UNIVERSIDADE FEDERAL DO PARANÁ

CAROLINA MACHADO DA ROSA

RESTAURAÇÃO ECOLÓGICA PARA RECUPERAÇÃO DA BIODIVERSIDADE E MITIGAÇÃO DE MUDANÇAS CLIMÁTICAS: UMA REVISÃO CRÍTICA

CURITIBA

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Quando não ouvirmos mais o cantar de um passarinho
Por não encontrar sementes,
nem galhos pra fazer ninhos.
Quando silenciarem os rios, mortos pela poluição
A própria raça humana estará em extinção!

Carlos Alberto Dos Santos Betinho

Nosso tesouro está onde estão as
colmeias do nosso conhecimento.
Estamos sempre a caminho delas,
sendo por natureza criaturas aladas e
coletoras do mel do espírito.

Friedrich Nietzsche

RESUMO

A ação antropogênica tem gerado grandes impactos, modificando alguns aspectos da Terra. Diante disso, foram realizados acordos internacionais, como as Metas de Aichi e o Acordo de Paris, tornando a recuperação da biodiversidade e a mitigação de mudanças climáticas prioridade na agenda ambiental de muitos países. Desse modo, a restauração ecológica em larga-escala, proposta pelo Desafio de Bonn, é reconhecida como uma das metas mais ambiciosas de atingir esses objetivos. A restauração reverte as principais causas de perda de biodiversidade, criando novos habitats, permitindo conectividade e tornando o ecossistema mais resiliente. Já a mitigação de efeitos das mudanças climáticas é possível por meio do sequestro e acúmulo de carbono atmosférico nas plantas, indicado pela função ecossistêmica de produtividade (biomassa). A teoria ecológica biodiversidade-funcionamento ecossistêmico tem demonstrado a existência de uma relação positiva entre essas facetas. Contudo, não se sabe se a biodiversidade e a função de acúmulo de carbono seguem o mesmo padrão no processo de restauração. Assim, o objetivo deste trabalho foi avaliar se um mesmo projeto de restauração é capaz de recuperar a biodiversidade e mitigar mudanças climáticas. Tendo isso por base, foi realizada uma revisão de literatura, buscando uma melhor compreensão a respeito dessa relação no âmbito da restauração ecológica. Adicionalmente, foi realizado um estudo de caso em florestas tropicais, a fim de investigar a natureza desta relação. De um modo geral, diversidade e função se relacionam positivamente e a restauração é capaz de recuperá-las. Foi encontrada uma alta correlação linear positiva entre biodiversidade e biomassa. Pode-se concluir, então, que a restauração é um modo eficiente de atingir metas para ambos os acordos internacionais. Assim, espera-se que esse trabalho possa subsidiar políticas ambientais no Brasil e outras partes do mundo.

Palavras-chave: acordo de Paris, desafio de Bonn, Metas de Aichi, relação biodiversidade-funcionamento ecossistêmico

ABSTRACT

The anthropogenic action has generated great impacts, modifying some aspects of the Earth. International agreements such as the Aichi Targets and the Paris Agreement have been made, making biodiversity recovery and climate change mitigation a priority in the environmental agenda of many countries. Thus, the large-scale ecological restoration, proposed by Bonn Challenge, is recognized as one of the most ambitious targets to reach those goals. The restoration reverses main causes of biodiversity loss, creating new habitats, allowing connectivity and making the ecosystem more resilient. On the other hand, the mitigation of climate changes effects is possible due to atmospheric carbon sequester and accumulation on plants, indicating the ecosystem function of productivity (biomass). The ecological biodiversity-ecosystem functioning theory has demonstrated a positive relationship between those facets. However, it is not known if biodiversity and the function of carbon accumulation follow the same pattern along the restoration process. Therefore, this study aimed to evaluate if the same restoration project is able to recover biodiversity and mitigate climate changes. Based on that, we reviewed a literature, looking for a better comprehension about this relationship and how restoration can recover both facets. Add to that, we performed a case study in tropical forest to investigate this relationship. In general, diversity and function have a positive relationship and restoration is able to recover both. A high positive correlation between biodiversity and biomass was found on the case study. Then, we can conclude that restoration is an effective way to accomplish both agreements. In this sense, we hope that this study can subsidize environmental policies actions in Brazil and across the world.

Keywords: Aichi Targets, biodiversity-ecosystem functioning theory, Bonn Challenge, Paris Agreement

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LISTA DE SIGLAS

AFR100	African Forest Landscape Restoration Initiative
BEF	Biodiversity and Ecosystem Functions/ Biodiversidade e Funções Ecossistêmicas
BES	Biodiversity and Ecosystem Services/ Biodiversidade e Serviços Ecossistêmicos
BP	Biodiversity-Productivity
CBD	Convention of Biological Conservation
COP	Conference of Parties
ER	Ecological Restoration
ES	Ecosystem Services
FLR	Forest Landscape Restoration
MEA	Millennium Ecosystem Assessment
NDC	Contribuição Nacionalmente Determinada
ONG	Organização Não-Governamental
ONU	Organização das Nações Unidas
PACTO	Pacto para a Restauração da Mata Atlântica
PLANAVEG	Plano Nacional de Recuperação da Vegetação Nativa
PROVEG	Política Nacional de Recuperação da Vegetação Nativa
RE	Restauração Ecológica
SE	Serviço Ecossistêmico
SER	Society of Ecological Restoration
SDG	Sustainable Development Goal
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Changes

WWF	World Wide Fund for Nature

SUMÁRIO

1 INTRODUÇÃO GERAL

A ação antropogênica tem causado grandes impactos e alterado vários aspectos do funcionamento do planeta Terra (STEFFEN et al., 2011). Os efeitos das ações humanas são notáveis, ao ponto de geólogos indicarem a época atual como um novo período geológico, denominado Antropoceno (CRUTZEN; STOERMER, 2000). As florestas tropicais, bem como outros ecossistemas, têm sofrido grandes impactos das ações humanas, tais como desmatamento para expansão agropecuária, extração madeireira, fragmentação da paisagem, invasão de espécies exóticas, disseminação de patógenos, perda de biodiversidade natural. Além disso, o aumento da concentração de gás carbônico na atmosfera que tem levado ao aquecimento global e, consequentemente, às mudanças climáticas (MALHI et al., 2014).

A restauração ecológica (RE) é entendida como um método de reverter ou mitigar parte dos impactos causados por ações humanas (VALIKCHALI; POURMAJIDIAN; DARVISHI, 2014). Pode ser definida como o processo de recuperação de um ecossistema que sofreu algum distúrbio, dano ou degradação (SER, 2004). Ao se planejar a restauração, deve-se considerar a estratégia a ser empregada. A estratégia de restauração passiva aguarda o retorno espontâneo de um ecossistema através da regeneração natural (CHAZDON, 2012). Já a restauração ativa exige uma ação humana direta, como, por exemplo, plantio de mudas ou sementes. Esta estratégia ativa pode ser financeiramente inviável quando se trata de larga-escala e, por isso, o potencial da regeneração natural deve ser aproveitado quando as condições econômicas e ecológicas forem favoráveis (CHAZDON; GUARIGUATA, 2016; CHAZDON; URIARTE, 2016).

