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REVIEW ARTICLE

Costs and benefits of restoration are still poorly quantified: evidence from a systematic literature review on the Brazilian Atlantic Forest

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The achievement of international forest restoration goals requires economically viable land-use options. The Brazilian Atlantic Forest is a priority area for ecosystem restoration, as it is widely deforested to make place for intensive agriculture and one of the most threatened biodiversity hotspots in the world. We systematically reviewed existing scientific literature on the biome to highlight the evidence on economic benefits and costs of forest restoration. A total of 15 publications were identified that quantify costs and/or economic benefits of forest restoration. We observed that most studies (11) [Correction added on 15 May 2024, after first online publication: In the preceding phrase, (12) was corrected to (11) in this version.] were published after 2018 and that research on the topic was biogeographically biased as 12 publications referred to study sites in Brazil's Southeast Region. Given its beneficial natural conditions, the Atlantic Forest is predestined for a wide range of restoration-related opportunities, yet economic benefits of restoration are underexplored (seven studies). Moreover, benefits from a multifunctional use of restored forests are almost absent in the literature with only three studies presenting primary data. Elaboration of restoration costs is also limited to 10 studies that focus predominantly on active restoration. Thus, we argue that the economic costs and benefits of forest restoration are not well understood. Clarity thereon is, however, critical for policy formulation and to mobilize private investments. We therefore call for studies to fill in the knowledge gap on restoration economics in the Atlantic Forest biome, and to study restoration economics in other biomes as well.

Key words: economic feasibility, forest restoration, landscape planning, multifunctional forest use, reforestation, restoration economy, tropical forests

Implications for Practice

- The costs and benefits of existing national and international forest restoration agreements may be calculated with insufficient accuracy.
- Decisions for and against future forest restoration commitments may be based on faulty economic assumptions which can lead to involuntary inaction or unexpected expenses.
- A quantification of expected returns through the development and presentation of restoration-based business cases can establish a basis for decision-making on the landowner level.

Introduction

Ecological restoration is a strategic mainstay to mitigate climate change and counter biodiversity loss and receives ample attention in the global environmental agenda (Wolff et al. 2018). Its importance is mirrored in various ambitious initiatives and associated targets set by the international community, with the UN Decade on Ecosystem Restoration functioning as a catalyst for multiple opportunities (Aronson et al. 2020). The Kunming-Montreal Global Biodiversity Framework under the

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Convention on Biological Diversity calls for at least 30% of degraded ecosystems to be restored by 2030 (CBD 2022), representing around 775–1,650 Mha (Leadley et al. 2022), and land degradation is envisaged to come to a halt within the same period as part of Target 15.3 of the Sustainable Development Goals (van der Esch et al. 2021). Moreover, under the Bonn Challenge, 350 million hectares of degraded and deforested ecosystems were pledged to be restored by 2030 (IUCN 2016). Animating efforts of such magnitudes, it was calculated that an accomplished Bonn Challenge, for instance, could generate around US$170 billion annually in net benefits, e.g. through enhanced crop yields and the exploitation of forest products (IUCN 2017). To leverage such benefits, forest restoration requires considerable public and private investments (Löfqvist et al. 2023; Mirzabaev & Wuepper 2023). These costs are, however, insufficiently quantifiable on a global level (Bodin et al. 2022). A projection from 2021 estimated that the implementation of all effective restoration commitments could cost between 0.04 and 0.21% of the annual global GDP for 10 years, or between US$300 billion and US$1,670 billion (van der Esch et al. 2021). With these figures in mind, the societal value of investing in restoration emerges, especially when considering the medium to long-term benefits. Surprisingly, however, restoration scholars and practitioners often downplay or ignore economic benefits (Aronson et al. 2010).

In achieving internationally defined restoration targets, tropical forests play a pivotal role (Brancalion et al. 2019). Brazil, hosting 31% of the world's tropical forest areas (FAO 2003), has committed itself to contribute 12 million hectares to the Bonn Challenge (IUCN 2016). Even more ambitious, Brazil's Atlantic Forest Restoration Pact intends to restore 15 million hectares by 2050 (Calmon et al. 2011) in the Atlantic Forest alone. Covering 15% of Brazil's terrestrial area, the Atlantic Forest biome accounts for 27% of agricultural lands, encompassing the production of 52% of food crops and 56% of animal fodder in the country (Pinto et al. 2022). Besides, the area is the most densely populated in the country, with at least 70% of the Brazilian population living in the region (Metzger 2009). The combination of high human pressure making it one of the main environmental degradation hotspots in the world on the one hand, and its immeasurable value for conservation on the other hand, substantiates the Atlantic Forest's elevated position in global restoration efforts.

If we compare current pledges to the 3.1 million hectares that has been effectively restored between 1985 and 2019 in the Atlantic Forest (Piffer et al. 2022), scaling up previous efforts is urgently needed to accomplish national and international target levels. While anthropic activities continue to cause detrimental effects to the biome (Rosa et al. 2021), the importance of restoration remains unchallenged as the potential ecological benefits are extensive (Rother et al. 2023). It helps to recover degraded soils (Bieluczyk et al. 2023), enhance water provision (Lozano-Baez et al. 2019; Teixeira et al. 2021), sustain the cultivation of pollinator-dependent crops (González-Chaves et al. 2023), secure biodiversity, and provide several other ecosystem services, including those related to culture and human well-being (Brancalion et al. 2014). Besides holding ecological value, the restoration of the Atlantic Forest can also contribute to the region's socioeconomic development. It is estimated that up to 2.5 million jobs could be created if Brazil manages to achieve its international restoration commitments of 12 million hectares (Brancalion et al. 2022).

