ScienceDirect

Biological Conservation
Volume 283, July 2023, 110126

Review

The breakdown of ecosystem functionality driven by deforestation in a global biodiversity hotspot

Deborah Faria [a], José Carlos Morante-Filho [a], Júlio Baumgarten [a], Ricardo S. Bovendorp [a], Eliana Cazetta [a], Fernanda A. Gaiotto [a], Eduardo Mariano-Neto [b], Marcelo S. Mielke [a], Michaele S. Pessoa [c], Larissa Rocha-Santos [a], Alesandro S. Santos [a], Leiza A.S.S. Soares [a], Daniela C. Talora [a], Emerson M. Vieira [d], Maíra Benchimol [a]

Show more

Share Cite

https://doi.org/10.1016/j.biocon.2023.110126
Get rights and content

Highlights

- Deforestation leads to biodiversity collapse in remaining forest fragments.
- Fragments in highly deforested landscapes present a reduce in forest quality.
- Landscape forest loss drives to impoverishment of biological communities.
- Species composition change leads to pervasive effect on ecological processes.
- Forest cover maintaining and restoration are vital to ensure ecosystem functioning.

Abstract

The pace of deforestation in tropical forests has achieved unprecedented rates, requiring effective and achievable conservation mitigations that are also easily understood by society and policy makers. In this context, we report the outcomes from a large-scale project located in the threatened Atlantic Forest (SISBIOTA network) to understand how deforestation affects ecological patterns and processes in human-modified landscapes. In particular, we compiled data from 28 studies that evaluated habitat quality, biodiversity maintenance or ecological processes and scrutinised their responses along the gradient of forest loss. After a decade of research effort, we provide evidence of key changes in forest quality, species diversity and ecological processes that are ultimately affecting forest functioning of the remaining patches. As deforestation progresses, we unveiled a clear retraction of local vegetation structure, in which forests become similar to secondary forests, as are characterised by retaining shorter and thinner trees, higher foliage density and increased canopy openness. Besides being hotter, patches embedded within deforested landscapes present reduced quality, evidenced by low fruit production and quality. Such changes cascade to disruptions in biodiversity maintenance and ecological processes. Specifically, forest-specialist species exhibit reduced diversity (e.g., juvenile and adult trees, birds and mammals) and for some groups, are compensated by the increase in habitat-generalist species. Furthermore, forest patches immersed in deforested landscapes experience strong alterations in nutrient cycling and carbon stocks, increase of leaf herbivory, reduction of frugivory, and finally, a simplification in bird-plant interactions. Preventing deforestation is imperative, but restoration and rewilding are also required to safeguard forest-dweller species and, consequently, enable ecological functionality.

Introduction

Deforestation has been rapidly increasing around the globe, with tropical forest loss alone accounting for >90% of the global deforestation from 2000 to 2018 (Fao, 2020). Most of the remaining tropical forest patches become small, degraded and isolated to each other by anthropogenic land use types, leaving the biota with the challenge to survive and play their ecological roles in these human-modified landscapes (Melo et al., 2013). In fact, several forest-dweller species are rapidly succumbing to forest loss and degradation, whereas other species with specific life-history traits are likely to survive and even thrive in human-modified landscapes (Davies et al., 2000; Henle et al., 2004). Therefore, ecological services performed by those sensitive species are likely to become compromised with pervasive consequences for ecosystem integrity. Given the rapid pace of tropical forest loss, coupling the responses of a wide range of wildlife taxa and the provision of ecosystem services in modified landscapes are required to reveal general patterns that can be translated to effective management strategies.

Conservation planning in human-modified landscapes usually recommends maintaining or increasing forest cover, especially at the landscape scale (Arroyo-Rodríguez et al., 2020). Indeed, forest amount is a good proxy for habitat loss, and offers the advantages of being an easy metric to be obtained and understood by policy makers (Fahrig, 2013). For instance, according to the Brazilian Forest Code - one of the main federal environmental legislation in Brazil - private properties should maintain (or restore) a minimum of 20 and 50% of forest cover at the property-scale within the Atlantic Forest and Amazon, respectively (Brazil, 2012). The monitoring of compliance of the law becomes feasible due to the availability of high-resolution annual satellite images, enabling the assessment of the amount of forest cover maintained at the property over the years.

