physiognomy and local diversity [2,52]. Thus, the physiognomy, composition and structure of the restored community, considering its various strata and life forms, should be used as indicators for the evaluation and monitoring of vegetation because they express the effective restoration of ecological processes and the possibility of perpetuating these processes in the restored area [52].

Studies on the ecological restoration processes of degraded environments have intensified, generating important knowledge on the dynamics of natural formations [69]. This improved information has led to an important change in the direction of restoration programs, from seeking only the reintroduction of tree species in a given area to also taking into account the difficult task of rebuilding the ecological processes and, therefore, the complex interactions of the communities in an area [69]. Human intervention in degraded areas through management techniques can accelerate the regeneration of tree species, allowing the succession process to proceed more efficiently and preventing the loss of biodiversity [70]. These authors also suggest that restoration areas should be constantly monitored to correct any problems, such as herbivory, exotic species invasion and erosion, through mowing, crowning, and fighting ants and other threats to the restoration of a degraded environment [2].

Special care should be given to the monitoring time of restoration projects. For example, Instruction 04/2011 IBAMA defines the "procedures for project design recovery of degraded areas - PRAD or altered area, for purposes of compliance with environmental legislation" and establishes a minimum period for monitoring projects (in simplified cases) of three years, which may be extended for up to six years. This period of time is minimal with regard to forest dynamics, and therefore, a very careful assessment should be made to guarantee the future of ecosystem restoration in a particular area.

6. Conclusion

Herein, we have demonstrated the relevance of floristic and community structural data for restoration practices, with an emphasis on Atlantic Forest vegetation. However, the development of more effective restoration processes is still in the early stages, while degradation of the Atlantic Forest hotspot continues. It is therefore urgent that restoration ecologists pay attention to data from basic studies of vegetation to better address and overcome current challenges and contribute meaningfully to biodiversity conservation.

Conflict of interest

There is no conflict of interest.

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