To unlock the economic potential arising from restoring the Atlantic Forest, an enabling environment is needed. This requires adequate technologies in place, a sound legislative framework, local expertise and, ultimately, effective economic instruments and incentives that can drive restoration action (Melo et al. 2013). Therefore, to make restoration financially work, policymakers and landowners need a clear indication of the costs involved but also of the existing economic opportunities that may facilitate the process. Eventually, they need to know how the costs of forest restoration can be covered by leveraging funding streams that are both available and sustainable, e.g. in terms of a feasible business venture or a possible land-use trajectory (d'Albertas et al. 2023). However, scholars focusing on tropical forest areas other than the Atlantic Forest have found mixed results regarding the role of restoration as a promising business case for private investment (Harrison et al. 2020; Gasparinetti et al. 2022).

The objective of this paper is to highlight the extent to which economic benefits and costs of restoration in the Atlantic Forest have been quantified and understood by scholars, and to identify research gaps associated with the economic viability of restoration in the biome at a local level. This study reviews current scientific literature systematically to capture this information whereby we intend to support decision-making processes, improve the economic appeal for landowners to engage in restoration endeavors, and, ultimately, boost the scale of restoration in the Atlantic Forest.

Methods

We developed a systematic literature review (SLR) and adopted the PSALSAR (protocol, search, appraisal, synthesis, analysis, and report) method, which is considered appropriate for SLRs in environmental science that involves quantitative and qualitative studies (Mengist et al. 2020). Following the PSALSAR method, our first step was to develop a research protocol (protocol) to define the scope of the study, including the research objectives and inclusion criteria. With the protocol established, we conducted a literature search (search) and evaluated the resulting literature to determine if the publications would provide relevant insights (appraisal). After applying the inclusion criteria, we examined the selected papers (synthesis) as well as extracted and analyzed both qualitative and quantitative data that could help meet the research objective (analysis). The final phase focused on reporting the study's results in the write-up (report). These steps are discussed in detail below.

Geographic Scope

This SLR is geographically set on the Brazilian Atlantic Forest. The biome stretches along large parts of the country's Atlantic coast from the South to the Northeast over 17 states (Walker 2012) and consists of seven distinct biogeographical subregions (Silva & Casteleti 2003), leading to extraordinarily high levels of biodiversity in general and endemism in particular (Myers et al. 2000).

Restoration in the Atlantic Forest is particularly relevant as it addresses an ecosystem that is, as a biodiversity hotspot (Laurance 2009), eminently threatened by human activities (Brancalion et al. 2019). Historical deforestation as well as forest degradation and fragmentation escalated with the arrival of European settlers to Brazil more than 500 years ago. Agricultural expansion during various land-use cycles, among others the production of sugar cane, coffee, and livestock, have exacerbated the situation in the past (Tabarelli & Pinto 2005; Joly et al. 2014) and are likely to do so in the future (Zabel et al. 2019). As a result of the biome's land-use history, it is estimated that the Atlantic Forest area left today represents only 28% of its original forest cover that once spanned over 162 million hectares. After decades of perceived stability and despite aforementioned restoration efforts, Atlantic Forest cover has recently started to decline again (Rezende et al. 2018; MapBiomas 2022).

Inclusion Criteria

For this review, the selection of literature was based on a set of inclusion criteria. We selected scientific publications that referred to any type of forest restoration in previously degraded or deforested areas in the Atlantic Forest in Brazil. Here, we followed Gann et al. (2019), who distinguished between natural regeneration, assisted natural regeneration, and active restoration. Natural regeneration is a process of unassisted recovery of forests, usually where the damage to the ecosystem is low, where the restoration process is not tightly time-bound, and where there is an adequate source of propagules, seed dispersal, or seed bank (Chazdon et al. 2017). In areas with higher degrees of damage, interventions may be necessary that trigger biotic recovery. This assisted natural regeneration may include silvicultural practices like the reduction of competition, pest control, pruning and thinning of trees, fencing, or the promotion of dispersal agents (FAO 2019; Gann et al. 2019). Active restoration, finally, goes further by reintroducing large parts of the original or desirable species, e.g. by directly sowing seeds or planting trees (Gann et al. 2019). Due to the different restoration conditions that presuppose a more comprehensive understanding of water and soil properties (Lewis 2009; Macdonald et al. 2015), regeneration of peritidal habitats or previous mining areas were disregarded. Moreover, publications had to contain information on economic aspects of forest restoration and particularly provide primary data on the monetary quantification of costs or benefits. These criteria were employed for screening of identified publications following the implementation of the search strategy.

Search Strategy

To identify literature relevant to the topic, the SLR was based on a search string whose development consisted of two stages. First, a naïve search string was designed based on thorough deliberations followed by a search of synonyms and related expressions in a thesaurus as well as by screening of abstracts and keywords from a selection of studies deemed relevant to this review. The keywords were grouped and then connected to one another using Boolean operators. The clustering of the keywords that defined the use of the respective operator was thematic and structured along the following categories: (1) country, (2) region, (3) ecosystem, (4) restoration activity, and (5) economic costs and benefits. With the help of the naïve string, a first search was conducted on three multidisciplinary research databases, namely Scopus, Web of Science, and SciELO. From each article of the naïve search result, the titles, abstracts, and keywords were exported and then merged into a combined spreadsheet for all three platforms. Second, additional keywords were generated using the *litsearchr* package (Grames et al. 2019) for R (v.4.2). The package applies the Rapid Automatic Keyword Extraction algorithm (Rose et al. 2010) by using the entries of the spreadsheet to detect relevant co-occurring keywords that can refine the search string. In comparison to the naïve search string, the *litsearchr* procedure resulted in three more keywords that were then allocated in the respective category. Table 1 shows the combination of keywords that was identified and deployed to search for relevant literature.

