New Forests (2021) 52:1–16
https://doi.org/10.1007/s11056-020-09777-3

REVIEW

An overview of forest loss and restoration in the Brazilian Amazon

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Received: 3 May 2019 / Accepted: 26 January 2020 / Published online: 3 February 2020

Abstract

Forest restoration is a strategy to reverse forest loss and degradation. We overviewed deforestation in the period 1975–2018 in the Brazilian Amazon and the projects, techniques, and scientific publications conducted to recover forest in the area by 2019. We used GIS to assess forest loss and a systematic data collection gathered from 12 universities, five major environmental agencies, and an ad-hoc bibliographic survey that rendered information from 405 restoration projects and 152 published studies. The Brazilian Amazon has undergone an accelerated deforestation in the last 43 years, resulting in 20% (788,353 km^2) of its territory deforested by 2018. Deforestation rate was 27,033 $km^2\ yr^{-1}$ between 1975 and 1987 and 14,542 $km^2\ yr^{-1}$ between 1988 and 2018 (1.97% yr^{-1} of forest loss between 1975 and 2018). In 2018, 41 Amazonian municipalities were classified as priority areas for monitoring and control deforestation and 21 additional municipalities were deemed as areas with controlled deforestation. Our survey identified 405 projects of forest restoration in 191 municipalities between 1950 and 2017. The majority (229) of these projects used seedling planting as the main forest restoration technique. Forest restoration projects based upon agroforestry systems (144), assisted natural regeneration (27), and natural regeneration (5) were also identified. Despite a considerable number of projects and publications, the region still lacks scientific studies that reinforce the choice of best practices for forest restoration, and the information currently available is not enough to quantify what has already been recovered or the potential area to be restored.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11056-020-09777-3) contains supplementary material, which is available to authorized users.

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Keywords Bibliographic survey · Deforestation · Silviculture · Socioeconomic context · Succession · Tree plantation

Introduction

Human activities have resulted in large worldwide extents of forest loss and degradation (Kindermann et al. 2008; Hansen et al. 2013) and the associated loss of biodiversity, functions and ecosystem services such as water provision, nutrient cycling and climate regulation (Thompson et al. 2013). Forest loss and degradation greatly affect human well-being, including economy and health (Newman et al. 2014; Liu et al. 2016).

The ability of forests to withstand disturbance and to recover is variable (Fahey et al. 2016; O'Connor et al. 2017), and some studies point to secondary forests as highly valuable for biodiversity conservation (Crouzeilles et al. 2016; Lindenmayer 2019). A number of forest restoration techniques and methods have stemmed from different professional guilds including silviculturists, agroforesters and ecologists (Sarr and Puettmann 2008; Stanturf et al. 2014a). However, traditionally, forest restoration aimed at recovering the same or very close conditions of the original forest (Stanturf et al. 2014b). Landscape forest restoration is mostly based upon active revegetation (Ciccarese et al. 2012; Gilman et al. 2016), natural regeneration or mixed approaches, which can be accomplished by planting seedlings of native and/or exotic species, natural regeneration, assisted natural regeneration, or establishing agroforestry systems (Stanturf et al. 2014a; Macdonald et al. 2015; Viani et al. 2017). The most currently used technique beyond natural regeneration to restore deforested areas is seedling planting (Palma and Laurance 2015; Grossnickle and Ivetic 2017; Freitas et al. 2019).

In the Brazilian Amazon, the conversion to pastureland and cropland, road opening, fires, and wood and ore extraction have historically been the main causes of forest loss and degradation (Solar et al. 2016). As a result, numerous environmental and social problems have been documented in the region, including biodiversity loss (Barlow et al. 2016; Winemiller et al. 2016), greenhouse gas emissions (Sarmiento et al. 2010; Pearson et al. 2017; Song et al. 2018), and the decline of traditional cultures (Fearnside 2002), which generate concern and awareness regarding the need of natural resource conservation (Malhi et al. 2014). Forest loss and degradation in the Brazilian Amazon has gained strong momentum under the current President Bolsonaro's government, which is leading the country to "its worst recession and political divisions in a generation—a daunting time to take up the reins. Unfortunately, his immediate solutions are a threat to the Amazon forest—a resource that most Brazilians want to protect" (Artaxo 2019). Bolsonaro claims that the recent Amazon burnings are the result of climate change; however, scientists have dismissed this statement and reinforce the idea that the numerous fires in the region and, consequently, forest loss and degradation are motivated by a weaker environmental law and encouraged development (Escobar 2019a). Deforestation in the region has been on the rise since the beginning of Bolsonaro´s mandate (Escobar 2019b).

