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SPECIES DIVERSITY AND FOREST LOSS. HOW TO RECOVER BIODIVERSITY IN THE BRAZILIAN AMAZON?

DIVERSIDADE DE ESPÉCIES E PERDA FLORESTAL: COMO RECUPERAR A BIODIVERSIDADE NA AMAZÔNIA BRASILEIRA?

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ABSTRACT

Tropical forests, despite occupying only 7% of the Earth's surface, harbor more species of animals and plants than all the other biomes on the planet combined. The Brazilian Amazon has one-third of all these forests (4 million km^2), covering a greater extension than that of all the countries in the European Union, with trees that can reach 80 meters in height, the region also has one of the largest sources of fresh water in the world (6 million km^2). For all this Amazonian potential, Brazil is considered a megadiverse country, crucial for global climate regulation. Due to its economic relevance and government incentives for development, the Brazilian Amazon was invaded and irrationally exploited for many years, resulting in 20% (788,353 km^2) forest loss, which caused a significant decrease in its forest area and irreversible biodiversity loss. In an attempt to stem the loss of biodiversity, several actions to combat deforestation have been created over the years and projects, and techniques and restoration have been implemented in the region. This article aims to conduct a review of the potential biodiversity exists, the process of biodiversity loss as a result of deforestation, and to evaluate the possibilities of restoration in the Brazilian Amazon.

Keywords: Brazilian Amazon; Biodiversity; natural resources; forest degradation; forest restoration.

RESUMO

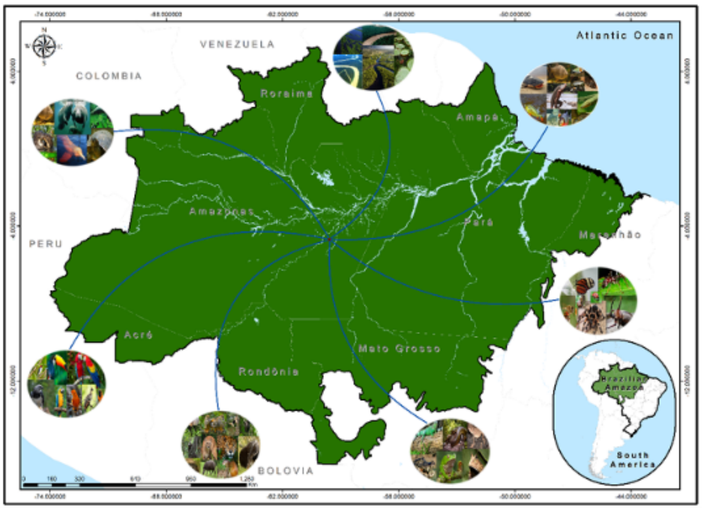
As florestas tropicais, apesar de ocuparem apenas 7% da superfície terrestre, abrigam mais espécies de animais e plantas do que todos os outros biomas do planeta combinados. A Amazônia brasileira possui um terço de todas essas florestas (4 milhões de km^2), cobrindo uma extensão maior do que a de todos os países da União Europeia, com árvores que podem atingir 80 metros de altura. A região também possui uma das maiores fontes de água doce do

mundo (6 milhões de km^2). Diante de todo esse potencial amazônico, o Brasil é considerado um país megadiverso, crucial para a regulação climática global. Devido à sua relevância econômica e aos incentivos governamentais para o desenvolvimento, a Amazônia brasileira foi invadida e explorada irracionalmente por muitos anos, resultando em 20% (788.353 km^2) de perda florestal, o que causou uma diminuição significativa de sua área florestal e perda irreversível de biodiversidade. Na tentativa de conter a perda de biodiversidade, várias ações para combater o desmatamento foram criadas ao longo dos anos, e projetos, técnicas e estratégias de restauração foram implementados na região. Este artigo objetiva realizar uma revisão do potencial de biodiversidade existente, do processo de perda de biodiversidade como resultado do desmatamento, e avaliar as possibilidades de restauração na Amazônia brasileira.
Palavras-chave: Amazônia brasileira; Biodiversidade; recursos naturais; degradação florestal; restauração florestal.

High biodiversity levels in the Brazilian Amazon are threatened

The Brazilian Amazon extends over a territory of approximately 4,196,943 million km2 (IBGE, 2004), which is greater than the territorial extent of all 27 European Union countries combined (**Figure 1**). The region's hydrographic basin is the largest in the world, corresponding to one fifth of all fresh water on the planet. It covers about 6 million km2 and has approximately 1,100 tributaries, among which is the Amazon River, flowing into the Atlantic Ocean and launching approximately 175 million liters of water per second (MMA, 2018). It holds an immensity of forests, and its exuberant tree tops can reach more than 80 m in height (Gorgens et al., 2019). The Brazilian Amazon is the largest area in the world with dominance of primary vegetation (Pailler, 2016).

Figure 1. Map of the Brazilian Amazon Region.

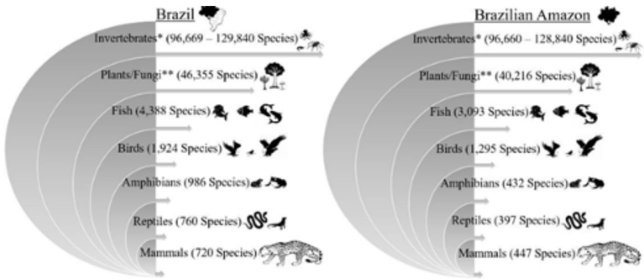


Source: databases of IBGE - Brazilian Institute of Geography and Statistics, available from https://www.ibge.gov.br/geociencias/informacoes-ambientais/15842-biomas.html, and of CNIG - National Geographic Information Center, available from http://centrodedescargas.cnig.es/CentroDescargas/catalogo.do?Serie=CAANE.

The number of species on the planet is still unknown; however, from 5 to 10 million eukaryote species have been estimated (May, 2010). The tropical forests contain most of such biodiversity and, according to Barlow et al., (2018), approximately 91% of birds on the planet spend at least part of their life in the tropics. Despite advances in research, one of the biggest gaps in biodiversity concerns the real magnitude of species diversity. There is a huge difference between what has already been described by science and what may actually exist. Such discrepancy was called the "Linnean Shortfall" by Lomolino et al., (2010), who also coined the term used to refer to little knowledge about species distribution as the "Wallacean Shortfall".

Brazil is considered one of the "megadiversity" countries. It is estimated, from all that is known about the different species identified in the world, that between 10 and 15% of them are found in the country. There are more than 100,000 animal species (vertebrates and invertebrates) and 46,000 plant and fungi species (WWF, 2010; Valsecchi et al., 2017). Such megadiversity is due to the Amazon region, which shelters more than half of the known species from tropical forests (May, 2010; Miranda et al., 2012). Thus, it is considered the most biodiverse region on the planet (Ceballos & Ehrlich, 2006; Carvalho & Esposito, 2010; Barbosa et al., 2016). Ca. 40,000 out of the 46,000 plant and fungi species were registered in the Amazon region (Valsecchi et al., 2017; **Figure 2**). Recent studies that report the outstanding levels of the Amazonian tree diversity are those of Wittmann et al., 2006; Sakschewski et al., 2016; and Rayol et al., 2019.

Figure 2. Species recorded for the whole Brazilian territory and the Brazilian Amazon according to major taxonomic groups.



Source: Data from MMA - Ministry of the Environment, available from https://www.mma.gov.br/biodiversidade/conservacao-de-especies/fauna-ameacada.html, 5th National Report for the Convention on Biological Biodiversity, available from http://www.terrabrasilis.org.br/ecotecadigital/images/abook/pdf/2017/Marco/Mar.17.39.pdf, and World Wildlife Fund 2010 Report, available from https://www.wwf.org.br/informacoes/bliblioteca/?26345/Amazonia-Viva-uma-decada-de-descobertas-1999-2009; and 2017 Report, available from https://www.wwf.org.br/?60464/Novas-espcies-de--vertebrados-e-plantas--na-Amaznia-2014-2015. *Estimated number of invertebrate species according to Lewinsohn (2005). **Number of species among which the following are plants: 40,629 species - Brazil; 30,216 species - Brazilian Amazon.

There is still much to discover about the Amazonian biodiversity. According to a survey conducted by the WWF, approximately 637 species of plants, 257 of fish, 216 of amphibians, 55 of reptiles, 39 of mammals and 16 of birds were discovered in the Amazon biome from 1999 to 2009 (WWF, 2010). Some 381 more new species in the region were described only from 2014 to 2015, of which 216 are plants, 93 fish, 32 amphibians, 19 reptiles, 20 mammals and one bird (Valsecchi et al., 2017). This biodiversity is the basis for the production of food, beverages, medicines, cosmetics, energy and much of the industrial raw material consumed by humans, which contribute to the high economically strategic value of the region (Ten Kate & Laird, 2019).

Forest loss in Brazilian Amazon

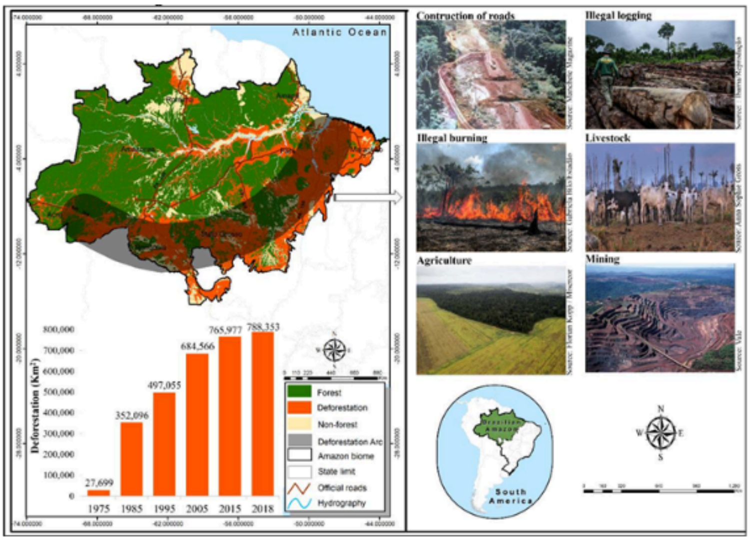
All the greatness of the Amazon does not exempt it from its fragility. Forests live through their own resources, and their balance is extremely susceptible to any interference, whether by anthropic or natural actions, but the changes caused by humans can be irreversible (Singh, 2014). There are a number of environmental problems in the region (Hoeinghaus et al., 2016), caused mainly by uncontrolled use of natural resources over the years. The opening of roads, extraction of wood and ores, urban and industrial growth, fires and, chiefly, deforestation for the expansion of agricultural and livestock frontiers, have been mainly responsible for the current devastation of the Brazilian Amazon (Rodrigues et al., 2015; Barlow, 2016).