Forest cover is directly related to resource availability (see Fahrig, 2013), with patches inserted in highly forested landscapes harbouring a high number of faunal and floristic species (Rigueira et al., 2013; Carrara et al., 2015). This high richness enhances the provision of ecological processes pivotal to forest ecosystem functioning, such as seed dispersal (San-Jose et al., 2020), nutrient cycle (Bisui et al., 2021) and herbivorous control (Macedo-Reis et al., 2019). Since the review published by Andrén in 1994 on the responses of birds and mammals in patches within landscapes with different proportions of habitat, researchers have been greatly interested in assessing the effects of habitat amount on biodiversity maintenance, and when feasible, unveiling whether ecological responses (such as species richness) abruptly and non-linearly change below a certain amount of habitat loss (i.e., critical thresholds, see With and King, 1999). Overall, species tend to be more sensitive to extinction below 30% of remaining habitat (Andrén, 1994; Banks-Leite et al., 2014), yet species ecological attributes (e.g., dispersion ability) and landscape features (e.g., matrix quality) exert a great influence on both the presence and value of this critical threshold (Swift and Hannon, 2010). However, identifying either robust biological patterns and/or the minimum amount of forest cover necessary to maintain biodiversity in human-modified landscapes requires comprehensive biological data. Ideally, these data must include studies assessing different biological groups, ecological interactions, and delivery of ecosystem services at regional scales (see Banks-Leite et al., 2014). In addition, it is essential that information on ecological patterns and processes are obtained simultaneously within the same forest fragments, and that these fragments are inserted in landscapes composed of distinct amounts of forest cover. Although extremely important, few research groups have consistently gathered a great amount of evidence for tropical landscapes, mostly due to the combination of associated expensive field costs and the need of a great number of specialised researchers for surveying and identifying different taxa. In addition, previous studies that assessed the effects of habitat loss on biodiversity were conducted either at local scales, overlooking the landscape context (e.g., Margules, 1992; Laurance et al., 2011) or investigated potential critical thresholds for single (e.g., Estavillo et al., 2013) or several biological groups (e.g., Banks-Leite et al., 2014) but ignored consequences of habitat loss on ecological processes.

Following species losses, ecological interactions are likely to be disrupted and trigger cascade effects. In particular, the disappearance of certain species can lead to the loss of its predators, dispersers or pollinators, resulting in profound ecosystem imbalances - the so-called ecological meltdown (Montoya, 2005). Terborgh et al. (2001) brilliantly showed this process in islands formed after a hydroelectric dam construction in Venezuela, in which predators of vertebrates vanished in those small islands, resulting in high increase of herbivores with subsequent consequences in forest regeneration. In forest patches of the Biological Dynamics of Forest Fragments Project (BDFFP) in Brazilian Amazonia, the longest-running fragmentation project worldwide, a set of profound changes in community structure and functioning has been detected over three decades, including since the reduced densities of mammal seed dispersers and the consequent reduction in seed dispersal of zoochoric tree species to changes in dung beetle assemblages that ultimately led to changes in biomass and guild structure and consequently in nutrient cycling and secondary seed dispersal (Laurance et al., 2011). Likewise, Villar and Medici (2021) recently showed the short-term decline of plant communities driven by changes on large herbivore communities in a forest fragment in the Brazilian Atlantic Forest, which has been rapidly undergoing ecological meltdown. In the long-term, if no management practices are adopted in those landscapes, forest integrity can be seriously compromised reaching a collapse of biodiversity and ecosystem functionality. Hence, we urge on studies that evaluate different taxa and processes and propose effective recommendations in averting the long-term collapse of biodiversity and ecosystem services.