To limit the number of retrieved references, the search was restricted to the "title,", "abstract," and "keyword" fields of the database engines. The keywords were entered only in English as the databases require publications to have the title and abstract translated to English regardless of the main body's language. Besides the platform searches, we scanned the references of the selected articles (snowball searching) and inquired about specific literature recommendations from restoration experts for additional publications. Gray literature was not considered.

The final search was carried out on 18 November 2022, with no year restriction and using the same platforms, whereby Web of Science returned 532, Scopus 714, and Scielo 111 results. After deduplicating the articles present on more than one database, an overall number of 861 publications remained. The inclusion criteria were then used to conduct a title and abstract screening of all 861 identified publications. Afterwards, the full texts of those studies whose titles or abstracts matched the criteria were screened using the same criteria.

All eligible publications were subject to a formal quality assessment. For that purpose, an appraisal checklist (Supplement S1) was used to determine the credibility and the robustness of the study design, the research methods, and analysis performed in a particular study, ensuring that the selected studies would make a relevant contribution to the review (Greenhalgh & Brown 2017).

One study was excluded (Richards et al. 2020) that appeared to meet the inclusion criteria as formulated earlier. However, as a choice experiment, the paper did not estimate relevant values and thus did not contain information relevant to this study.

As a result of the screening and appraisal procedure (Fig. 1), the final selection included a total of 15 papers that present primary data relevant to this review. The publication years of these articles ranged from 2001 to 2021. There was, however, a strong temporal imbalance with 11 studies being published between 2018 and 2021.

Data Extraction

A spreadsheet was generated to manage and summarize the data from the selected studies (Supplement S2). We defined categories of quantitative and qualitative indicators that we considered

Table 1. Combination of keywords used in the SLR including the Boolean operators AND/OR.

Category	*Keywords and Operators Used*
Country	brazil* AND
Region	atlantic AND
Ecosystem	forest* OR rainforest OR woodland OR wooded AND
Restoration activity	restor* OR regenerat* OR reforest* OR rehabilitat* OR reestablish* OR restock* OR revegetat* OR recover* AND
Economic costs and benefits	cost* OR benefi* OR pric* OR income OR expen* OR earn* OR revenue OR return OR incentiv* OR stimul* OR compensat* OR remunerat* OR reward OR disburs* OR fund* OR refund* OR viab* OR profit* OR invest OR investing OR investment OR pay* OR econom* OR financ* OR commercial* OR market* OR mone* OR "carbon trad*" OR "emission trad*" OR "carbon offset*" OR "carbon certificat*" OR "payment for ecosystem service*" OR "payment for environmental service*" OR PES OR REDD OR REDD+ OR NTFP OR product* OR bioproduct OR "bio-product" OR valor* OR value OR commodity OR dollar OR reais OR euro OR pound OR cash OR bioeconom* OR "bio-econom*" OR biobased OR "bio-based" OR "bio based" OR biotechnology OR "green growth" OR job* OR agroforest* OR "agro-forest*" OR silvicultur* OR project* OR plantation OR planting

relevant for our review and that we targeted specifically when screening the articles (Table 2). Indicators related to restoration costs were aligned with Verdone (2015) where the total restoration costs consist of opportunity costs from foregone land use, transaction costs from overheads, planning or management, and implementation costs for the actual physical restoration. However, we disaggregated implementation costs, where possible, into establishment and maintenance costs to distinguish between initial one-off costs and recurring expenses. The indicators for possible economic benefits from restoration were based on Brancalion et al. (2012) and included income from timber production, nontimber forest products (NTFP), agroforestry, and Payments for Ecosystem Services (PES) schemes. Therefore, except for PES, the study focused on provisioning ecosystem services without considering supporting, regulating, and cultural ecosystem services such as an increase in income due to enhanced pollination, pest control, or recreation.

The differentiation between costs and benefits was conducted from a landowner's perspective and the respective data was distilled accordingly to both ensure consistency in the analyses and to embed it in the rationale of potential business cases that may provide a basis for policymakers to leverage restoration. This becomes particularly relevant for benefits within the field of PES as in some literature these schemes are referred to as costs which may be the case from a donor perspective, but not from a landowner one.

Data Analysis and Synthesis

The extraction spreadsheet provided the basis for the data analysis. The information was aggregated and analyzed along the indicators outlined above with the help of pivot tables. We adapted the analysis depending on the type of data generated per indicator, that is, count for qualitative data as well as count, percentage, sum, mean, and range for quantitative data. These basic descriptive statistical analyses allowed to generate information suitable to be either used readily in the write-up or to be further processed and visualized using Microsoft Excel or, for spatial data, QGIS (v.3.28 Firenze). All values were inflation-adjusted using the Consumer Price Index by the Bureau of Labor Statistics. When values were presented in BRL, we also converted them to US$ following historic exchange rates from the Brazilian Central Bank.

Limitations

Besides limitations inherent to the SLR method (Haddaway et al. 2020), the results of this study were constrained by the requirement that publications would stringently have a restoration background. While this is imperative for the dimension of restoration costs and economic viability as such, there are presumably more studies on income generation from (old-growth) forest conservation (e.g. PES) or silvicultural land-use systems (e.g. agroforestry, NTFP, timber) that may not originate from restoration but pose similar opportunities to make a shift in land use economically reasonable. However, the rationale to base the review exclusively on restoration literature is based on the economic potential that is prevalent only in the process of forest restoration due to its sequential character (Brancalion et al. 2012; see Discussion).