Before European colonization, the Amazon was occupied by hundreds of indigenous tribes, who extracted resources from the forest only for their subsistence (Dowie, 2011). From the 17th century on, the landscape in the region underwent profound changes that were promoted by the extraction of wood and non-wood products (Gradwohl & Greenberg, 2013). In the late 19th century and early 20th century, there was intense exploration of latex from rubber trees (*Hevea brasiliensis*), which brought approximately 500 thousand migrants to the region (Barlow, 1997). The period of greatest degradation in the Brazilian Amazon occurred from the second half of the 20th century on, due to deforestation encouraged by the Brazilian government to colonize and develop the region. It was a period marked by large projects that were installed in the Amazon (da Cruz et al., 2020a).

The major projects in the Brazilian Amazon began with the creation of the Amazon Development Plan (PDA) in the 1950s. After that plan was implemented, a military dictatorship was established in the country in the 1960s. The dictatorship wanted the unification of the country; "Integrate so as not to Forfeit" was its slogan (Becker, 2000). In the 1970s, the opening of the Amazon began with the construction of large highways, connecting it to the other regions of the country (Serra & Fernández, 2004; Perz et al., 2005). The major projects were: a) Great Carajás Project - Projeto Grande Carajás (1979-1986), with the greatest mineral potential on the planet; b) Polamazônia - Program for Agricultural and Agribusiness Centers in the Amazon (1979-1985), responsible for the implementation of industrial agricultural exploitation; and c) Polonoroeste - Program for the Integrated Development of Northwestern Brazil (1981-1985), responsible for paving BR-364, one of the strategic highways in the colonization actions for the Amazon (Reid, 2014; Mesquita, 2015).

The result of this historical and political process of economic development is a highly altered Amazon. By 1975, only 0.5% (27.699 km2) of the Amazon was deforested. But after 10 years of operation of the major projects mentioned above, approximately 7% (352,096 km2) of the territory had been devastated (an increase of 1,171% in deforestation), and, in 2018, approximately 20% (788,535 km^2) of the region had already been deforested and converted into other uses (**Figure 3;** da Cruz et al., 2020a). The regions of maximum deforestation in the Amazon were along the southern and eastern edges, an area known as the "Arc of Deforestation", which were and still are strategic regions for expansion of agriculture and livestock (Costa & Pires, 2010).

Figure 3. Deforestation in the Brazilian Amazon for the 1975-2018



Source: The data for deforestation figures were extracted from INPE - National Institute for Space Research (http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes) and CNIG (http://centrodedescargas.cnig.es/CentroDescargas/catalogo.do?Serie=CAANE).

Deforestation and forest degradation have major consequences for humankind, such as greenhouse gas emissions (Van der Werf et al., 2009). The estimated annual quantity of carbon emitted in the region is between 150 and 250 million tons, which represents around 10 to 15 % of the total global emissions (Houghton et al., 2005; Dias-Filho et al., 2011). Over the years, the damage caused to the environment has decreased significantly thanks to national government actions and international interests (Rodrigues, 2018; Simonet, 2019). The government has implemented several legal mechanisms against forest loss in the region; the PPCDAm - Action Plan for Deforestation Prevention and Control of the Legal Amazon, created in 2004, is among such measures (Soares-Filho et al., 2010). However, the goal of reducing illegal deforestation comes against the attitudes of Brazil's new president Jair Bolsonaro, who is not interested in protecting forests. The reflection of his comments and his development policy has resulted in high rates of forest loss and degradation since the beginning of his term (Escobar, 2019a).

Further, deforestation of the Amazon has soared under cover of the coronavirus-19 crisis (Diele-Viegas & Pereira, 2020; INPE, 2020).

This forest loss and degradation increase in Brazil has occurred mainly in the Amazon region, which accounted for 1,320 km2 of deforested areas from January to August 2019, with an increase of 75% as compared to the same period in 2018 (755 km2). August 2019 was the month with the largest degraded areas, exactly when the countless fires occurred in the Amazon. In that month alone, almost 40 thousand seats of fires were recorded in the region, an increase of 161% as compared to the same period in 2018 (15 thousand seats) (INPE, 2019; Escobar, 2019a). Despite the president's claims that Non-Governmental Organizations (NGOs) are involved with the fires in the Amazon, to "draw attention" against the government, there is evidence that fires were due to weak laws, poor supervision and incentives for the country's economic development (Vazquez & Dey 2019; Escobar, 2019b). A note released by the Climate Observatory, a group that gathers approximately 50 NGOs, points out that the fires occurring in the region reflects the President's own irresponsibility towards the biome, the health of Brazilians and the climate in the world (OC, 2019).

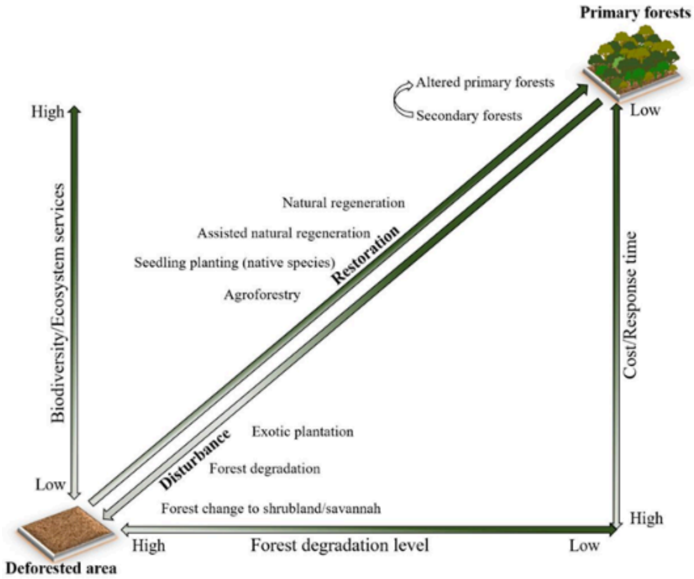
Biodiversity loss in Brazilian Amazon

Biodiversity reduction directly affects the provision of goods and services to humans (Balvanera et al., 2006; Cardinale, 2012; Hoeinghaus et al., 2016; Vieilledent et al., 2018; Díaz et al., 2019a). Forests are normally resilient to natural disturbances and can recover after major changes (Gunderson, 2000, Folke et al., 2004, Walker et al., 2004); however, excessive species loss reduces their resilience (Díaz et al., 2005; Pardini et al., 2010).

We are experiencing a crisis of unprecedented biodiversity loss across the planet, at a much accelerated rate, which has been induced mainly by human action (Ferreira, 2014; Richards, 2014; Díaz et al., 2019b). The magnitude of such loss is so great and so strongly linked to ecosystem processes (Thompson et al., 2013) and to the use of natural resources by society that it is currently considered of global interest (Thom & Seidl, 2016; Betts et al., 2017; Curtis et al., 2018). The Amazon, in addition to portraying some of the greatest biodiversity on the planet (Miranda et al., 2012; Barbosa et al., 2016; Tedesco et al., 2017; Barlow et al., 2018; The World Bank, 2019), is one of the biomes that has the most vulnerable characteristics to environmental variation (Seddon et al., 2016).

Biodiversity loss in the Brazilian Amazon is mainly due to deforestation of large areas for agricultural and livestock activities (Barlow et al., 2016; Hoeinghaus et al., 2016) and the introduction of exotic species (Simberloff et al., 2002, Strayer et al., 2006, Pejchar & Mooney, 2009). Forest loss generates a significant decline in goods and services (Hoeinghaus et al., 2016; Vieilledent et al., 2018). Depending on the degradation level of a given area, the financial resources used, and the recovery actions adopted, good levels of biodiversity and ecosystem services can be recovered in a relatively short period of time (Chazdon, 2008; Thompson et al., 2013; **Figure 4**).

Figure 4. Co-variation of biodiversity and ecosystem services,



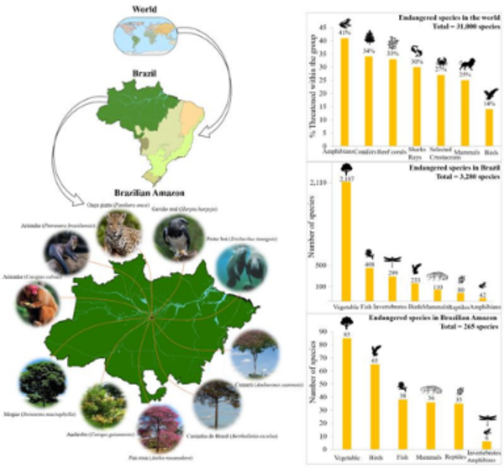
Source: Co-variation of biodiversity and ecosystem services provided by forests according to a gradient of forest loss and degradation. Adapted from Chazdon, 2008 and Thompson et al., 2013. Biodiversity and ecosystem service decrease considerably with increasing levels of degradation and, conversely, they can increase with forest restoration.

