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Ecosystem restoration supply chain and jobs in Brazil

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Abstract:	1. The central motivation to restore ecosystems at a planetary scale has been to reverse degradation and provide multiple environmental benefits, but key global players like governments may be more interested in other restoration outcomes, such as job creation. Understanding the restoration supply chain is the first step towards mapping job opportunities in this activity, yet the persistent knowledge gap on restoration socioeconomics is a critical limitation to estimate the number of green jobs it can provide. 2. Here, we describe the ecosystem restoration supply chain in Brazil and evaluate its potential to generate jobs. Based on a widely-distributed online survey performed in 2020 and led by the main restoration networks in the country, we explored the structure, job distribution, and outputs of the national restoration supply chain. 3. 4,713 temporary and 3,510 permanent jobs were created, nearly 60% of which were generated by organizations specialized in restoration, mainly from the non-profit (48%) and private (37%) sectors. 4. Restoration jobs were concentrated in organizations working in one (58%) or two (28%) biomes, and mainly in the Atlantic Forest, where 85% of the restoration jobs reported were totally or partially located. Similarly, most restoration jobs were concentrated in the southeast

	region (61%), with one-third in the state of São Paulo. This geographical distribution was more strongly associated with the states' GDP than with the legal deficit of native vegetation area. 5. Nearly 20% of the restoration jobs were terminated during the COVID-19 pandemic in 2020. 6. We estimate that the restoration supply chain can generate 0.42 jobs per hectare, which could potentially create 1.0 to 2.5 million direct jobs during the implementation of Brazil´s target of restoring 12 million hectares. 7. We conclude by reinforcing the value of ecosystem restoration in promoting economic development and creation of jobs, which can be crucial to promote countries' effective engagement in the UN Decade on Ecosystem Restoration and highlight the critical role of grassroots organizations to maximize restoration opportunities for socioeconomic development during the post-pandemic economic recovery.

Ecosystem restoration supply chain and jobs in Brazil

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Abstract

1. The central motivation to restore ecosystems at a planetary scale has been to reverse degradation and provide multiple environmental benefits, but key global players like governments may be more interested in other restoration outcomes, such as job creation. Understanding the restoration supply chain is the first step towards mapping job opportunities in this activity, yet the persistent knowledge gap on restoration socioeconomics is a critical limitation to estimate the number of green jobs it can provide.
2. Here, we describe the ecosystem restoration supply chain in Brazil and evaluate its potential to generate jobs. Based on a widely-distributed online survey performed in 2020 and led by the main restoration networks in the country, we explored the structure, job distribution, and outputs of the national restoration supply chain.
3. 4,713 temporary and 3,510 permanent jobs were created, nearly 60% of which were generated by organizations specialized in restoration, mainly from the non-profit (48%) and private (37%) sectors.
4. Restoration jobs were concentrated in organizations working in one (58%) or two (28%) biomes, and mainly in the Atlantic Forest, where 85% of the restoration jobs reported were totally or partially located. Similarly, most restoration jobs were concentrated in the southeast region (61%), with one-third in the state of São Paulo. This geographical distribution was more strongly associated with the states' GDP than with the legal deficit of native vegetation area.
5. Nearly 20% of the restoration jobs were terminated during the COVID-19 pandemic in 2020.

6. We estimate that the restoration supply chain can generate 0.42 jobs per hectare, which could potentially create 1.0 to 2.5 million direct jobs during the implementation of Brazil´s target of restoring 12 million hectares.
7. We conclude by reinforcing the value of ecosystem restoration in promoting economic development and creation of jobs, which can be crucial to promote countries' effective engagement in the UN Decade on Ecosystem Restoration and highlight the critical role of grassroots organizations to maximize restoration opportunities for socioeconomic development during the post-pandemic economic recovery.

Keywords: Ecological restoration, Forest restoration, Green economy, Green jobs, Large-scale restoration, Restoration economy, Restoration socioeconomics, Sustainable development

Introduction

Ecosystem restoration has received unprecedented support from different sectors of society, often being considered as a 'silver bullet' for myriad environmental and social problems. Restoration programs have proliferated immensely, including pledges from over 60 countries to restore >200 million hectares of forest landscapes by 2030 as part of the Bonn Challenge, several tree planting programs promoted by influential organizations like the World Economic Forum and the United Nations Environmental Program, and thousands of other initiatives led by varied groups such as large corporations, entrepreneurs, NGOs, local communities, and celebrities (Holl & Brancalion 2020). These initiatives were recently leveraged by the United Nations' Decade on Ecosystem Restoration (2021-2030), which is expected to mainstream dispersed programs as part of a unified global restoration movement (Aronson *et al.* 2020).

The central motivation to restore ecosystems at a planetary scale has been to reverse degradation and achieve multiple environmental benefits, including climate change mitigation and adaptation, biodiversity conservation and water security (Chazdon & Brancalion 2019; Strassburg *et al.* 2020). Although most of the narrative and evidence-based practice supporting ecosystem restoration has relied on environmental gains (Romanelli *et al.* 2021), key global players like governments may be more interested in social and economic outcomes for their constituents, such as job creation (BenDor *et al.* 2015b; Mansuy & MacAfee 2019). Unlike most restoration benefits, which often take decades to accrue (Moreno-Mateos *et al.* 2017) and therefore are perceived by society as long-term strategies, most jobs within the restoration supply chain are created at the beginning of the process. Promoting restoration is also expected to result in attractive return on investment, which varied from US$7 to as much as US$30 per dollar spent across over 100 projects distributed in different ecosystems and global regions (Bullock *et al.* 2011; Ding *et al.* 2017).

In spite of the potential environmental benefits of large-scale restoration, there are important uncertainties related to the local social impacts, which highlight the value of understanding the contribution of restoration as a source of jobs. For instance, the implementation of global restoration commitments could displace local people and compromise local agro-pastoral production, in such a way that environmental benefits desired by developed countries (e.g. carbon sequestration) come at the expense of local economies and livelihoods in developing countries (Brancalion & Holl 2020). It is critical that restoration initiatives are based on the free and informed consent of local communities and stakeholders. Timing, societal support, and economic benefits are crucial for government decisions, so the creation of jobs is expected to be a key restoration outcome and to become part of the agenda of several countries in the near future, as clearly expressed by global leaders in the Climate Summit

2021. The global recession resulting from the COVID-19 pandemic has magnified the appeal of restoration as an emerging source of green jobs (Hanna, Xu & Victor 2020; Mansuy 2020). Past and current initiatives such as the Civilian Conservation Corps in the United States (Maher 2007), the Green Belt Movement in Kenya (Maathai 2004), the Working for Water in South Africa (Bek, Nel & Binns 2017), and the Grain for Green in China (Dang *et al.* 2020), are emblematic of the enormous potential of restoration activities to generate green jobs. In particular, these initiatives have favored rural communities marginalized from the modern economy and contributed to economic recovery following the shocks resulting from natural resources depletion and economic recessions.

Understanding the restoration supply chain is critical for mapping job opportunities. Ecosystem restoration relies on an integrated supply chain of products (e.g., seeds and seedlings) and services (e.g., implementation, maintenance and monitoring) to be efficient. Bottlenecks in this supply chain, such as the lack of seedling (Silva *et al.*, 2017), may constrain the flow of restoration activities, limit the amount and quality of restoration, and prevent achieving both social and environmental benefits. The knowledge of the biophysical factors driving restoration success and the ecological gains resulting from it has advanced rapidly (Palmer, Zedler & Falk 2016), but this activity will only be able to transform the planet in the coming decade if efficient supply chains are developed and sufficient financing is mobilized and allocated for implementation (Menz, Dixon & Hobbs 2013).

The persistent knowledge gap concerning restoration socioeconomics remains a barrier to effective design and efficient implementation (Aronson *et al.* 2010; Martin 2017; Fernández-Manjarrés, Roturier & Bilhaut 2018). Only a few studies address individual parts of the restoration supply chain (Urzedo *et al.* 2020) or the whole supply chain of specific regions

(Benini *et al.* 2016). The limited information available in the literature provides promising estimates, including the generation of 0.016-0.033 jobs per US$1,000 spent on restoration in the United States (Nielsen-Pincus & Moseley 2013; BenDor *et al.* 2015a), and ~0.2 jobs per hectare restored in Brazil (Calmon *et al.* 2011; Costa 2016; Brasil 2017), yet the numbers for Brazil are rough estimates not based on surveys or on the restoration supply chain. Much uncertainty remains regarding the potential of ecosystem restoration to create jobs in Brazil, a global hotspot for this activity (Brancalion *et al.* 2019; Strassburg *et al.* 2020).

Here, we aimed to understand and quantify the ecosystem restoration supply chain in Brazil. Based on an online survey led by the main restoration networks in the country, we explored the structure, job distribution, and outputs of the national restoration supply chain. We estimated the number of jobs that could be created through Brazil´s target to restore and reforest 12 million hectares of degraded land and ecosystems by 2030. Our overarching objective was to identify bottlenecks for upscaling ecosystem restoration and identify opportunities for policy interventions to transform restoration into an effective, vibrant economic activity with the potential to deliver critical benefits to people and nature during the UN Decade on Ecosystem Restoration. To our knowledge, this is one of the largest assessments of the ecological restoration supply chain ever made, including the six Brazilian biomes and a variety of ecosystem types. Previous reviews have broadly addressed the importance of restoration for providing income and improving livelihoods (Adams *et al.* 2016; Erbaugh & Oldekop 2018), yet have not quantified restoration jobs and characterized the restoration supply chain.

A first step to evaluating restoration outcomes is clearly understanding the regional framing and project specific goals (Brancalion and Holl 2020). Currently in Brazil restoration

projects are mostly established to comply with a national legislation – the 2012 Native Vegetation Protection Law (Brancalion *et al.* 2016). To comply with this law, landowners must restore the original native vegetation (e.g., forests, savannas, grasslands) in environmentally fragile areas that were converted in the past, particularly around water bodies and along riparian buffers, and to achieve a minimum percentage of the landholding covered by native vegetation (80% in the Amazon Forest and 20% in other ecosystems; Guidotti *et al.* 2020). Restoration has been mostly financed by the landowner, who can be fined or not receive environmental certification for exporting agricultural commodities if targeted areas are not restored. Quite often, NGOs provide financial support to such compliance-led restoration in small to medium landholdings through payments for ecosystem services schemes and conservation programs. This primary goal of legal compliance can be complemented by myriad other objectives (e.g., conservation of a targeted species, watershed protection, carbon stocking funded by international organizations) depending on the motivations and requirements of stakeholders financing restoration interventions. Therefore, ecosystem restoration in Brazil is mostly a private entrepreneurship, and the jobs created are a direct consequence of the market demand for supplying restoration inputs and services.