According to the DEGRAD/INPE (Brazilian National Institute for Space Research) system (INPE 2018a), which monitors forest loss and degradation in the Brazilian Amazon, approximately 138,516 km^2 of degraded areas were mapped in the region from 2007 to 2019. There have been records of restoration projects in degraded areas in Brazil since 1862, when the current Tijuca Forest located at Rio de Janeiro state was reforested. However, the first steps towards forest restoration based on scientific research in the Amazon began in the 1970s through reclamation programs in Rio do Norte Mining areas depleted by bauxite exploitation, with some experiments carried out in academic environments (Brancalion et al. 2015). The selection of the most appropriate technique(s) to restore a given lost or degraded forest requires to evaluate changes occurring in the site as well as an analysis of factors that led to loss or degradation (Hutto et al. 2014; Crouzeilles et al. 2016).

The aim of this study is to provide an overview of forest loss, on one side, and projects, techniques, and publications on the recovery of degraded areas carried out in the Brazilian Amazon, on the other side. To achieve this goal, we analyzed: (1) deforestation rates in the period 1975–2018, which will be discussed within the historical, political and socioeconomic context of the region; (2) the major projects used to restore forests, on the basis of a survey conducted in environmental agencies and universities that comprised the 1950–2017 period; and (3) the results of a systematic search in Web of Science related to forest restoration between the years 1910–2018.

Methods

Forest loss in the period 1975–2018

We analyzed deforestation rates in the Brazilian Amazon for the period 1975–2018 with data from the Amazon Deforestation Calculation Program (PRODES/INPE; http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes; Piketty et al. 2015). The PRODES method measures the extent of annual deforestation in the Brazilian Amazon through satellite image classification, from an average pixel spatial resolution of 0.36 ha. The land cover classes considered in the program classification are forest, deforestation, non-forest area, hydrology, and cloud area (INPE 2018b). The PRODES database is available every year in a vector, shapefile file format. We used ArcGis© 10.1 GIS software (ESRIA 2012) to map all vector files analyzed here, and mapped data were later exported to Excel© for the generation of statistics and graphs. We estimated deforestation rates for two periods, namely 1975–1987 and 1988–2018. Estimates for the period 1975–1987 were extracted from INPE´s deforestation reports, whereas estimates for the period 1988–2018 were directly obtained by the authors of this study.

We also analyzed the priority areas to combat and control deforestation in the Brazilian Amazon. The detection of high illegal deforestation rates led the federal Government to issue Decree No. 6321/2007 that established measures to prevent, monitor, and control deforestation. A “black list” of the most deforested municipalities in the Amazon was created as a result of this decree, which became a priority for surveillance and monitoring actions through the Rural Environmental Registry (*Cadastro Ambiental Rural*). This list has been published annually by the Environment Ministry (*Ministério de Meio Ambiente*) based on the following criteria: (i) total deforested area; (ii) total deforested area in the last 3 years; and (iii) an increase in deforestation rates in at least three of the last 5 years. Once in the black list, landowners are imposed with transport and document restrictions to sell their products (Ordinance No. 362/2017). In order to leave this black list and join the "green list" of municipalities deemed as of controlled deforestation, the municipality must maintain deforestation under 40 km^2 in the last 4 years and 80% of its territory.

Survey of forest restoration projects

We systematically surveyed forest restoration projects in the Brazilian Amazon between 1950 and 2017 in the repositories of 12 universities and five major environmental agencies (Table S1). For each assessed project, we looked at (1) the used restoration technique (i.e. seedling planting, agroforestry, assisted natural regeneration, and natural regeneration); (2) the financing support; and (3) the species type used for restoration (native and/or exotic).

Survey of the scientific literature

We carried out a systematic search in Web of Science to assess forest restoration in the Brazilian Amazon. The search pursued all publications between 1910 and 2018 with selected keywords in the title. The Boolean operator used was OR between the following terms: "area* reclamat*", "area* recov*", "ecologic* restorat*", "environmental restorat*", "forest recove*", "forest rehabilitat*", "forest remediat*", "forest restorat*", "land reclamat*", "recov* degrad*", "reforest*", "rehabilitat* forest", "rehabilitation of degrad*", "remediation degrad*", remediation of degrad*", "remediation of forest", "restorat* of tropical", and "revegetat*"; the operator AND linked to "Brazilian Amazon".

In this search, only 152 studies published since 1985 were identified. We assessed (1) the number of published studies per year, (2) the institution that supported the involved research; (3) type of publication (i.e. international or national journals and other Brazilian publication types); (4) the used restoration technique (see categories in the previous section); (5) the species type (see above); and (6) the major topic of research addressed by each study.

We assessed as well the network structure of the identified published studies in terms of connectivity among studies based on the words in the title and in the abstract and on the journals where they were published. The individual studies were grouped into clusters by means of VOSviewer (Van and Waltman 2017; www.vosviewer.com), a software tool for constructing and visualizing bibliometric networks.

