Vítor Zago de Almeida Paciello

Restauração florestal e disponibilidade de habitat da Mata Atlântica: variação histórica e ganhos potenciais.

Atlantic Forest restoration and habitat availability: historical changes and potential gains.

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Dissertação apresentada ao Instituto de Biociências da Universidade de São Paulo, para a obtenção de Título de Mestre em Ecologia, na Área de Ecologia de ecossistemas terrestres e aquáticos

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“It has always been easier to destroy than to create”

Spock – Star Trek

Dedicatória

Para meu filho Ícaro
(e todos os pequenos
que vierem depois)

Agradecimentos

Este mestrado foi um período marcado por mudanças. Dois anos e meio pode parecer pouco tempo para o tanto de transformações que aconteceram em minha vida, mas elas aconteceram. Nesse pouco tempo, mudei de tema do projeto, mudei de casa, arranjei uma bolsa, cancelei a bolsa, arranjei um emprego, mudei de casa de novo, mudei de emprego .... e tive um filho. Este último foi o mais transformador... e gratificante. Com seus sorrisinhos, choradinhas de madrugada e fraldinhas sujas, me impressiono com a força e o foco que você me deu para produzir e entregar o melhor de mim. A dedicatória já foi para você e o primeiro obrigado também. Obrigado, meu filho Ícaro!!

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Contents

Resumo

A restauração florestal é um processo caro e os recursos são limitados para alcançar os compromissos globais de restauração. Para reduzir esses custos, projetos de restauração precisam focar em áreas com maior probabilidade de sucesso e que aumentem os benefícios para a biodiversidade. Uma das formas de atingir maiores taxas de sucesso é por meio do aumento da conectividade funcional e disponibilidade de habitat, promovendo maior fluxo de organismos e propágulos para a área em restauração. Neste trabalho, avaliamos as mudanças na disponibilidade de habitat promovida pelas florestas restauradas na Mata Atlântica nas últimas décadas e a comparamos com os benefícios promovidos por diferentes cenários de restauração. Nossos resultados mostram que as áreas restauradas nas últimas décadas proporcionaram um aumento médio de 6% na disponibilidade de habitat em comparação com um cenário em que não houvesse nenhuma restauração, mas esse aumento foi em média 4% menor do que uma restauração espacialmente planejada na paisagem poderia alcançar. A diferença entre um cenário espacialmente planejado e o real foi maior nas paisagens com menor cobertura florestal e para as espécies com menor capacidade de dispersão, mostrando os maiores benefícios que uma seleção espacialmente planejada de áreas para restauração podem promover para a conservação de espécies em paisagens fragmentadas.

Abstract

Forest Restoration is an expensive process and resources are limited to achieve global restoration commitments. To reduce such costs, restoration projects need to focus on areas that are most likely to succeed and that increase the benefits to biodiversity. One of the ways to achieve higher success rates is by increasing the functional connectivity and habitat availability, promoting a higher flow of organisms and propagules to the area under restoration. Here, we evaluate the changes in habitat availability provided by restored forests in the Atlantic Forest in the past decades and compared to benefits provided by different restoration scenarios. Our results show that areas restored in the last decades have provided a mean increase of 6% in habitat availability compared to a scenario where no restoration would occur, but this increase was on average 4% lower than what a spatially planned restoration could achieve. This difference was higher for landscapes with lower forest cover and for species with lower dispersal capability. Our results show that spatially planned restoration can provide greater benefits for species conservation in fragmented landscapes.

1. Introduction

In recent decades, forest restoration of degraded areas has become a global priority (Aronson et al, 2013). If deforestation continues at current rates, world forest cover will decrease below 10% of its original cover by 2030 (Dias et al., 2016). Forest cover loss can worsen climate changes (IPCC, 2014), accelerate biodiversity loss (Banks-Leite et al., 2014) and diminish ecosystem services provision (MEA, 2003). Several international initiatives have emerged in an attempt to mitigate the consequences of this alarming rate of forest loss through forest restoration. As an example, we may cite the “New York Declaration on Forest”, an international effort to restore up to 200 million hectares of native forests worldwide before 2030 (Forest Declaration, 2014). However, forest restoration is an expensive process and resources are limited (Rodrigues et al., 2009). In view of this, we need better strategies to select target areas for forest restoration (Holl & Aide, 2011), where we can use our limited resources in a more efficient way and in which restoration success rates are higher.

Restoration on degraded areas is a complex process and highly dependent on seeds and individuals arrival from neighbor areas. When neighbor forest fragments are abundant, closer to the restored area and have higher quality, ecological fluxes among then are also higher and more individuals and seeds can arrive and colonize the new forests in the restored area (Leite et al., 2013). Species functional aspects can influence the arrival rates at these areas. Species with higher dispersal capability are less sensitive to forest fragmentation, can travel longer distances in the matrix, reaching isolated restoration sites. On the other hand, species with low dispersal capability have lower probabilities to cross the matrix and have reduced probabilities to colonize and disperse seeds to restored areas (Saura et al., 2014).

Consequently, landscape connectivity, which is the degree to which a landscape can facilitate or impede the movement of organism and other ecological fluxes (Taylor, 1993), is an important driver of restoration success (Crouzeilles et al., 2016, Garcia et al., 2016). Due to the influence of landscape connectivity on organism flow through the landscape, there is a synergy between restoration success and landscape connectivity. When connectivity is higher, restoration success rates increases and the new forests that emerge through restoration can also increase connectivity (Sunaguma et al., 2018), making more habitat available for species in fragmented landscapes.

In the past decades, thousands of hectares were restored as a result of natural regeneration or active restoration in the Atlantic Forest biome (Crouzeilles et al., 2017). In addition, thousands of hectares were also deforested in the Atlantic Forest during the same period (Hirota, 2019), resulting in highly dynamic landscapes (Ferraz et al., 2014, Lira et al., 2012). The concurrent deforestation can reduce the potential benefits of forest restoration by reducing landscape connectivity and habitat availability. However, we still lack measures on how much or whether restored areas are increasing forest connectivity and habitat availability, which is a key issue for biodiversity conservation in the Atlantic Forest (Metzger at al., 2009, Banks-Leite et al., 2014, Almeida-Gomes et al., 2019).