Biodiversity loss occurs both immediately (Gibson et al., 2011; Pereira et al., 2012; He & Hubbell, 2011 and 2013; Hanski et al., 2013; Keil et al., 2015) and at long-term scales, including the extinction debt and those species committed to extinction (Shandra et al., 2010; Jackson & Sax, 2010; He & Hubbell, 2011; Wearn et al., 2012; Doherty et al., 2016; Hidasi-Neto et al., 2019). The number of living organisms lost per km2 of forest loss is not yet known. Some authors estimate that 45 thousand to 55 thousand trees (Ter Steege et al., 2003), approximately 1,910 birds (Terborgh et al., 1990), and 35 to 81 primates (Peres & Dolman, 2000) may exist in one km2 of the Amazon forest. When multiplying these figures by what had already been deforested by 2018 (788,535 km^2, da Cruz et al., 2020a), it is estimated that approximately 35,484,075,000 to 43,369,425,000 trees have been cut. Similarly, 1,506,101,850 birds and 27,598,725 to 63,871,335 primates may have been affected by deforestation.

There is multiple evidence that forest restoration is capable of recovering substantial levels of biodiversity and ecosystems services (Benayas et al., 2009; Stanturf, 2014; Spake et al. 2015; Crouzeilles et al. 2016; Moreno-Mateos et al., 2017; Meli et al. 2017; Jones et al., 2018; Reid et al. 2018; and Chazdon et al., 2020). However, species de-extinction it is very difficult if not impossible and extraordinarily expensive anyway (Sherkow & Greely, 2013). Thomas et al., (2004) evaluated the risk for species extinction on approximately 20% of the Earth's surface and concluded that from 15% to 37% of species would be at risk of extinction by the year 2050. For the Amazon rainforest, Feeley et al., (2009) estimated that from 5 to 9% of all species in the region are also threatened with extinction by 2050. The results reported by Miles et al., (2004) showed that persistence of 43% of the tree species analyzed in the Amazon would be compromised by the year 2095. The loss of some species significantly impairs some ecosystem services (Díaz & Cabido, 2001; Ellison et al., 2005; He & Hubbell, 2011), and many species are rare, with small populations and, therefore, highly sensitive to any environmental changes (Terborgh et al., 2008 and 2013). For these reasons, it is thought that countless animal and plant species have gone extinct in the Amazon to date.

Approximately one million species are threatened with extinction in the world (IPBES, 2019). According to official data from the Red List by the International Union for Conservation of Nature (IUCN), approximately 27% (31 thousand species) of the more than 116 thousand different species of animals and plants are threatened with extinction in the world (IUCN, 2020). In Brazil, ICMBio (Chico Mendes Institute for Biodiversity Conservation), MMA (Ministry of the Environment) and CNCFlora/JBRJ (National Center for Plant Conservation of the Botanical Gardens of Rio de Janeiro) have updated the list of species endangered with extinction and identified 1,173 animal and 2,107 plant species (MMA, 2019). Of this total, 180 of animal species and 85 of plant species are in the Amazon region (ICMBio, 2018; **Figure 5**).

Figure 5. Species threatened with extinction in the world, in Brazil and in the Brazilian Amazon



Sources: Red List (IUCN; https://www.iucnredlist.org/) for the species threatened with extinction in the world, and ICMBio (Chico Mendes Institute for Biodiversity Conservation; https://www.icmbio.gov.br/portal/especies-ameacadas-destaque), MMA (Ministry of the Environment; https://www.mma.gov.br/biodiversidade/conservacao-de-especies/fauna-ameacada.html) and 274 CNCFlora/JBRJ (National Center for Plant Conservation of the Botanical Gardens of Rio de Janeiro; http://www.cncflora.jbrj.gov.br/portal) for the list of species threatened in Brazil and in the Brazilian Amazon.

How to recover the Amazonian biodiversity?

We face, on one hand, the significant loss of forest biodiversity (Gibson et al., 2011; Hoeinghaus et al., 2016; Vieilledent et al., 2018) and, on the other, the need to recover millions of hectares of extirpated and degraded forest area (Menz et al., 2013; Crouzeilles et al., 2016; Lindenmayer, 2019). To address these challenges, there are some general principles that can help guide the conservation of forest biodiversity and the recovery of forest ecosystems (Lindenmayer & Franklin, 2002; Lamb, 2010). Among these principles is the need to conserve the attributes and characteristics of native ecosystems, to protect and recover populations of key species and their habitats and to maintain the main ecological processes that influence forest succession, which includes, for example, pollination and seed dispersal (Lindenmayer & Franklin, 2002).

The relationship between biodiversity, ecosystem services and landscape change has been gaining momentum in scientific studies in recent years (Tscharntke et al., 2005; Pauchard et al., 2006; Nelson et al., 2009; Haines-Young & Potschin, 2010; Bürgi et al., 2015; Brockerhoff et al., 2017; Quijas et al., 2019; Williams et al., 2020). Some studies report that numerous forest species are sensitive to forest degradation (Lindenmayer et al. 2002, Colles et al., 2009; Vranckx et al., 2012). For this reason, plant species must be carefully selected in order to achieve better results in forest restoration programs (Colles et al., 2009). Phytosociological knowledge of species groups is commonly used in the Amazon as an indicator to monitor the effects of conservation and restoration actions on plant communities (Attanasio, 2008; Lewandowski et al., 2010; Neri et al., 2011; Salomão et al., 2012a; b).

The over-time evaluation of tree species composition in a forest provides information that is directly related to ecosystem change (Liebsch, 2008; Morin et al., 2018). The selected indicators are a fundamental step in the evaluation and monitoring of the recovery of degraded areas (Audino, 2014; Suganuma & Durigan, 2015; Gatica-Saavedra et al., 2017; Viani et al., 2018). Some forest species are selected in monitoring assessments because changes in population size or distribution may suggest that habitat amount or quality has changed (Kuruneri-Chitepo & Shackleton, 2011; Bjørneraas et al., 2012). Some species are more relevant than others because they have certain functions in the ecosystem (Díaz et al., 2003). The objective of forest recovery is to improve ecosystem functions without an absolute commitment to reestablishing the original plant composition (DellaSala et al., 2003; SER, 2004; Mansourian & Vallauri, 2005; Clewell & Aronson, 2007; Corbin & Holl, 2012; Stanturf, 2014; Bastin et al., 2019; Chazdon, 2019). However, it is necessary to consider the vertical structure and the main families and genera in the new restored forest (Paul & Yavitt, 2011; Salomão et al., 2012b; Hilje et al., 2015).

In addition to tree community composition, another good indicator of the forest state is the presence of certain animal groups with specific ecological functions (Díaz-García, 2017), such as pollination and seed dispersal (Wright et al., 2007; Terborgh et al., 2008). Insectivorous birds, for example, can regulate populations of herbivorous insects and act as dispersing and pollinating agents for plants (Bridgeland et al., 2010). For this reason, many insectivorous birds respond negatively to degradation in tropical forests (McCarthy, 2012; Edwards et al., 2014), and, therefore, can be used as indicators in the recovery process.

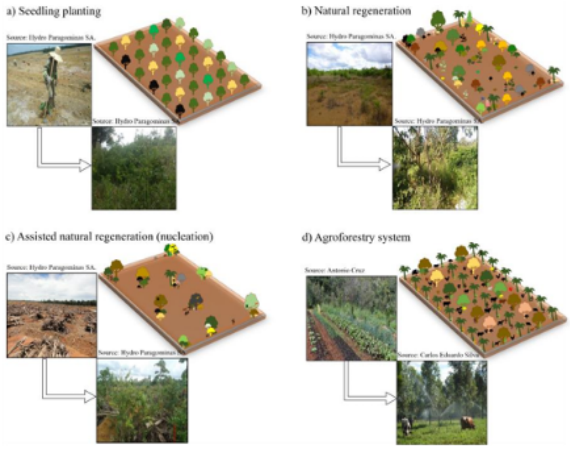
Recovery experiences have focused on species selection according to their successional stage, growth and survival (Menge & Chazdon, 2016; Boukili, 2017). It is suggested that the restorative planting should be heterogeneous by combining species from different succession stages, such as pioneers, secondary and climax (Massad et., 2011; Wang et al., 2014). These experiences have generated recovery models that have been shown to be adequate in particular areas (Meli et al., 2014; Laughlin, 2014; Lu et al., 2017). In order to define which species from a specific functional group and at what stage of the forest restoration process they will be used for restorative activities, the purpose of the work must be clearly defined (Volis, 2016; Martins, 2017; Monks et al., 2019). With good knowledge of functional groups, it is possible to propose better conservation and restoration actions for the ecosystem.

There are laws and regulations that have been created over the years and determine procedures to be adopted in forest recovery activities. Brazilian legislation, for example, requires that areas be recovered with native species to the region (Brazilian Forest Code, Law no. 12,727/2012). However, a study conducted by da Cruz et al., (2020a) identified that a large number of recovery projects used exotic species in the Brazilian Amazon. This fact can be explained by two reasons: a) a large number of commercial projects that use exotic species and b) landowners who resort to legal restrictions for the economic use of native species (Butler & Laurence, 2009).

Revegetation of a degraded area can be accomplished by a suite of different techniques with different intensity of intervention (Stanturf, 2014). Major techniques for forest restoration are a) seedling planting, b) natural regeneration, c) assisted natural regeneration by nucleation, and d) agroforestry systems (Rodrigues et al., 2015; **Figure 6**). All these restoration techniques are ultimately linked to secondary succession (Chazdon & Uriarte, 2016), i.e., they both affect and are affected by this process. Seedling planting aims to produce a forest with a starting specific composition or structure. It provides a relatively rapid tree coverage and does not depend on dispersing agents or seed sources (Stanturf, 2014; Wallertz et al., 2018). It is the most often used technique in the Brazilian Amazon (Palma & Laurance 2015; Viani et al., 2017; da Cruz et al., 2020b).