Assim, a restauração deve ser planejada de tal forma a ter seus objetivos finais previamente definidos (SER, 2004). Ela busca, de um modo geral, recuperar a biodiversidade e função do ecossistema (PALMER; AMBROSE; POFF, 1997). A teoria ecológica a partir da qual a restauração se desenvolveu é a sucessão secundária (YOUNG, 2000), que é definida como o processo natural que ocorre em um ecossistema após um distúrbio (ENGEL; PARROTTA, 2003). A teoria prediz que ao longo da trajetória sucessional os ecossistemas apresentam um aumento em sua complexidade estrutural e funcional (CHAZDON, 2012), com um aumento na estrutura (espécies e complexidade) e na função (biomassa e nutrientes) do ecossistema (GUARIGUATA; OSTERTAG, 2001; LUGO; BROWN, 1992). A primeira discussão sobre esta relação entre biodiversidade e função ecossistêmica (BEF) no contexto da restauração ecológica foi realizada por Bradshaw (1984), que sugeriu que as variáveis estruturais e funcionais aumentam conjuntamente, caracterizando um modelo linear. Apesar de essas relações serem, majoritariamente, positivas, não se sabe exatamente como elas ocorrem em diferentes situações.

A esta discussão estrutural e funcional da restauração foi posteriormente incorporada a ideia dos serviços ecossistêmicos (SEs), ou seja, as funções ecossistêmicas que trazem benefícios para o ser humano (DE GROOT et al., 2010). Assim, dada a provisão de SEs pelo ecossistema, a restauração também possibilita promover o bem-estar humano. Com isso, os estudos sobre as relações da biodiversidade e serviços ecossistêmicos (BES) passaram a ser relevantes também dentro da restauração ecológica.

Bradshaw (1987) propõe que a restauração é um teste ácido para o entendimento da ecologia. Assim, a teoria da relação BEF e BES pode e deve ser testada no contexto da restauração ecológica, uma vez que a ecologia da restauração pode se beneficiar da pesquisa sobre essas relações e vice-versa (NAEEM, 2006; WRIGHT et al., 2009). A relação entre diversidade e produtividade é uma BEF comumente estudada (LOREAU et al., 2001). A produtividade representa a função de sequestro e acúmulo de carbono que, por sua vez, auxilia na mitigação de efeitos das mudanças climáticas. Assim, no atual contexto ambiental, essa relação entre a biodiversidade e produtividade é de extrema relevância.

Dados os efeitos da perda de biodiversidade e do aquecimento do planeta Terra que caracterizam a presente era, alguns acordos internacionais foram propostos. Com objetivo de recuperar e proteger a biodiversidade, foram estabelecidas, em 2010, durante a 10ª Conferência das Partes (COP) da Convenção da Diversidade Biológica (CDB), as Metas de Aichi (LEADLEY et al., 2014). Este documento assinado por 193 países compreende 20 metas, organizadas em cinco objetivos estratégicos, sendo eles: a) tratar as verdadeiras causas da perda de biodiversidade internalizando o tema “biodiversidade” em todo o governo e sociedade; b) reduzir as pressões diretas sobre biodiversidade e promover utilização sustentável; c) melhorar a situação (*status*) da biodiversidade, protegendo ecossistemas, espécies e diversidade genética; d) ressaltar os benefícios da biodiversidade e dos serviços ecossistêmicos a todos; e) aprimorar e ampliar a implementação das metas por meio do planejamento participativo, gestão de conhecimento e capacitação. Explicitamente, as metas 14 e 15, pertencentes ao objetivo estratégico *d*, afirmam a necessidade de restaurar áreas degradadas, a fim de recuperar e proteger a biodiversidade e promover o fornecimento de serviços ecossistêmicos, por meio da retomada do funcionamento ecológico do ecossistema (LEADLEY et al., 2014). Considerando, por outro lado, a questão da provisão do serviço ecossistêmico de mitigação das mudanças climáticas, por meio do sequestro e estoque de carbono, foi assinado por 173 países o Acordo de Paris. Este acordo foi proposto na 21ª COP da Convenção-Quadro das Nações Unidas sobre Mudanças Climáticas (UNFCCC) e tem por objetivo reduzir a emissão de gases do efeito estufa e manter a temperatura global a menos de 2°C comparado aos níveis pré-industriais (UNFCCC, 2015). O documento reitera a necessidade de aumento do estoque de carbono em florestas, como medida de mitigação.

Diante dessa necessidade de restaurar áreas degradadas em larga-escala, o desafio de Bonn foi proposto para promover a restauração de 150 milhões de hectares até 2020 e de 350 milhões de hectares até 2030, ao longo dos biomas no mundo inteiro (IUCN, 2011). Este desafio não é, necessariamente, um novo acordo, mas sim um modo prático e efetivo de cumprir o que foi proposto pelos acordos anteriores. Assim, o desafio de Bonn é uma iniciativa global de restauração e foi posteriormente aprovado e ampliado pela Declaração de Nova York sobre Florestas da Cúpula do Clima da ONU de 2014. Além disso, baseado neste desafio, há iniciativas mais regionais de restauração, como a Iniciativa 20x20 na América Latina e Caribe (WRI, 2018a), e a AFR100, na África (WRI, 2018b).

Por ser um dos países com maior biodiversidade do planeta (JENKINS, 2003) e sofrer perdas significativas de vegetação nativa, o Brasil está inserido neste contexto ambiental global. Especialmente a Mata Atlântica, bioma brasileiro considerado um dos *hotspot* de conservação da biodiversidade em nível global (MYERS et al., 2000) e, por fornecer serviços ecossistêmicos para a maior parte da população brasileira, é um dos principais focos das iniciativas de restauração. Por conta disso, nos últimos anos, houve um aumento de áreas de restauração e de florestas secundárias no Brasil, na busca pela retomada da funcionalidade das florestas, recuperando sua estrutura e seus processos ecológicos anteriores aos distúrbios (LIEBSCH; MARQUES; GOLDENBERG, 2008).

Alguns biomas brasileiros sofrem com ações antropogênicas, como o Cerrado, o qual já perdeu 50% da sua área original (WWF-BRASIL, 2017). A Amazônia, por sua vez, teve mais de 20% de sua área desflorestada (DAVIDSON et al., 2012). A Mata Atlântica brasileira possui, atualmente, apenas 12,5% de sua cobertura original (SOS: Mata Atlântica, 2017), portanto é alvo de muitos programas de restauração, inclusive o Pacto para Restauração da Mata Atlântica (PACTO), uma iniciativa de restauração em larga-escala existente neste bioma (RODRIGUES; BRANCALION; ISERNHAGEN, 2009).

Nesse sentido, o Brasil possui um papel protagonista diante dos grandes acordos globais. Como signatário do desafio de Bonn, assumiu o compromisso de recuperar 12,5 milhões de hectares da vegetação nativa até 2035. Para isso, o governo brasileiro instituiu o Plano Nacional de Recuperação da Vegetação Nativa (PLANAVEG) e a Política Nacional de Recuperação da Vegetação Nativa (PROVEG) (decreto n° 8972, 2017). Enquanto o PLANAVEG busca expandir e fortalecer políticas públicas, a PROVEG objetiva promover políticas e ações para recuperar florestas e outras formas de vegetação nativa. Algumas diretrizes propostas são a mitigação das mudanças climáticas, incentivo à recuperação e conservação da biodiversidade e de serviços ecossistêmicos, bem como estímulo da recuperação da vegetação com finalidade de se obter benefícios sociais e econômicos (BRASIL, 2017).