Methods

The survey

A questionnaire (Appendix S1) was prepared and disseminated online from 11 August to 30 September 2020 through an outreach and engagement campaign led by the Brazilian Society for Ecological Restoration (584 associates), The Brazilian Coalition on Climate, Forests and Agriculture (281 organizations), The Alliance for Restoration of the Amazon (80 organizations), and The Atlantic Forest Restoration Pact (298 organizations) (Appendix S2), plus the valuable collaboration of several other formal and informal networks. This survey

also resulted in the creation of an online platform to offer restoration products and services and serve as a hub for restoration organizations and individuals ("Restoration Glassdoor" or *Vitrine da Restauração*, in Portuguese). A total of 356 organizations responded to the survey, each of them represented by a single questionnaire. Some organizations did not answer all questions, so the sample size is not the same for every question. Our survey included organizations from 24 of the 26 Brazilian states and Brasília (the Federal District), missing only organizations from the states of Piauí and Tocantins, and covered many different ecosystem types (wetlands, temperate grasslands, tropical savannas, shrublands, dry and wet tropical and subtropical forests).

Data analysis

We focused our analysis on the number of jobs rather than the number of questionnaires, to better represent the participation and level of influence of organizations in the ecosystem restoration supply chain (see Figure S2 for an overview of it). We classified jobs as "temporary" (i.e., seasonal jobs, in which people are only hired for part of the year) and permanent (i.e., jobs in which people become part of the ongoing staff of a given organization). We described how restoration jobs are distributed across the following classes:

- *types of activity*: seed collection, seedling production, implementation and maintenance, technical services (e.g., consultancy, project preparation, monitoring), others (Figure S2);
- *stakeholder groups*:
  - non-profit sector: cooperatives, associations, and seed networks, which were further classified as local/municipal, state/regional, and national/international;
  - private companies: classified according to their gross annual revenue, in Brazilian real (BRL) - large: revenue >R$300M, medium: R$4.8M < revenue <R$300M,

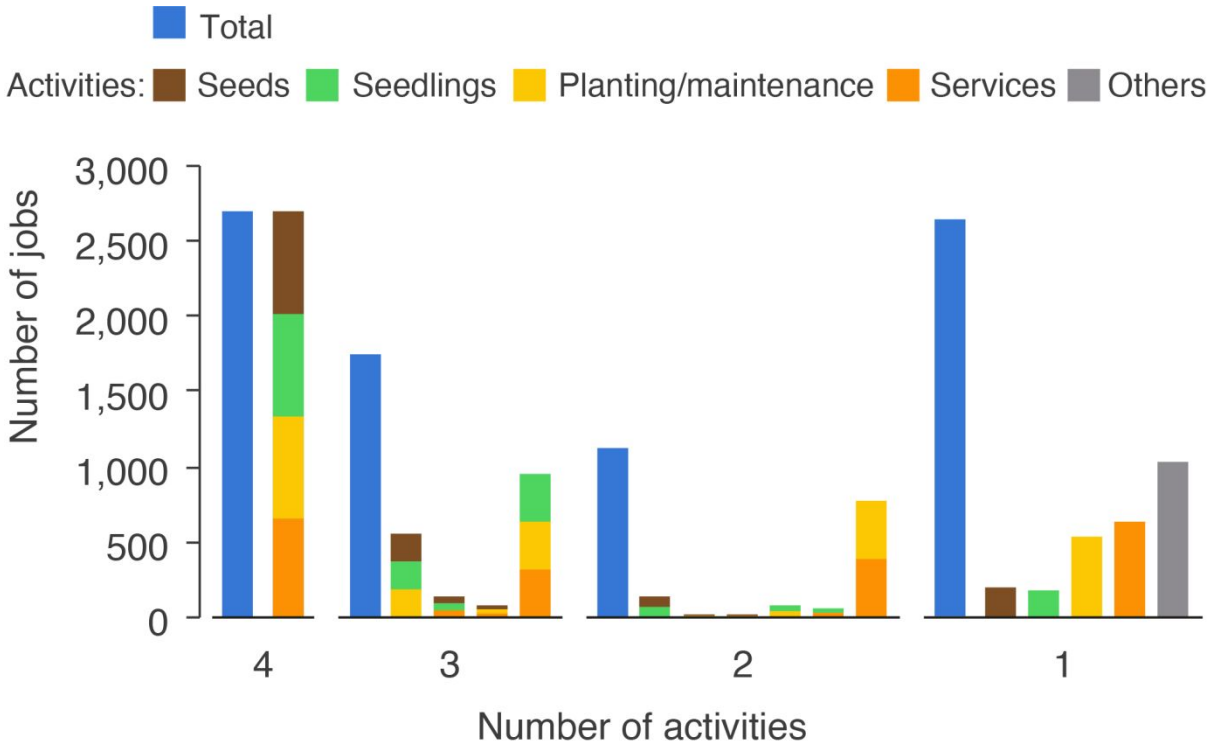
199 small: R$0.36M < revenue < R$4.8M, and micro companies: revenue <R$0.36M
200 (US$1 = ~R$5.0);
201 - individual micro-entrepreneur;
202 - farmers;
203 - governments: classified as federal, state, and municipal;
204 - watershed committees;
205 • *biomes*: Pampas, Atlantic Forest, Cerrado, Pantanal, Caatinga, and Amazon;
206 • *regions*: South, North, Northeast, Southeast, and Central West (Figure S1);
207 • *states*: 26 states + the federal district (Figure S1).
208
209 We further collected information on state gross primary product (GDP) and legal deficit of
210 native vegetation in riparian areas (areas buffering water bodies and springs) according to the
211 2012 Native Vegetation Protection Law (Soares *et al.*, 2014), and evaluated through linear
212 regressions whether the number of jobs was more associated with the GDP of states or with
213 their legal deficit of native vegetation. We excluded São Paulo data in this analysis because it
214 was an outlier. For the analyses, we used information reported in 2019 (the most recent year
215 before the pandemic) and GDP data from 2018. We also asked in the questionnaires how
216 many jobs were terminated due to the COVID-19 pandemic.
217
218 We then estimated the number of jobs that could be created by the implementation of Brazil´s
219 target to restore and reforest 12 million hectares of degraded lands and forests, which is
220 associated with the National Plan for Native Vegetation Recovery, the national pledge to the
221 Bonn Challenge, and the Nationally Determined Contribution to the Paris Climate
222 Agreement. We based our estimates on the following assumptions: (i) the survey accurately
223 represented the various elements of the restoration supply chain in Brazil; and (ii) all reported

activities and jobs (8,223 jobs) are associated with the total restoration implementation area covered by the survey (19,426 ha). It is not possible to define the proportion of areas to be restored through passive and active restoration in Brazil's target, so we considered the scenarios established by Brazil's National Plan for Native Vegetation Recovery (20, 30, 40 and 50% of active restoration; Brasil 2017). We recognize that the survey may be biased towards active restoration and failed to estimate the number of jobs created by passive restoration, as reported by Brancalion *et al.*, 2019a.

Results

The organizations that reported production data (325 out of 352) produced 93.6 t of seeds (49 questionnaires) and 19.6 million seedlings (97), planted 4.6 million seedlings (40), implemented 19,426 ha of restoration (72), and maintained 27,440 ha (67) during 2019. A total of 8,223 restoration jobs were created, 57.3% of which were temporary and 42.7% were permanent. When organizations were asked to select one or more activities in which they were involved in (i.e., seed collection, seedling production, implementation and maintenance, and technical services), nearly one-third of these jobs were generated by that specialized in one particular restoration activity, mainly planting/maintenance and services in general; the rest were distributed across organizations performing multiple restoration activities (Figure 1). Jobs from seed and seedling production were mostly generated by multitask restoration organizations (Figure 1). Most of the jobs were in organizations (e.g., local NGOs, companies specialized in restoration services) that focus on ecosystem restoration (28.3 and 21.1% of jobs in organizations for which restoration is their exclusive or main activity, respectively), whereas a lower proportion of restoration jobs were offered by organizations for which restoration was not a central activity (e.g., forest nurseries that primarily produce commercial

248 tree species, consultant offices that mostly provide environmental licensing services); 13.7
249 and 19.2% had restoration as a secondary and marginal activity, respectively.
250



251
252 Figure 1. Distribution of restoration jobs according to the number of activities performed by
253 organizations. The colour(s) of the bars (except for the blue bar – total) represent the
254 composition of activities.
255
256 Most jobs were created by organizations from the non-profit (48%) and private (37%) sectors
257 (Figure 2). In particular, (i) cooperatives, associations, and seed networks, (ii) regional/state
258 NGOs (iii) national/international NGOs, and (iv) small private companies were the main
259 sources of jobs, each of them accounting for nearly 15% of jobs (Figure 2). During the
260 COVID-19 pandemic in 2020, nearly 20% of these jobs (512 permanent and 1,043
261 temporary) were terminated; the jobs generated by farmers, medium-sized private companies,
262 and local/municipal NGOs were the most negatively impacted (Figure 2).
263