Natural regeneration involves the colonization of sites by any plants and animals that may disperse from the surrounding habitats and subsequently establish themselves (Shiferaw, 2018); it therefore has a highly stochastic outcome. Assisted natural regeneration represents an intermediate technique that involves acting in focal areas for facilitating vegetation recovery (Benayas, 2008; Corbin & Holl, 2012). Nucleation, a type of assisted natural regeneration, pursues the establishment of woody recruits in these focal areas or nuclei to trigger forest expansion in larger areas over time through natural regeneration as the established nuclei attract animals that participate in seed dispersal (Benayas, 2008; Corbin & Holl, 2012). Assisted natural regeneration, which is widely used in post-mining recovery (Tomazi et al., 2010; Reis et al., 2014), seeks to facilitate natural regeneration through the cyclical relationship of producers, consumers and decomposers (Zahawi et al., 2013; Bechara et al., 2016). Finally, agroforestry systems are intercropped cultivars of tree species with agricultural crops and/or domestic animals (Martins, 2013). They enhance the structure and increase of soil nutrient levels by means of nutrient cycling promoted by roots and leaf litter accumulation (Vaz, 2000).

Figure 6. Some forest restoration techniques used in the Brazilian Amazon.



Source: Database containing experiences from the degraded area recovery program of the BRC project - Biodiversity Consortium

Choosing the best practice to recover a degraded area is still a challenge with regard to ecological restoration, as it depends on numerous factors (Nepstad, 1991; Callicott, 2002; Holl & Aide, 2011; Rodrigues et al., 2011; Similä & Junninen, 2012; Thomas et al., 2014; Chazdon & Uriarte, 2016; Burger & Zipper, 2018). Plant identification and knowledge of functional groups and ecological interactions of pollination and seed dispersal in forest dynamics are critical to understand forest regeneration (Van Breugel et al., 2019; Rozendaal et al., 2019; Barros et al., 2020) and establish appropriate recovery techniques. Therefore, selecting which techniques are most appropriate to recover a certain deforested or degraded forest requires an assessment of the changes that occur at the site, as well as an analysis of the factors that have led to such changes (Crouzeilles et al., 2016).

CONCLUSION

The study demonstrates that the Brazilian Amazon, one of the largest areas of primary vegetation in the world and home to 10 to 15% of all known species on the planet, faces an unprecedented crisis of forest loss and biodiversity decline. In 1975, only 0.5% of the Amazon had been deforested; by 2018, this figure had reached approximately 20%, an increase of 1,171% driven by large-scale development projects, highway construction, timber and mineral extraction, and, above all, the expansion of agricultural and livestock frontiers. The acceleration under discourses and policies that deprioritize forest protection, exacerbated by the COVID-19 crisis, demonstrates that deforestation is not merely an environmental problem, but a direct consequence of political and economic decisions.

Biodiversity loss is not only numerical but functional. The study estimates that, with the 788,535 km^2 deforested by 2018, between 35 and 43 billion trees may have been lost, along with 1.5 billion birds and 27 to 63 million primates affected. More critically, projections indicate that 5% to 9% of all Amazonian species may be threatened with extinction by 2050, and the persistence of 43% of tree species may be compromised by 2095. This loss reduces ecosystem resilience, compromises essential services such as pollination and seed dispersal, and directly affects the production of food, medicines, and raw materials that sustain economies and populations.

Despite the critical scenario, the study points to concrete pathways for recovery. Techniques such as seedling planting, assisted natural regeneration, nucleation, and agroforestry systems are already being applied in the Amazon, and there is solid evidence that forest restoration is capable of recovering substantial levels of biodiversity and ecosystem services. The challenge lies in selecting appropriate species, considering functional groups, successional stages, and ecological interactions, and in overcoming contradictions such as the use of exotic species in recovery projects, in disagreement with Brazilian legislation. The central conclusion is clear: the window of opportunity to reverse the damage still exists, but it requires political will, compliance with environmental laws, and investment in science and ecological restoration.

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REFERENCES

Alves, L. W. R., Carvalho, E. J. M., Silva, L. G. T. (2014). Diagnóstico agrícola do município de Paragominas, PA. *Embrapa Amazônia Oriental - Boletim de pesquisa e desenvolvimento, (INFOTECA-E),* 91, 1–26.

Attanasio, C. M. (2008). *Manual Técnico Restauracao e Monitoramento da Mata Ciliar e da Reserva Legal para a Certificacao AgrícolaConservacao da Biodiversidades na Cafeicultura.* IMAFLORA.

Audino, L. D., Louzada, J., Comita, L. (2014). Dung beetles as indicators of tropical forest restoration success: Is it possible to recover species and functional diversity? *Biological Conservation,* 169, 248–257. https://doi.org/10.1016/j.biocon.2013.11.023.

Balvanera, P., Pfisterer, A. B., Buchmann, N., He, J. S., Nakashizuka, T., Raffaelli, D., & Schmid, B. (2006). Quantifying the evidence for biodiversity effects on ecosystem functioning and services*. Ecology letters,* 9(10), 1146–1156. http://dx.doi.org/10.1111/j.1461-0248.2006.00963.x.

Barbosa, B. C., Detoni, M., Maciel, T. T., Prezoto, F. (2016). Studies of social wasp diversity in Brazil: Over 30 years of research, advancements and priorities. *Sociobiology,* 63(3), 858–880. http://dx.doi.org/10.13102/sociobiology.v63i3.1031.

Barlow, C. (1997). Growth, structural change and plantation tree crops: the case of rubber. *World Development,* 25(10), 1589–1607. https://doi.org/10.1016/S0305-750X(97)00059-4.

Barlow, J., França, F., Gardner, T. A., Hicks, C. C., Lennox, G. D., Berenguer, E., ... & Leal, C. G. (2018). The future of hyperdiverse tropical ecosystems. *Nature,* 559(7715), 517–526. https://doi.org/10.1038/s41586-018-0301-1.

Barlow, J., Lennox, G. D., Ferreira, J., Berenguer, E., Lees, A. C., Mac Nally, R., ... & Parry, L. (2016). Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. *Nature,* 535(7610), 144–147. https://doi.org/10.1038/nature18326.

Barral, M. P., Benayas, J. M. R., Meli, P., & Maceira, N. O. (2015). Quantifying the impacts of ecological restoration on biodiversity and ecosystem services in agroecosystems: A global meta-analysis. *Agriculture, Ecosystems & Environment,* 202, 223–231. https://doi.org/10.1016/j.agee.2015.01.009.

Barros, T. C., Elias, F., Romano, L. L., & Ferreira, J. (2020). Natural recovery of plant species diversity in secondary forests in Eastern Amazonia: contributions to passive forest restoration. *Brazilian Journal of Botany,* 43, 165–175. https://doi.org/10.1007/s40415-020-00585-9.

Bastin, J. F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., ... & Crowther, T. W. (2019). The global tree restoration potential. *Science,* 365(6448), 76–79. https://doi.org/10.1126/science.aax0848.

Bechara, F. C., Dickens, S. J., Farrer, E. C., Larios, L., Spotswood, E. N., Mariotte, P., & Suding, K. N. (2016). Neotropical rainforest restoration: comparing passive, plantation and nucleation approaches. *Biodiversity and Conservation,* 25(11), 2021–2034. https://doi.org/10.1007/s10531-016-1186-7.

Becker, B., & Egler, C. (2000). *Sustentabilidade e Desenvolvimento Regional da Amazônia. Opções Estratégicas para a Dimensão Ambiental do Plano de Desenvolvimento da Amazônia (PDA–2000-03)., Belém: SUDAM.* mimeo.

Benayas, J. M. R, Bullock, J. M., & Newton, A. C. (2008). Creating woodland islets to reconcile ecological restoration, conservation, and agricultural land use. *Frontiers in Ecology and the Environment,* 6(6), 329–336. https://doi.org/10.1890/070057.

Benayas, J. M. R., Newton, A. C., Diaz, A., & Bullock, J. M. (2009). Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. S*cience,* 325(5944), 1121–1124. https://doir.org/10.1126/science.1172460.

Betts, M. G., Wolf, C., Ripple, W. J., Phalan, B., Millers, K. A., Duarte, A., ... & Levi, T. (2017). Global forest loss disproportionately erodes biodiversity in intact landscapes. *Nature,* 547(7664), 441–444. https://doi.org/10.1038/nature23285.

Bjørneraas, K., Herfindal, I., Solberg, E. J., Sæther, B. E., van Moorter, B., & Rolandsen, C. M. (2012). Habitat quality influences population distribution, individual space use and functional responses in habitat selection by a large herbivore. *Oecologia,* 168(1), 231–243. https://doi.org/10.1007/s00442-011-2072-3.

Boukili, V. K., & Chazdon, R. L. (2017). Environmental filtering, local site factors and landscape context drive changes in functional trait composition during tropical forest succession. *Perspectives in Plant Ecology, Evolution and Systematics,* 24, 37–47. https://doi.org/10.1016/j.ppees.2016.11.003.

Bridgeland, W. T., Beier, P., Kolb, T., & Whitham, T. G. (2010). A conditional trophic cascade: birds benefit faster growing trees with strong links between predators and plants. *Ecology,* 91(1), 73–84. https://doi.org/10.1890/08-1821.1.

Brockerhoff, E. G., Barbaro, L., Castagneyrol, B., Forrester, D. I., Gardiner, B., González-Olabarria, J. R., ... & Thompson, I. D. (2017). Forest biodiversity, ecosystem functioning and the provision of ecosystem services. *Biodiversity and Conservation,* 26, 3005–3035. https://doi.org/10.1007/s10531-017-1453-2.

Burger, J. A., & Zipper, C. E. (2018). How to restore forests on surface-mined land.

Bürgi, M., Silbernagel, J., Wu, J., & Kienast, F. (2015). Linking ecosystem services with landscape history. *Landscape Ecology,* 30(1), 11–20. https://doi.org/10.1007/s10980-014-0102-3.

Butler, R. A., and Laurance, W. F. (2009). Is oil palm the next emerging threat to the Amazon? *Tropical Conservation Science,* 2 (1), 1–10. https://doi.org/10.1177/194008290900200102.

Callicott, J. B. (2002). Choosing appropriate temporal and spatial scales for ecological restoration. *Journal of biosciences,* 27(4), 409–420. https://doi.org/10.1007/BF02704969.