O Brasil também se propôs a cumprir as Metas de Aichi e assinou o Acordo de Paris. O país, então, criou suas próprias metas nacionais para recuperação e conservação da biodiversidade autóctone (BRASIL, 2013). Após a assinatura do Acordo de Paris, o Brasil criou a Contribuição Determinada Nacionalmente (NDC), que pretende reduzir a emissão de gases do efeito estufa em 37% até 2025 e 43% até 2030. De acordo com a NDC, outras medidas são evitar o desmatamento da Amazônia, realizar o manejo sustentável das florestas e promover a restauração de áreas degradadas (BRASIL, 2015). Adicionalmente, foi estabelecida a Política Nacional sobre Mudanças do Clima (Lei n° 12187, 2009), a qual contém planos para mitigação e adaptação às mudanças climáticas e objetiva a proteção do sistema climático.

Diante do exposto, o objetivo desta dissertação é discutir as questões conceituais e teóricas da relação entre a biodiversidade e as funções ecossistêmicas, no contexto da restauração ecológica. De maneira mais objetiva, pretende-se avaliar se um mesmo projeto de restauração é capaz de recuperar a biodiversidade e mitigar efeitos das mudanças climáticas. O trabalho discute, por meio de revisão da literatura e de um estudo de caso em florestas tropicais, a relação entre biodiversidade e acúmulo de biomassa em áreas em restauração. Assim, este estudo apresenta uma abordagem global de restauração ecológica, em vista dos acordos anteriormente mencionados. Contudo, ele também contém uma aplicabilidade local e nacional, uma vez que o Brasil é elemento fundamental no panorama mundial de restauração.

2 CAPÍTULO 1

É possível restaurar a biodiversidade e mitigar os efeitos das mudanças climáticas num mesmo projeto de restauração? Uma revisão do contexto, conceitos e paradigmas por trás desta questão*

* artigo preparado de acordo com as normas da seção “Perspectives” da revista “Biological Conservation” (vide Anexo 1).

Is it possible to restore the biodiversity and mitigate the effects of climate changes in the same restoration project? A review of the context, concepts and paradigms behind this question

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ABSTRACT

In order to accomplish global agreements, such as the Aichi Targets and Paris Agreement, many countries aim to recover biodiversity and mitigate climate changes. Based on that and, also, against the Bonn Challenge, these countries are restoring their degraded lands, with the idea that restoration is able to reach both goals. The ecological theory has showed that there is a relationship between biodiversity and ecosystem functions and services, mostly. However, it is not clear if biodiversity and carbon storage (related to the ecosystem service of mitigation of climate changes) follow the same pattern along the restoration process. In this context, we asked if the same restoration initiative can recover biodiversity and mitigate the effects of climate changes. We reviewed literature about the relationships between diversity and ecosystem function and how ecological restoration recovers both of them. Furthermore, we used a case study in tropical forests to discuss the restoration as a tool for fulfilling the international agreement. In general, biodiversity and function are positively related and restoration can recover them. We found a high linear and positive correlation between biodiversity and ecosystem function of carbon storage in tropical forests. Thus, we conclude that the same restoration project is able to accomplish both goals. In this way, with the results here presented, we hope to help and subsidize policies and actions for restoration, considering biodiversity and climate changes together.

Keywords: Aichi Targets, Bonn Challenge, carbon stocks, diversity, ecosystem function/service, Paris Agreement

HIGHLIGHTS:

- Restoration is a way to recover biodiversity and mitigate climate changes.
- Ecological restoration is a way to accomplish the Aichi Targets and Paris Agreement.
- Tropical forests present high correlation between biodiversity and biomass.

1. Introduction

In the present scenario of exceeded planetary boundaries of biodiversity loss and climate changes (Rockström et al., 2009), large scale ecological restoration has been used as a potential tool to minimize these issues. In other words, the planet is changing and the ecological restoration is a realistic tool to reverse part of those changes (Valikchali et al., 2014). On this, the ecological restoration has received more attention in the last three decades (Young, 2000), attracting researchers, managers and decision makers worldwide (SER, 2017). For instance, the current global agreements for biodiversity conservation (Aichi Targets), climate change mitigation (Paris Agreement) and world sustainability (Sustainable Development Goals) consider restoration as an objective to reach the proposed achievements (Leadley et al., 2014; UN, 2015; UNFCCC, 2015). Therefore, understanding the possible scope and limitations of restoration is important for global strategies for biodiversity conservation and global warming mitigation.

The first step for ecological restoration planning is defining their goals, based on ecological, economical and social contexts (SER, 2004). The main focus of ecological restoration is to recover biodiversity, functions or both (Lamb et al., 2005; Wright et al., 2009) of the degraded ecosystem. Thus, biodiversity and ecosystem functions are usually considered together in a restoration project, despite the fact that relationship between both is neglected. In the seminal study of Bradshaw (1984) (Fig. 1), the restoration is shown conceptually as an action that results in a gradual increase of ecosystem structure (species and complexity) and function (biomass and nutrient content), that are linearly related. Thereby, a gain in number of species (or functional groups) is followed by a gain in ecosystem functions. Although we do not know exactly how the relationship between ecosystem structure (biodiversity) and ecosystem function (productivity, decomposition, nutrient cycling) operates across different restoration strategies and scales, there is an idea that it is needed more species for a constant ecosystem functioning and even more for ecosystem stability (Loreau et al., 2001), although some models indicate that the ecosystem function can stabilize from a given species diversity (Naeem, 1998). Theoretically, ecosystem processes are dependent on biodiversity (Hooper et al., 2005), and the restoration is seen as the way to reestablish both of them (Bullock et al., 2011). However, it is not clear if, in empirical studies and at large scales, this relationship is sustained.

Inserted in this context in which the global agreements are in course, it is extremely important to consider the human needs. For that, we should consider the ecosystem services, i.e., the functions that the ecosystems have that can bring benefits to human well-being (Costanza et al., 1997; De Groot et al., 2010). Based on that, it is also necessary to understand and discuss the relationship between biodiversity and ecosystems services (BES).

In this paper, we discussed the ecological concepts and paradigms involving biodiversity-ecosystem functioning theory (BEF) in the ecological restoration context. We reviewed the ecological literature on the BEF and BES, discussed this relationship in restoration areas, and used a case study in tropical forests, aiming to evaluate and discuss if the same restoration initiative is potentially able to recover biodiversity and mitigate the effects of climate changes. In other words, we asked if these two goals are congruent and how this relationship operates. Since there is, apparently, a relationship between diversity and ecosystems functions and services, it is expected that restoration trajectory can recover both of them.