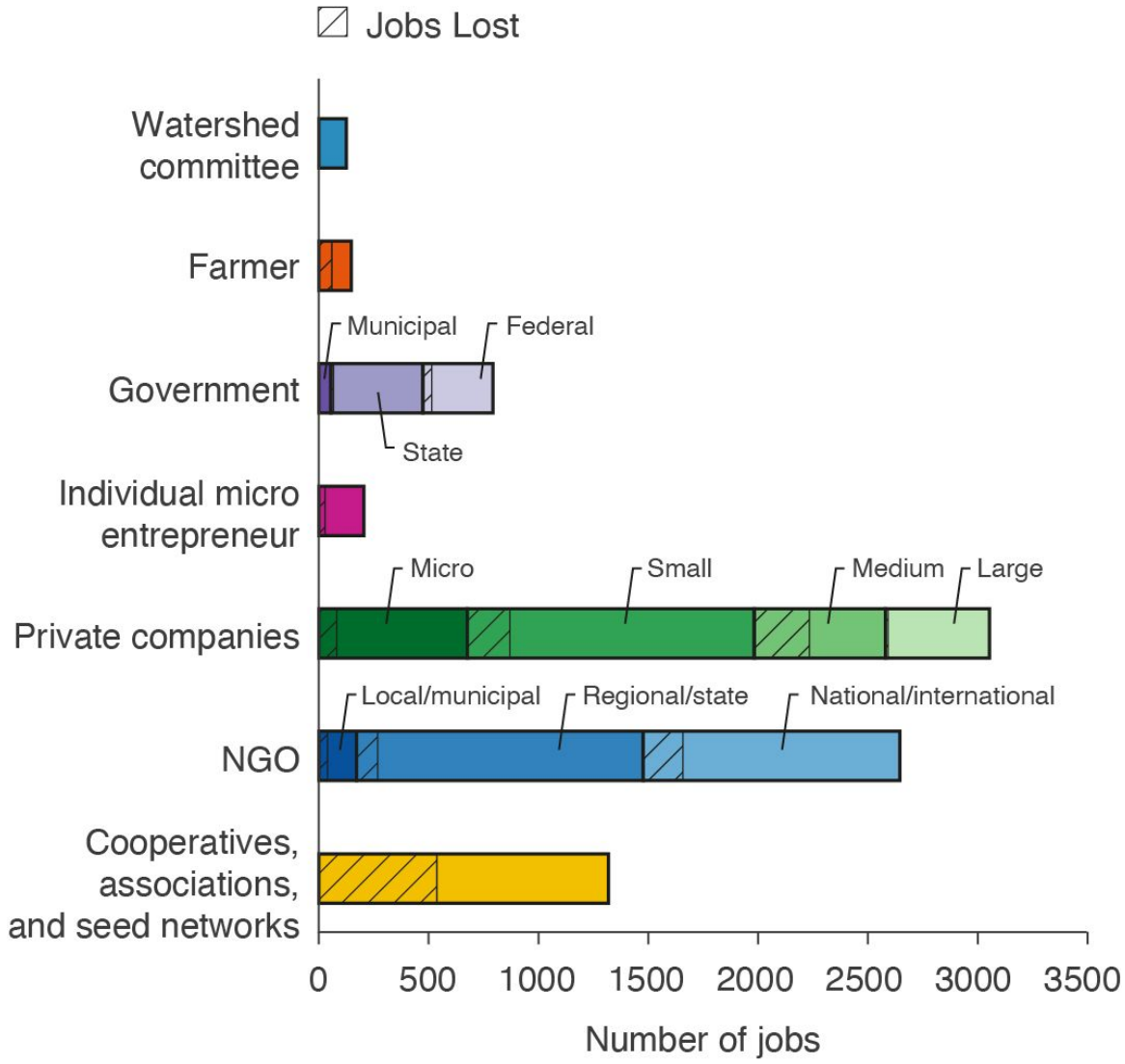


Figure 2. Distribution of restoration jobs according to stakeholder groups and number of jobs terminated during the COVID-19 pandemic in 2020.

Most organizations worked in one (58%) or two (28%) biomes (Figure 3) and most restoration jobs were supplied by those restoring the Atlantic Forest exclusively (44%) and the Atlantic Forest and Cerrado together (16%; Figure 3). Only 15% of the restoration jobs reported in this survey did not involve any activity in the Atlantic Forest. Similarly, most restoration jobs were concentrated in the southeast region (61%; Figure 4), with nearly three quarters concentrated in five states (33.7% in São Paulo state, 13.5% in Minas Gerais, 10.0% in Rio de Janeiro, 8.6% in Bahia, and 6.6% in Paraná; Figure S1). This geographical

concentration was more strongly associated with the states' GDP than with the legal deficit of native vegetation (Figure 5), and was not correlated with state area ($R^2 = 0.01$) or population ($R^2 = 0.003$).

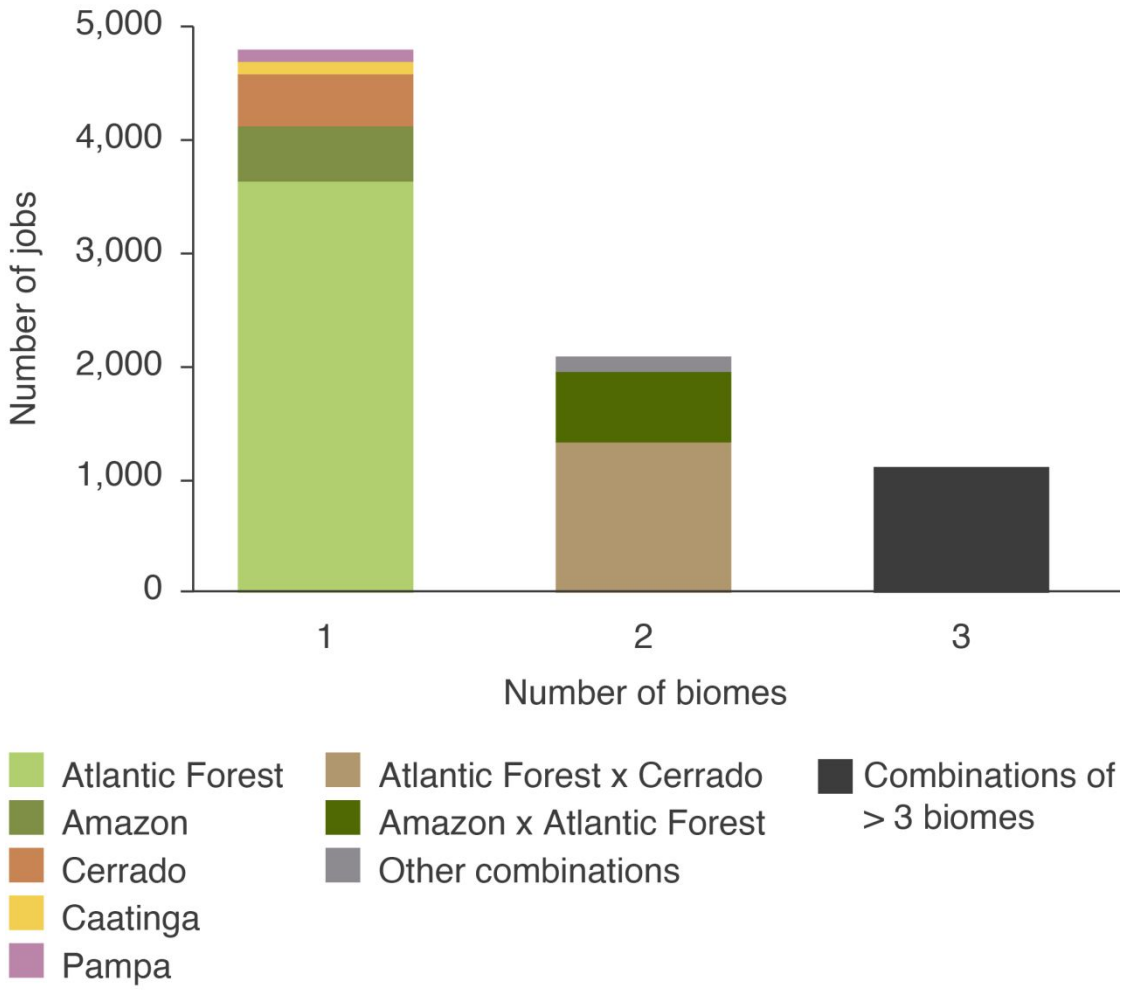
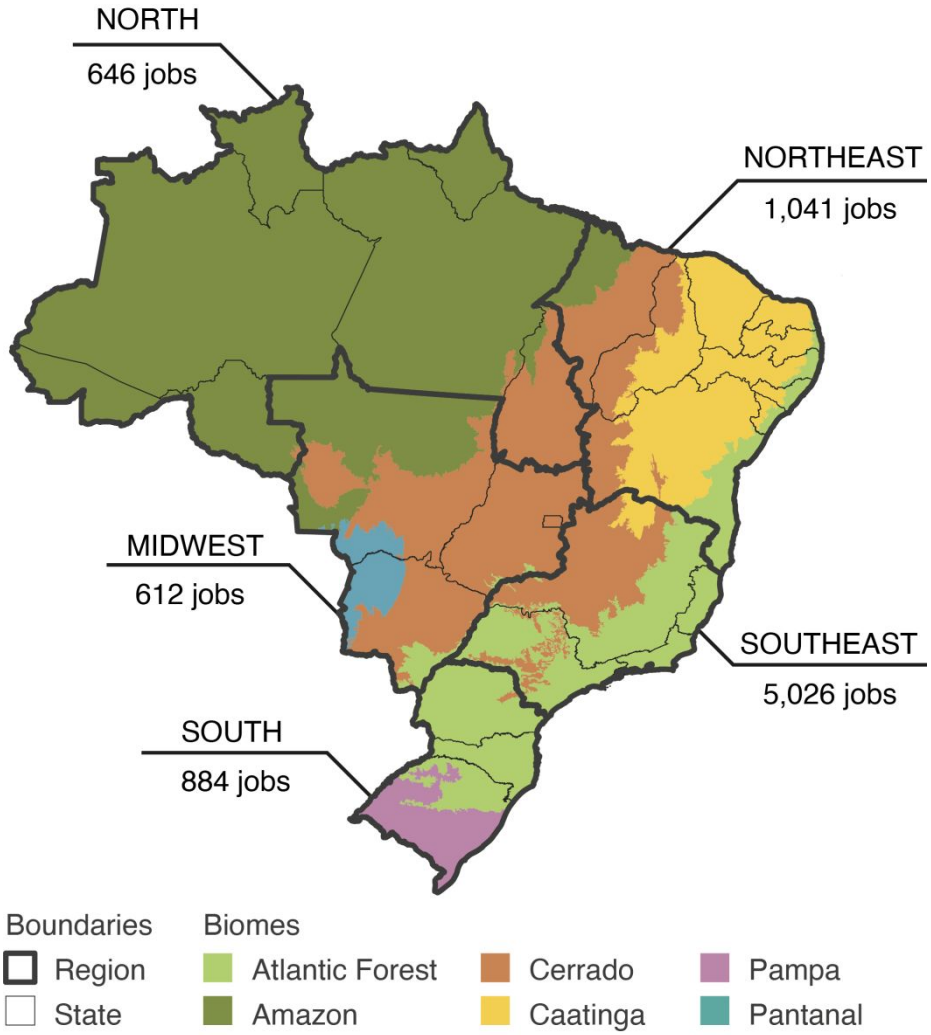


Figure 3. Distribution of restoration jobs across the Brazilian biomes. Bars represent the number of jobs generated by organizations that work (i) exclusively in one biome (colours represent the number of jobs per biome type), (ii) in two biomes (colour classes represent the number of jobs per different combinations of biomes), and (iii) three or more biomes.