Another study limitation is the landowner perspective. First, the information generated is rather localized with the risk that both costs and benefits may not be adequately accounted for on the landscape level, potentially limiting the suitability of the data for extrapolation and thus its validity as a basis for respective decision-making. Second, other potentially monetizable benefits may be overlooked as the impact of forest landscape restoration exceeds the monetary dimension of the landowner, including (1) incentives for local communities, e.g. income and employment generation (Brancalion et al. 2022), health effects and well-being (Erbaugh & Oldekop 2018), and economic resilience tied to natural resource use (Krainovic et al. 2023), and (2) positive effects linked to forest connectivity and species diversity promotion which can strongly influence the speed, type, and cost of restoration while fostering functional connectivity (Metzger et al. 2017).

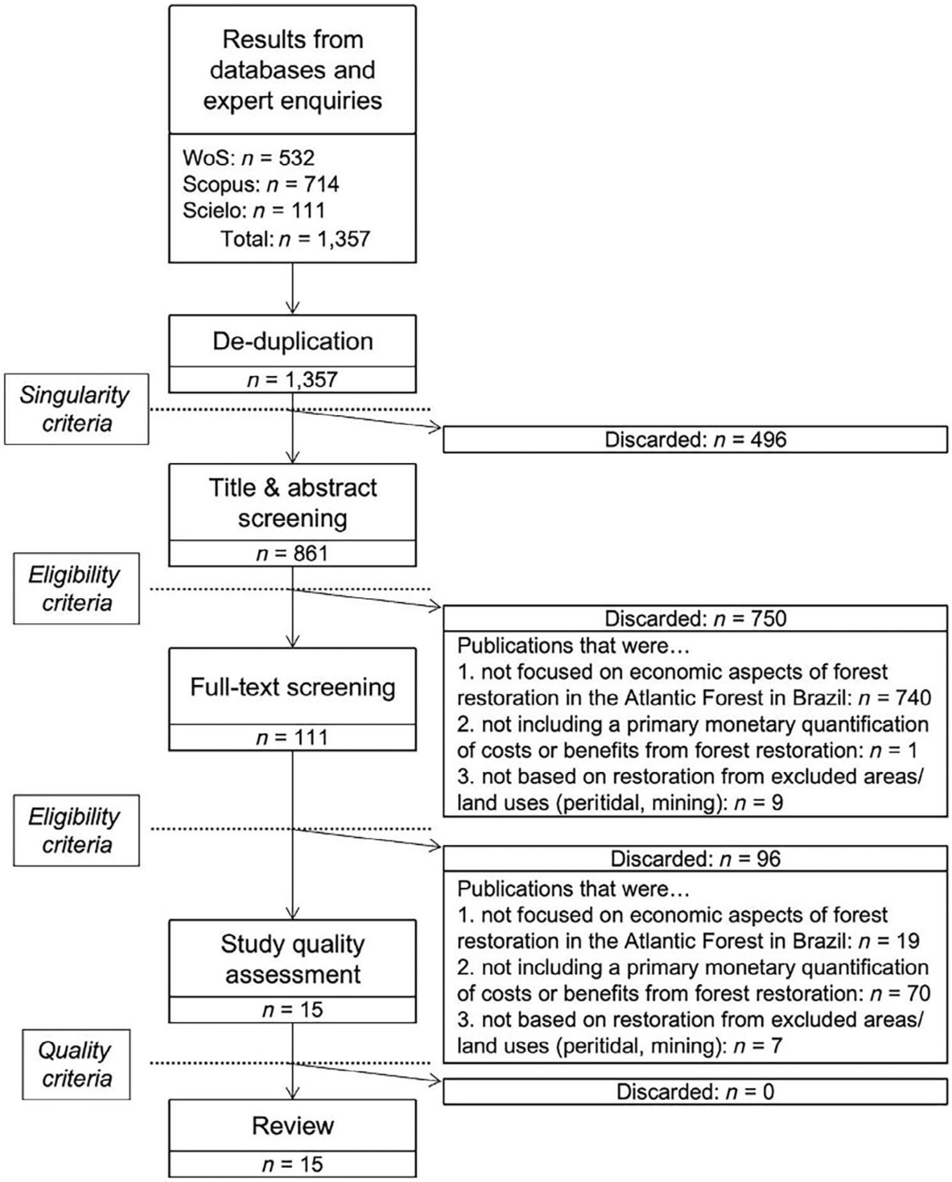

Figure 1. Flow diagram of the study selection procedure based on PRISMA guidelines.

Results

Restoration Context

Out of the 15 publications, 14 focused exclusively on the Brazilian Atlantic Forest while one also included information on the Cerrado and the Amazon. For that publication, data not associated with the Atlantic Forest was separated and disregarded.

Regarding the different states of Brazil, nine studies referred to locations in São Paulo as part of the study area, followed by Minas Gerais (two) as well as Paraná and Santa Catarina (both one). One publication had study sites in both Bahia and Espírito Santo and another one did not specify the location nor the state (Fig. 2). All other states that host parts of the Atlantic Forest domain did not appear as specific study sites in the publications.

The largest share of studies (seven) looked exclusively into active restoration. One publication studied restoration through the removal of non-native species followed by natural regeneration. The remainder referred to an assemblage of different types of restoration, with active restoration featuring in all, assisted restoration in six and natural regeneration in three studies.

Apart from one study that referred to the total restoration area on a municipal level, all publications presented data from research plots that, aggregated per study, ranged from 0.5 to 17 ha.

Economics of Restoration

Ten studies focused on quantifying costs of forest restoration in the Atlantic Forest and seven on quantifying economic benefits thereof, translating to 1.2% and 0.8% of the 861 publications

Table 2. Indicators used for data extraction.