2. Global Political Context

The most important global agreements on sustainability established in the last years explicitly point the restoration as a way to reach their goals (Chazdon et al., 2016). The Aichi's Targets, established in the 10ª COP of Convention on Biological Diversity (CBD) in 2010, were signed by 193 countries and aim to reduce the biodiversity losses until 2020. Specifically, the targets 14 and 15 explicit that the ecosystems that provide essential services should be restored and safeguarded and, also, the contribution of biodiversity to carbon stocks must be enhanced, contributing to climate change mitigation. Also, it is expected that at least 15 per cent of degraded ecosystems in the world to be recovered (Leadley et al., 2014). In this way, it is recognized that only conservation cannot provide biodiversity maintenance, being restoration also necessary (Dobson et al., 1997; Moreno-Mateos et al., 2012). So, although the knowledge about ecological restoration is still developing, this action has a significant role in helping the threat to biodiversity (Aronson and Alexander, 2013). Based on this, the 11ª COP of Convention on Biological Diversity (CBD) in 2012 in Hyderabad highlighted the importance of restoring degraded lands to achieve the Aichi Targets (CBD, 2012). The Paris Agreement signed by 175 countries in the 21ª COP of United Nations Framework Convention on Climate Change (UNFCCC) aims to strengthen the global response to the threat of climate changes, to maintain the increase in global temperature below 2°C, to reduce the greenhouse gas emissions and to increase the capacity of adaptation to climate changes (UNFCCC, 2015). For that, among several actions, the restoration and adequate management of forests as carbon sinks, in order to increase carbon storage, are necessary (Griscom et al., 2017). Also, the Sustainable Development Goals (SDG) launched in 2015 by the United Nations and agreed by 193 member states established goals to combat climate change and biodiversity losses. The SDG 13 determines that reforestation of degraded and degrading landscapes should increase to combat global warming and the SDG 15 lays down that terrestrial ecosystems should be protected and restored in order to halt biodiversity losses (UN, 2015).

All these agreements place restoration as the best (or only) way out to reverse the severe rates of loss of biodiversity and global warming (Bullock et al., 2011). As a consequence, some other initiatives established a pact for large-scale restoration as the Bonn Challenge, a global effort to restore 150 million hectares of degraded land by 2020 and 350 million hectares by 2030 (IUCN, 2011a); the 20x20 Initiative, the Latin American and Caribbean initiative of countries to restore 20 million hectares by 2020 (WRI, 2017b); the African Forest Landscape Restoration Initiative (AFR100), the African initiative to restore 100 million hectares by 2030 (WRI, 2017a); and the Brazil’s Atlantic Forest Restoration Pact, the Brazilian initiative to recover 15 million hectares by 2050 (Rodrigues et al., 2009). From these initiatives, several other approaches have been unrolled, for instance, the Forest Landscape Restoration initiative, that aims to retake the ecosystem functionality and improve the human well-being (IUCN, 2011b), and the New York Declaration on Forests (UN, 2014) that aims to strive to decrease the forest losses, restore forests and croplands, and reduce the greenhouse effect gases in 4.5-8.8 billion of tons until 2030 (UN, 2014). Thus, the ecological restoration is a worldwide concern and has been prioritized on the agenda of most countries.

3. Biodiversity and Ecosystem Functions (BEF) and Services (BES) Relationships

The relationship between biodiversity and ecosystem function has been a central issue and intrigues ecologists for a long time (Loreau et al., 2001). That is the reason why it is one of the 100 fundamental ecological questions and extremely relevant for the future of ecology (Sutherland et al., 2013). The biodiversity may influence both ecosystem functions (productivity, soil stability and nutrient cycling) and ecosystem services (soil fertility, provisioning of plant products, erosion control, invasion resistance, pest and pathogen regulation and water supply), so the biodiversity loss can drastically affect ecosystem processes (Hector et al., 2007; Naeem et al., 1999; Quijas et al., 2010). Considering the ecological restoration, the BEF approach allows to evaluate the restoration in ecosystem functioning context, besides responding to several gaps of knowledge in restoration ecology (Aerts and Honnay, 2011). According to Vitousek and Hooper (1993), there are three possible types of BEF relationships, being the type I a linear function; type II an asymptotic curve; and type III assumed no effects of biodiversity on ecosystem function (Fig. 2). Thus, the discussion about BEF involves searching for a pattern for this relationship.

The first and more heated debate about BEF was the biodiversity-productivity relationship (BP) from 1960's. At this time, it was accepted that productivity is the cause of diversity (Preston, 1962), and the unimodal pulse (increased diversity until a maximum, then decreased) was taken as the default (Abramsky and Rosenzweig, 1984; Fox, 1985; Tilman, 1983). However, robust studies have showed that this pattern is present in only 30% of the studies across terrestrial or aquatic ecosystem (Waide et al., 1999), being also linear positive (Abrams, 1988; Cusens et al., 2012), linear negative (Owen, 1988; Wang et al., 2001) and, in some cases, there were no relationship (Cermeño et al., 2013; Wang et al., 1999), indicating great unconformities among ecosystems patterns (Mittelbach et al., 2001). In the 1990's the perspective of diversity driving productivity began to be debated and tested

(Moorthi et al., 2008; Naeem et al., 1994; Schläpfer and Schmid, 1999; Striebel et al., 2012), leading to the actual consensus that both directions of the BEF are interrelated, but context-dependents (Cardinale et al., 2009; Gross and Cardinale, 2007). Throughout this period, several ecological drivers of the BP were identified such as the density of herbivores (Declerck et al., 2007; Hillebrand and Lehmpfuhl, 2011; Yee and Juliano, 2007), the way a community was assembled (Steiner and Leibold, 2004), the interaction within trophic levels (Rakowski and Cardinale, 2016; Thébault and Loreau, 2006), and spatial (Braschler et al., 2004; Chase and Leibold, 2002; Dodson et al., 2000) and temporal (Dodson et al., 2000) scales.

Along this time, the mechanisms underlining the BP were also proposed. High-productivity areas are able to have more species (Preston, 1962) because the increase of available energy, proportioned by productivity, allows more species in the food web (Connell and Orias, 1965; MacArthur, 1955). This mechanism explains the effects of productivity on diversity. On the other hand, the selection effect, i.e., the greatest chance of more productive species existing in more diverse environments being selected, and the niche complementarity, i.e., species with different functions occupying different niches, explained the effects of diversity on productivity (Tilman, 1999).

The BP started to be of high relevance when the anthropogenic drivers were considered in ecosystem functioning (Liang et al., 2016). As well as ecosystems functions, ecosystem services are affected by biodiversity. The relationship between biodiversity and ecosystem services is mostly positive (MEA, 2005), despite this relationship being scale-dependent (Chisholm et al., 2013) and varying with climate, soil and elevation (Di Marco et al., 2018). Even so, biodiversity has different roles in the provision of ecosystem services, acting as regulator of some ecosystem processes, and, also, as a service in itself (Mace et al., 2012). In short, there is a great evidence that biodiversity has positive influence in ecosystem functions and services (Balvanera et al., 2006; Tilman et al., 2012). Thereby, the diversity influences the biomass and carbon storage (Díaz et al., 2009). More diverse communities suffer less losses of biomass due to perturbation than communities with lower diversity (Tilman, 1996). In this way, more diverse communities are more stable and resistant to disturbance (Gross et al., 2014).

Despite existing a lot of studies about the BP in lakes, wetlands and grasslands, it is poorly studied in forests (Ojha and Dimov, 2017; Vilà et al., 2007). There are evidences of positive BP in Mediterranean sclerophylous (Vilà et al., 2007), temperate and mixed (Lei et al., 2009; Paquette and Messier, 2011) and tropical forests (Häger and Avalos, 2017; Lasky et al., 2014; Poorter et al., 2015), even with different measures of biodiversity, such as species richness, diversity index and functional and phylogenetic diversities (Henry et al., 2009; Ojha and Dimov, 2017; Potter and Woodall, 2014; Zhang et al., 2011). Although there are few studies about BP in forests, there is predominant positive worldwide and it appears to be asymptotic (Liang et al., 2016). Along forest restoration, the positive BP is still pervasive (Bu et al., 2014; Salisbury and Potvin, 2015). However, the greater evidence about the positive BP should be treated cautiously, because these consensus results can be caused by publication bias, once supporting evidence is more easily published (Braga et al., 2017). Thus, this relationship must be better studied and we should make decisions carefully.