In the Brazilian Atlantic Forest hotspot, the network of Research in Anthropogenic Landscape Ecology funded by National Biodiversity Research System (hereafter, SISBIOTA) was established in 2011 aiming to understand how forest loss affects both species diversity of multiple taxa and biological processes in human-modified landscapes of the southern Bahia region, one hotpoint of biodiversity within this highly endangered biome (Mori et al., 1983; Martini et al., 2007). In particular, a total of six biological groups, including vascular plants, invertebrates and vertebrates, was surveyed in up to 40 forest sites embedded within contrasted landscapes, specially composed of different forest amounts (ranging from 6 to 85%). In addition, several features often used to describe forest quality (i.e. local vegetation structure, light regime, and fruit production) were measured. Furthermore, different ecological processes, including leaf herbivory, carbon stocks, nutrient cycling, frugivory and seed dispersal were assessed in the same forest patches to enable the understanding of ecosystem functionality of Atlantic Forest patches. The initiative resulted in dozens of scientific publications until to date, in addition to several master and thesis dissertations. Based on the gathered ecological data, we provide a comprehensive review on the effects of landscape deforestation on a wide range of ecological metrics to (i) reveal either an overall or specific pattern of each investigated habitat quality variable, biological group or ecological process along the gradient of forest cover loss and (ii) recommend specific and achievable goals to curb the current rates of biodiversity loss in this keystone tropical biome.

Section snippets

Methods

The study region of the SISBIOTA is located in southern Bahia State, northeastern Brazil (Fig. 1). This region is dominated by the Atlantic Forest biome, one of the most threatened global hotspots due to the high levels of endemism combined with high rates of deforestation (Thomas et al., 1998).

Indeed, only 29% of the biome is currently composed by forests, whereas nearly 65% has been converted into agricultural land uses (Mapbiomas, 2021). Therefore, the once pristine Atlantic Forests have …

Forest structure

Forest quality, measured by the structure of vegetation on surveyed forest patches, was pervasively affected by landscape forest loss. In particular, we observed an overall shrinkage in forest structure in patches embedded within deforested landscapes, evidenced by shorter and thinner trees, higher foliage density and increased canopy openness in these sites (Rocha-Santos et al., 2016). We also revealed that some structural modifications (e.g., tree diameter, basal area and vertical …

Conclusions

After 10years of substantial ecological research, we found a gloomy current scenario - and possibly future - of forest patches in the highly biodiverse but threatened Atlantic Forest. Altogether, our results indicate that forest loss markedly changed the structure, composition, and functioning of the remaining forests in our study region which, currently, are what is left from the northern part of the Brazilian Atlantic Forest. Even more, our findings also allowed us to propose the underlying …

Next steps

Despite the massive effort in surveying different taxa and unveiling ecological processes in human-modified landscapes of Brazilian Atlantic Forest, it turns important to continuously monitor these already studied biological components and a larger number of ecological processes and ecosystem services, such as pollination and water quality, among others not covered in our previous studies. In particular, focusing on plant dynamics is vital, since their reorganisation over time will be directly …

CRediT authorship contribution statement

DF, JB, EC, FG, EM-N, DT: Conceptualization, Methodology and Funding acquisition. JCM-F, MP, LR-S, AS, LS: Methodology and Data collect. DF: Project administration. EM-N: Data analysis. MB, JCM-F: Original draft. DF, JCM-F, JB, RB, EC, FG, EM-N, MM, MP, LR-S, AS, LS, DT, EV, MB: Writing, review and editing. …

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

Acknowledgements

We thank the reviewers and editor for all the suggestions and improvements on the manuscript. We thank the owners of the forest patches for granting access to their properties. We are thankful to all the experts who help with the taxonomic identification, especially José L. Paixão, Vanessa G. Sttaggemeier, Jair E. Q. Faria Junior, Domingos B.O.S. Cardoso, André Â. M. Amorim, Jomar Jardim and Fernando Vaz-de-Mello. We also thank all field assistants, especially Rubens V. Lopes. We are grateful …

Recommended articles

References (136)

E.R. Andrade *et al.*
Effects of habitat loss on taxonomic and phylogenetic diversity of understory Rubiaceae in Atlantic forest landscapes
For. Ecol. Manage. (2015)

C.B. Batista *et al.*
Downscaling the Atlantic Forest biodiversity hotspot: using the distribution of bats to find smaller hotspots with conservation priority
Biol. Conserv. (2021)

M. Benchimol *et al.*
Predicting local extinctions of Amazonian vertebrates in forest islands created by a mega dam
Biol. Conserv. (2015)

M. Benchimol *et al.*
Translating plant community responses to habitat loss into conservation practices: forest cover matters
Biol. Conserv. (2017)