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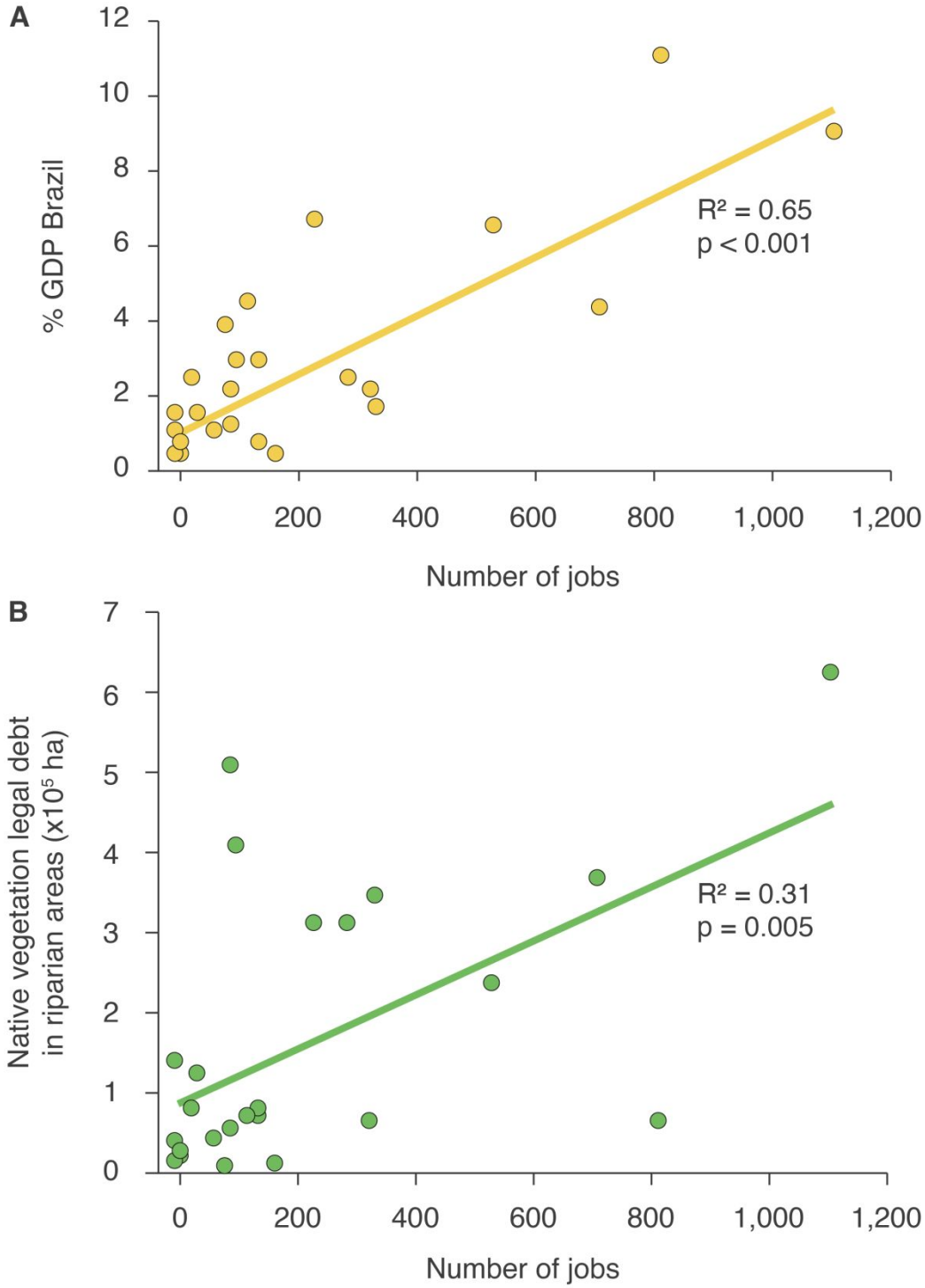
287 Figure 4. Distribution of restoration jobs across Brazilian regions (see Figure S1 for

288 distribution among states).

289



290

291 Figure 5. Association between the number of restoration jobs and state GDP and the legal

292 def[illegible] of native vegetation in riparian areas. Lines represent linear regressions without São

293 Paulo state data, an outlier.

294

We estimated that the restoration supply chain can generate 0.42 jobs per hectare (19,426 ha of restoration implementation created 8,223 jobs), which could potentially create 1.0 to 2.5 million jobs based on the scenarios of 20 to 50% of Brazil´s restoration target, respectively, being implemented through active restoration.

Discussion

Our assessment of the ecosystem restoration supply chain in Brazil revealed that restoration is a complex, multistakeholder activity with marked geographical differences. We showed several idiosyncrasies of restoration as an economic activity that must be addressed to evaluate the economic impact of restoration. Our estimates that each hectare of restoration creates 0.42 jobs is nearly the double of previous estimates of restoration jobs in Brazil (e.g., Calmon *et al.* 2011; Costa 2016; Brasil 2017), and indicates the potential to create 1.0 to 2.5 million direct jobs through the implementation of the national restoration target of 12 million hectares. Considering the estimate of BenDor *et al.* (2015a) for the United States that each direct restoration job was associated with 0.76 indirect jobs, the total number of jobs created by restoration in Brazil could reach 1.76-4.40 million.

Previous studies have demonstrated that restoration activities can be important for job creation in the United States (Edwards, Sutton-Grier & Coyle 2013), South Africa (van Wilgen & Wannenburgh 2016), and the United Kingdom (GreenAlliance 2021), and particularly for sectors of society with high unemployment. However, these studies were based on different methodologies and contexts, and for the most part did not conduct detailed analyses by region and restoration activity, so it is challenging to compare their results with ours. Despite the uniqueness of our study, we draw some general lessons that could potentially be extrapolated to other contexts and improve future surveys.

320

321 ***Profile of restoration jobs***

322 We found a predominance of temporary, seasonal jobs in the restoration supply chain, with
323 work concentrated in periods of peaking demand (i.e., during the rainy season in Brazil) and
324 reduced offers for stable, longer-term job opportunities. Indeed, the seasonal nature of
325 restoration jobs is a concern for growing the global restoration economy (Baker & Quinn-
326 Davidson 2011; BenDor *et al.* 2015a). Our results show that many restoration organizations
327 focus on one or two primary activities, whereas diversifying the restoration activities that
328 organizations perform can be a valuable strategy to increase the permanence of restoration
329 jobs, since seed collection, seedling production, some maintenance activities, and project
330 planning and monitoring require labor throughout the year. The quantity and quality of
331 restoration jobs could then be expanded, and the chances of restoration failure reduced, if the
332 maintenance period is increased and monitoring and adaptive management become integral
333 components of projects (Holl 2020). At the same time diversification may enhance the overall
334 management of restoration projects, it may reduce the efficiency of individual restoration
335 activities as compared to specialization.

336

337 ***Restoration employers***

338 The high proportion of non-specialized, multitask restoration organizations may also reflect
339 the high level of instability of the restoration market. The lack of stable and predictable
340 demand for restoration inputs and services over time may force restoration organizations to
341 diversify their activities into different directions, either to activities not directly associated
342 with restoration or different types of restoration activities within the supply chain. For
343 instance, 71% of the nurseries in Brazil that produce native tree seedlings also commercialize
344 exotic species as a way to diversify their income and be financially viable (Silva *et al.* 2017).

Conversely, this result may suggest that organizations not previously dedicated to restoration are progressively including it as part of their portfolio of products and services, and can expand their participation in this sector if supportive market and policy instruments are established (Brancalion *et al.* 2017).

The prominent role the non-profit and private sectors play in restoration shows that it is an entrepreneurial activity. Although government regulations and policy interventions play a central role in restoration, and EMBRAPA (the Brazilian Agricultural Research Corporation, a federal government agency) has contributed to the creation of restoration jobs in different Brazilian regions, our findings suggest that more jobs could be created if the market demand for restoration inputs and services increased. Conversely, many jobs can be terminated abruptly if market demand is reduced and environmental policies are weakened (BenDor *et al.* 2015b), as potentially occurred during the COVID-19 pandemic when nearly 20% of restoration jobs were terminated. The restoration sectors with higher proportion of terminated jobs during the COVID-19 pandemic were those with lower levels of capital and higher dependency from external financial support, as farmers (46% of restoration jobs terminated), medium-sized private companies (42%), cooperatives, associations, and seed networks (41%), and local/municipal NGOs (28%).

Cooperatives, seed networks, NGOs operating at the regional/state level, and small private companies provide nearly half of all jobs, and were also some of the most impacted organizations by the COVID-19 pandemic, so these local, grassroots organizations require special financial aid to recover after the pandemic. In addition to providing a larger share of restoration jobs, local and community-based organizations can maximize the social benefits of those jobs and opportunities, improving local livelihoods while involving indigenous

participation and promoting environmental justice throughout targeted territories (Urzedo *et al.* 2021). Brazil, like a number of Latin American countries, has been going through a long and intense process of rural outmigration, followed by a concentration of jobs in urban centers and reduction of jobs in the rural area due to agriculture mechanization (Aide & Grau 2004; Baptista & Rudel 2006; García-Barrios *et al.* 2009). Ecosystem restoration can become a powerful alternative to generate green jobs in rural areas, contributing to economic development and alleviating social problems in urban centers, as well as providing environmental benefits to society and the planet (Mansuy 2020; GreenAlliance 2021).

Spatial distribution of restoration jobs

The high concentration of restoration jobs and overall investment in restoration in Brazil (Brancalion et al. 2019a) in the southeastern region and in the Atlantic Forest biome is a result of multiple, intertwined factors that are difficult to disentangle. First, it likely reflects the economic inequalities among Brazilian states and suggests that restoration has been a "luxury" environmental intervention promoted for those that can pay for it. Rather than concentrating restoration where it is most needed in terms of legal compliance, restoration jobs have been mostly promoted where the GDP is higher and organizations can afford to pay for it (Figure 5). Conversely, given that more than 40 and 60% of Brazil's population lives within the Southeast region and the Atlantic Forest biome, one could argue that restoration jobs are concentrated where they have the potential to supply ecosystem services to the most people, and potentially where environmental agencies and policies are more efficient.

Second, this geographic pattern of restoration may reflect historical legacies, as the restoration movement in Brazil originated in the Atlantic Forest (Rodrigues *et al.* 2009) and currently restoration research is concentrated in this region (Guerra *et al.* 2020). More

funding needs to be invested in restoration of other biomes in Brazil. This geographical bias may be progressively reduced over time as the implementation of the 2012 Native Vegetation Protection Law advances (Brancalion *et al.* 2016). This revised law established a more efficient governance system than the previous 1965 Forest Code, including the creation of a national system for registering the legal native vegetation deficit, a program to foster legal compliance, economic incentives for restoration, and a national policy for native vegetation recovery (Brancalion *et al.* 2016). Once this program is fully operational, the number of jobs should increase substantially and be more equitably distributed across the country. However, there is a great deal of uncertainty regarding the impact of this law, as initial studies have not found clear evidence that the national registry has changed landowners' willingness to protect and restore native ecosystems (Rasmussen *et al.* 2016; Jung *et al.* 2017), and the current presidential administration has promoted a massive deregulation of environmental policies (Vale *et al.* 2021).

Survey limitations

We acknowledge a slight geographic bias of our survey responses, as most of the leaders of the survey work in the Atlantic Forest and are based in the southeast region, despite the fact that it was an online, national survey and we received responses from nearly all states. Further, on-line surveys may underrepresent important restoration stakeholder groups, such as indigenous and traditional communities, small farmers, and local NGOs and companies, who have less access to internet and may prefer to be contacted through in-person meetings. We recommend that future surveys census restoration jobs in targeted regions, which could yield estimates less biased by sampling. Finally, we note that the assumptions we used to estimate job creation by achieving Brazil's restoration plan are simplistic and necessarily subject to the uncertainty regarding the extent of its implementation.