4. Restoration and biodiversity recovery

In general, the losses in biodiversity have five main causes: habitat degradation and fragmentation, biological invasion, overexploitation, pollution and diseases (McGill et al., 2015; Vitousek et al., 1997; Wilcove et al., 1998). In all these situations restoration can act in different ways to revert those losses partial or totally (Halme et al., 2013; Jordan III, 1997; Young, 2000). For example, ecological restoration creates new habitats (Jordan III et al., 1988), establishes the landscape elements to provide connectivity (Tambosi and Metzger, 2013), and protects fragments from edge effects (Brancalion et al., 2013), avoiding the biodiversity losses by habitat degradation and fragmentation. Restoration strategies based on native species plantation increase the resilience and resistance of an ecosystem to invasive species (Wilson, 2013), decreasing biodiversity losses by biological invasion (Simberloff and Vitule, 2014). The support of economic development and the creation of sustainable livelihood by restoration projects protect biodiversity, since the lack of employment generates forest degradation and overexploitation (Cao et al., 2017). Finally, the restoration of degraded lands can reduce the effects of air and water pollution and increase biodiversity (Lee et al., 2007; Wong, 2003). Besides that, restoration makes the ecosystem more diverse and resistant to diseases (Carnus et al., 2006). Thus, the restoration can be effective to reverse the impacts of human activity on the biodiversity (Qin et al., 2016).

Whereas the restoration reverses the effects of main causes of biodiversity loss, it allows the number of species to increase quickly when the restoration is in course (Brown and Lugo, 1990; Guariguata and Ostertag, 2001). There are evidences that plant species richness (Liebsch et al., 2007; Saldarriaga et al., 1988; Tabarelli and Mantovani, 1999), phylogenetic (Qin et al., 2016) and functional (Cadotte et al., 2011; Marcilio-Silva et al., 2016; Purschke et al., 2013) diversities increase along the restoration. Also, the diversity of animals, such insects (Piper et al., 2009), amphibians (Brodman et al., 2006; Hilje and Aide, 2012), reptiles (East et al., 1995), birds (Catterall et al., 2012) and mammals (Kalies et al., 2012), increases substantially with the restoration.

There are many evidences of increased biodiversity with ecological restoration. Considering aquatic and terrestrial ecosystems across the world, restoration increases the biodiversity in 44% compared to the degraded ecosystem (Benayas et al. 2009). These rates of biodiversity recovery can be even higher in tropical terrestrial ecosystems (250%, Benayas et al., 2009) or agrosystems (68%, Barral et al., 2015), ranging from 54% for vertebrates to 79% for invertebrates (Barral et al., 2015). Considering forests in general, the biodiversity recovery varies between 15 to 84% (Crouzeilles et al., 2017, 2016) and, specifically in tropical forests, is around 53% (Shimamoto et al., in prep). The rates of biodiversity recovery vary across life forms and type of ecosystem. For example, the restoration recovers 108% of invertebrates' biodiversity in Chinese forests (Ren et al., 2017), and only 15% of aquatic invertebrates' biodiversity in wetlands (Meli et al., 2014).

Despite this, it is important to highlight that the influence restoration has on biodiversity recovery is dependent on degradation type, restoration strategy and age, landscape context and taxonomic group (Crouzeilles et al., 2016; Ren et al., 2017).

5. Restoration and recovery of ecosystem functions and services

Many ecosystem functions are recovered along a restoration process, such as nutrients and biogeochemical cycles (Amazonas et al., 2011; Macedo et al., 2008), water regulation (Simões et al., 2002; Stromberg, 2001), carbon sequestration

(Shimamoto et al., 2014), decomposition (Smith and Chadwick, 2014) and pollination (Forup et al., 2008; Williams, 2011).

In general, the restoration recovers 25% of ES of degraded lands across the globe (Benayas et al., 2009). These rates vary across ecosystems, types of ecosystem function and services, and restoration strategy. For example, in agrosystems the restoration recovered a maximum of 120% (Barral et al., 2015) and in passive restoration strategies 319% of regulating services (Ren et al., 2017). Restoration of wetlands increased in 36% of services of provisioning, regulating and supporting (Meli et al., 2014), and for tropical forests, 52% of regulating services (Shimamoto et al., in prep). Despite the differences in recovery rates, it was a consensus that restoration can enhance both, ecosystem functions and services.

Some of the most important ecosystem function and service recovered by restoration in terrestrial ecosystems are productivity and carbon sequestration, respectively (Aide, 2000; Dixon et al., 1994; Parrotta et al., 2012). In such situations, productivity is measured as biomass, which is the carbon accumulated by plants (He et al., 2005). Therefore, the excess of atmospheric carbon should be sequestered and accumulated in ecosystems along the restoration (Cao and Woodward, 1998; Jones and Donnelly, 2004; Lal, 2004; McGuire et al., 2001; Newell and Stavins, 2000). Specifically in early successional stages of restoration, when fast growing species are more abundant, carbon sequestration is faster (Montagnini and Porras, 1998; Shimamoto et al. 2014; Sierra et al., 2012).

The main effect of carbon sequestration to ecosystem is the decreasing of carbon dioxide in atmosphere (Alves et al., 1997; Sierra et al., 2012), pottentially minimizing the effects of climate changes (Holl and Zahawi, 2014; Locatelli et al., 2015; van der Sande et al., 2017). Thereby, the restoration can be a good strategy to respond efficiently to the alterations in regional and global climate (Harris et al., 2006), acting as a carbon offset for at least 40 to 80 years (Silver et al., 2000). Thus, as the restoration of degraded lands allows more carbon uptake, it is a key to mitigate the impacts of global climatic changes (Houghton et al., 1993).

6. Restoring biodiversity and biomass in Tropical Forests: a case study

Tropical forests are the most biological diverse ecosystem in the world (Brown, 2014; Holl, 2002) and have been suffering losses of native vegetation (Mittermeier et al., 2004). These forests provide also many ecosystem services, like carbon sequestration (Lugo and Brown, 1992; Sierra et al., 2012), purification of water (Ellison et al., 2012) and maintenance of soil fertility (Ditt et al., 2010). The tropical forests operate as carbon sinks (Lugo and Brown, 1992; Ngo et al., 2013), once sequester amounts of carbon and store around 45% of terrestrial carbon, 11% of soil carbon pool and it is also responsible for 50% of net primary production (Bonan, 2008; Brown and Lugo, 1982; Chazdon et al., 2016; van der Sande et al., 2017). Specifically the tropical America has the capacity to sequester 46% of total carbon in tropics, while tropical Asia can sequester 34%, followed by tropical Africa with 20% (Brown, 1996). Thus, besides the high diversity present in tropical region (Brown, 2014), it has also large productivity and potential to sequester carbon (Gillman et al., 2015).

Due to their importance and high rate of deforestation, tropical forests have been pointed as the main focus for ecological restoration in the next decades (Chokkalingam and Jong, 2001; Holl, 2017, 2002). In order to assess if restoration projects are able to recover the losses in biodiversity and sequester carbon in atmosphere acting in global warming mitigation, we reviewed studies of tropical forests ongoing ecological restoration. From these studies we extracted two ecological indicators, the Shannon-Wiener index and the basal area. We used the Shannon diversity index because it is a good indicator of biodiversity and, also, more common in studies (Morris et al., 2014). The basal area is extremely correlated to the aboveground biomass, which is an indicator of the amount of carbon absorbed from the atmosphere (Brown and Lugo, 1990). Details of the literature review and analysis are found in Appendix 1 from Supplementary Material.