Results

Forest loss in the period 1975–2018

The results of our analysis of deforestation in the Brazilian Amazon based upon the INPE reports are summarized in Fig. 1 and Fig. S1. Overall, deforestation rate was 27,033 $km^2\ yr^{-1}$ between 1975 and 1987 and 14,542 $km^2\ yr^{-1}$ between 1988 and 2018,

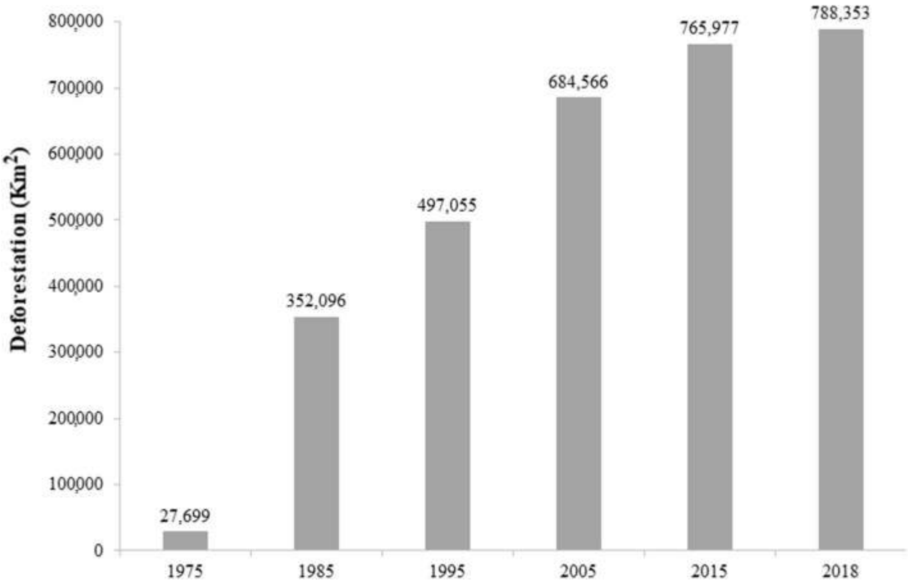

Fig. 1 Deforestation extension in the Brazilian Amazon between 1975 and 2018 based on *PRODES-INPE* (Satellite Monitoring Project of the Brazilian Amazon Forest—*Projeto de Monitoramento da Floresta Amazônica Brasileira por Satélite*)

resulting in 1.97% yr^{-1} of forest loss for the 1975–2018 period (Fig. S1), with a net forest loss of 760,654 km^2. In 1975, when large development projects were created or started, 27,699 km^2 (0.5%) of deforested area was identified (Fig. 1). Ten years later, deforestation attained 352,096 km^2 (7%), an increase of 1171% since 1975. After 1985, deforestation continued to advance but at lower rates; thus, forest loss in 2015 and 2018 are quite similar (765,977 km^2 or 19.26% and 788,353 km^2 or 20%; Fig. 1). The map of Fig. 2 shows current remaining forest, non-forest biome, and deforested land until 1987 and until 2018.

By 2007, 45% (5175 km^2) of all deforested land in the Brazilian Amazon occurred in the 36 so far priority municipalities to combat and control deforestation. By 2018, 41 Amazonian municipalities were classified as priorities and 21 additional municipalities were deemed as of controlled deforestation. Deforestation accumulated in these 41 municipalities represented 23% (183,567 km^2) of deforested area in the region. On the other side, the 21 municipalities with controlled deforestation comprised 11% (82,058 km^2) of deforested area by 2018. Further, between 2007 and 2018, the referred 41 and 21 municipalities underwent a total deforestation amount of 4.4% and 3.9% of their land, respectively. The remaining 713 (66%, 520,313 km^2) municipalities were not in the priority list to combat and control deforestation (Fig. 3, Table S2).

Forest restoration projects and techniques to recover forest

We identified 405 projects located in 191 municipalities in the Brazilian Amazon that were run between 1950 and 2017 (Fig. 4). These projects were established and managed by governmental (6 projects, 1.5%) and non-governmental (2, 0.5%) organizations, forestry