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., ... & Kinzig, A. P. (2012). Biodiversity loss and its impact on humanity. *Nature,* 486(7401), 59–67.

Carvalho, F. F., & Esposito, M. C. (2010). A new species of Bricelochlorops Paganelli and the first record of Urubambina rufa (Duda) (Diptera: Chloropidae) from Brazil. *Neotropical entomology,* 39(5), 742–745. http://doi.org//10.1590/s1519-566x2010000500012.

Ceballos, G., & Ehrlich, P. R. (2006). Global mammal distributions, biodiversity hotspots, and conservation. *Proceedings of the National Academy of Sciences,* 103(51), 19374–19379. https://doi.org/10.1073/pnas.0609334103.

Chazdon, R. L. (2008). Beyond deforestation: restoring forests and ecosystem services on degraded lands. *Science,* 320(5882), 1458–1460. http://dx.doi.org/10.1126/science.1155365.

Chazdon, R. L. (2019). Towards more effective integration of tropical forest restoration and conservation. *Biotropica,* 51(4), 463–472. https://doi.org/10.1111/btp.12678.

Chazdon, R. L., & Uriarte, M. (2016). Natural regeneration in the context of large-scale forest and landscape restoration in the tropics. *Biotropica,* 48(6), 709–715. https://doi.org/10.1111/btp.12409.

Chazdon, R. L., Lindenmayer, D., Guariguata, M. R., Crouzeilles, R., Benayas, J. M. R., & Chavero, E. L. (2020). Fostering natural forest regeneration on former agricultural land through economic and policy interventions. *Environmental Research Letters,* 15(4), 043002. https://doi.org/10.1088/1748-9326/ab79e6.

Clewell, A. F., & Aronson, J. (2007). *Ecological restoration: Principles, values, and structure of an emerging profession.* Washington: Island Press.

Colles, A., Liow, L. H., & Prinzing, A. (2009). Are specialists at risk under environmental change? Neoecological, paleoecological and phylogenetic approaches. *Ecology letters,* 12(8), 849–863. http://dx.doi.org/10.1111/j.1461-0248.2009.01336.x.

Corbin, J. D., & Holl, K. D. 2012. Applied nucleation as a forest restoration strategy. *Forest Ecology and Management,* 265, 37–46. https://doi.org/10.1016/j.foreco.2011.10.013.

Costa, M. H., & Pires, G. F. (2010). Effects of Amazon and Central Brazil deforestation scenarios on the duration of the dry season in the arc of deforestation. *International Journal of Climatology,* 30(13), 1970–1979. https://doi.org/10.1002/joc.2048.

Crouzeilles, R., Curran, M., Ferreira, M. S., Lindenmayer, D. B., Grelle, C. E., & Benayas, J. M. R. (2016). A global meta-analysis on the ecological drivers of forest restoration success. *Nature communications,* 7(1), 1–8. https://doi.org/10.1038/ncomms11666.

Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science,* 361(6407), 1108–1111. https://doi.org/10.1126/science.aau3445.

da Cruz, D. C., Benayas, J. M. R., Ferreira, G. C. et al. (2020a). An overview of forest loss and restoration in the Brazilian Amazon. *New Forests,* 51 (2), 1–16. https://doi.org/10.1007/s11056-020-09777-3.

da Cruz, D. C., Benayas, J. M. R., Ferreira, G. C., & Ribeiro, S. S. (2020b). Tree Communities in Three-Year-Old Post-Mining Sites Under Different Forest Restoration Techniques in the Brazilian Amazon. *Forests,* 11(5), 527. https://doi.org/10.3390/f11050527.

DellaSala, D., Martin, A., Spivak, R., Schulke, T., Bird, B., Criley, M., ... & Aplet, G. (2003). A citizen's call for ecological forest restoration: forest restoration principles and criteria. *Ecological Restoration,* 21(1), 15.

Dias-Filho, M. B., Davidson, E. A., & Carvalho, C. J. R. (2001). Linking Biogeochemical Cycles to Cattle Pasture Management and Sustainability. *The Biogeochemistry of the Amazon Basin. Oxford University Press, New York,* 84–105.

Díaz-García, J. M., Pineda, E., López-Barrera, F., & Moreno, C. E. (2017). Amphibian species and functional diversity as indicators of restoration success in tropical montane forest. *Biodiversity and Conservation,* 26(11), 2569–2589.

Díaz, S., Settele, J., Brondízio, E. S., Ngo, H. T., Agard, J., Arneth, A., ... & Garibaldi, L. A. (2019a). Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science,* 366(6471). https://10.1126/science.aax3100.

Díaz, S., Settele, J., Brondízio, E., Ngo, H., Guèze, M., Agard, J., & Zayas, C. (2019b). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and

Ecosystem Services [Report or Working Paper]. Retrieved July 8, 2019.

Díaz, S., Symstad, A. J., Chapin III, F. S., Wardle, D. A., & Huenneke, L. F. (2003). Functional diversity revealed by removal experiments. *Trends in Ecology & Evolution,* 18(3), 140–146. http://dx.doi.org/10.1016/S0169-5347(03)00007-7.

Díaz, S., Tilman, D., Fargione, J., Chapin III, F. S., Dirzo, R., & Ktzberber, T. (2005). Biodiversity regulation of ecosystem services. *Trends and conditions,* 279–329.

Diele-Viegas, L., & Pereira, E. (2020). COVID-19 and Amazonia: Sustainable alternatives for an economic collapse. http://doi.org/10.20944/preprints202004.0501.v1.

Díaz, S., & Cabido, M. (2001). Vive la différence: plant functional diversity matters to ecosystem processes. *Trends in ecology & evolution,* 16(11), 646–655. http://dx.doi.org/10.1016/S0169-5347(01)02283-2.

Doherty, T. S., Glen, A. S., Nimmo, D. G., Ritchie, E. G., & Dickman, C. R. (2016). Invasive predators and global biodiversity loss. *Proceedings of the National Academy of Sciences,* 113(40), 11261–11265. https://doi.org/10.1073/pnas.1602480113.

Dowie, M. (2011). *Conservation refugees: the hundred-year conflict between global conservation and native peoples.* MIT press.

Edwards, D. P., Tobias, J. A., Sheil, D., Meijaard, E., & Laurance, W. F. (2014). Maintaining ecosystem function and services in logged tropical forests. *Trends in ecology & evolution,* 29(9), 511–520. https://doi.org/10.1016/j.tree.2014.07.003.

Ellison, A. M., Bank, M. S., Clinton, B. D., Colburn, E. A., Elliott, ... & Mohan, J. (2005). Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Frontiers in Ecology and the Environment,* 3(9), 479–486. http://dx.doi.org/10.1890/1540-9295(2005)003[0479:LOFSCF]2.0.CO;2.

Escobar, H (2019b). Brazilian president attacks deforestation data. *Science* 365(6452),419. https://doi.org/10.1126/science.365.6452.419.

Escobar, H. (2019a). Amazon fires clearly linked to deforestation. *Science,* 365(853), 853–853. https://doi.org/10.1126/science.365.6456.85.

Feeley, K. J., & Silman, M. R. (2009). Extinction risks of Amazonian plant species. *Proceedings of the National Academy of Sciences,* 106(30), 12382–12387. https://doi.org/10.1073/pnas.0900698106.

Ferreira, J., Aragão, L. E. O. C., Barlow, J., Barreto, P., Berenguer, E., Bustamante, M., ... & Pardini, R. (2014). Brazil's environmental leadership at risk. *Science,* 346(6210), 706–707. http://doi.org/10.1126/science.1260194.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., & Holling, C. S. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics,* 35, 557–581. http://dx.doi.org/10.1146/annurev.ecolsys.35.021103.105711.

Gatica-Saavedra, P., Echeverría, C., & Nelson, C. R. (2017). Ecological indicators for assessing ecological success of forest restoration: a world review. *Restoration Ecology,* 25(6), 850–857. https://doi.org/10.1111/rec.12586.

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T.A., Barlow, J., Peres, C.A., Bradshaw, C. J. A., Laurance, W. F., Lovejoy, T. E., Sodhi, N. S., (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature,* 478(7369), 378–381. https://doi.org/10.1038/nature10425.

Gorgens, E. B., Motta, A. Z., Assis, M., Nunes, M. H., Jackson, T., Coomes, D., ... & Ometto, J. P. (2019). The giant trees of the Amazon basin. *Frontiers in Ecology and the Environment,* 17(7), 373–374. https://doi.org/10.1002/fee.2085.

Gradwohl, J., & Greenberg, R. (2013). *Saving the tropical forests.* Routledge.

Gunderson, L. H. (2000). Ecological resilience—in theory and application. *Annual review of ecology and systematics,* 31(1), 425–439. https://doi.org/10.1146/annurev.ecolsys.31.1.425.

Haines-Young, R., & Potschin, M. (2010). The links between biodiversity, ecosystem services and human well-being*. Ecosystem Ecology: a new synthesis,* 1, 110–139.

Hanski, I., Zurita, G. A., Bellocq, M. I., & Rybicki, J. (2013). Species–fragmented area relationship. *Proceedings of the National Academy of Sciences,* 110(31), 12715–12720. https://doi.org/10.1073/pnas.1311491110.

He, F., & Hubbell, S. P. (2011). Species–area relationships always overestimate extinction rates from habitat loss. *Nature,* 473(7347), 368–371. https://doi.org/10.1038/nature09985.

He, F., & Hubbell, S. P. (2013). Estimating extinction from species–area relationships: why the numbers do not add up. *Ecology,* 94(9), 1905–1912. https://doi.org/10.1890/12-1795.1.

Hidasi-Neto, J., Joner, D. C., Resende, F., de Macedo Monteiro, L., Faleiro, F. V., Loyola, R. D., & Cianciaruso, M. V. (2019). Climate change will drive mammal species loss and biotic homogenization in the Cerrado Biodiversity Hotspot. P*erspectives in Ecology and Conservation,* 17(2), 57–63. https://doi.org/10.1016/j.pecon.2019.02.001.