Conclusion

We and other (e.g. BenDor *et al.* 2015a; van Wilgen & Wannenburgh 2016; Green Alliance 2021) demonstrate that ecosystem restoration is an emerging economic activity with relevant potential to generate jobs, especially through local organizations. In Brazil, this potential mostly has been leveraged by the financial capacity of states to pay for restoration activities, which highlight the critical role of financial incentives, appropriate policies, and the development of markets for restoration goods and services to create new jobs, especially in less economically developed regions. We conclude by reinforcing the potential value of ecosystem restoration to promote economic development and the creation of jobs, which can be crucial for the effective engagement of countries in the U.N. Decade on Ecosystem Restoration (Aronson *et al.* 2020; Edwards *et al.* 2021), and highlighting the critical role of grassroots organizations to maximize restoration opportunities for the socioeconomic development in times of post-pandemic economic recovery. Restoration jobs are one of the most efficient options to address prosperity not only with social inclusiveness, the predominant focus across many U.N. Sustainable Development Goals, but also adding ecological inclusiveness (Gupta & Vegelin 2016). However, to realize these potential outcomes requires that successful restoration have a funding commitment longer than 1-2 years (Iftekhar *et al.* 2017), and that restoration funding, particularly from national and international players, should be expanded and more equitably distributed across regions and biomes (Brancalion & Holl 2020).

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Authors' contributions: P.H.S.B., L.P.S., A.F.M., E.L.S., R.R.R., M.C., R.B., J.R.C.T., and R.B.C. conceived the idea and designed the study. N.T.A. and M.B.R. conducted the surveys. N.T.A., M.B.R. and P.H.S.B. analyzed data. P.H.S.B. and K.D.H. led the writing. All authors contributed to the writing and gave final approval for publication.

Research ethics: This research was carried out by the NGOs Atlantic Forest Restoration Pact, The Nature Conservancy, and World Resources Institute, which have internal ethical procedure that this survey was signed off against. Participants of the online survey signed a consent term of participation.

Figure captions

Figure 1. Distribution of restoration jobs according to the number of activities performed by organizations. The colour(s) of the bars (except for the blue bar – total) represent the composition of activities.

Figure 2. Distribution of restoration jobs according to stakeholder groups and number of jobs terminated during the COVID-19 pandemic in 2020.

Figure 3. Distribution of restoration jobs across the Brazilian biomes. Bars represent the number of jobs generated by organizations that work (i) exclusively in one biome (colours represent the number of jobs per biome type), (ii) in two biomes (colour classes represent the number of jobs per different combinations of biomes), and (iii) three or more biomes.

469

470 Figure 4. Distribution of restoration jobs across Brazilian regions (see Figure S1 for
471 distribution among states).

472

473 Figure 5. Association between the number of restoration jobs and state GDP and the legal
474 deficit of native vegetation in riparian areas. Lines represent linear regressions without São
475 Paulo state data, an outlier.

476

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Ecosystem restoration jobs

The implementation of Brazil´s restoration target could potentially create 1.0 to 2.5 million direct jobs and contribute to alleviate poverty and social inequalities. Although ecosystem restoration has been broadly promoted to generate environmental benefits, it is critical to understand the capacity of this activity to contribute with human wellbeing. Past and current initiatives such as the Civilian Conservation Corps in the United States, the Green Belt Movement in Kenya, the Working for Water in South Africa, and the Grain for Green in China, are emblematic of the enormous potential of restoration activities to generate green jobs, but this potential has been rarely assessed in a systematic way. We created and widely distributed an online survey in 2020 through the main restoration networks Brazil to explore the structure, job distribution, and outputs of the national restoration supply chain. Our assessment revealed that restoration is a complex, multistakeholder activity with marked geographical differences and potential to alleviate the economic shocks of the COVID-19 pandemic in the most vulnerable. We conclude by reinforcing the potential value of ecosystem restoration to promote economic development and the creation of jobs, which can be crucial for the effective engagement of countries in the U.N. Decade on Ecosystem Restoration, and highlighting the critical role of grassroots organizations to maximize restoration opportunities for the so[illegible]economic development in times of post-pandemic economic recovery.

Women working in a forest nursery producing native tree seedlings for restoration projects in the Pontal do Paranapanema region, southeastern Brazil.

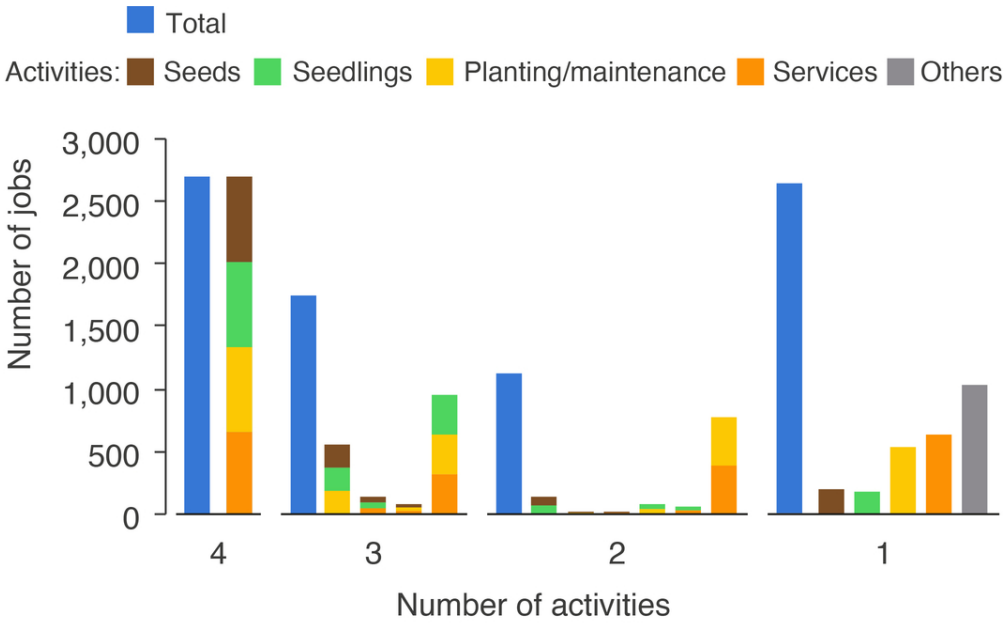

Figure 1. Distribution of restoration jobs according to the number of activities performed by organizations. The colour(s) of the bars (except for the blue bar – total) represent the composition of activities.

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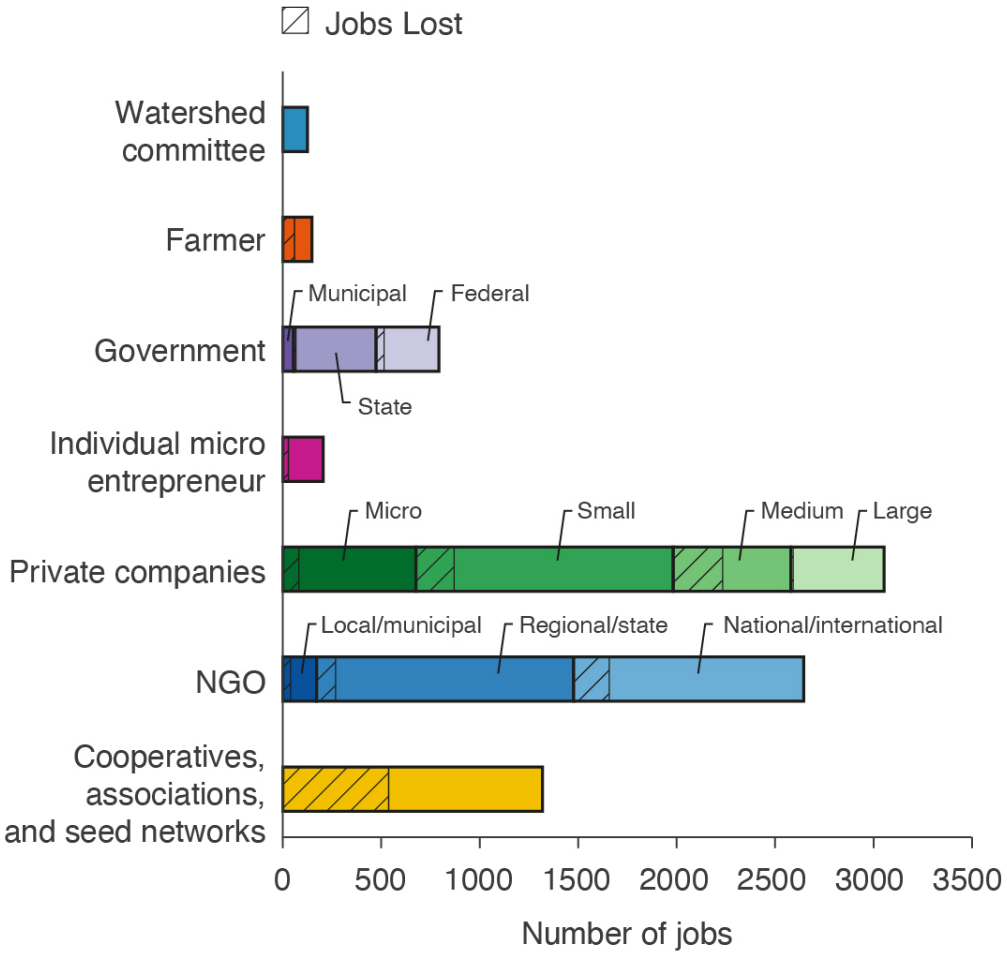

Figure 2. Distribution of restoration jobs according to stakeholder groups and number of jobs terminated during the COVID-19 pandemic in 2020.