We evaluated the benefits to landscape habitat availability provided by the restoration that occurred in the past decades in the Atlantic Forest. We also compared this restoration with what a spatial planned approach could have achieved. The Atlantic Forest is a highly degraded biome in Brazil undergoing intense land-use changes in the past decades (Lira et al., 2012, Calaboni et al., 2018) and a focus of several large-scale restoration projects (Calmon et. al, 2011). Our aim was to answer these specifics questions: (i) what was the contribution of restored areas to the habitat availability of the Atlantic in the past decades and what would be the contribution if restoration was spatially planned. (ii) how does habitat availability change according to the species dispersal capability. We expect that restored forests could increase habitat availability in the Atlantic Forest. However, since these new forests are not necessarily located where connectivity is maximized, we also expect that this habitat availability increase was lower than what a spatial planned restoration could achieve.

2. Methods

2.1 Study Area and Landscape selection

We used the Brazilian Atlantic Forest Biome (BAF) as a case study for our simulations. This Biome is highly degraded (Ribeiro et al., 2009), has undergone intense land-use changes in the past decades (Lira et. al, 2012) and is the focus of several large-scale restoration projects (Melo et al., 2013). Atlantic Forest cover decreased to around 28% of its original size (Rezende et al, 2018) and around 8% (2.72Mha) of this forest cover results from naturally regenerated forests from the last 30 years (Crouzeilles et al, 2020). Due to the high variability in forest cover and spatial configuration of forest fragments in its landscapes (figure S1 and Ribeiro et al., 2009), BAF is a good model for studying habitat availability changes promoted by forest restoration.

To measure the effects of forest dynamics on habitat availability we split the Atlantic Forest map in equally sized hexagonal landscapes of 5,000ha, resulting in 17,810 possible landscapes (figure 1), following previous study on restoration prioritization (Tambosi et al., 2014). To avoid interference in the analyses from land-uses that are rarely available for restoration, we excluded from this pool all landscapes with urban or water cover higher than 5% and 1%, respectively. From the resulting pool, we selected 90 landscapes according to the forest cover belonging to two categories: “Old Forest” and “New Forest”. We used the land-use maps from 1985 and 2017 from MapBiomas collection 3.0 with 30x30m spatial resolution (Project MapBiomas) to calculate these categories for each landscape (figure 1). Using the year 2017 as a base for the selection, “Old Forest” are forests that existed in the landscape since 1985, while “New Forest” are the forests that emerged in the landscape after 1985 and persisted until 2017.

From the MapBiomas maps, we could not infer the origin of the fragments in the category “New Forests”. They could have originated as a result of land abandonment and natural regeneration processes, assisted regeneration or active restoration projects. These types of restoration might differ in the location and configuration of the new forests they provide. Naturally regenerated forests, for example, tend to originate closer to existing forest fragments (less than 192m distant, Niemeyer et al, 2020), while some active restoration projects can create fragments distant from existing forest fragments, focusing on creating corridors or stepping stones (Santos et al., 2018). Real world land-use changes might include a mix of these restoration processes. Despite all these drivers of forest recovery, our aim in this work was to compare habitat availability changes in different restoration scenarios and show the benefits that the Atlantic Forest would have gained if restoration sites were spatially planned.

To select our studied landscapes, we used three levels of "Old Forest" cover. There is a known forest cover threshold of ~30% for species extinction in Atlantic Forest (Banks-Leite et al., 2014). Thus, we selected 30 landscapes in each of three forest cover levels: 1- below the threshold (8-12%); 2 - around the threshold (25-35%); 3- above the threshold (45-55%). In each level, selected landscapes varied continuously for the amount of "New Forest", ranging from 0.1 to 40% of landscape area (figure 1b and figure S1b).

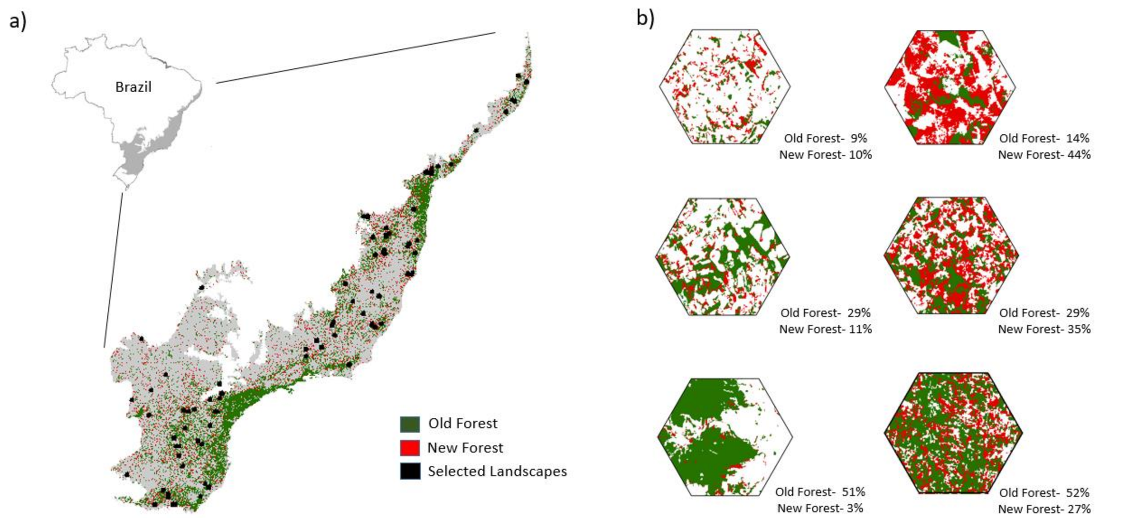

Figure 1 – Study area location showing (a) the Brazilian Atlantic Forest Biome and the forest remnants classified in two forest categories and the selected landscapes. (b) Examples of the selected landscapes with varying amount of "Old Forest" and "New Forest.