Hilje, B., Calvo-Alvarado, J., Jiménez-Rodríguez, C., & Sánchez-Azofeifa, A. (2015). Tree species composition, breeding systems, and pollination and dispersal syndromes in three forest successional stages in a tropical dry forest in Mesoamerica. *Tropical Conservation Science,* 8(1), 76–94. https://doi.org/10.1177/194008291500800109.

Hoeinghaus, D. J., Zuanon, J. A. S., Ou, C., Pelicice, F. M., Arantes, C., Albert, J. S., ... & Pavanelli, C. S. (2016). Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. https://doi.org/10.1126/science.aac7082.

Holl, K. D., & Aide, T. M. (2011). When and where to actively restore ecosystems?. *Forest Ecology and Management,* 261(10), 1558–1563. https://doi.org/10.1016/j.foreco.2010.07.004.

Houghton, R. A. (2005). Tropical deforestation as a source of greenhouse gas emissions. *Tropical deforestation and climate change,* 13.

IBGE - Instituto Brasileiro de Geografia e Estatística. (2004). Mapa de biomas do Brasil. Primeira aproximação.

IBGE - Instituto Brasileiro de Geografia e Estatística. (2019). População estimada [2019]. Brasil/Pará/Paragominas/Panorama. Retrieved from https://cidades.ibge.gov.br/brasil/pa/paragominas/panorama.

ICMBio - Instituto Chico Mendes de Conservação da Biodiversidade. (2018). Livro Vermelho da Fauna Brasileira Ameaçada de Extinção.

INPE – Instituto Brasileiro de Pesquisas Especiais. (2019). SIG Queimadas: monitoramento de focos. Retrieved from: http://queimadas.dgi.inpe.br/queimadas/bdqueimadas.

INPE – Instituto Nacional de Pesquisa Espacial. (2020). Deter - Amazônia Legal Brasileira - Avisos de Desmatamento. Retrieved from website: Terrabrasilis.dpi.inpe.br. Available at: http://terrabrasilis.dpi.inpe.br/app/dashboard/alerts/legal/amazon/aggregated/. Accessed 10 May 2020.

IPBES – Plataforma Intergovernamental sobre Biodiversidade e Serviços Ecossistêmicos. (2019). Media Release: Nature’s Dangerous Decline ‘Unprecedented’; Species Extinction Rates ‘Accelerating’. Retrieved from: https://www.ipbes.net/news/Media-Release-Global-Assessment.

IUCN – International Union for Conservation of Nature (2020). The IUCN red list of threatened species. Version 2019-1. IUCN, Gland, Switzerland. Retrieved from: http://www.iucnredlist.org.

Jackson, S. T., & Sax, D. F. (2010). Balancing biodiversity in a changing environment: extinction debt, immigration credit and species turnover. *Trends in ecology & evolution*, 25(3), 153–160. https://doi.org/10.1016/j.tree.2009.10.001.

Jones, H. P., Jones, P. C., Barbier, E. B., Blackburn, R. C., Rey Benayas, J. M., Holl, K. D., ... & Mateos, D. M. (2018). Restoration and repair of Earth's damaged ecosystems. *Proceedings of the Royal Society B: Biological Sciences,* 285(1873), 20172577. https://doi.org/10.1098/rspb.2017.2577.

Keil, P., Storch, D., & Jetz, W. (2015). On the decline of biodiversity due to area loss. *Nature communications,* 6(1), 1–11. https://doi.org/10.1038/ncomms9837.

Kuruneri-Chitepo, C., & Shackleton, C. M. (2011). The distribution, abundance and composition of street trees in selected towns of the Eastern Cape, South Africa. *Urban Forestry & Urban Greening,* 10(3), 247–254. https://doi.org/10.1016/j.ufug.2011.06.001.

Lamb, D. (2010). *Regreening the bare hills: tropical forest restoration in the Asia-Pacific region* (Vol. 8). Springer Science & Business Media.

Laughlin, D. C. (2014). Applying trait-based models to achieve functional targets for theory-driven ecological restoration. *Ecology letters,* 17(7), 771–784. https://doi.org/10.1111/ele.12288.

Lewandowski, A. S., Noss, R. F., & Parsons, D. R. (2010). The effectiveness of surrogate taxa for the representation of biodiversity. *Conservation Biology,* 24(5), 1367–1377. https://doi.org/10.1111/j.1523-1739.2010.01513.x.

Lewinsohn, T. M., & Prado, P. I. (2005). Quantas espécies há no Brasil. *Megadiversidade,* 1(1), 36–42.

Liebsch, D., Marques, M. C., & Goldenberg, R. (2008). How long does the Atlantic Rain Forest take to recover after a disturbance? Changes in species composition and ecological features during secondary succession. *Biological Conservation,* 141(6), 1717–1725.

Lindenmayer, D. B. (2019). Integrating forest biodiversity conservation and restoration ecology principles to recover natural forest ecosystems. *New Forests,* 50(2), 169–181. https://doi.org/10.1007/s11056-018-9633-9.

Lindenmayer, D. B., & Franklin, J. F. (2002). *Conserving forest biodiversity: a comprehensive multiscaled approach*. Island press.

Lindenmayer, D. B., R. B. Cunningham, C. F. Donnelly, and R. Lesslie. (2002). On the use of landscape surrogates as ecological indicators in fragmented forests. *Forest Ecology and Management* 159(3), 203–216. http://dx.doi.org/10.1016/S0378-1127(01)00433-9.

Lomolino, M. V., Brown, J. H., & Sax, D. F. (2010). Island biogeography theory. *The theory of island biogeography revisited,* 13.

Lu, Y., Ranjitkar, S., Harrison, R. D., Xu, J., Ou, X., Ma, X., & He, J. (2017). Selection of native tree species for subtropical forest restoration in Southwest China. *PloS one,* 12(1). https://doi.org/10.1371/journal.pone.0170418.

Mansourian, S., & Vallauri, D. (Eds.). (2005). *Forest restoration in landscapes: beyond planting trees*. Springer Science & Business Media.

Martins, E., Loyola, R., Martinelli, G. (2017). Challenges and Perspectives for Achieving the Global Strategy for Plant Conservation Targets in Brazil. *Annals of the Missouri Botanical Garden,* 102(2), 347–356. https://doi.org/10.3417/D-16-00009A.

Martins, S. V. (2013). Recuperação de Áreas Degradadas: como recuperar áreas de preservação permanente, voçorocas, taludes rodoviários e áreas de mineração. *Ed. Aprenda Fácil, Viçosa.*

Massad, T. J., Chambers, J. Q., Rolim, S. G., Jesus, R. M., & Dyer, L. A. (2011). Restoration of pasture to forest in Brazil's Mata Atlântica: The roles of herbivory, seedling defenses, and plot design in reforestation. *Restoration Ecology,* 19(201), 257–267. https://doi.org/10.1111/j.1526-100X.2010.00683.x.

May, R. M. (2010). Tropical arthropod species, more or less? *Science,* 329(5987), 41–42. http://doi.org/10.1126/science.1191058.

McCarthy, B. (2012). 'The effects of logging and fragmentation on bird diversity', *The Plymouth Student Scientist,* 5(2), 558–568. http://hdl.handle.net/10026.1/14000.

Meli, P., Holl, K. D., Benayas, J. M. R., Jones, H. P., Jones, P. C., Montoya, D., & Mateos, D. M. (2017). A global review of past land use, climate, and active vs. passive restoration effects on forest recovery. *PloS one,* 12(2). https://doi.org/10.1371/journal.pone.0171368.

Meli, P., Martínez-Ramos, M., Rey-Benayas, J. M., & Carabias, J. (2014). Combining ecological, social and technical criteria to select species for forest restoration. *Applied vegetation science,* 17(4), 744–753. https://doi.org/10.1111/avsc.12096.

Menge, D. N., & Chazdon, R. L. (2016). Higher survival drives the success of nitrogen-fixing trees through succession in Costa Rican rainforests. *New Phytologist,* 209(3), 965–977. https://doi.org/10.1111/nph.13734.

Menz, M. H., Dixon, K. W., & Hobbs, R. J. (2013). Hurdles and opportunities for landscape-scale restoration. *Science,* 339(6119), 526–527. http://dx.doi.org/10.1126/science.1228334.

Mesquita, Z. (2015). Os “Espaços” do Espaço Brasileiro em Fins do Século XX. *Terra livre,* (4).

Miles, L., Grainger, A., Phillips, O. (2004) The impact of global climate change on tropical forest biodiversity in Amazonia. *Global Ecology and Biogeography,* 13, 553–565. https://doi.org/10.1111/j.1466-822X.2004.00105.x.

Miranda, P. N., Oliveira, M. A., Baccaro, F. B., Morato, E. F., & Delabie, J. H. C. (2012). Check list of ground-dwelling ants (Hymenoptera: Formicidae) of the eastern Acre, Amazon, Brazil. *Check List,* 8(4), 722–730. http://dx.doi.org/10.15560/8.4.722.

MMA – Ministério de Meio Ambiente. (2018). Biomas da Amazônia. Retrieved from https://www.mma.gov.br/biomas/amaz%C3%B4nia.

MMA – Ministério de Meio Ambiente. (2019). Biodiversidade, conservação de espécies e espécies ameaçadas. Retrieved from https://www.mma.gov.br/biodiversidade/conservacao-de-especies/fauna-ameacada.

Monks, L., Barrett, S., Beecham, B., et al. (2019). "Recovery of threatened plant species and their habitats in the biodiversity hotspot of the Southwest Australian Floristic Region". *Plant diversity,* 41(2), 59–74. https://doi.org/10.1016/j.pld.2018.09.006.

Moreno-Mateos, D., Barbier, E. B., Jones, P. C., Jones, H. P., Aronson, J., López-López, J. A., ... & Benayas, J. M. R. (2017). Anthropogenic ecosystem disturbance and the recovery debt. *Nature Communications,* 8(1), 1-6. https://doi.org/10.1038/ncomms14163.