Type of Data	*Category*	*Indicator*
Qualitative	Bibliographic information	Name of authors
		Affiliation of authors
		Title
		Year of publication
		Type of publication
		Publisher
		Edition
	Context of study	Study location
		Type of restoration
Quantitative		Area under restoration
	Economics of restoration	Establishment costs
		Maintenance costs
		Opportunity costs
		Transaction costs
		Benefits from PES
		Benefits from NTFP
		Benefits from agroforestry
		Benefits from timber
		Other benefits
		Benefit-related transaction/ production costs

identified in the first selection step. Two studies (0.2%) quantified both costs and economic benefits. Nine of the studies were based on field experiments and one on a survey with restoration practitioners.

Table 3 presents all publications containing information on restoration costs. The larger share of studies (six) presented both establishment and maintenance costs, while two publications presented primary data on overall total restoration costs without showing sub-classifications. Maintenance costs presented in the studies were considered for 2–5 years with an average of 2.8 years. Two studies considered either only establishment or maintenance costs, while transaction and opportunity costs were not considered in any publication. In this set of studies, the costs of restoration differed depending on the respective restoration context.

Seven studies explored the economic benefits of forest restoration. Hereby, benefits from NTFP and agroforestry combined were quantified in three studies and those from timber production and PES schemes on watershed protection were presented in two publications each. Three of these seven studies considered transaction costs that come along with tapping into such income opportunities. In line with the stated research aim, two studies presented information on both costs and benefits. Table 4 provides contextual information about the seven studies containing monetary information on restoration benefits.

Discussion

General Considerations

We found a large gap in knowledge about costs and economic benefits of forest restoration in the Atlantic Forest, with both dimensions explored little within scientific publications. The knowledge gap is less pronounced in the state of São Paulo but even more so in all other Brazilian states with none or few studies on the topic. We also found that economic aspects were predominantly explored in studies focusing on active restoration. Finally, we highlight the lack of scientific publications that demonstrate business cases for restoration or that present cost–benefit analyses using novel data.

Restoration Context

The spatial distribution of study sites referred to in the publications reveals a clustering of associated research in the Southeast of Brazil. Although the Southeast Region accounts for almost half of the remaining Atlantic Forest (45%), the spatial distribution of study sites referred to in the publications still shows an underrepresentation of other regions that equally host considerable parts of the biome, that is, the south (39%), northeast (15%), and center-west regions (1%) (MapBiomas 2022). This somewhat reflects the unequal state R&D expenditures in Brazil with 70% apportioned to the State of São Paulo alone. Similarly, the southeast and south regions of Brazil host most research-intensive companies and most productive universities in the country (Chaimovich & Pedrosa 2021). Especially in a biome with such a high level of landscape variability (Silva & Casteleti 2003), evidence from other biogeographical regions would add value to a differentiated understanding of restoration economics in the Atlantic Forest.

The prevalence of research on active restoration reflects the findings of scholars who suggest that natural regeneration is often not part of specific restoration projects as they are implemented mostly on medium to large properties while, in contrast, natural regeneration happens rather gradually on small properties in areas of agricultural abandonment (Gastauer et al. 2021). Generally, the choice between active and passive restoration approaches depends on the respective site conditions and management objectives (Reid et al. 2018). However, considering abovementioned socioeconomic dimension and that natural regeneration is regarded as a more feasible approach to large scale restoration (Crouzeilles et al. 2020), a stronger research focus on such passive approaches could be worthwhile.

Economic Costs

The present analysis demonstrates that scientific production considers only total costs of restoration or establishment and maintenance costs. Opportunity and transaction costs were widely neglected or not separately quantified. The same applies to economic benefits of restoration that come with overhead costs. Such expenses can be manifold and vary among the different income streams from restoration. Finney (2015) pointed out that transaction costs in PES schemes can surpass 20% of project expenses and should therefore not be disregarded in cost calculations.

Although the studies show a high variation in costs, with costs of up to US$7,519 per hectare for establishment and up to US$4,709 per hectare and year for maintenance, active restoration is found to be consistently more expensive than (assisted) natural regeneration that ranged from US$60 for total costs to