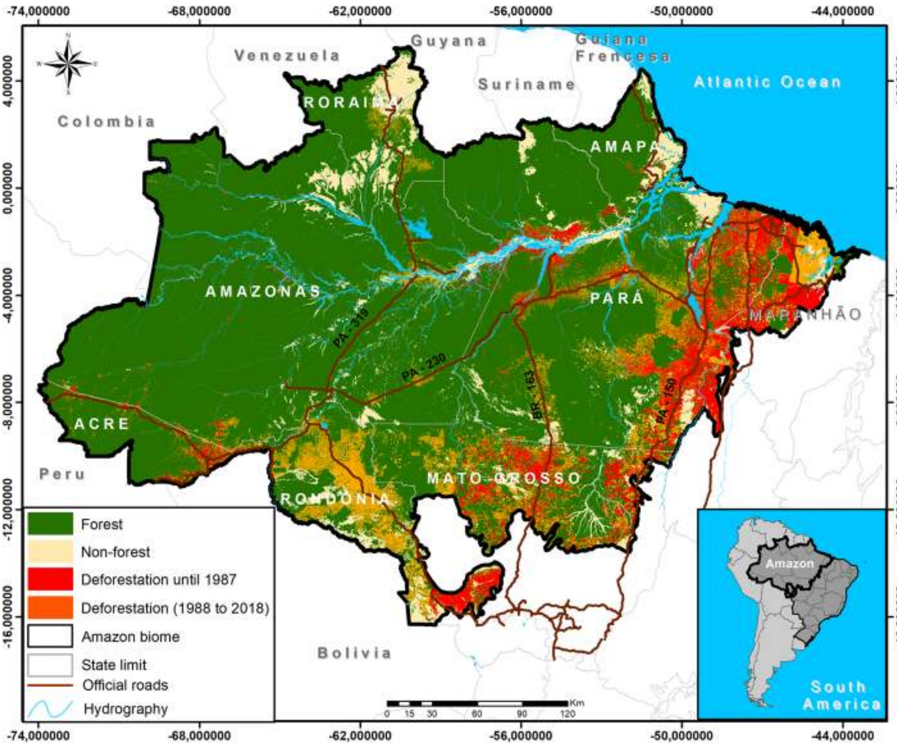

Fig. 2 Forest, non-forest, and deforested area in the Brazilian Amazon by 2018. The deforested area by 1987 is also distinguished. This map is based on data from PRODES-INPE. We used ARCGIS (Esri 2012) for mapping and area calculations

companies (202, 50%), and family farmers (195, 48%). The commercial tree plantations mainly used exotic tree species such as teak (*Tectona grandis*), acacia (*Acacia mangium*), and eucalyptus (*Eucalyptus* spp.), and fulfilled only part of the legal constraints in environmental licensing required to restore degraded lands in the Brazilian Amazon. The techniques used to restore forest land were seedling planting (229 projects, 57%), agroforestry (144, 36%), assisted natural regeneration (27, 7%), and natural regeneration (5, 1%; Fig. S2a).

These restoration projects were financially supported by private companies (129 projects, 32%), agreements between federal and state research institute and environmental agencies (37, 9%) and private companies (36, 9%), environmental agencies (33, 8%), the National Research Institute (19, 5%), and agreements between international research institutes and private companies (9, 2%); the support for 142 projects (35%) could not be identified in our survey (Fig. S2b). The restoration projects used native species (148 projects, 36%), exotic species (121, 30%) and both native and exotic species (55, 14%); 81 projects (20%) did not report any information on the type of species used (Fig. S2c).