Morin, X., Fahse, L., Jactel, H., Scherer-Lorenzen, M., García-Valdés, R., & Bugmann, H. (2018). Long-term response of forest productivity to climate change is mostly driven by change in tree species composition. *Scientific reports,* 8(1), 5627.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., ... & Lonsdorf, E. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment,* 7(1), 4-11. https://doi.org/10.1890/080023.

Nepstad, D. C., Uhl, C., & Serrao, E. A. (1991). Recuperation of a degraded Amazonian landscape: forest recovery and agricultural restoration. *Ambio (Sweden),* 20(6), 248–255.

Neri, A. V., Soares, M. P., Neto, M., Alves, J. A., & Dias, L. E. (2011). Espécies de cerrado com potencial para recuperação de áreas degradadas por mineração de ouro, Paracatu-MG. *Revista Árvore,* 35(4), 907–918. https://doi.org/10.1590/S0100-67622011000500016.

OC – Observatório do Clima. (2019). Recorde de queimadas reflete irresponsabilidade de Bolsonaro. São Paulo, Brasil.: Retrieved from http://www.observatoriodoclima.eco.br/recorde-de-queimadas-reflete-irresponsabilidade-de-bolsonaro/.

Oliveira, J. (2019). Os incêndios na Amazônia desatam críticas mundiais ao Governo Bolsonaro. São Paulo, Brasil.: Retrieved from https://brasil.elpais.com/brasil/2019/08/22/politica/1566501636_486466.html.

Pailler, S. (2016). *Local politics and deforestation in the Brazilian Amazon.* Clark University.

Palma, A. C., & Laurance, S. G. (2015). A review of the use of direct seeding and seedling plantings in restoration: what do we know and where should we go?. *Applied Vegetation Science,* 18(4), 561–568. https://doi.org/10.1111/avsc.12173.

Pardini, R., de Arruda Bueno, A., Gardner, T. A., Prado, P. I., & Metzger, J. P. (2010). Beyond the fragmentation threshold hypothesis: regime shifts in biodiversity across fragmented landscapes. PloS one, 5(10). http://dx.doi.org/10.1371/journal.pone.0013666.

Pauchard, A., Aguayo, M., Peña, E., & Urrutia, R. (2006). Multiple effects of urbanization on the biodiversity of developing countries: the case of a fast-growing metropolitan area (Concepción, Chile). *Biological conservation,* 127(3), 272–281. https://doi.org/10.1016/j.biocon.2005.05.015.

Paul, G. S., & Yavitt, J. B. (2011). Tropical vine growth and the effects on forest succession: a review of the ecology and management of tropical climbing plants. *The Botanical Review,* 77(1), 11–30. https://doi.org/10.1007/s12229-010-9059-3.

Pejchar, L., & Mooney, H. A. (2009). Invasive species, ecosystem services and human well-being. *Trends in ecology & evolution,* 24(9), 497–504. http://dx.doi.org/10.1016/j.tree.2009.03.016.

Pereira, H. M., Borda-de-Água, L., & Martins, I. S. (2012). Geometry and scale in species–area relationships. *Nature,* 482(7386), E3-E4. https://doi.org/10.1038/nature10857.

Peres, C. A. & Dolman, P. M. (2000). Density compensation in neotropical primate communities: evidence from 56 hunted and nonhunted Amazonian forests of varying productivity. *Oecologia,* 122, 175–189.

Perz, S. G., Souza Jr, C., Arima, E., Caldas, M., Brandao Jr, A. O., Souza, F. K. A., & Walker, R. (2005). O dilema das estradas nãooficiais na Amazônia. *Ciência Hoje,* 37(222), 56–58.

Quijas, S., Romero-Duque, L. P., Trilleras, J. M., Conti, G., Kolb, M., Brignone, E., & Dellafiore, C. (2019). Linking biodiversity, ecosystem services, and beneficiaries of tropical dry forests of Latin America: Review and new perspectives. *Ecosystem services,* 36, 100909. https://doi.org/10.1016/j.ecoser.2019.100909.

Rayol, B. P., Do Vale, I., & Miranda, I. S. (2019). Tree and palm diversity in homegardens in the Central Amazon. *Agroforestry Systems,* 93(2), 515–529. https://doi.org/10.1007/s10457-017-0144-z.

Reid, J. L., Fagan, M. E., & Zahawi, R. A. (2018). Positive site selection bias in meta-analyses comparing natural regeneration to active forest restoration. *Science advances,* 4(5), eaas9143. https://doi.org/10.1126/sciadv.aas9143.

Reid, M. (2014). *Brazil: The troubled rise of a global power*. Yale University Press.

Reis, A., Bechara, F. C., Tres, D. R., & Trentin, B. E. (2014). Nucleação: concepção biocêntrica para a restauração ecológica. *Ciência Florestal,* 24(2), 509–519. https://doi.org/10.5902/1980509814591.

Richards, P. D., Walker, R. T., & Arima, E. Y. (2014). Spatially complex land change: The Indirect effect of Brazil's agricultural sector on land use in Amazonia. *Global Environmental Change,* 29, 1–9. https://doi.org/10.1016/j.gloenvcha.2014.06.011.

Rodrigues, M., Silva, D. C. C., & Junior, W. C. A. (2018). Redução do Desmatamento na Amazônia: o papel dos mecanismos institucionais. *Revista de Administração e Negócios da Amazônia,* 10(1), 108–123. https://doi.org/10.18361/2176-8366/rara.v10n1p108-123.

Rodrigues, R. R., Gandolfi, S., & Brancalion, P. H. S. (2015). *Restauração florestal.* Oficina de Textos.

Rodrigues, R. R., Gandolfi, S., Nave, A. G., Aronson, J., Barreto, T. E., Vidal, C. Y., & Brancalion, P. H. (2011). Large-scale ecological restoration of high-diversity tropical forests in SE Brazil. *Forest Ecology and Management,* 261(10), 1605–1613. https://doi.org/10.1016/j.foreco.2010.07.005.

Rozendaal, D. M., Bongers, F., Aide, T. M., Alvarez-Dávila, E., Ascarrunz, N., Balvanera, P., ... & Calvo-Rodriguez, S. (2019). Biodiversity recovery of Neotropical secondary forests. *Science advances,* 5(3), eaau3114. https://doi.org/10.1126/sciadv.aau3114.

Sakschewski, B., Von Bloh, W., Boit, A., Poorter, L., Peña-Claros, M., Heinke, J., ... & Thonicke, K. (2016). Resilience of Amazon forests emerges from plant trait diversity. *Nature Climate Change,* 6(11), 1032–1036. https://doi.org/10.1038/nclimate3109.

Salomão, R. P., Santana, A. C., Brienza Júnior, S. (2012b). Análise da florística e estrutura de floresta primária visando a seleção de espécies-chave, através de análise multivariada, para a restauração de áreas mineradas em unidades de conservação. *Revista Árvore,* 36(6), 989–1007. https://doi.org/10.1590/S0100-67622012000600001.

Salomão, R. P., Santana, A. C., Brienza Júnior, S., Gomes, V. H. F. (2012a). Análise fitossociológica de floresta ombrófila densa e determinação de espécies-chave para recuperação de área degradada através da adequação do índice de valor de importância. *Boletim do Museu Paraense Emílio Goeldi, Ciências Naturais,* 7(1), 57–102.

Seddon, A. W., Macias-Fauria, M., Long, P. R., Benz, D., & Willis, K. J. (2016). Sensitivity of global terrestrial ecosystems to climate variability. *Nature,* 531(7593), 229–232. https://doi.org/10.1038/nature16986.

SER - Society for Ecological Restoration International Science & Policy Working Group. (2004). *The SER international primer on ecological restoration.* Tucson, USA. Retrieved from www.ser.org.

Serra, M. A., & Fernández, R. G. (2004). Perspectivas de desenvolvimento da Amazônia: motivos para o otimismo e para o pessimismo. *Economia e Sociedade,* 13(2), 23.

Shandra, J. M., McKinney, L. A., Leckband, C., & London, B. (2010). Debt, structural adjustment, and biodiversity loss: a cross-national analysis of threatened mammals and birds. *Human ecology review,* 17(1), 18–33.

Sherkow, J. S., & Greely, H. T. (2013). What if extinction is not forever?. *Science,* 340(6128), 32–33. https://doi.org/10.1126/science.1236965.

Shiferaw, W., Demissew, S., and Bekele, T. (2018). "“Ecology of soil seed banks: implications for conservation and restoration of natural vegetation”: a review." *Int. J. Biodiversity Conservation,* 10(10), 380–393. https://doi.org/10.5897/IJBC2018.1226.

Simberloff, D., Relva, M. A., & Nuñez, M. (2002). Gringos en el bosque: introduced tree invasion in a native Nothofagus/Austrocedrus forest. *Biological Invasions,* 4(1–2), 35–53. http://dx.doi.org/10.1023/A:1020576408884.

Similä, M., & Junninen, K. (2012). Ecological restoration and management in boreal forests–best practices from Finland. *Metsähallitus Natural Heritage Services, Vantaa.* http://julkaisut.metsa.fi/assets/pdf/lp/Muut/ecological-restoration.pdf

Simonet, G., Subervie, J., Ezzine-de-Blas, D., Cromberg, M., & Duchelle, A. E. (2019). Effectiveness of a REDD+ project in reducing deforestation in the Brazilian Amazon. *American Journal of Agricultural Economics,* 101(1), 211–229. https://doi.org/10.1093/ajae/aay028.

Singh, S. K., Srivastava, P. K., Gupta, M., Thakur, J. K., & Mukherjee, S. (2014). Appraisal of land use/land cover of mangrove forest ecosystem using support vector machine. *Environmental earth sciences,* 71(5), 2245–2255. https://doi.org/10.1007/s12665-013-2628-0.