2.2 Habitat Availability and Species Dispersal Capability

We used the Equivalent Connected Area (ECA) index to estimate landscape habitat availability (Saura, 2011). This index is a derived form of the probability of connectivity index (PC – Saura & Pascual-Hortal, 2007), which considers landscape through graph theory perspective, where each forest fragment is a node linked with others in a graph. Links are weighted by the distance between fragments and the dispersal capability of a focal species. Therefore, one landscape can have different habitat availability values for different species. ECA is the area of a single patch that would provide the same habitat of the fragmented landscape. Landscape ECA value is calculated by the square root of the PC index. Here, we will show our results using the ECA normalized by landscape area, according to the equation:

$$ECA = \sqrt{PC} = \sqrt{\frac{\sum_i^n \sum_j^n a_i \cdot a_j \cdot p_{ij}}{A_L^2}} \quad (1)$$

where n is the number of forest fragments in the landscape. a_i and a_j are the area of fragments i and j. p_{ij} is the probability of connection between fragments i and j. A_L is the landscape area.

The maximum value that the ECA can achieve is equal to the percentage of forest cover in the landscape, which means that all habitat would be located in a single patch and accessible by all organisms inside this patch. Therefore, to measure how far a restoration scenario is from reaching the highest habitat availability possible for that amount of forest, we divided the ECA value of each landscape and scenario by its respective forest cover, obtaining the proportion of habitat availability achieved in the landscape to its maximum possible value (ECA_{prop}):

$$ECA_{prop} = \frac{ECA}{FC} \quad (2)$$

where FC is the landscape forest cover.

We evaluated habitat availability for two theoretical species with different dispersal capabilities. One with low dispersal capability (50% probability to disperse at 100m) and other with high dispersal capability (50% probability to disperse at 300m. The resolution of the maps we used (30m) did not allow us to simulate restoration for species with lower dispersal capabilities. However, the dispersal capabilities we used are in accordance to the functional aspects of multiple species in the Atlantic Forest (Hansbauer et al., 2008, Crouzeilles et al., 2010).

2.2 Landscape Restoration Scenarios

To quantify the benefits of forest restoration, we evaluated habitat availability in five different scenarios. The first scenario measures the habitat availability in the landscapes if no “New Forest” emerged after 1985. This first scenario will reflect landscape conditions due to existing forests in 1985 minus deforested areas during the studied period, from now on we will call it “no-restoration” scenario. The second scenario is the “real case” scenario that shows the contribution to habitat availability of forests that emerged after 1985 and persisted until 2017. These first two scenarios are the baseline for comparisons with other simulation scenarios.

The next three scenarios are simulations using three different methods to select areas for restoration (figure 2). In these simulations, we split the non-forest areas in each landscape in equally sized hexagonal patches that were taken as possible targets for restoration. Each hexagon in a particular landscape had an area equal to the mean size of all fragments belonging to the “New Forest” category. The number of restoration target hexagons varied in each landscape in order to restore an area equal to the amount of “New Forest” in the “real case” scenario. First, we calculated how much habitat availability each hexagon would provide to the landscape if we restored a forest in it. For the scenario that we call “non-iterative”, we selected the hexagons with the highest values of habitat availability increase and restored then. In the second simulated scenario, called “iterative” scenario, we did the selection in several consecutive steps. In each step, only the hexagon with the highest value of habitat availability contribution to the landscape was selected and restored. For the next step, we recalculated the contribution of every other hexagon to habitat availability in the restored landscape and then selected the next hexagon with highest contribution to habitat availability, repeating this procedure until reaching the desired restoration area.

Last scenario is the “random”, in which we randomly selected hexagons in the landscape to simulate restoration. To measure random restoration variability, we repeated the random scenario 50 times in each landscape. Source code for the simulations is available at: https://github.com/vitorpaciello/RestLand .