In a total of 32 plots along tropical region (Table A1), we found a strong linear relationship between the Shannon-Wiener index and the basal area of the tropical forests ongoing restoration ($t = 5.44$, DF = 30, $r = 0.70$; $p < 0.0001$; Fig. 3). Based on this, we can conclude that there is a linear positive relation between biodiversity and the ecosystem function of carbon storage in tropical forests along the ecological restoration, as the type I proposed by Vitousek and Hooper (1993) (Fig. 2). In this way, our case study corroborates with the theoretical model proposed by Bradshaw (1984) and reinforced by Dobson et al. (1997) where biodiversity and ecosystem function increase together during restoration.

Despite there being studies that found negative relationships between species diversity or richness and C stocks, the larger proportion of the studies found positive relationships (Ali and Yan, 2017). The positive BES relationship was also found in wetlands (Meli et al., 2014), agrosystems (Barral et al., 2015) and grasslands (Ren et al., 2016). Although some studies found an asymptotic relationship between biodiversity and ecosystem functions and services, the functions evaluated are not the same, which can change the pattern of the relationship. For example, some studies considered ecosystem functions in general or several ecosystem processes and services together (Benayas et al., 2009; Hector and Bagchi, 2007; Hobbs, 1992; Naeem, 2006; Wright et al., 2009). In this way, it is possible that different functions and services have divergent patterns of the relationship with biodiversity, once distinct functions present dissimilar recovery rates (Ren et al., 2017).

7. Conclusion

In this paper, we discussed the relationship between biodiversity and ecosystem functions, and asked if restoration initiatives are able to recover both of them. According to our review, carbon accumulation and biodiversity conservation can be simultaneously achieved in aquatic or terrestrial ecosystems ongoing restoration. Also, in tropical forests, the two targets are linearly related indicating sinergy in contrastant restoration objectives, confirming previous general studies (Strassburg et al., 2010; van der Sande et al., 2017).

These findings are especially important for planning restoration at large spatial and temporal scales, and empirical studies are not sufficient to capture the total variation of the BES relationships. Thus, in simulations of gain in biodiversity and carbon sequestration with a restoration project, it is possible to predict their recovery in a similar way. However, once the relationship between diversity and biomass changes along a successional trajectory (Lasky et al., 2014) and none all restoration project is able to recover totally the ecosystem structure and function as in the undisturbed ecosystem (Ren et al., 2017), generalizations should be made cautiously (Di Marco et al., 2018).

In the actual scenario of global targets for recovering biodiversity (Aichi Targets) and mitigating the global warming (Paris Agreement), ecological restoration has been in a central role (Thompson et al., 2009; Deal et al., 2012). Considering both objectives together and planning restoration at larger spatial scales and longer time periods (Holl, 2017; Reyers et al., 2012) is possibly more effective to have a global impact, once the same area can achieve both goals, it should be prioritized for ecological restoration.

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Fig. 1. Linear relationship between ecosystem structure and function. The ecosystem can be quantified in two dimensions: structure (species and complexity) and function (biomass and nutrient content). When ecosystems are degraded, there is a decrease in both dimensions. The restoration (red arrow) is the recovery in those two dimensions as they were before (the closest possible). If this recovery is not completely successful, it is called rehabilitation (blue arrow). The replacement (yellow arrow) is when an alternative to the original ecosystem is produced. Figure adaptated from the theoretical model proposed by Bradshaw (1984).

Fig. 2. Possible functional relationships between biological diversity and ecosystem functions. Type I curve (red) demonstrates a linear relationship, type II (blue) indicates an asymptotic curve and type III (green) suggests that there is no relationship. Figure adaptated from Vitousek and Hooper (1993).

Fig. 3. Linear relationship between basal area and Shannon-Wiener index in tropical forests ongoing restoration (n=32).

Fig. 1.

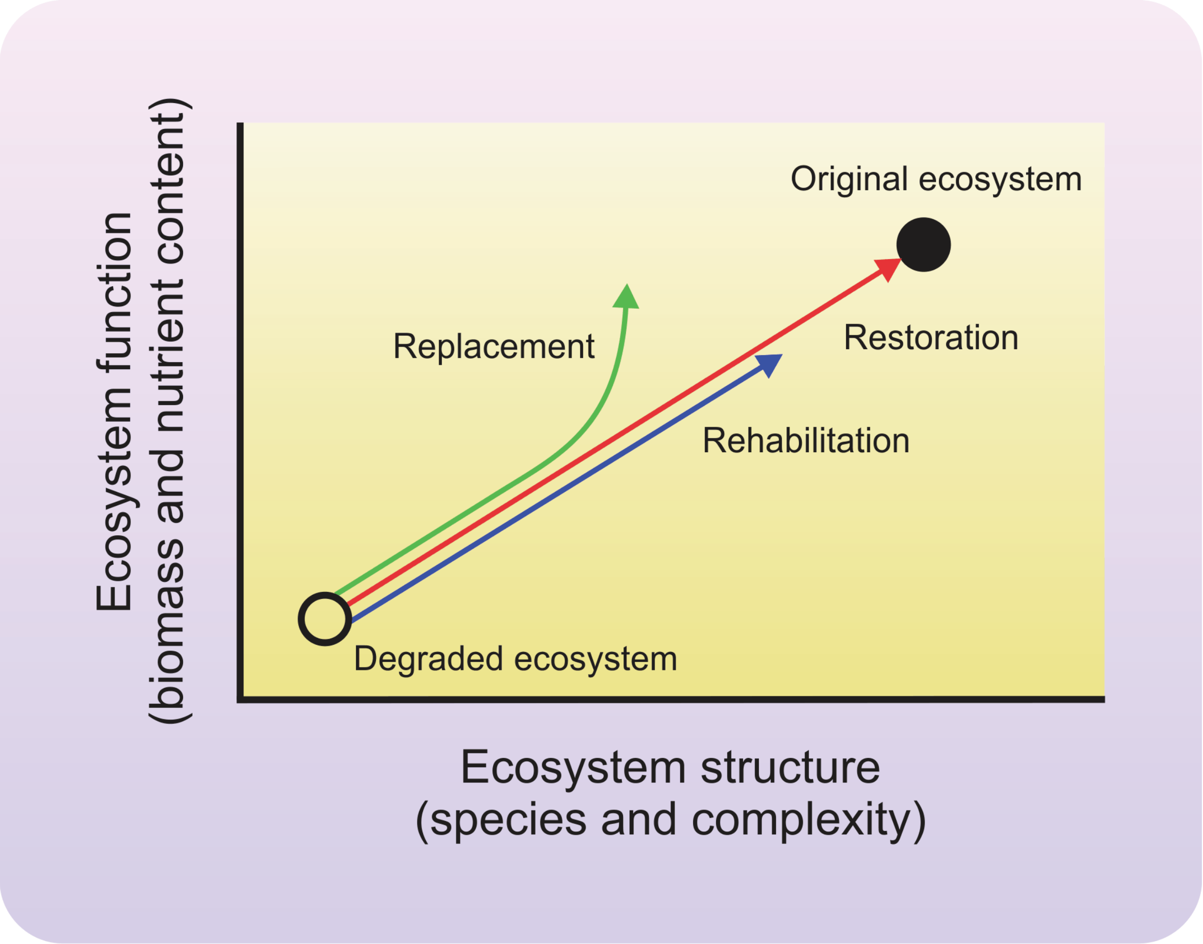

Ecosystem function
(biomass and nutrient content)
Original ecosystem
Replacement
Restoration
Rehabilitation
Degraded ecosystem
Ecosystem structure
(species and complexity)

Fig. 2.