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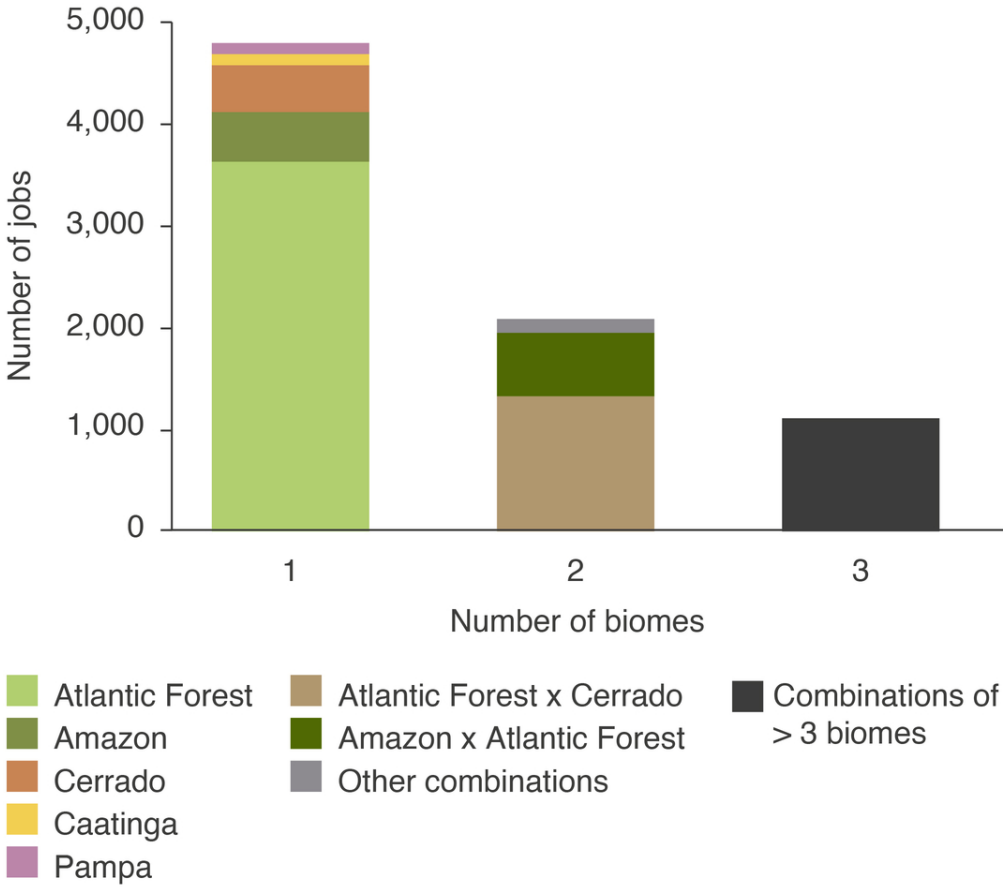

Figure 3. Distribution of restoration jobs across the Brazilian biomes. Bars represent the number of jobs generated by organizations that work (i) exclusively in one biome (colours represent the number of jobs per biome type), (ii) in two biomes (colour classes represent the number of jobs per different combinations of biomes), and (iii) three or more biomes.

90x80mm (300 x 300 DPI)

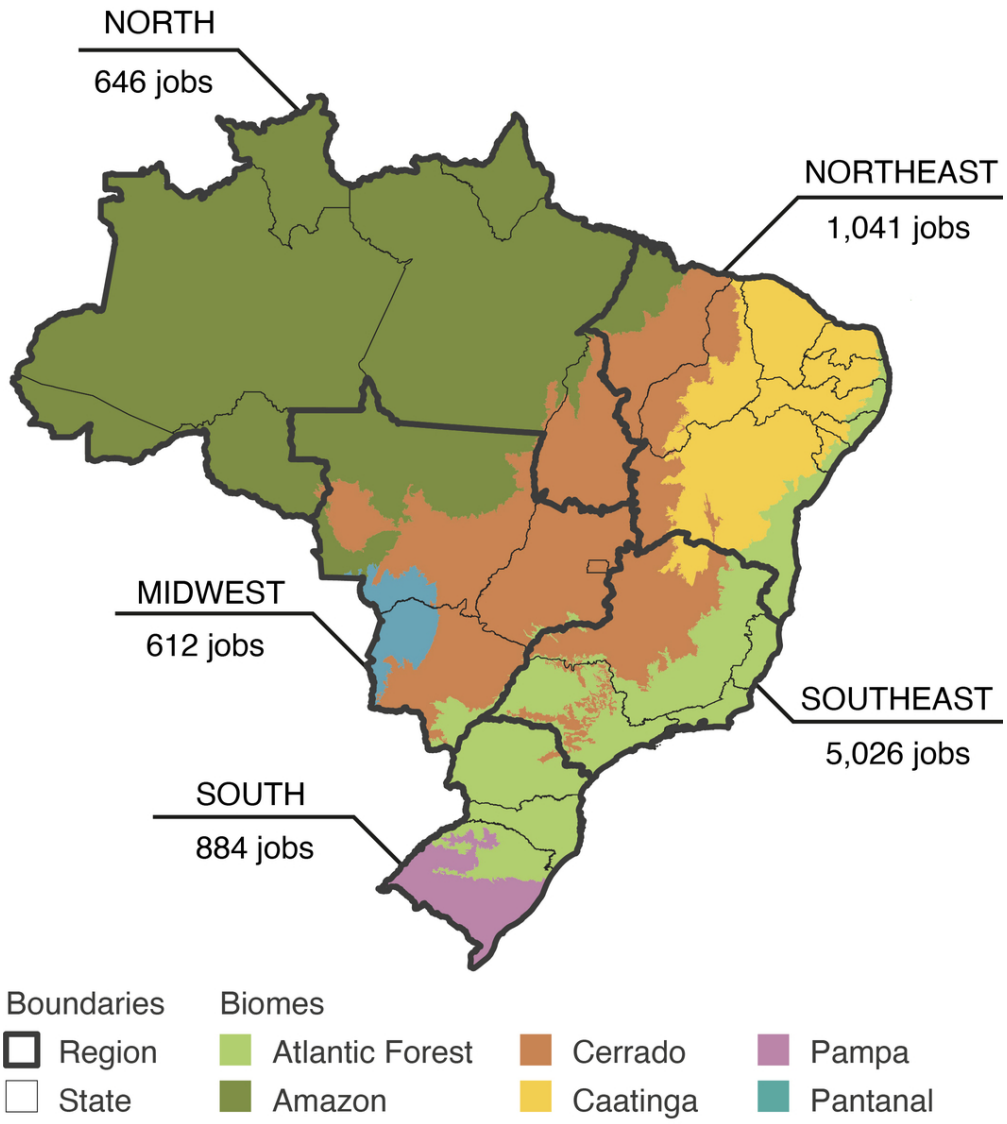

Figure 4. Distribution of restoration jobs across Brazilian regions (see Figure S1 for distribution among states).

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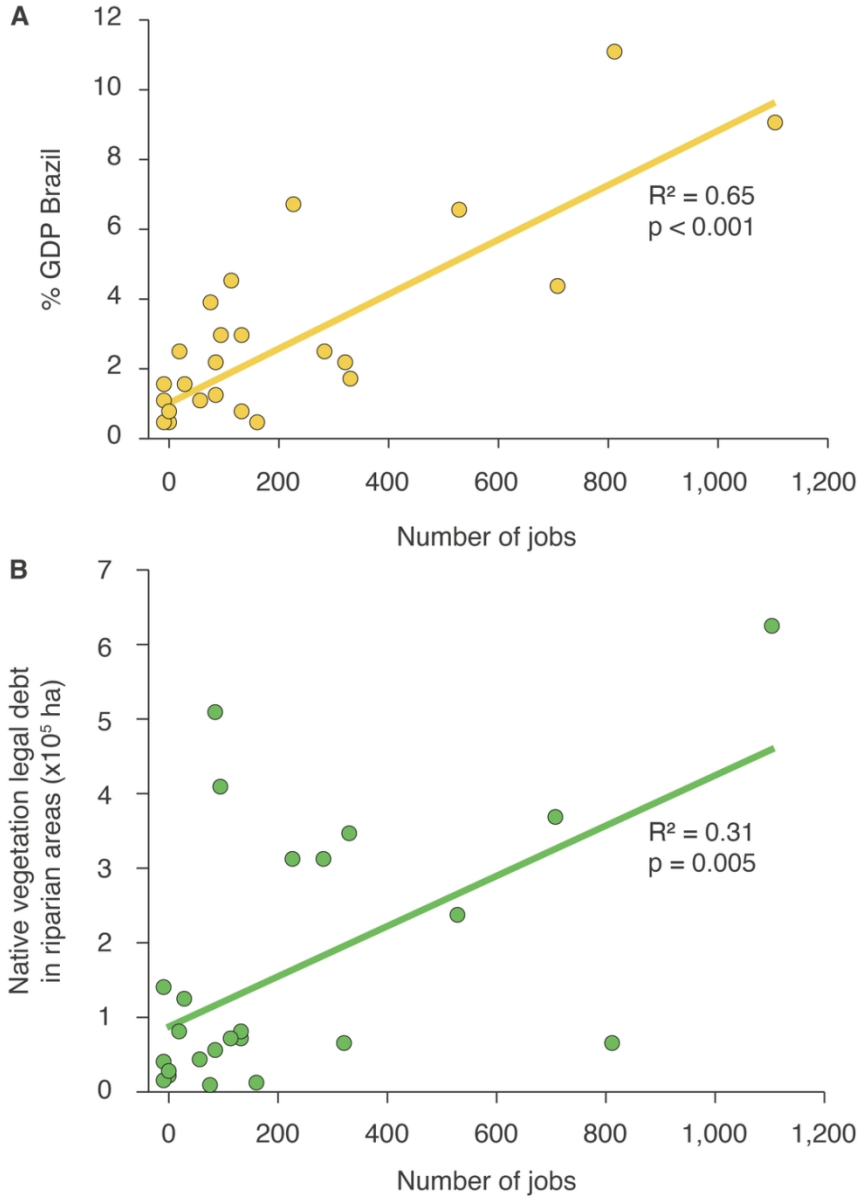

Figure 5. Association between the number of restoration jobs and state GDP and the legal deficit of native vegetation in riparian areas. Lines represent linear regressions without São Paulo state data, an outlier.

90x127mm (300 x 300 DPI)

Ecosystem restoration supply chain and jobs in Brazil

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Abstract

1. The central motivation to restore ecosystems at a planetary scale has been to reverse degradation and provide multiple environmental benefits, but key global players like governments may be more interested in other restoration outcomes, such as job creation. Understanding the restoration supply chain is the first step towards mapping job opportunities in this activity, yet the persistent knowledge gap on restoration socioeconomics is a critical limitation to estimate the number of green jobs it can provide.
2. Here, we describe the ecosystem restoration supply chain in Brazil and evaluate its potential to generate jobs. Based on a widely-distributed online survey performed in 2020 and led by the main restoration networks in the country, we explored the structure, job distribution, and outputs of the national restoration supply chain.
3. 4,713 temporary and 3,510 permanent jobs were created, nearly 60% of which were generated by organizations specialized in restoration, mainly from the non-profit (48%) and private (37%) sectors.
4. Restoration jobs were concentrated in organizations working in one (58%) or two (28%) biomes, and mainly in the Atlantic Forest, where 85% of the restoration jobs reported were totally or partially located. Similarly, most restoration jobs were concentrated in the southeast region (61%), with one-third in the state of São Paulo. This geographical distribution was more strongly associated with the states' GDP than with the legal deficit of native vegetation area.
5. Nearly 20% of the restoration jobs were terminated during the COVID-19 pandemic in 2020.

6. We estimate that the restoration supply chain can generate 0.42 jobs per hectare, which could potentially create 1.0 to 2.5 million direct jobs during the implementation of Brazil´s target of restoring 12 million hectares.
7. We conclude by reinforcing the value of ecosystem restoration in promoting economic development and creation of jobs, which can be crucial to promote countries' effective engagement in the UN Decade on Ecosystem Restoration and highlight the critical role of grassroots organizations to maximize restoration opportunities for socioeconomic development during the post-pandemic economic recovery.