Soares-Filho, B., Moutinho, P., Nepstad, D., Anderson, A., Rodrigues, H., Garcia, R., ... & Silvestrini, R. (2010). Role of Brazilian Amazon protected areas in climate change mitigation. *Proceedings of the National Academy of Sciences,* 107(24), 10821–10826. https://doi.org/10.1073/pnas.0913048107.

Spake, R., Ezard, T. H., Martin, P. A., Newton, A. C., & Doncaster, C. P. (2015). A meta-analysis of functional group responses to forest recovery outside of the tropics. *Conservation Biology,* 29(6), 1695–1703. https://doi.org/10.1111/cobi.12548.

Stanturf, J. A., Palik, B. J., Dumroese, R. K. (2014). Contemporary forest restoration: A review emphasizing function. *Forest Ecology and Management,* 331, 292–323. https://doi.org/10.1016/j.foreco.2014.07.029.

Strayer, D. L., Eviner, V. T., Jeschke, J. M., & Pace, M. L. (2006). Understanding the long-term effects of species invasions. *Trends in ecology & evolution,* 21(11), 645–651. http://dx.doi.org/10.1016/j.tree.2006.07.007.

Suganuma, M. S., & Durigan, G. (2015). Indicators of restoration success in riparian tropical forests using multiple reference ecosystems. *Restoration Ecology,* 23(3), 238–251. https://doi.org/10.1111/rec.12168.

Tedesco, P. A., Beauchard, O., Bigorne, R., Blanchet, S., Buisson, L., Conti, L., ... & Jézéquel, C. (2017). A global database on freshwater fish species occurrence in drainage basins. *Scientific data,* 4, 170141. https://doi.org/10.1038/sdata.2017.141.

Ten Kate, K., & Laird, S. A. (2019). *The commercial use of biodiversity: Access to genetic resources and benefit-sharing* (Vol. 15). Routledge.

Ter Steege, H., Pitman, N., Sabatier, D., Castellanos, H., Van Der Hout, P., Daly, D. C., ... & Duivenvoorden, J. (2003). A spatial model of tree α-diversity and tree density for the Amazon. *Biodiversity & Conservation,* 12(11), 2255–2277. https://doi.org/10.1023/A:1024593414624.

Terborgh, J., & Estes, J. A. (Eds.). (2013). *Trophic cascades: predators, prey, and the changing dynamics of nature.* Island Press.

Terborgh, J., Nuñez-Iturri, G., Pitman, N. C., Valverde, F. H. C., Alvarez, P., Swamy, V., ... & Paine, C. T. (2008). *Tree recruitment in an empty forest. Ecology,* 89(6), 1757–1768. http://dx.doi.org/10.1890/07-0479.1.

Terborgh, J., S. K., Robinson, T. A., Parker III, C. A., Munn, and N. Pierpont. (1990). Structure and organization of an Amazonian forest bird community. *Ecological Monographs* 60, 213–238.

The World Bank. (2019). A importância fundamental da biodiversidade da Amazônia para o mundo: uma entrevista com Thomas Lovejoy. Retrieved from website: https://www.worldbank.org/pt/news/feature/2019/05/22/why-the-amazons-biodiversity-is-critical-for-the-globe. Accessed 27 May 2020.

Thom, D., & Seidl, R. (2016). Natural disturbance impacts on ecosystem services and biodiversity in temperate and boreal forests. *Biological Reviews,* 91(3), 760–781. https://doi.org/10.1111/brv.12193.

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collinham, Y. C. et al. (2004). Extinction risk from climate change. *Nature,* 427, 145–148. https://doi.org/10.1038/nature02121.

Thomas, E., Jalonen, R., Loo, J., Boshier, D., Gallo, L., Cavers, S., ... & Bozzano, M. (2014). Genetic considerations in ecosystem restoration using native tree species. *Forest Ecology and Management,* 333, 66–75. https://doi.org/10.1016/j.foreco.2014.07.015.

Thompson, I. D., Guariguata, M. R., Okabe, K., Bahamondez, C., Nasi, R., Heymell, V., & Sabogal, C. (2013). An operational framework for defining and monitoring forest degradation. *Ecology and Society*, 18(2).https://www.ecologyandsociety.org/vol18/iss2/art20/.

Tomazi, A. L., Zimmermann, C. E., & Laps, R. R. (2010). Poleiros artificiais como modelo de nucleação para restauração de ambientes ciliares: caracterização da chuva de sementes e regeneração natural. *Biotemas,* 23(3), 125–135.

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. *Ecology letters,* 8(8), 857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x.

Valsecchi, J., Marmontel, M., Franco, C. L. B., Cavalcante, D. P., Cobra, I. V. D., Lima, I. J., ... & Monteiro, V. (2017). Atualização e composição da lista–Novas Espécies de Vertebrados e Plantas na Amazônia 2014–2015. *Brasília/DF e Tefé/AM: WWF e Instituto de Desenvolvimento Sustentável Mamirauá.*

Van Breugel, M., Craven, D., Lai, H. R., Baillon, M., Turner, B. L., & Hall, J. S. (2019). Soil nutrients and dispersal limitation shape compositional variation in secondary tropical forests across multiple scales. *Journal of Ecology,* 107(2), 566–581. https://doi.org/10.1111/1365-2745.13126.

Van der Werf, G. R., Morton, D. C., DeFries, R. S., Oliver, J. G. J., Kasibhatla, P., Jackson, R. B., ... & Randerson, J. T. (2009). C02 emissions from deforestation. *Nature Geoscience,* 2, 737–738.

Vaz, P. (2000). Sistemas agroflorestais como opção de manejo para microbacias. *Informe agropecuário,* 21(207).

Vazquez, K. C., & Dey, R. (2019). Geopolitics over Amazon fire taking complex turn for Brazil.

Veríssimo, A., Barreto, P., Mattos, M., Tarifa, R., & Uhl, C. (1992). Logging impacts and prospects for sustainable forest management in an old Amazonian frontier: the case of Paragominas. *Forest ecology and management,* 55(1–4), 169–199. https://doi.org/10.1016/0378-1127(92)90099-U.

Viani, R. A., Barreto, T. E., Farah, F. T., Rodrigues, R. R., & Brancalion, P. H. (2018). Monitoring young tropical forest restoration sites: how much to measure?. *Tropical Conservation Science,* 11, 1–9. https://doi.org/10.1177/1940082918780916.

Viani, R. A., Holl, K. D., Padovezi, A., Strassburg, B. B., Farah, F. T., Garcia, L. C., ... & Brancalion, P. H. (2017). Protocol for monitoring tropical forest restoration: perspectives from the Atlantic Forest Restoration Pact in Brazil. *Tropical Conservation Science,* 10, 1–8. https://doi.org/10.1177/1940082917697265.

Vieilledent, G., Grinand, C., Rakotomalala, F. A., Ranaivosoa, R., Rakotoarijaona, J. R., Allnutt, T. F., & Achard, F. (2018). Combining global tree cover loss data with historical national forest cover maps to look at six decades of deforestation and forest fragmentation in Madagascar. *Biological Conservation,* 222, 189–197. https://doi.org/10.1016/j.biocon.2018.04.008.

Volis, S. (2016). "How to conserve threatened Chinese plant species with extremely small populations?". *Plant Diversity,* 38(1), 45–52. https://doi.org/10.1016/j.pld.2016.05.003.

Vranckx, G. U. Y., Jacquemyn, H., Muys, B., & Honnay, O. (2012). Meta-analysis of susceptibility of woody plants to loss of genetic diversity through habitat fragmentation. *Conservation biology,* 26(2), 228–237. https://doi.org/10.1111/j.1523-1739.2011.01778.x.

Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and society,* 9(2).

Wallertz, K., Björklund, N., Hjelm, K., Petersson, M., & Sundblad, L. G. (2018). Comparison of different site preparation techniques: quality of planting spots, seedling growth and pine weevil damage. *New forests,* 49(6), 705–722. https://doi.org/10.1007/s11056-018-9634-8.

Wang, H., Feng, H., Zhang, Y., & Chen, H. (2014). Contrasting regeneration strategies in climax and long-lived pioneer tree species in a subtropical forest. *PloS one,* 9(11). https://doi.org/10.1371/journal.pone.0112385.

Wearn, O. R., Reuman, D. C., Ewers, R. M. (2012). Extinction debt and windows of conservation opportunity in the Brazilian Amazon. *Science* 337, 228–232. https://doi.org/ 10.1126/science.1219013.

Williams, B. A., Grantham, H. S., Watson, J. E., Alvarez, S. J., Simmonds, J. S., Rogéliz, C. A., ... & Walschburger, T. (2020). Minimising the loss of biodiversity and ecosystem services in an intact landscape under risk of rapid agricultural development. *Environmental Research Letters,* 15(1), 014001. https://doi.org/10.1088/1748-9326/ab5ff7.

Wittmann, F., Schöngart, J., Montero, J. C., Motzer, T., Junk, W. J., Piedade, M. T., ... & Worbes, M. (2006). Tree species composition and diversity gradients in white-water forests across the Amazon Basin.

Journal of biogeography, 33(8), 1334–1347. https://doi.org/10.1111/j.1365-2699.2006.01495.x.

Wright, S. J., Stoner, K. E., Beckman, N., Corlett, R. T., Dirzo, R., Muller-Landau, H. C., ... & Wang, B. C. (2007). The plight of large animals in tropical forests and the consequences for plant regeneration. *Biotropica,* 39(3), 289–291. http://dx.doi.org/10.1111/j.1744-7429.2007.00293.x.

WWF – World Wildlife Fund. Amazônia Viva!: uma década de descobertas, 1999-2009. Brasília, 2010. Retrieved from https://d3nehc6yl9qzo4.cloudfront.net/downloads/6set17_wwf_relatorio_final.pdf

Zahawi, R. A., Holl, K. D., Cole, R. J., & Reid, J. L. (2013). Testing applied nucleation as a strategy to facilitate tropical forest recovery. *Journal of Applied Ecology,* 50(1), 88–96. https://doi.org/10.1111/1365-2664.12014.

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