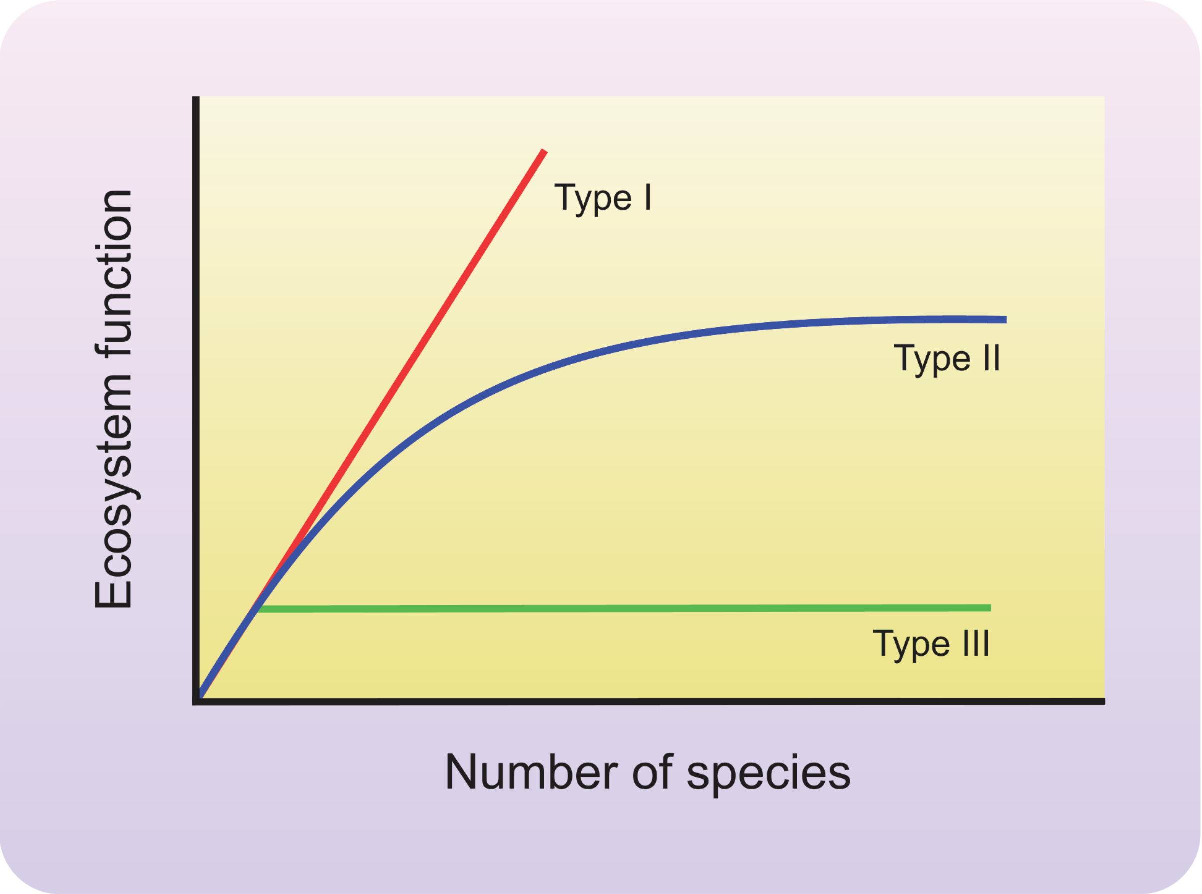
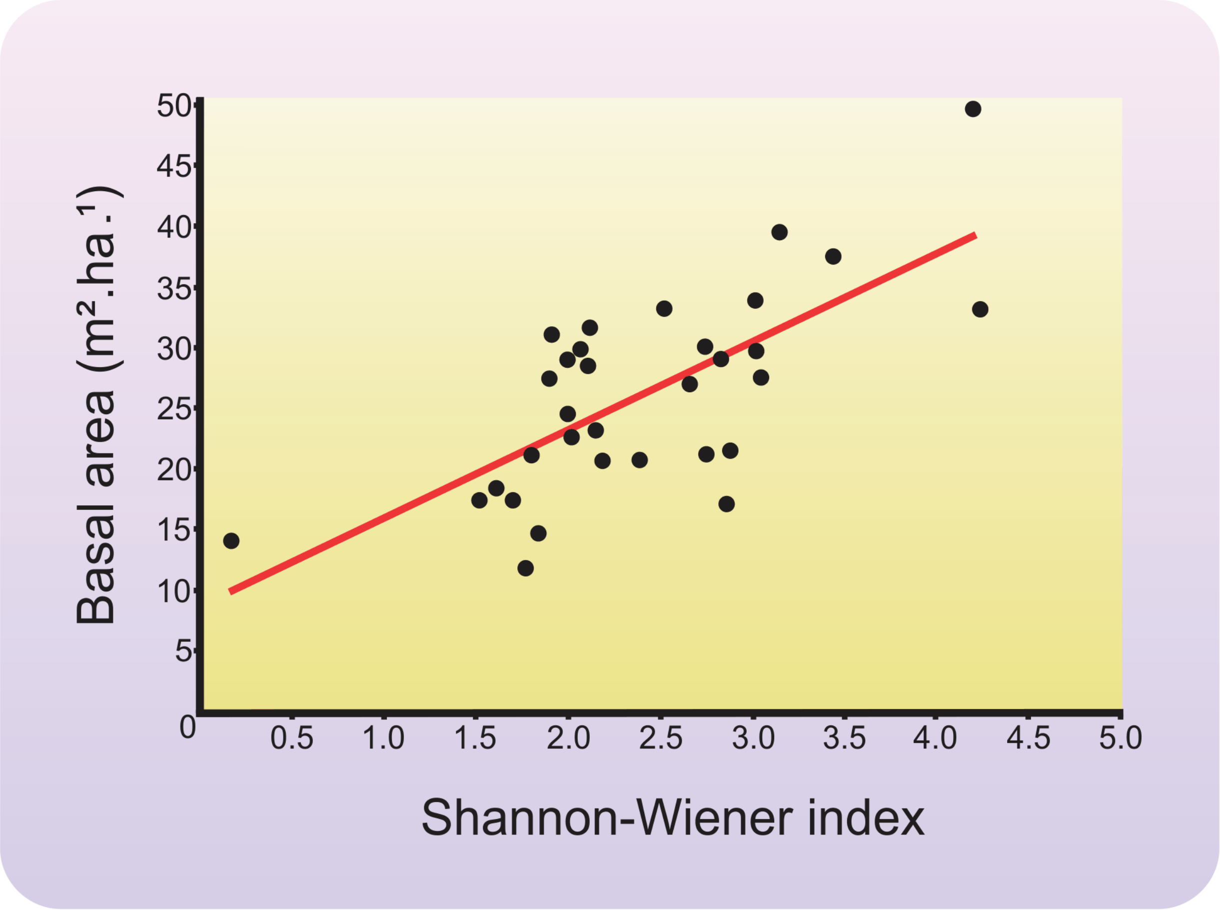

Ecosystem function
Type I
Type II
Type III
Number of species

Fig. 3.