Keywords: Ecological restoration, Forest restoration, Green economy, Green jobs, Large-scale restoration, Restoration economy, Restoration socioeconomics, Sustainable development

Introduction

Ecosystem restoration has received unprecedented support from different sectors of society, often being considered as a 'silver bullet' for myriad environmental and social problems. Restoration programs have proliferated immensely, including pledges from over 60 countries to restore >200 million hectares of forest landscapes by 2030 as part of the Bonn Challenge, several tree planting programs promoted by influential organizations like the World Economic Forum and the United Nations Environmental Program, and thousands of other initiatives led by varied groups such as large corporations, entrepreneurs, NGOs, local communities, and celebrities (Holl & Brancalion 2020). These initiatives were recently leveraged by the United Nations' Decade on Ecosystem Restoration (2021-2030), which is expected to mainstream dispersed programs as part of a unified global restoration movement (Aronson *et al.* 2020).

The central motivation to restore ecosystems at a planetary scale has been to reverse degradation and achieve multiple environmental benefits, including climate change mitigation and adaptation, biodiversity conservation, and water security (Chazdon & Brancalion 2019; Strassburg *et al.* 2020). Although most of the narrative and evidence-based practice supporting ecosystem restoration has relied on environmental gains (Romanelli *et al.* 2021), key global players like governments may be more interested in social and economic outcomes for their constituents, such as job creation (BenDor *et al.* 2015b; Mansuy & MacAfee 2019). Unlike most restoration benefits, which often take decades to accrue (Moreno-Mateos *et al.* 2017) and therefore are perceived by society as long-term strategies, most jobs within the restoration supply chain are created at the beginning of the process. Promoting restoration is also expected to result in attractive return on investment, ~~varying~~ which varied from US$7~~,00~~ to as much as US$30~~,00~~ per dollar spent ~~among~~across over 100 projects distributed in different ecosystems and global regions (Bullock *et al.* 2011; Ding *et al.* 2017).

In spite of the potential environmental benefits of large-scale restoration, there are important uncertainties related to the local social impacts, which highlight the value of understanding the contribution of restoration as a source of jobs. For instance, the implementation of global restoration commitments could displace local people and compromise local agro-pastoral production, in such a way that environmental benefits desired by developed countries (e.g. carbon sequestration) come at the expense of local economies and livelihoods in developing countries (Brancalion & Holl 2020). Timing, societal support, and economic benefits are crucial for government decisions, so the creation of jobs is expected to be a key restoration outcome and to become part of the agenda of several countries in the near future, as clearly expressed by global leaders in the Climate Summit 2021. The global recession resulting from

the COVID-19 pandemic has magnified the appeal of restoration as an emerging source of green jobs (Hanna, Xu & Victor 2020; Mansuy 2020). Past and current initiatives such as the Civilian Conservation Corps in the United States (Maher 2007), the Green Belt Movement in Kenya (Maathai 2004), the Working for Water in South Africa (Bek, Nel & Binns 2017), and the Grain for Green in China (Dang *et al.* 2020), are emblematic ~~showcases~~ of the enormous potential of restoration activities to generate green jobs. In particular, these initiatives have favored ~~in~~ rural communities~~,~~ marginalized from the modern economy, and ~~to~~ contributed to economic recovery following the shocks resulting from natural resources depletion and~~,~~ economic recessions~~, and, potentially, the current pandemic~~.

Understanding the restoration supply chain is critical for ~~the first step towards~~ mapping job opportunities. Ecosystem restoration ~~is a human endeavor that~~ relies on an integrated supply chain of products (e.g., seeds and seedlings) and services (e.g., implementation, maintenance and monitoring) to be efficient. Bottlenecks in this supply chain, such as the lack of seedlings (Silva *et al.*, 2017), may constrain the flow of restoration activities, limit the amount and quality of restoration, and prevent achieving both social and environmental benefits. The knowledge ~~on~~ of the biophysical factors driving restoration success and the ecological gains resulting from it has advanced rapidly (Palmer, Zedler & Falk 2016), but this activity will only be able to transform the planet in the coming decade if efficient supply chains are developed and sufficient financing is mobilized and allocated for implementation (Menz, Dixon & Hobbs 2013).

The persistent knowledge gap concerning restoration socioeconomics remains a barrier to effective design and efficient implementation~~The persistent knowledge gap on restoration socioeconomics is, however, a critical "Achilles' heel" of this activity~~ (Aronson *et al.* 2010;

Martin 2017; Fernández-Manjarrés, Roturier & Bilhaut 2018). Only a few studies address individual parts of the restoration supply chain (Urzedo *et al.* 2020) or the whole supply chain of specific regions (Benini *et al.* 2016). The limited information available in the literature provides promising estimates, including the generation of 0.016-0.033 jobs per US$1,000 spent on restoration in the United States (Nielsen-Pincus & Moseley 2013; BenDor *et al.* 2015a), and ~0.2 jobs per hectare restored in Brazil (Calmon *et al.* 2011; Costa 2016; Brasil 2017), yet the numbers for Brazil are rough estimates not based on surveys or on the restoration supply chain. Much uncertainty remains regarding the potential of ecosystem restoration to create jobs in Brazil, a global hotspot for this activity (Brancalion *et al.* 2019; Strassburg *et al.* 2020).

Here, we aimed to understand and quantify the ecosystem restoration supply chain in Brazil. Based on an ~~widely distributed~~ online survey led by the main restoration networks in the country, we explored the structure, job distribution, and outputs of the national restoration supply chain. We estimated the number of jobs that could be created through Brazil´s target to restore and reforest 12 million hectares of degraded land and ecosystems by 2030. Our overarching objective was to identify bottlenecks for upscaling ecosystem restoration and identify opportunities for policy interventions to transform restoration into an effective, vibrant economic activity with the potential to deliver critical benefits to people and nature during the UN Decade on Ecosystem Restoration. To our knowledge, this is one of the largest assessments of the ecological restoration supply chain ever made, including the six Brazilian biomes and a variety of ecosystem types. Previous reviews have broadly addressed the importance of restoration for providing income and improving livelihoods (Adams *et al.* 2016; Erbaugh & Oldekop 2018), yet have not quantified restoration jobs and characterized the restoration supply chain.

A first step to evaluating restoration outcomes is clearly understanding the regional framing and project specific goals (Brancalion and Holl 2020). Currently in Brazil restoration projects are mostly established to comply with a national legislation – the 2012 Native Vegetation Protection Law (Brancalion *et al.* 2016). To comply with this law, landowners must restore the original native vegetation (e.g., forests, savannas, grasslands) in environmentally fragile areas that were converted in the past, particularly around water bodies and along riparian buffers, and to achieve a minimum percentage of the landholding covered by native vegetation (80% in the Amazon Forest and 20% in other ecosystems; Guidotti *et al.* 2020). Restoration has been mostly financed by the landowner, who can be fined or not receive environmental certification for exporting agricultural commodities if targeted areas are not restored. Quite often, NGOs provide financial support to such compliance-led restoration in small to medium landholdings, through payments for ecosystem services schemes and conservation programs. This primary goal of legal compliance can be complemented by myriad other objectives (e.g., conservation of a targeted species, watershed protection, carbon stocking funded by international organizations) depending on the motivations and requirements of stakeholders financing restoration interventions. Therefore, ecosystem restoration in Brazil is mostly a private entrepreneurship, and the jobs created are a direct consequence of the market demand for supplying restoration inputs and services.

Methods

The survey

A questionnaire (Appendix S1) was prepared and ~~widely~~ disseminated online from 11 August to 30 September 2020 through an outreach and engagement campaign led by the Brazilian

Society for Ecological Restoration (~~413~~ 584 associates), The Brazilian Coalition on Climate, Forests and Agriculture (281 organizations), The Alliance for Restoration of the Amazon (80 organizations), and The Atlantic Forest Restoration Pact (298 organizations) (Appendix S2). This survey also resulted in the creation of an online platform to offer restoration products and services and serve as a hub for restoration organizations and individuals ("Restoration Glassdoor" or *Vitrine da Restauração*, in Portuguese). A total of 356 organizations ~~participated in~~responded to the survey, each of them represented by a single questionnaire. Some organizations did not answer all questions, so the sample size is not the same for different questions. Our survey included organizations from 24 of the 26 Brazilian states and Brasília (the Federal District), missing only organizations from the states of Piauí and Tocantins, and covered many different ecosystem types (wetlands, temperate grasslands, tropical savannas, shrublands, dry and wet tropical and subtropical forests).

Data analysis

We focused our analysis on the number of jobs, rather than the number of questionnaires, to better represent the participation and level of influence of organizations in the ecosystem restoration supply chain. We classified jobs as "temporary" (i.e., seasonal jobs, in which people are only hired for part of the year) and permanent (i.e., jobs in which people become part of the ongoing staff of a given organization). We described how restoration jobs are distributed across the following classes:

- *types of activity*: seed collection, seedling production, implementation and maintenance, technical services (e.g., consultancy, project preparation, monitoring), others;
- *stakeholder groups*:

198 - non-profit sector: cooperatives, associations, and seed networks, which were
199 further classified as local/municipal, state/regional, and national/international;
200 - private companies: classified according to their gross annual revenue, in Brazilian
201 real (BRL) - large: revenue >R$300M, medium: R$4.8M < revenue <R$300M,
202 small: R$0.36M < revenue < R$4.8M, and micro companies: revenue <R$0.36M
203 (US$1 = ~R$5.0);
204 - individual micro-entrepreneur;
205 - farmers;
206 - governments: classified as federal, state, and municipal;
207 - watershed committees;
208 • *biomes*: Pampas, Atlantic Forest, Cerrado, Pantanal, Caatinga, and the Amazon;
209 • *regions*: South, North, Northeast, Southeast, and Central West (Figure S1);
210 • *states*: 26 states + the federal district (Figure S1).
211
212 We further collected information on state gross primary product (GDP) and legal deficit of
213 native vegetation in riparian areas (areas buffering water bodies and springs) according to the
214 2012~~'s~~ Native Vegetation Protection Law (Soares *et al.*, 2014), and evaluated through linear
215 regressions whether the number of jobs was more associated with the GDP of states or with
216 their legal deficit of native vegetation. We excluded São Paulo data in this analysis because it
217 was~~represented~~ an outlier. For the analyses, we used information reported in 2019 (the most
218 recent year before the pandemic) and GDP data from 2018. We also asked in the
219 questionnaires how many jobs were terminated due to the COVID-19 pandemic.
220
221 We then estimated the number of jobs that could be created by the implementation of Brazil´s
222 target to restore and reforest 12 million hectares of degraded lands and forests, which is

associated with the National Plan for Native Vegetation Recovery, the national pledge to the Bonn Challenge, and the Nationally Determined Contribution to the Paris Climate Agreement. We based our estimates on the following assumptions: (i) the survey accurately represented the various elements of the restoration supply chain in Brazil; and (ii) all reported activities and jobs (8,223 jobs) are associated with the total restoration implementation area covered by the survey (19,426 ha). It is not possible to define the proportion of areas to be restored through passive and active restoration in Brazil's target, so we considered the scenarios established by Brazil's National Plan for Native Vegetation Recovery (20, 30, 40 and 50% of active restoration; Brasil 2017). We recognize that the survey may be biased towards active restoration and failed to estimate the number of jobs created by passive restoration, as reported by Brancalion *et al.*, 2019a.