M. Benchimol *et al.*
Losing our palms: the influence of landscape-scale deforestation on Arecaceae diversity in the Atlantic forest
For. Ecol. Manage. (2017)

J.A. Bogoni *et al.*
Effects of mammal defaunation on natural ecosystem services and human well being throughout the entire Neotropical realm

Ecosyst. Serv. (2020)

T.P. Bregman *et al.*
Global patterns and predictors of bird species responses to forest fragmentation: implications for ecosystem function and conservation
Biol. Conserv. (2014)

E. Carrara *et al.*
Impact of landscape composition and configuration on forest specialist and generalist bird species in the fragmented Lacandona rainforest
Mexico Biol. Conserv. (2015)

F.M.V. Carvalho *et al.*
Food habits of sympatric opossums coexisting in small Atlantic Forest fragments in Brazil
Mammal Biol. (2005)

G.A. Cerbu *et al.*
Locating REDD: a global survey and analysis of REDD readiness and demonstration activities
Environ. Sci. Policy (2011)

View more references

Cited by (55)

Critical review on fostering sustainable progress: An in-depth evaluation of cleaner production methodologies and pioneering innovations in industrial processes
2024, Journal of Cleaner Production

> *Citation Excerpt :*
> …The choice not to concentrate just on greenhouse emissions is deliberate; it seeks to better comprehend industrial environmental impacts. The complicated relationship between industrial activity and the environment, including the many factors that cause environmental degradation and ecosystem disturbance, is shown in this comprehensive study (Faria et al., 2023). Environmental degradation, biodiversity loss, and water usage, the production things and services create heaps of plastic, dangerous chemicals, and heavy metals.…

Show abstract

Land use footprints and policies in Brazil
2024, Land Use Policy

Citation Excerpt :

…Following the rationale used to define some thresholds for the build environment LUEF (Section 4.2.2), the trendline of Fig. 10b indicates the need of keeping cropland LUEF < 900 m2/hab to achieve organic carbon stocks in the 0 – 30 cm layer of soils around the National average (46.4 Mg/ha). Deforestation was (and still is) a motor of economic growth (Fig. 7b), but was (and still is) also accompanied by numerous environmental consequences such as amplified greenhouse gas emissions, water quality deterioration, biodiversity decline (Faria et al., 2023; Galán-Acedo et al., 2021; Galinato and Galinato, 2016; Kong et al., 2022), among other damages. As regards the greenhouse gas emissions, for example, the ongoing monitoring conducted by the SEEG platform (https://plataforma.seeg.eco.br/) shows how the emissions of CO2 in Brazil since 1998 can be mostly explained by deforestation and described through a linear relationship CO2(t) = 0.335×Deforestation (R2 = 0.99), where the CO2 emissions are given in Gton/yr and the deforested area in Mha/yr.…

Show abstract

The Atlantic Forest of South America: Spatiotemporal dynamics of the vegetation and implications for conservation

2024, Biological Conservation

Citation Excerpt :

…This change illustrates in time a large-scale process which includes both natural forest regeneration (Crouzeilles et al., 2020) and forest transitions (Bicudo da Silva et al., 2023) related to other processes, and confirms the results found by Rosa et al. (2021), Piffer et al. (2022b) and Dias et al., 2023, who highlighted the replacement of older vegetation by younger vegetation in the AF. This replacement can lead to the loss of habitat quality in vegetation fragments, altering landscape features and affecting vital ecological processes and ecosystem functioning, such as carbon cycling (Piffer et al., 2022a) and vegetation structure (Faria et al., 2023). We also found a large effect of roads and railways on fragment size, more pronounced in FV than in NV due to greater density of these linear infrastructures in large forest fragments located in Serra do Mar and southern Bahia in Brazil, and in the region of Misiones in Argentina.…

Show abstract

Potential of Brazilian berries in developing innovative, healthy, and sustainable food products

2023, Sustainable Food Technology

Show abstract

Alarming patterns of mature forest loss in the Brazilian Atlantic Forest ↗

2025, Nature Sustainability

Quantifying landscape fragmentation and forest carbon dynamics over 35 years in the Brazilian Atlantic Forest ↗

2024, Environmental Research Letters

View all citing articles on Scopus ↗

View full text