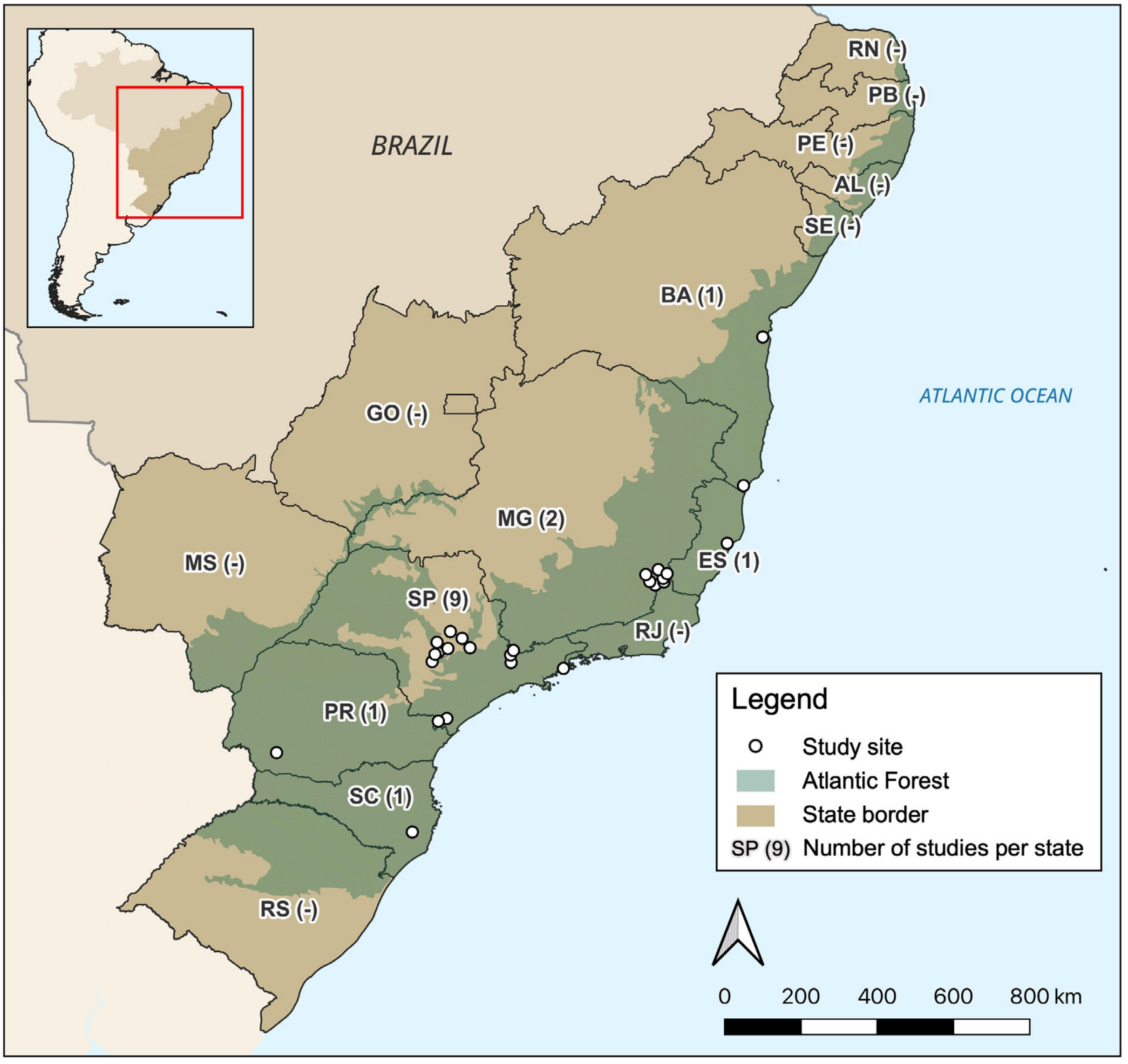

Figure 2. Map of the Atlantic Forest biome with the number of studies and their respective study sites. South region: RS (Rio Grande do Sul), SC (Santa Catarina), PR (Paraná); southeast region: São Paulo (SP), Rio de Janeiro (RJ), Minas Gerais (MG), Espírito Santo (ES); center-west region: Mato Grosso do Sul (MS), Goiás (GO); northeast region: Bahia (BA), Sergipe (SE), Alagoas (AL), Pernambuco (PE), Paraíba (PB), Rio Grande do Norte (RN).

US$394 for only maintenance over 3 years. Among the observed studies on costs of forest restoration, arguably the most conclusive one to draw a reliable picture of expectable expenses was based on a survey that uses empirical values from 32 restoration projects in the Atlantic Forest and reported their observed costs (Brancalion et al. 2019). According to those results, full seedling planting comes with total restoration costs of US $2,506, enrichment planting US$1,349, assisted natural regeneration US$132, and natural regeneration US$60 per hectare (Brancalion et al. 2019). Nevertheless, there is no clear indication in how far the calculations in this study include all costs accrued under the label of overall restoration costs.

From the above insights, a more detailed and complete economic research is missing. Even if this kind of information, based on field experiences, may exist in gray literature, e.g. technical reports or practical implementation guidelines for forest restoration, there is a need to scientifically describe, analyze, and synthesize the different types of costs that come along with forest restoration to realistically evaluate the necessary investment at different scales. For instance, costs related to labor, specific technical assistance, and the incurred labor taxes could be explicitly described to allow for a more comprehensive and accurate analysis.

Economic Benefits

There is a multitude of potential benefits that is inherent to the process of forest restoration due to its successional nature.

Table 3. Quantification and qualification of restoration costs. It is distinguished between active restoration (AR), assisted natural regeneration (ANR), or natural regeneration (NR).

Information on Restoration		*Economic Costs Per Hectare*			
Type	*Specification/Treatment*	*Establishment*	*Maintenance*	*Total*	*Publication*
AR	Full planting with both high-diversity plantation and applied nucleation	US$4,256–4,623	US$2,146–5,058 over 3 years		Bechara et al. (2021)
ANR	Leafcutter ant control		US$394 over 3 years		
AR	Full planting with different propagation systems			US$1,696–2,949	Simões et al. (2021)
AR	Full planting of native species with and without eucalyptus	US$2,005–2,130	US$1,654–1,826 over 2/5 years		Brancalion et al. (2020)
AR	Full planting of native species with or without direct seeding of different legume species	US$1,177–4,709	US$2,355–>4,709 over 1 year		Vásquez-Castro et al. (2020)
AR	Full planting			US$2,506	Brancalion et al. (2019)
AR	Enrichment planting			US$1,349	
ANR	Fencing			US$132	
NR	—			US$60	
AR	Full planting at different densities as well as weeding and fertilization intensities	US$2,046–3,623	US$2,952–5,732 over 3 years		Brancalion et al. (2019)
AR	Enrichment planting with differently sized seedlings	US$3,169–7,519			Mangueira et al. (2019)
AR	Enrichment planting	US$1,613	US$1,684 over 2 years		Maier et al. (2018)
AR & ANR	Enrichment planting and assisted natural regeneration of native and exotic species in agroforests		US$1,048 over 1 year		Souza et al. (2010)
AR	Direct seeding on three different sites	US$806–1,067	US$472–503 over 2 years		Engel and Parrotta (2001)