Basal area (m².ha.¹)
50
45
40
35
30
25
20
15
10
5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Shannon-Wiener index

APÊNDICE 1

SUPPLEMENTARY MATERIAL

Appendix 1: Case study

Material and Methods

We searched for scientific papers with the following key words in *Web of Science* in all fields: “tropical forest”, “restoration or regeneration or recovery or succession”, “basal area”, “Shannon” and “plant or vegetation”. The key words for *Science Direct* were (tropical* forest) and (restoration* OR regeneration* OR recovery* OR succession*) and (basal area) and (Shannon) and (plant OR vegetation) and including the followed topics ("species, forest, tree, soil, secondary forest, tree species, species richness, site, management, base area, united states, fire, plant, plot, puerto rico, basal area"). Both searches were made until November, 2017 and returned 168 papers. After that, we read the titles and abstracts to evaluate if the papers were in accordance with our purposes. Then, we selected the data of basal area and Shannon-Wiener index (only index calculated using the natural logarithmic). From the 168 studies, 16 (11%, Table A1, Figure A1) had sufficient data, and represented 14 countries (Table A1). Next, we made a correlation between Shannon-Wiener index and the biomass and adjusted the best model using the Akaike Information Criterium. We considered $\alpha=0,05$ and the premises of normality and homogeneity of variance were fulfilled. There is no spatial autocorrelation based on Moran I analysis (Legendre and Legendre, 2000). All analysis were made in the Platform R Core Team.

Table A1. The 16 studies used for the case study. Complete references below.

Reference	Country	Restoration age (years)	Number of plots
Atkinson and Marín-Spiota, 2015	U.S. Virgin Islands	10 and 40	3
Chinea and Helmer, 2003	Puerto Rico	NA	3
Chua et al., 2013	Singapore	56	2
Covey et al., 2015	Bhutan	NA	1
Cuni-Sanchez et al., 2017	Kenya	NA	2
Ding et al., 2012	China	40 and 55	4
Gallardo-Cruz et al., 2012	Mexico	2 to 60	1
Garcia-Florez et al., 2017	Australia	48	1

Kalacska et al., 2004	Costa Rica	NA	3
Meng et al., 2011	China	15 and 30	2
Onofre et al., 2010	Brazil	NA	1
Shibayama et al., 2006	Sri Lanka	20	1
Valencia et al., 2014	Mexico	NA	1
Zhang et al., 2016	China	NA	1
Zhu et al., 2007	China	55	5
Zhuang 1997	China	NA	1

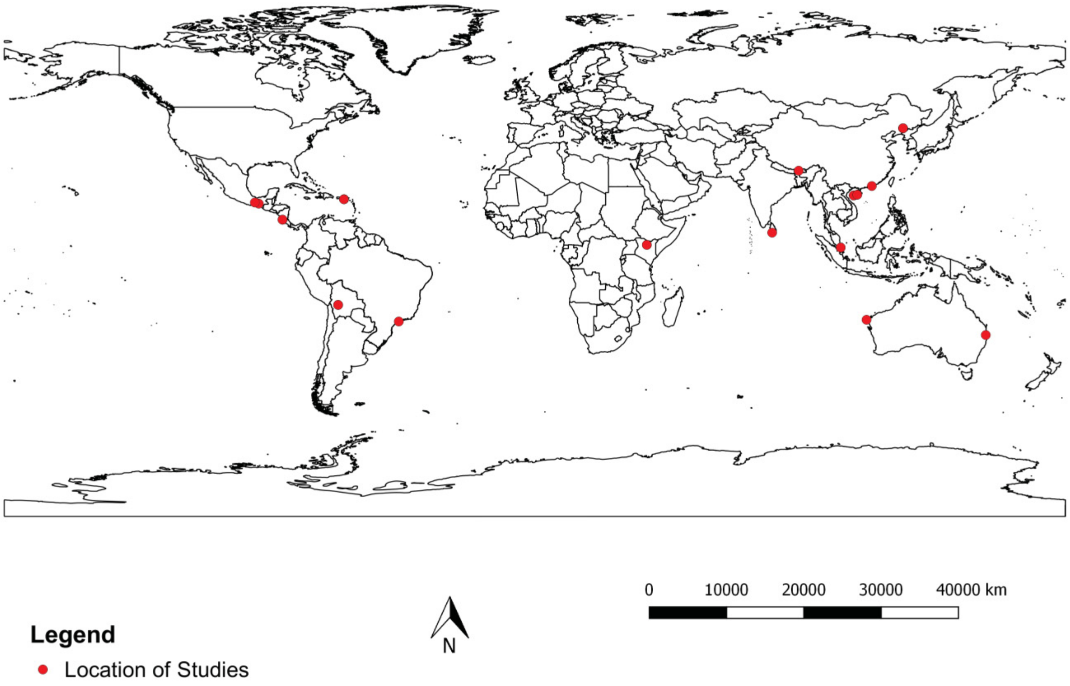


Fig. A1. Distribution of case study sites in tropical forest (n=16).

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3 CONSIDERAÇÕES FINAIS

Em um projeto de restauração ecológica, há duas dimensões que devem ser avaliadas: estrutura, representada pela diversidade biológica, e função, que indica o funcionamento ecossistêmico (BRADSHAW, 1984). No presente estudo, foram discutidas essas duas dimensões, no contexto da restauração, bem como a relação existente entre elas. Com base na revisão bibliográfica e no estudo de caso, pode-se concluir que a restauração é capaz de recuperar tanto a biodiversidade quanto mitigar efeitos de mudanças climáticas em florestas tropicais, uma vez que elas são positivamente correlacionadas, contudo, deve-se ter certa cautela ao expandir essa ideia para outros biomas (DI MARCO et al., 2018). Desse modo, considerando a sinergia entre as dimensões em questão, ao simular os ganhos de biodiversidade e acúmulo de carbono em um projeto de restauração, é possível prever que a recuperação ocorrerá de forma semelhante (STRASSBURG et al., 2010). Dada a atual conjuntura global de acordos internacionais, o estudo das relações BEF e BES na restauração também possui uma aplicabilidade política, social e econômica uma vez que provê serviços ecossistêmicos e permite a geração de empregos e atividades empreendedoras (BENDOR et al., 2015; KELMENSON; BENDOR; LESTER, 2017; REZENDE; SCARANO, 2017).

É extremamente difícil atingir objetivos de restauração sem um respaldo legal (BRANCALION et al., 2013), mas o Brasil possui uma legislação ambiental fundamentada, que integra a Lei de Proteção à Vegetação Nativa (LPVN) e a Política Nacional de Recuperação da Vegetação Nativa (PROVEG), o que o insere em uma situação propícia para implementar a restauração. Assim, há um contexto político favorável para a restauração, propiciando seu comprometimento internacional em restaurar 12,5 milhões de hectares até 2030 e 15% das áreas degradadas até 2020.

Diante da necessidade de cumprir o estabelecido pelas Metas de Aichi e pelo Acordo de Paris, a restauração é uma ferramenta essencial (HOLL, 2017). Assim, considerar os dois objetivos em conjunto e planejar a restauração em larga escala permite o cumprimento desses acordos de forma efetiva.

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