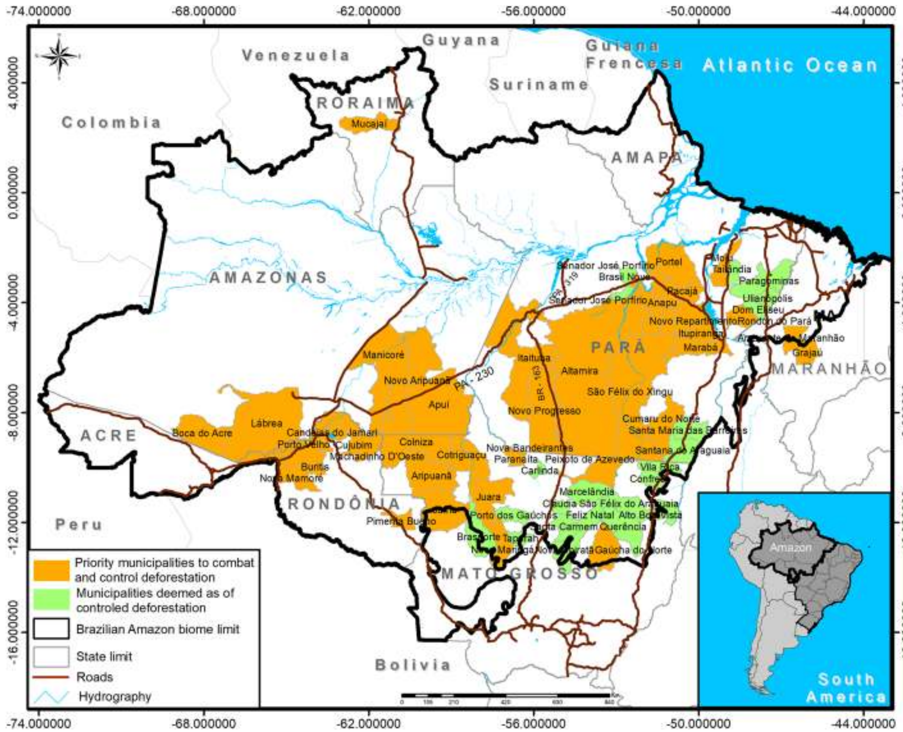

Fig. 3 Distribution of priority municipalities to combat and control deforestation and of municipalities deemed as of controlled deforestation in the Brazilian Amazon by 2017. This map based on data from MMA/geographic database of IBGE—https://ibge.gov.br/ (Ordinance No. 361, DOU of 09/13/2017 and No. 176, Section 1, p. 69)

Scientific production

The 152 studies published since 1985 that were identified in our literature survey belonged to nine areas of knowledge. They received 3224 citations in total and the number of publications grew exponentially since 2011 (Fig. S3a). The leading institutions of authors were Embrapa (21 publications), the National Institute of Amazonian Research (14) and the Emilio Goeldi Museum (10). The articles were published in 73 different (45 international and 28 national) scientific journals including *Forest Ecology and Management* (14 publications), *Acta Amazônica* (7), *Forest Science* (5), *Restoration Ecology* (5), and *Revista Árvore* (4).

The studies were carried out in 87 municipalities, of which only 35 were included in the 191 municipalities of restoration projects analyzed in the previous section (Fig. 4). Some 112 published studies (74%) reported the source of research support, namely research institutes (37 studies, 24%), private companies (23, 15%), federal and state governmental environmental bodies (19, 13%), and agreements among all these institutions (Fig. S3b). Other types of publications were also identified, such as reports by Embrapa–Brazilian Agricultural Research Corporation, congress proceedings, and Master's and PhD theses (Fig. S3c).

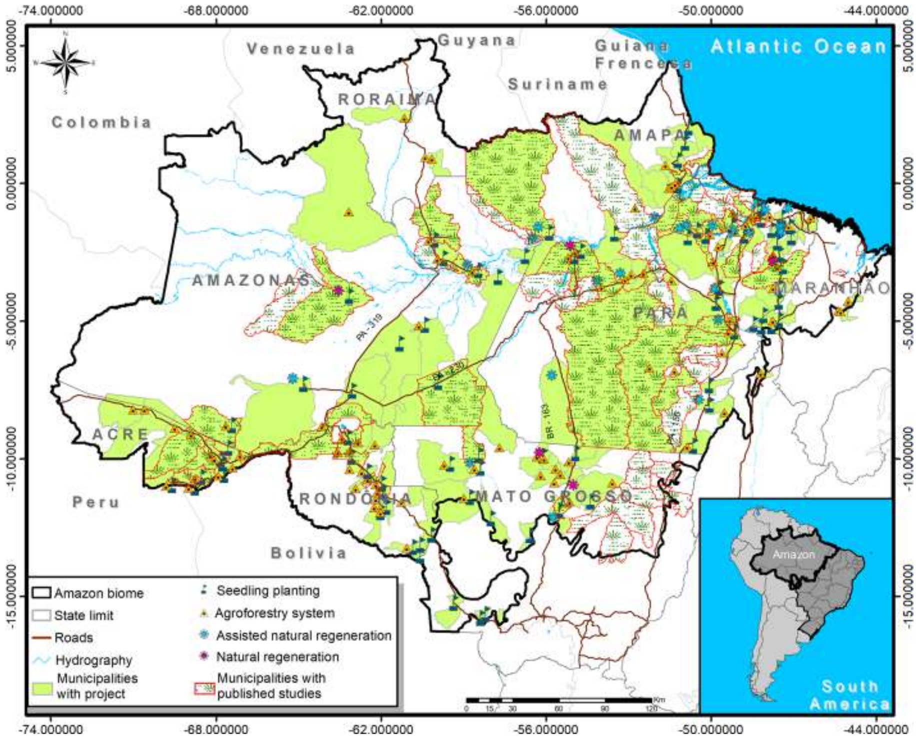

Fig. 4 Location of the 191 municipalities with forest restoration projects and published studies in the Brazilian Amazon that were run between 1950 and 2017. Projects are classified according to four major techniques used to restore forests in the region

The techniques to restore forests that were identified in the published studies were natural regeneration (59 published studies, 39%), seedling planting (54, 36%), agroforestry systems (21, 14%), assisted natural regeneration (5, 3%), and more than one technique (8, 5%). Five studies were conducted on priority areas for forest restoration (Fig. S3d).