However, while costs are incurred all locally, products and services accruing from restoration projects benefit people at multiple scales from local to global. One of the challenges of restoration projects is finding economic benefits that, at the local scale, may outweigh project costs. For instance, there are multiple opportunities for income generation in the early stages of restoration that are not necessarily feasible later on and vice versa (Brancalion et al. 2012; Brancalion et al. 2019). This dynamic design of income creation can be one of the keys to making forest restoration a workable solution for landowners (Brancalion et al. 2012) but, due to its higher level of sophistication compared to monofunctional land-use systems, requires sufficient capacity building structures and a solid foundation in research. With only seven studies focusing on possible monetary incentives for landowners, we find that scientific knowledge on local benefits of restoration projects is still lacking, while studies on the multifunctional use of forests were limited to the integration of NTFPs in agroforests.

Another question is the suitability of different restoration types for specific income streams. For instance, while PES schemes may not necessarily demand active steering of species composition in the restored forest, some timber- or NTFP-centered restoration models do require active restoration to a certain extent (Nunes et al. 2020). This aspect needs to be considered in cost calculations for restoration targets. It may also be assumed that the marginal costs from economic benefit generation would reduce with scale, resulting in additional incentives for restoration endeavors. This connects to the consideration of a possible size dependency of profitability, e.g. whether a restoration project needs a minimum size to be economically advantageous for a landowner and whether there is a linear relation between the economic benefits and the restored areas. Scholars have pointed out the role that natural regeneration can play in achieving restoration targets considering its cost-effectiveness in comparison to active restoration (Crouzeilles et al. 2020). However, despite the strategic role of

Table 4. Quantification and qualification of restoration benefits. *Data from one study was extracted directly from a diagram.

Type of Benefit	*Study Background*	*Economic Benefit Per Hectare*	*Additional Observations*	*Publication*
Timber	Active restoration at three sites with native species and eucalyptus trees with harvesting of the latter after 4–5 years.	Once-off benefit: US$3,134 to 5,822 from sale of timber	Sale of eucalyptus compensated between 44 and 75% of total restoration costs (including logging and transport)	Brancalion et al. (2020)
	Removal of a non-native species followed by natural regeneration in both an agroforestry system and a mixed forest plantation.	Once-off benefit: US$1,478 for firewood from the removal of non-native species	Removal of non-native species can generate money from forests that undergo restoration.	Podadera et al. (2015)
NTFP/ Agroforesty	Comparison of income from *Euterpe edulis* in protected areas (PA) where it grows as part of natural regeneration, in agroforests (AF) where it is intercropped, and in actively managed secondary forests (SF) where its regeneration was facilitated.	Projected benefit* over 10 years from nondestructive fruit harvest (f) and destructive palm heart harvest (p): SF (f): US$6,380 SF ($f + p$): US$4,113 AF (f): US$5,469 AF ($f + p$): US$2,279 PA (p): US$684	The use of native NTFP species in forest restoration can be financially and environmentally beneficial.	Chagas et al. (2020)
	Establishment of high biodiversity silvopastoral systems using active restoration as well as assisted and natural regeneration.	Benefit over 10 years: US$18,483 from sale of *E. edulis*, rose pepper, banana, honey etc.	Restoration costs are recovered through the sale of NTFPs after 7 years	Filho and Farley (2020)
	Coffee as the main cash crop in an agroforest, intercropped with native and exotic tree species, incl. *E. edulis*, avocado, mango, and jackfruit.	Annual benefit: US $2,147 from coffee; US$593 from other products	In comparison to full-sun coffee plantations, the studied agroforests provide considerably higher net benefits, contributing to the restoration and preservation of native forest systems.	Souza et al. (2010)
PES (water)	Active restoration and assisted regeneration within the framework of the Conservador das Águas PES program. Landowners were remunerated for loss of income.	Annual benefit: US $122	PES payments were based on grazing leases/ opportunity costs of pasture/milk/beef production. Restoration costs were covered by the program.	Richards et al. (2015)
	Analysis of forest conservation and restoration efforts, both assisted regeneration and enrichment planting in riparian areas, as part of the Produtor de Água PES program.	Annual benefit: US $37.24	PES payments were based on the opportunity costs of low-intensity cattle ranching. On a landscape level, the amount of PES paid should not only be based on the opportunity costs of the current land-use system but also consider developments. Restoration costs were covered by the program.	Viani et al. (2019)

natural regeneration, research indicates that this restoration model remains ephemeral in the Atlantic Forest, exhibiting a duration of less than 8 years in areas characterized by intense agricultural dynamics. In other words, it fails to compete with other land-use forms perceived as more profitable (Piffer et al. 2022). Detailed analyses of costs and benefits of individual forest restoration actions should therefore be conducted considering all types of restoration to help understand the factors that one approach preferable over another both from a landowner's and a policymaker's point of view.

Within the forest restoration process, there is a great opportunity to foster monetizable native species for NTFP that could contribute to a biodiversity-based economy. Considering that currently only few examples of an economic utilization of the Atlantic Forest's rich biodiversity exist (Trevisan et al. 2015; Maier et al. 2018), there are valuable lessons that can be learnt from the Amazon biome. The Amazon has a long history of biodiversity-based value chains, including rubber (*Hevea brasiliensis*), açaí (*Euterpe oleracea*) and Brazil nut (*Bertholletia excelsa*), among others (Richards 1993). Just in the state of Pará, there are more than 30 of such value chains that contributed US $1 billion to the GDP of Brazil in 2019 and have the potential to reach US$30 billion within the next 20 years (Costa et al. 2021). Such opportunities can also be sounded out for the Atlantic Forest to create and diversify income for farmers, providing not only ecological but also economic arguments for upscaling forest restoration. In this review, three studies considered NTFP, namely palm heart and fruit from the juçara palm (*Euterpe edulis*), as a means of generating income from restoration.