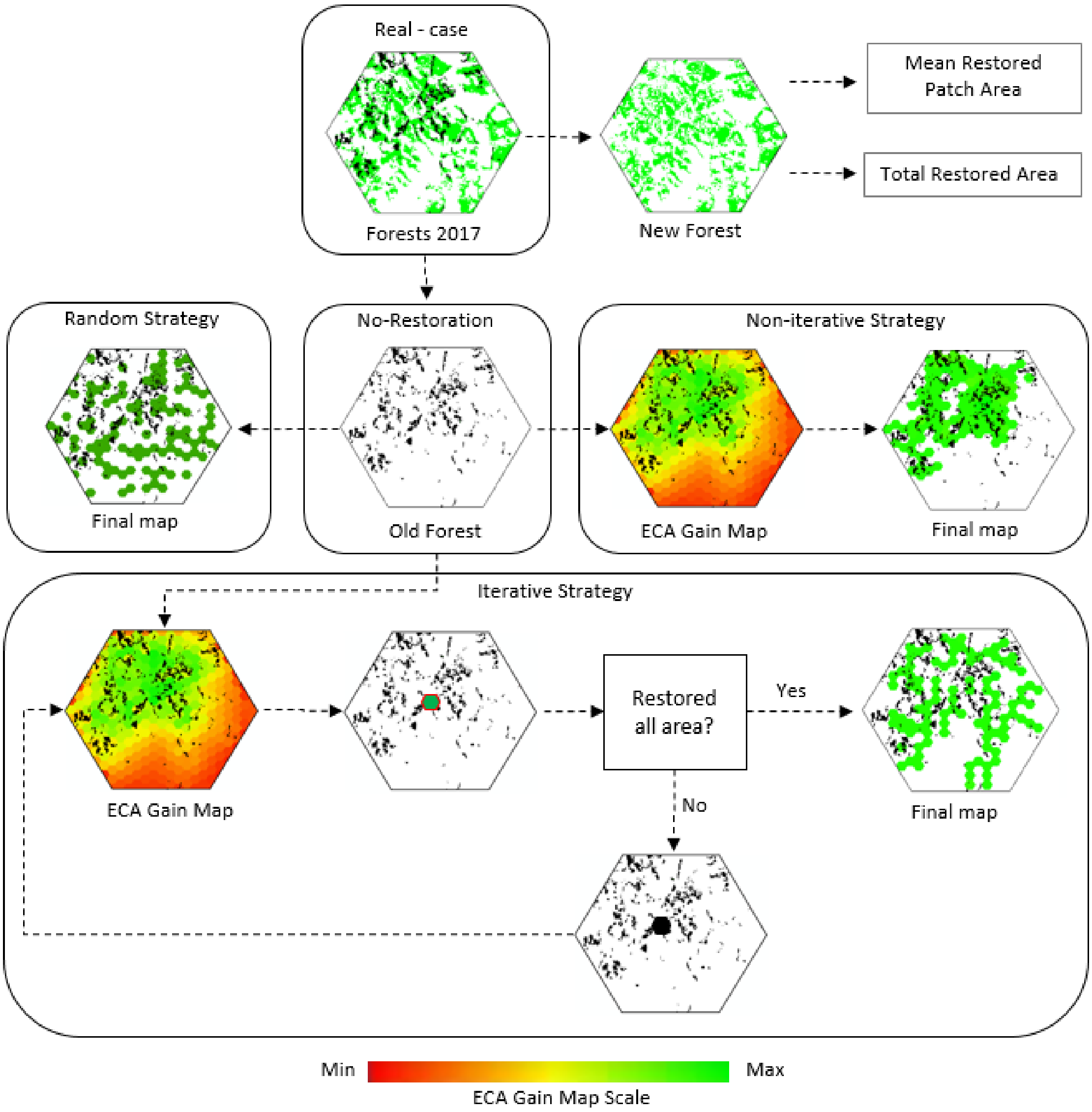

Figure 2- Restoration scenarios. The “real-case” scenario comprehends all forests in 2017. These forests belong to two categories: 1- Old Forests – forests that exists since 1985, which also represents the forests in the “no-restoration” scenario; 2- New Forests – forests that emerged since 1985 and persisted until 2017. We calculated the mean patch area and the total area of New Forests in each landscape to use as the patch area and the total area we restored in each of the restoration simulation scenarios. We split the landscape in equally sized hexagons. For each hexagon, we calculated how much ECA the landscape would gain if the hexagon were filled with forest, obtaining an ECA

Gain Map. For the non-iterative strategy, we selected the hexagons with the highest value in the ECA Gain Map end restored them. For the iterative strategy, we only selected the hexagon with the highest ECA gain value and restored it. Then, we recalculated the ECA Gain Map before selecting the next hexagon to restore. For the Random strategy, hexagons were selected at random.

2.4 Comparison among Scenarios and Species

We compared the performance of each simulation according to three aspects:

1- **ECA gain:** To answer if strategies are statistically different among each other and for different levels of forest cover, we used the two-way ANCOVA test, in which "Old Forest" and the strategy used are categorical variables and total restored area in the landscape is a continuous covariant. Response variables were calculated as the ECA difference between strategies and the real-case ECA.

2- **Overlap between selected areas and real-case:** to evaluate how much each strategy differ from the real-case regarding the location of areas selected for restoration in the landscape, we compared the maps of the restored landscapes of all strategies with the maps for the real-case scenario. For each strategy, we calculated the overlap as the percentage of simulated restored area in the same locations of a new forest fragment from the real-case scenario.

3- **Potential of using one species as surrogate for others:** Since selected areas for restoration obtained for different species may differ, we want to evaluate how much the species with low and high dispersal capability differ in the location of areas selected by the strategy that provides the highest increase in habitat availability.

3. Results

3.1 Habitat Availability Increase

The new forests that emerged in the last 35 years provided a mean increase of 6% in habitat availability for the landscapes in the Atlantic Forest compared with a scenario where no restoration would occur (figure 3 and figure S2). However, this increase is 2-4% lower than what both spatially planned restoration scenarios could achieve ($p<0.001$). The iterative strategy for selecting target areas for restoration achieved the highest values for habitat availability, regardless of the landscape and the dispersal capability. For landscapes with more than 10% of forest cover after the restoration, the iterative strategy achieved more than 90% of the maximum possible value for habitat availability. However, these values drops to 50% when the forest cover is below 10% after the restoration. We can also observe the reductions in habitat availability gains on the other scenarios. The real-case scenario achieved more than 70% of the maximum possible ECA for landscapes with more than 50% of forest cover after the restoration, but this value drops to less than 50% for landscapes with less than 30% forest cover restoration. The results for the non-iterative strategy performed halfway between the iterative and the real-case. Interestingly, the random scenario, that represents a strategy with no spatial planning, achieved the lowest values for habitat availability in landscapes with less than 30% forest cover. Only when forest cover gets higher than 50% in the landscape, the random scenario could perform similar to the real-case scenario. When we compare how the outcomes of spatially planned strategies differ from the real-case, we can observe that the higher the forest cover in the landscape, higher is the overlap between areas restored, despite of the dispersal capability evaluated (figure 4b).