Most of the published studies (98, 65%) used native species to restore forests, whereas 22 (14%) used both native and exotic species, only one study (1%) used exotic species, and 31 (20%) projects did not report this information (Fig. S3e). The main topics addressed by these studies were: (a) vegetation structure and phytosociological characterization (67 published studies, 44%); (b) assessment of soil properties and vegetation carbon (16, 11%); (c) overviews related to forest restoration (18, 12%), and (d) restoration techniques (12, 8%) (Fig. S3f).

The assessment of the network structure of the identified published studies, in terms of connectivity among studies based on the words in the title and in the abstract, resulted in four clusters that are shown in Fig. 5. The blue cluster was mostly related to floristic composition, the red cluster to forest loss and degradation, the green cluster to restoration techniques, and the yellow cluster to vegetation growth. The assessment of the network structure based on the journals where the studies were published highlighted six clusters led by the journals *Forest Ecology & Management* (red color), *Restoration*

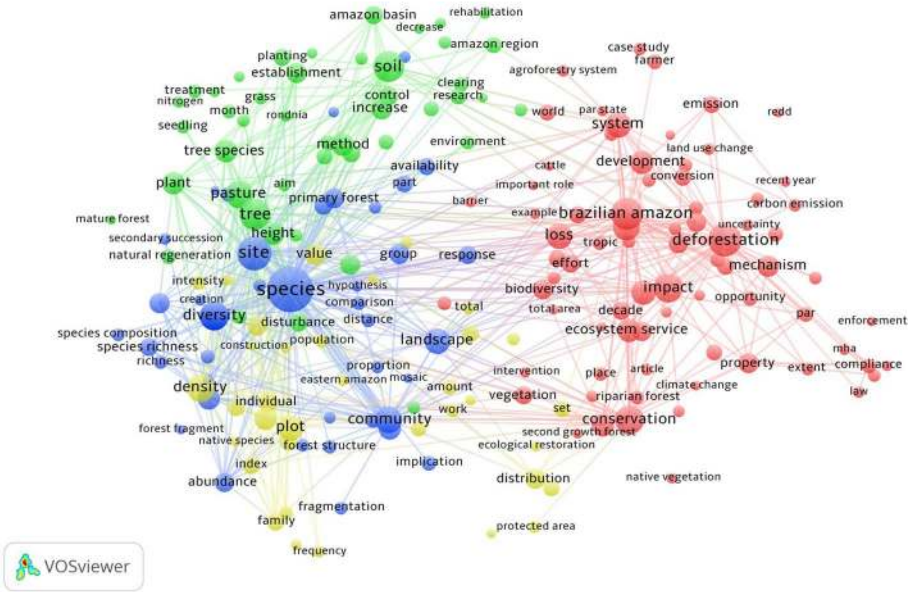

Fig. 5 Connectivity map of published forest restoration studies in the Brazilian Amazon based on the words in the titles and the abstracts. Frequency of studies is proportional to colored balls and font size

Ecology (navy blue), *J. of Range Management* (brown), *Science of the Total Environment* (green), *Forestry Chronicle* (orange), and *Agriculture Ecosystems & the Environment* (yellow, Fig S4).

Discussion

Overall, our overview of forest loss and restoration in the Brazilian Amazon hinted enormous deforestation rates starting in the 1970s and efforts to reverse this deforestation by means of forest restoration projects that were partly triggered by scientific and technical published research. Other studies have pointed to high deforestation rates in the Amazonia (Souza Jr et al. 2013; Barber et al. 2014) and in other areas of Central and South America (Steininger et al. 2001; Echeverría et al. 2006; Armenter and Romero 2006; Swenson et al. 2011).

Historical, political and socioeconomic context of forest loss and degradation in the Brazilian Amazon

The 17th and 18th centuries were marked by intense alteration of the Amazonian landscape, initially due to overexploitation of timber and non-timber forest products, which was followed by intense agricultural activity in the 19th and 20th centuries (Batista 2007). For example, the exploitation of rubber tree latex brought 500,000 migrants to the region between 1850 and 1945, who sought survival due to intense drought and work opportunities in the rubber tree plantations (Benchimol 1977). A second intense period of changes began in the mid-20th century due to deforestation for infrastructure, which was encouraged by the Brazilian government to colonize and develop the region. Large projects were implemented in the country by that time (Hall 1989; Mahar 1979), e.g. the construction of large highways such as the Transamazônica (Oliveira et al. 2017). This development period was influenced by the creation of the SPVEA (Superintendence for the Amazon Economic Valuation Plan—Superintendência do Plano de Valorização Econômica da Amazônia) and the PDA (Development Plan of the Amazon—Plano de Desenvolvimento da Amazônia), which stemmed out from the 1st PND (National Development Plan—Plano Nacional de Desenvolvimento).