Finally, also PES schemes that pay for ecosystem benefits accruing at other scales beyond local-farmer's scale (e.g. water quality, flood protection, and climate regulation) are income sources whose potential could be furthered to add to the economic viability of restoration in the Atlantic Forest. Among the reviewed papers, only two contained a quantification of benefits from PES and both referred to schemes for watershed protection only. Although PES programs have generally not emerged as expected and initiatives' design is often flawed (Wunder et al. 2020), PES implementation might grow rapidly in the upcoming years in Brazil, given that a federal law regulating the mechanism was recently approved (Federal Law 14.119/2021). Therefore, in the future, restoration related economic benefits (local scale) in combination with PES income from ecosystem positive externalities (other scales than local) could pose a lucrative revenue opportunity in restoration endeavors. Nonetheless, such remunerations should not be seen as a stand-alone solution but rather as complementary incentives for landowners to engage in restoration activities since it is expected that income generated from PES schemes may not suffice to solely depend on (Zanella et al. 2014) and that the number of additionally restored areas due to a PES incentive alone may be modest (Ruggiero et al. 2019).

Restoration as a Business Case?

Brancalion et al. (2020) and Souza et al. (2010) were the only publications that addressed both costs and benefits. The authors concluded that the benefits from restoration can offset large parts of the costs (Brancalion et al. 2020) or even exceed them (Souza et al. 2010).

Besides the benefit-related transaction costs stemming from logging and transportation, in Brancalion et al. (2020), costs were divided into upfront implementation costs and annual maintenance costs. While both categories were described in detail, with the former encompassing soil preparation, acquisition of seedlings, fencing and planting of trees and the latter weeding, leaf-cutter ant control and fertilization, cost-wise they were treated in aggregation. Souza et al. (2010) took a different approach and reported only the total expenses necessary to implement the described agroforest and to produce associated goods without providing a more detailed cost structure.

Considering that both studies focused on only a few small study sites, that the data was not consistently disaggregated, and that restoration was conducted with non-native species or through an agroforestry system, the results may, however, neither be scalable nor unconditionally applicable in other contexts aiming at ecological restoration.

Relevance for Policymaking

The availability of sound economic data is critical for policymakers to evaluate the impact of current policies and to inform the formulation of future policies that can help address major challenges for forest restoration in the Brazilian Atlantic Forest. For instance, understanding the costs of implementing and monitoring forest restoration activities, marketing resulting products or services, and the indirect costs that may occur due to leakage (e.g. deforestation to replace areas used for restoration or as a response to expanding rural economic activity) is an essential input in designing tailored policies. Incentives for restoration should be designed in such a way that restoration economic activities may compete with business-as-usual land use and not with other forested lands. Governmental programs moreover require detailed, upfront planning with multiyear budgets to ensure that policies are effective, efficient, easy to implement, and equitable. Therefore, having sound information on the expenses associated with different policy options and on how unnecessary costs can be minimized is paramount (OECD 2018). For governmental agencies, high transaction costs that occur in delivering financial stimuli, e.g. subsidies or grants, may interfere with their overall efficiency and hinder policy implementation (Wertz-Kanounnikoff 2008). Also, high transaction costs can disproportionately affect already disadvantaged and vulnerable groups as they may lack the resources to overcome sophisticated application processes or to comply with stringent requirements of associated programs (Gallemore et al. 2015). Besides, a lack of economic information related to the feasibility of forest restoration efforts affects the attractiveness for potential investors to engage in forest restoration action (Brancalion et al. 2017). Consequently, providing such evidence is essential to convince landowners, policymakers, and investors that managing forests under restoration is a true alternative to crop cultivation or extensive cattle ranching (Chazdon & Guariguata 2016).

Practically, restoration activities might as well be integrated into these conventional land uses, generating a series of socioenvironmental cobenefits such as income diversification and enhanced climate resilience which are particularly critical for the livelihoods of rural producers (Tedesco et al. 2022). Our results indicate that despite the importance that restoration has gained in recent years as a concept for policymakers and the potential benefits that accrue from restoration projects, there is still a lack of scientific knowledge regarding the analysis of restoration costs and benefits. Studies to deepen the knowledge on the economics of ecosystem restoration as such are a desirable step towards designing both public and private restoration programs that have high chances of success.

The findings of this study are also of concern beyond the boundaries of the Brazilian Atlantic Forest. The Atlantic Forest is not only a biodiversity hotspot and considered a global priority area for ecosystem restoration (Strassburg et al. 2020), but it is also the most studied biome in Brazil (Guerra et al. 2020), and probably one of the most studied regions in the world with regards to forest restoration. Yet, with a total of merely 15 studies that have investigated monetary costs and benefits at a small scale, and two studies putting the economic viability into perspective without, though, comprehensively disaggregating the indicators, reliable scientific data on the topic from the Atlantic Forest appears to be scarce. If a biome, despite this significance and general scholarly attention, lacks a good understanding of restoration economics, it stands to reason that other areas in Brazil and beyond may also require more investigation to translate regional and global restoration commitments into implementation in the field with financial foresight. Without clarity on the economic costs and incentives of forest restoration, however, achievement of the various national and international restoration commitments appears to be uncertain from both a landowner's and a policymaker's perspective.

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Supporting Information

The following information may be found in the online version of this article:

Supplement S1: Checklist for Study Quality Assessment as part of the selection process.

Supplement S2: Table with the search results and the information extracted from the selected publications.

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