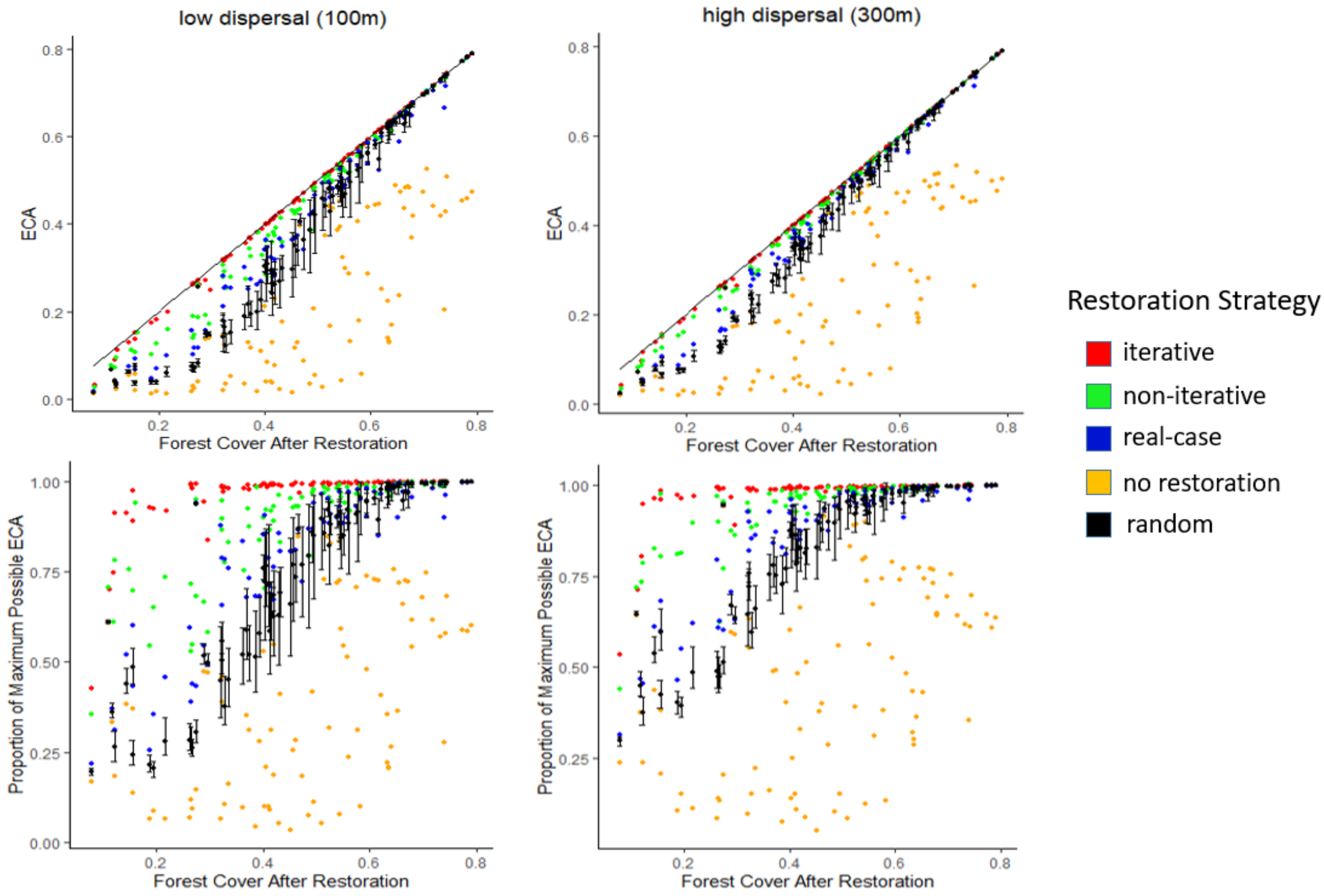

Figure 3 – Normalized Equivalent Connected Area (ECA) and proportion of Maximum Possible ECA (ECA_{prop}) for the species with low dispersal capability (left) and high dispersal capability (right). The black line in top figures show the maximum possible ECA value for a given forest cover. Black bars show the 95% confidence interval for random simulations.

3.2 Difference between Species

When we compare how the strategies perform for different dispersal capabilities, we can observe the same pattern of habitat availability increase for both distances (figure 3a-b). However, higher dispersal capability always achieves higher values for habitat availability. The difference in ECA among strategies are lower for high dispersal capability (figure 3a-b). When we compare the real-case scenario with the iterative strategy, the maximum absolute ECA difference observed occurs in landscapes with around 30% forest cover after restoration (figure 3a-b). This difference is in the order of 0.16 for low dispersal capability, but drops to 0.10 for high dispersal capability.

When we analyze the location of areas selected by the strategy that achieved the highest increase in ECA (iterative), we can observe that the selection of areas that are the same for both species increases when forest cover increases (figure 4a). For both dispersal capabilities, the iterative strategy tends to connect the same larger patches in the landscape (examples in figure 5 e and f).

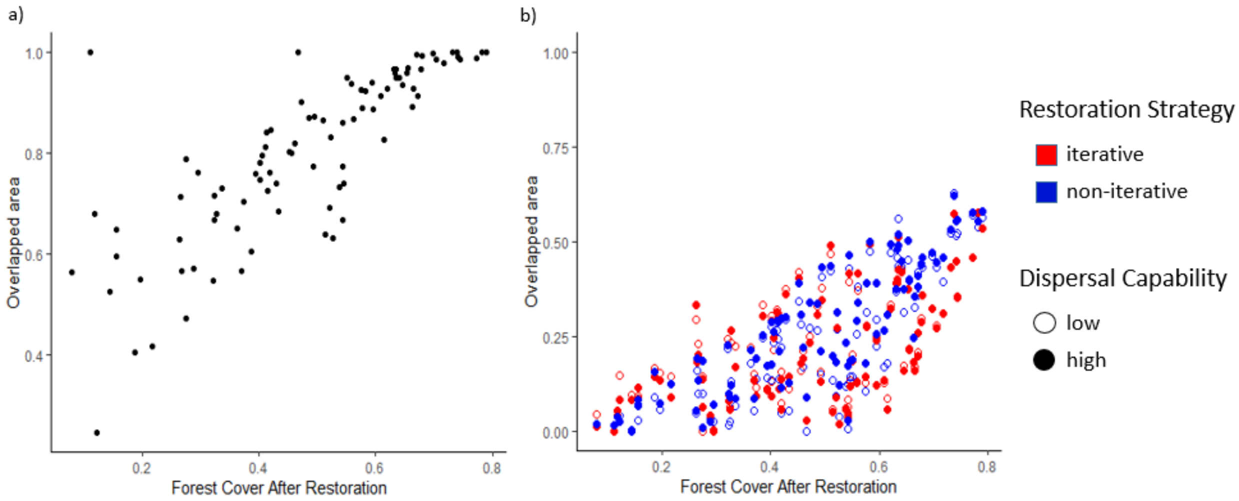

Figure 4 – (a) Percentage of selected areas for restoration that are equal for both dispersal capabilities in the iterative strategy. (b) Percentage of selected areas for different strategies that are equal to the real-case scenario.