The exploitation of natural resources in the Amazon was intensified after 1970. In response to the first oil crisis (Nye 2002), the government of the Brazilian president Ernesto Beckmann Geisel (1974–1979) created the 2nd PND that promoted the expansion of the infrastructure, transportation, energy and communication sectors, as well as exports of Amazonian products (Fonseca and Monteiro 2008). The Polamazonia (Agricultural and Agromineral Poles of Amazon) was created in 1974 to boost and develop the economy in the Brazilian Amazon through a set of economic activities and government tax incentives to attract companies to the region (Monteiro 2005). This program fostered the largest (900,000 km^2) mineral extraction project ever implemented in tropical forests worldwide—The Great Carajas Project (Projeto Carajás Grande–PGC) (Mesquita 2015). The 3rd PND was established in 1979 with the same focus of "integration and occupation" motto coupled with expanding exports aiming at minimizing foreign debt related to the second oil crisis (Goldenberg and Prado 2003). By this time, the Polonoroeste (The Northwest Brazil Integrated Development Program—Programa de Desenvolvimento Integrado do Noroeste do Brasil) was implemented in the Amazon in 1981. Deforestation in the Amazon increased significantly with the implementation of this program, mainly due to the agricultural activity. This agricultural activity mostly benefited large (*latifundium*) landowners and, as a consequence, several agrarian conflicts raised and brought instability and violence to the region (Pereira et al. 2016).

A milestone in the country's history was the implementation of the Real currency in 1994, which coincided with exports of soy and meat (Arima et al. 2014) and resulted in high deforestation rates in 1995. Deforestation rose again in the early 2000s, which led the Brazilian Federal Government to create the PPCDAm (Action Plan for Prevention and Control of Deforestation in the Legal Amazon) in 2004. One year after PPCDAm operation, deforestation was reduced mainly as the result of the new established and expansion of the existing protected areas (Soares-Filho et al. 2010). Another reason for this reduction was the strong international pressure against environmental crimes in the Amazon, including the murder of US missionary Dorothy Stang in 2005 (Le Breton 2008). The current version of PPCDAm (2016–2020) aims at reducing deforestation rates in the region by 80% by 2020. This goal is quite ambitious, considering the attitudes of the current Brazilian President, who apparently is not interested in protecting and restoring forests. Current deforestation rates are greater than in the near past and are expected to rise in the near future (Escobar 2019a; Artaxo 2019).

Forest conservation and restoration in the Brazilian Amazon

In spite historical changes in forest extent in the Brazilian Amazon have resulted in the deforestation of large areas (Prates and Bacha 2011), the efforts to redress this trend are also noticeable. These efforts have been mostly led by the Federal Government through the implementation of legal instruments, which obligate private companies to restore the forest cover in the areas they degrade (further explanation in Appendix S1 and Table S3). The regulatory laws in the country were initiated with the creation of the IBDF–Brazilian Institute of Forest Development (Federal Decree No. 289, 1967), the SEMA–Secretariat of the Environment (Decree No. 73030, 1973), and the CONAMA–National Environment Council and the SISNAMA–National System for the Environment (Law 6.938, 1981). Nevertheless, the most outstanding initiatives led by the Federal Government started in the mid-2000s. The PPCDAm and its positive effect in forest protection was commented earlier.

The federal government has also been taking environmental planning measures at the municipality level through the establishment of priority areas to combat and control deforestation in the Brazilian Amazon (Decree No. 6321/2007). In the light of the deforested area in the 36 priority municipalities by 2007, i.e. 45% or 5175 km^2 of all deforested land in the 775 municipalities that comprise the Brazilian Amazon, we can conclude that the selection of such municipalities was correct. However, since the implementation of this measure, the list of priority municipalities has increased and reached 62 municipalities in 2018. Most of these municipalities are located in the Pará, Mato Grosso and Rondônia states, which are part of the "Deforestation Arc", an area of agricultural frontier expansion, tension and conflicts (Ferreira et al. 2005; Castro 2008). Further, the 21 municipalities deemed as of controlled deforestation underwent a deforestation of just ca. 12% less than the deforestation in the 41 priority municipalities, meaning that this measure has not actually been very successful.