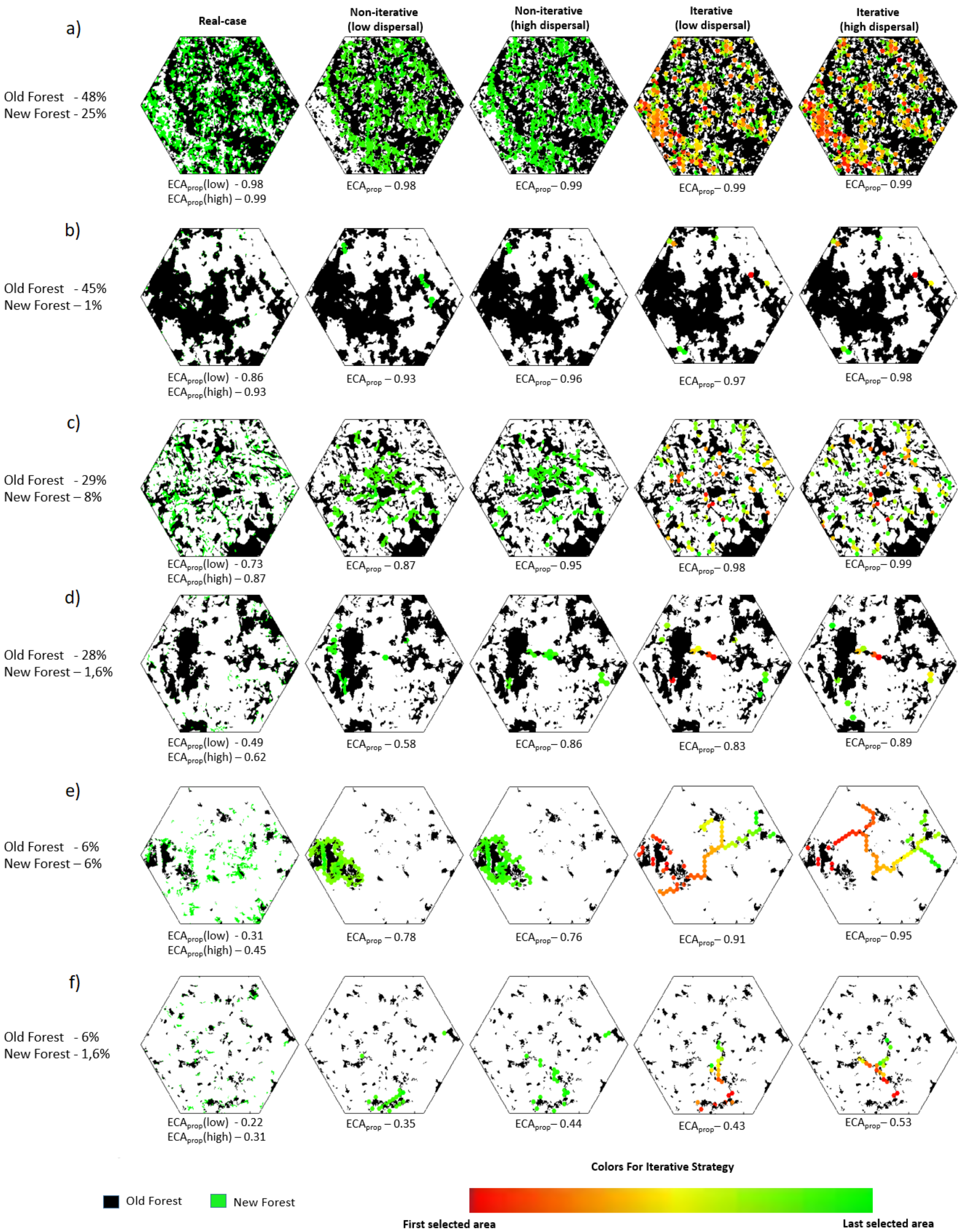

Figure 5 – Simulation results for some of the studied landscapes. Note the difference in corridors created by the iterative method for both dispersal capabilities.

4. Discussion

Our results show that the forests that emerged in the past 35 years provided a habitat availability improvement in the Atlantic Forest. The Atlantic Forest is a biome undergoing intense land-use changes (Lira et al., 2012). The recovery of forests through time, can temporary reduce the deleterious effects of deforestation in these dynamic landscapes (Martensen et al., 2017) and delay the species extinction debts caused by the forest cover loss and fragmentation (Lira et al., 2019), specially for species with larger time lag responses to fragmentation (Metzger et al., 2009). We can observe forest recovery promoted habitat availability gain throughout the entire Atlantic Forest (figure S2). However, habitat availability gain provided was lower than what a spatially planned restoration could provide. The difference between restoration gains was higher for landscapes with low forest cover. In these low forest landscapes, communities are under risk of suffering changes in community composition (Banks-Leite et al., 2014) and ecosystem services that rely on different ecological process (Boesing et al., 2017, Vidal et al., 2019), making a systematic approach for area selection more relevant in landscapes with lower forest cover.

Many studies focus on spatial planning in an attempt to find priority areas for restoration, taking in account tradeoffs among ecosystem services, conservation (Brancalion et al., 2019, Strassburg et al., 2019)and social and economic benefits (Larossa et al., 2019). However, these studies analyze restoration mainly in large scale with few of them focusing in landscape local scales (Tambosi et al., 2013, Blazquez-Cabrera et al. 2019, Liu et al., 2018). Our results show that restoration projects that do not take local scales in account can produce results 50% lower than the ideal, especially in landscapes with low forest cover.

Even though the new forests could not reach the maximum possible habitat availability for landscapes with low forest cover, they provided an increase in ECA higher than a strategy based on random area selection. We could not infer the origin of the new forests in the real case. They could result mainly by natural regeneration or active restoration projects. In both cases, new forests fragments benefit from being closer to old forest fragments. The propagules dispersal to them are higher in areas that are functionally connected to existing forest patches and restoration success rates increase (Sunaguma et al., 2018). Actually, natural regeneration in the Atlantic Forest tend to occur in areas closer than 192m to existing forests (Crouzeilles et al., 2020) and where land have lower opportunity costs (Brancalion et al, 2019). This could represent a pattern for the location of the restored forests in the real case scenario that differs from the other scenarios.

When forest cover increases, the difference among strategies decreases. This effect could be explained by the number of possible spatial configuration of fragments in a landscape. The number of spatial configuration that results in varied habitat availability amounts is higher when forest cover is around 30%, but decreases considerably for higher forest covers (figure S1, Villard & Metzger, 2014). The lower number of available areas for restoration in landscapes with higher forest cover and the lower number of possible spatial configuration for fragments in these landscapes reduce the differences among strategies. For example, in a landscape with high forest cover there is a lower number of possible areas available for restoration. If one randomly selects an area to restore in this landscape, the probability that this area is also selected by other strategies is higher.

Although the BAF presents around 28% of forest cover (Rezende et al. 2018), its heterogeneous distribution results in few areas with large continuous and the majority of landscapes is highly fragmented and with low values of forest cover (figure S2 - Tambosi et al., 2014). Most of these landscapes are in rural areas where landowners are legally obligated to maintain at least 20% of forest cover in their properties (called “legal reserve” in the Brazilian Forest Code). Landowners of properties in debt with the law can opt to restore their legal reserve in a period of 20 years, implementing the restoration of 1/10 of the total every 2 years (Soares-Filho et al., 2014). The iterative method suits the stepwise approach of the law. At each 2 year period, areas for restoration can be selected by simulating different steps of our iterative method. By considering temporal changes in landscapes we can have more accurate estimates of habitat availability changes due to land cover transitions (Martensen et al. 2017). Consequently, the planned increase in habitat availability through time can improve restoration success probabilities and reduce total costs for restoration.

Although the best strategy for both species simulated was the iterative, the areas selected for the species were different (figure 4 and 5). Species with a higher dispersal capability can travel longer distances in the matrix and a lower number of stepping-stones are required (Saura et al., 2014,). Using species with restricted living area and dispersal capability as surrogate for other species may lead to conservation plans that are unable to protect species that do not have area as a limiting factor (Dondina et al., 2020). When the amount of restored forest is not capable of reaching ECA values close to the maximum, a strategy that takes into account multiple species to select areas is desired (Diniz et al., 2018). However, our results show that when the amount of forest restored in the landscape increases, all fragments gets connected by the corridors and habitat availability reaches values close to the maximum possible value. When this happens, the landscape ECA gets less sensitive to species dispersal capability and one species can be used as an umbrella for others without significant loss in habitat availability.

5. Conclusion

In the past decades, forest restoration provided an improvement in habitat availability in the Atlantic Forest biome. This increase was higher than a random restoration in the landscape, but was considerably lower than the simulated strategies based on a systematic approach to select target areas for restoration, especially in landscapes with low forest cover. The benefits provided by a spatial planned restoration are more relevant in landscapes with low forest cover, which represents the majority of landscapes in the Atlantic Forest. Spatially planned restoration can maximize the functional connectivity of forest fragments regardless of the species analyzed. However, the areas selected for each species may differ according to its functional aspects. In order to promote the conservation of a higher number of species, large-scale restoration planning must combine natural regeneration in abandoned areas with spatially planned restoration actions. Moreover, the spatial planning must consider a variety of different functional aspects of species when selecting the target areas for restoration inside landscapes.