In the last two decades, knowledge on the outcomes of forest restoration has increased significantly (see recent meta-analyses by e.g. Spake et al. 2015; Crouzeilles et al. 2016; Meli et al. 2017; and Reid et al. 2018). These and other studies usually distinguish between passive and active forest restoration. Most restoration projects in the Brazilian Amazon use seedling planting as the main technique (Palma and Laurance 2015; Chaves et al. 2015; Viani et al. 2017), also evidenced in the survey conducted in this study. This technique provides good soil cover, greater species diversity and does not depend on dispersing agents or seed sources (Wallertz et al. 2018). We found projects that use one or a few fast-growing species and others that use more than a hundred species (Kanowski 2010; Rodrigues et al. 2011; Newton and Cantarello 2015). These projects aim to shade aggressive species, attract seed dispersers from neighboring forests, and improve microclimate and soil conditions (Kanowski 2010; Shoo and Catterall 2013). Brazilian law requires that the areas be restored with native species of the region (Brazilian Forest Code, No. 12.727/2012); however, in this study, we identified a large number of restoration projects using exotic species. This fact can be explained by the large number of commercial projects that use exotic species and because land owners trip on legal restrictions for economic use of native species (Butler and Laurence 2009). Agroforestry systems is another frequently used technique used to link economic and conservation interests when recovering degraded areas (Dubois et al. 1996). The use of these systems has been increased mostly in the Eastern Amazon over the last 15 years. For instance, Japanese immigrants in the municipality of Tomé-Açu (Pará) are producing large amounts of crops, tropical fruits, cocoa seeds, and timber while maintaining ecosystem services typical of forests (Yamada and Osaqui 2006). On the other side, assisted natural regeneration seems to be an underused restoration technique (Chazdon and Uriarte 2016).

Scientific production

In the last 30 years, there has been progress in the area of ecological restoration in the Brazilian Amazon, especially on studies involving forest dynamics and analyses of species of different functional groups (Rodrigues 2009). However, despite the numerous (405) restoration projects identified in this study, we found few scientific publications (152). In addition, the published studies were originated at only 47 of the 191 municipalities where we identified forest restoration projects.

The first scientific study on ecological restoration in the Brazilian Amazonian took place in 1970 and was motivated by planting models developed by universities and research institutions (Brancalion et al. 2015). National and international scientific research on forest restoration was born with the growing and urgent demand on the subject. In 1987, the International Society for Ecological Restoration was created, with the first volume (Ecological Restoration) published in 1993. During this period, the first restoration groups of degraded environments emerged in Brazil, namely: Sobre (Brazilian Society of Ecological Restoration), Rebre (Brazilian Network for Ecological Restoration) and Sobrade (Brazilian Society for the Recovery of Degraded Areas).

Bibliographic review is crucial to have a good theoretical background (Conboy 2009; Li et al. 2016) and support research (Webster and Watson 2002). In our review and connectivity analysis, we identified a high density and strong relationship among the terms *species, site, diversity, species composition,* and *species richness*. The relationship between terms in the blue cluster in Fig. 5 is reinforced by the fact that 44% of the scientific articles analyzed in this study addressed the topic of vegetation structure and phytosociological parameters. Particularly, the overriding importance of *species* recalls the strong, narrow focus or old paradigm of forest restoration in this structural level rather than on functions and processes (Stanturf et al. 2014a, b; Holl 2017).

Final considerations

The Brazilian Amazon has undergone an accelerated process of forest loss and degradation initiated in the 1970s and that was promoted by the government to economically develop the region. Numerous incentives programs and infrastructure projects, such as the opening of large roads and mineral extraction, have ultimately resulted in the deforestation of ca. 20% (780,967 km^2) of the region. Deforestation has been reduced thanks to united actions of international governmental and non-governmental organizations and research institutions in the last few decades. Efforts to reverse deforestation have produced a list of critical municipalities where landowners can't receive rural credits for their activities and thus they are forced to work legally. However, there is still much illegal deforestation in the Brazilian Amazon (Brancalion et al. 2018), although in smaller proportion than before 2007 when critical municipalities were established. In that year, deforested land attained 11,500 km^2 and 716,978 km^2 (14%) of the region had already been deforested.

Forest restoration has used a number of techniques including –in descending order of importance- seedling planting, agroforestry systems, assisted natural regeneration and natural regeneration. We emphasize that each restoration action and technique must be adapted to the local reality with a well-defined objective. We compiled a list of 405 forest recovery projects since 1950 but were not able to estimate the amount of recovered area. Despite of numerous restoration projects spread out in the Brazilian Amazon, there is still a lack of scientific production in this field. From the in-depth knowledge of forest restoration as a science, it will be possible to propose better actions for future projects to recover deforested and degraded areas. There are numerous land use regulations and guidelines as well as legal obligations to restore forests, spanning from the municipal to the federal scales. It is though necessary more governmental attention to manage forest land, both to punish those who are degrading the environment and to audit those who are under a recovery program. Unfortunately, current Bolosonaro´s government is not working in that direction. We hope that the motivated complains in the scientific community and further action redresses this situation (Escobar 2019).

Acknowledgements We acknowledge the support from the CNPq–National Council for Scientific and Technological Development of Brazil (203159/2014-4/GDE) and the REMEDINAL project (TE-CM S2018/EMT-4338) funded by the Madrid Autonomous Government. We are indebted to an anonymous reviewer whose comments contributed to improve both the contents and presentation of this study.

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