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7. Supplementary material

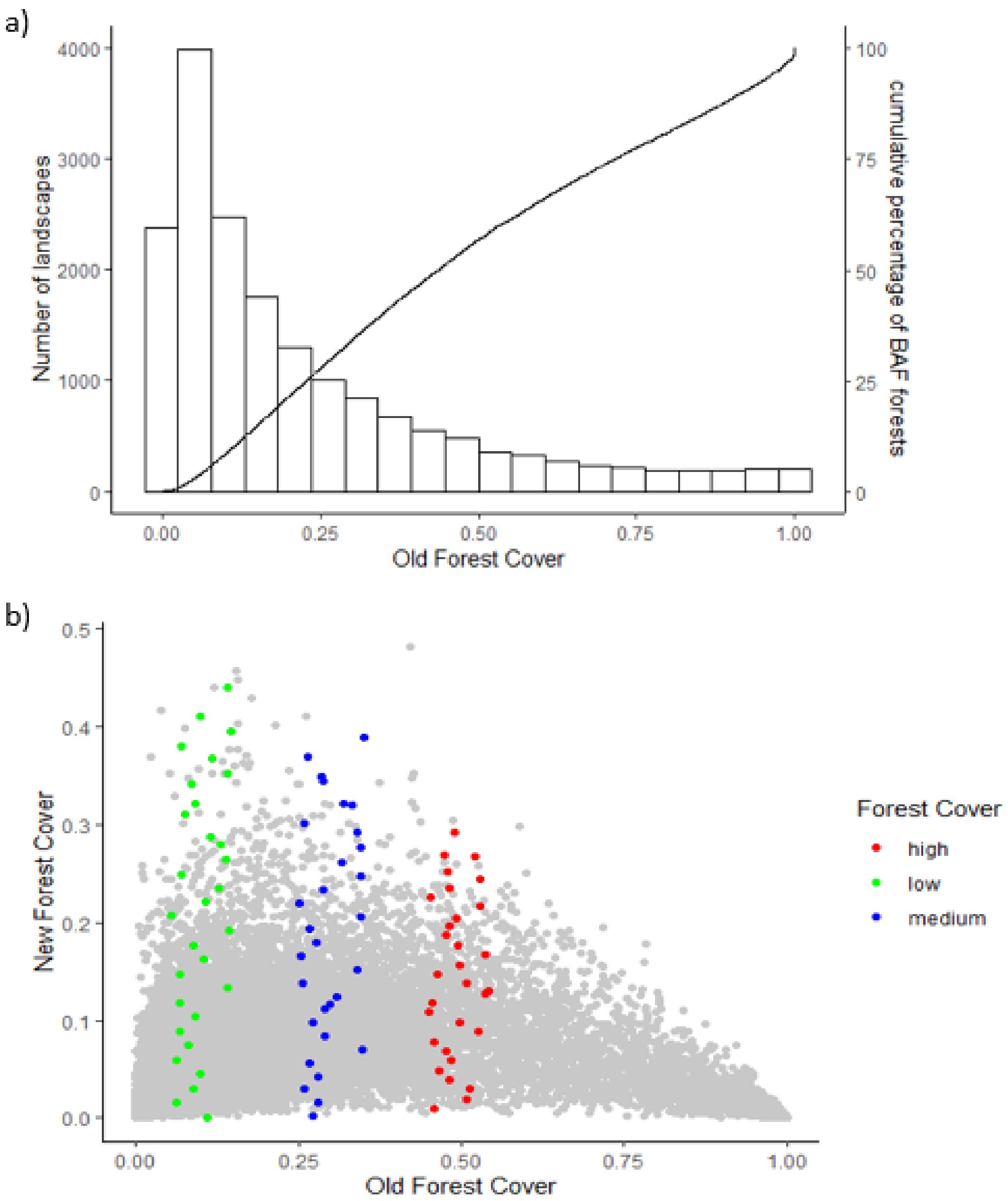

Figure S1 –Distribution of the 17.810 Atlantic Forest landscapes according to forest cover. (a) Histogram of old forest cover. The line shows the cumulative percentage of forests in the whole Atlantic Forest. (b) Landscapes distribution according to Old and New Forest Cover. Colored dots are the landscapes selected for this study. Gray shaded dots represent all the Atlantic Forest landscapes.

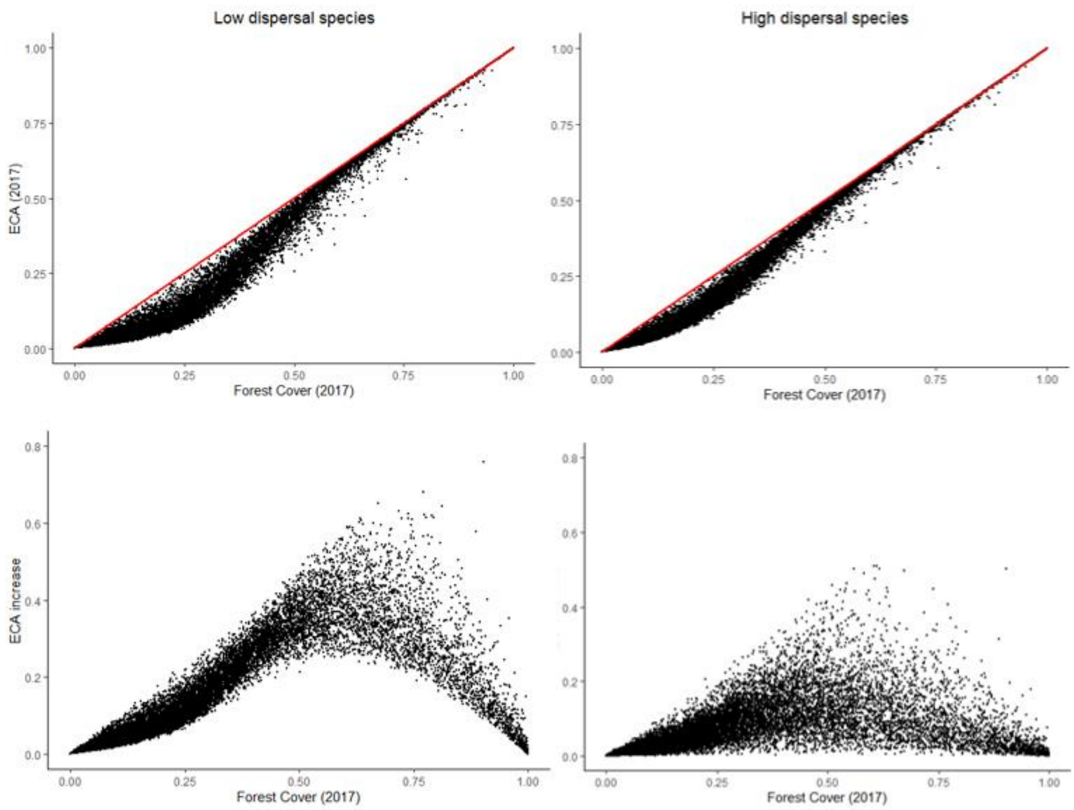

Figure S2 – (Top) Habitat Availability provided by forests in 2017 for species with low (50% probability of crossing 100m) and high (50% probability of crossing 300m) dispersal capabilities. The red line shows the maximum possible ECA value for a given percentage of forest cover. (Bottom) Habitat availability gain provided by restored areas between 1985 and 2017 in Atlantic Forest landscapes.