Results

The organizations that reported production data (325 out of 352) produced 93.6 t of seeds (49 questionnaires) and 19.6 million seedlings (97), planted 4.6 million seedlings (40), implemented 19,426 ha of restoration (72), and maintained 27,440 ha (67) during 2019. A total of 8,223 restoration jobs were created, 57.3% of which were temporary and 42.7% were permanent. When organizations were asked to select one or more ~~types of~~ activities~~y~~ in which they were involved in (i.e., seed collection, seedling production, implementation and maintenance, and technical services), ~~N~~nearly one-third of these jobs were generated by ~~organizations~~ thosethat specialized in one particular restoration activity, mainly planting/maintenance and services in general; ~~, whereas~~ the rest were distributed across organizations performing multiple restoration activities (Figure 1). Jobs from seed and seedling production were mostly generated by multitask restoration organizations (Figure 1). Most of the jobs were in organizations (e.g., local NGOs, companies specialized in

restoration services) that focus on ecosystem restoration (28.3 and 21.1% of jobs in organizations for which ~~having~~ restoration ~~i~~as their exclusive or main activity, respectively), whereas a lower proportion of restoration jobs were offered by organizations ~~(e.g., forest nurseries that mostly produce commercial tree species as eucalypts, consultant offices that mostly provide services on environmental licensing)~~ for which restoration was not a central activity (e.g., forest nurseries that primarily produce commercial tree species, consultant offices that mostly provide environmental licensing services); ~~(~~13.7 and 19.2% had restoration as a secondary and marginal activity, respectively~~)~~.

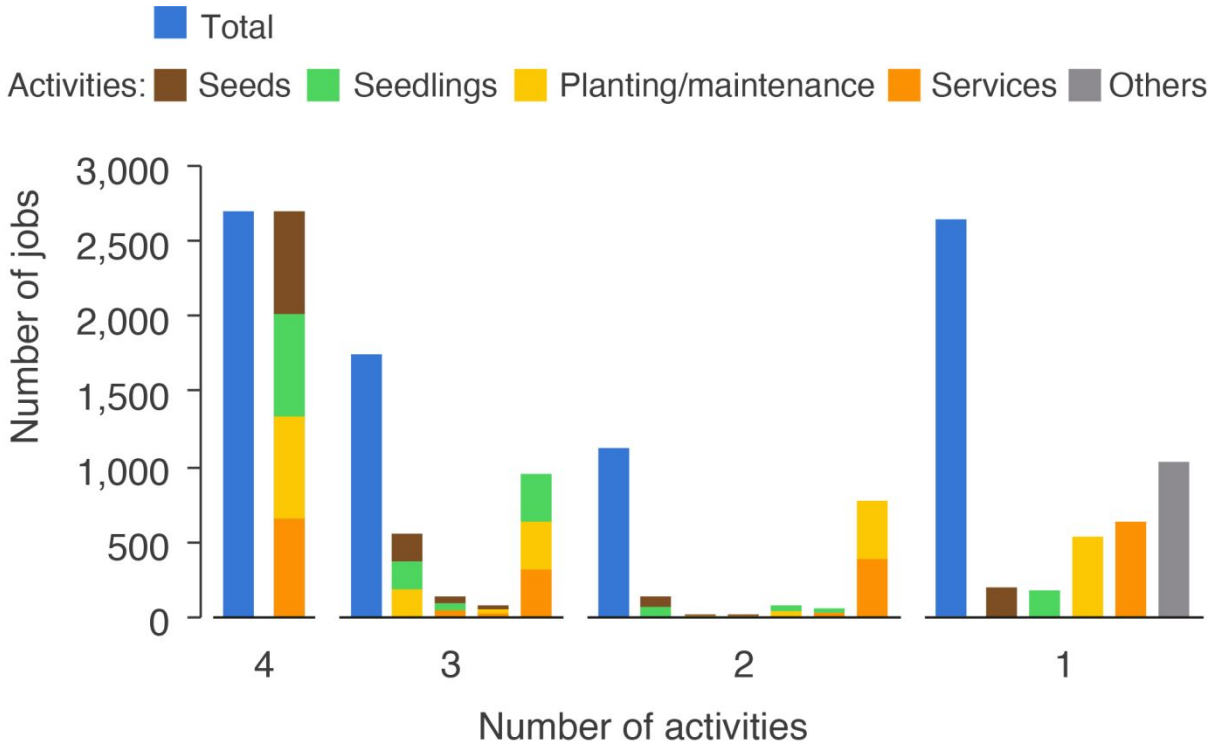
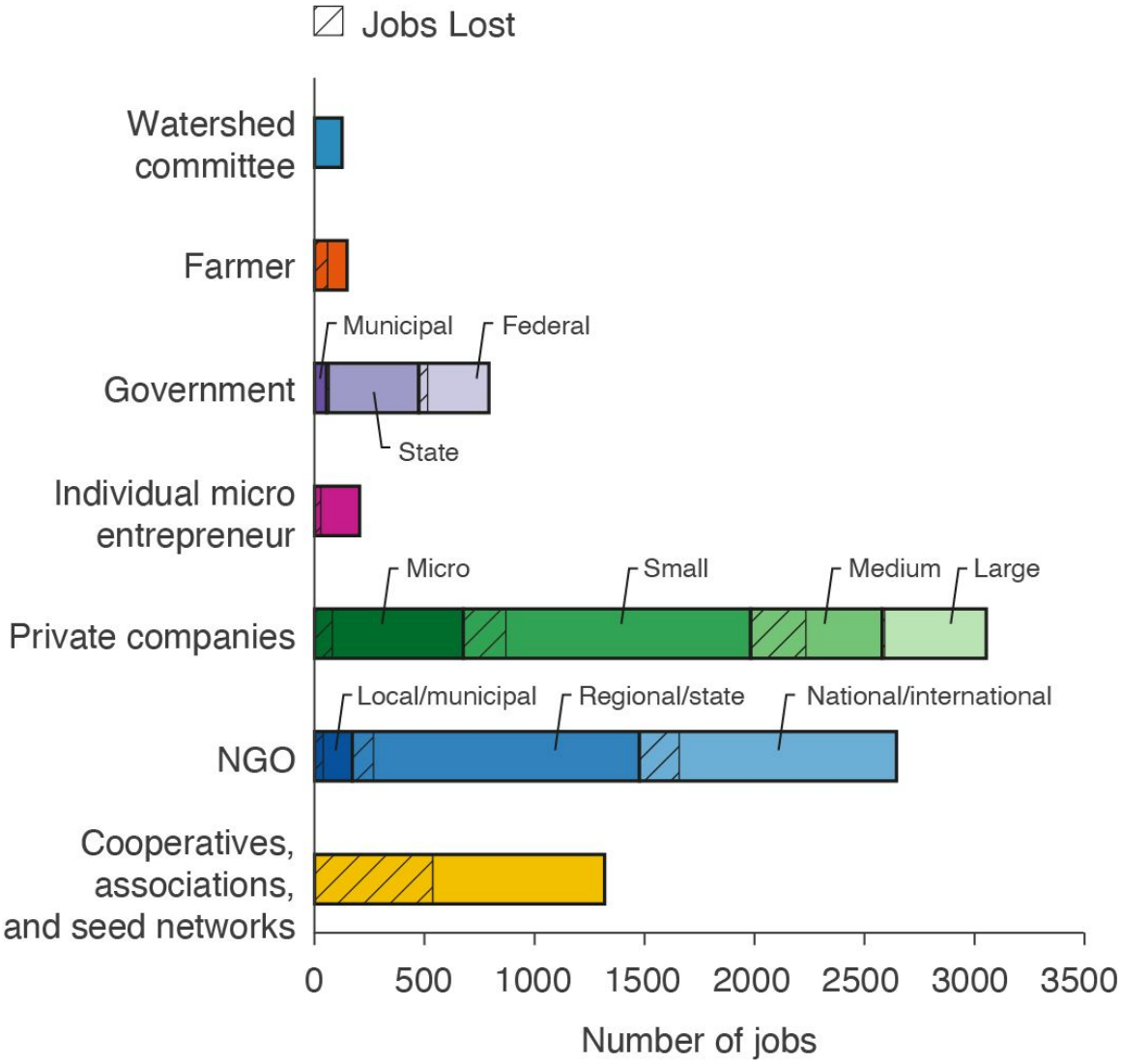


Figure 1. Distribution of restoration jobs according to the number of activities performed by organizations. The colour(s) of the bars (except for the blue bar – total) represent the composition of activities.

Most jobs were created by organizations from the non-profit (48%) and private (37%) sectors (Figure 2). In particular, (i) cooperatives, associations, and seed networks, (ii) regional/state

264 NGOs (iii) national/international NGOs, and (iv) small private companies were the main
265 sources of jobs, each of them accounting for nearly 15% of ~~all~~ jobs (Figure 2). During the
266 COVID-19 pandemic in 2020, nearly 20% of these ~~total~~ jobs (512 permanent and 1,043
267 temporary) were terminated; the jobs generated by farmers, medium-sized private companies,
268 and local/municipal NGOs were the most negatively impacted (Figure 2).
269



270

271 Figure 2. Distribution of restoration jobs according to stakeholder groups and number of jobs
272 terminated during the COVID-19 pandemic in 2020.
273

Most organizations worked in one (58%) or two (28%) biomes (Figure 3) and most restoration jobs were supplied by those restoring the Atlantic Forest exclusively (44%) and the Atlantic Forest and Cerrado together (16%; Figure 3). Only 15% of the restoration jobs reported in this survey did not involve any activity in the Atlantic Forest. Similarly, most restoration jobs were concentrated in the southeast region (61%; Figure 4), with nearly three quarters concentrated in five states (33.7% in ~~the state of~~ São Paulo state, 13.5% in Minas Gerais, 10.0% in Rio de Janeiro, 8.6% in Bahia, and 6.6% in Paraná; ~~see~~ Figure S1 ~~for a map of Brazilian states~~). This geographical concentration was more strongly associated with the states' GDP than with the legal deficit of native vegetation (Figure 5), and ~~did not have~~ ~~any~~was not correlated ~~association with~~ with state area ($R^2 = 0.01$) or population ($R^2 = 0.003$).

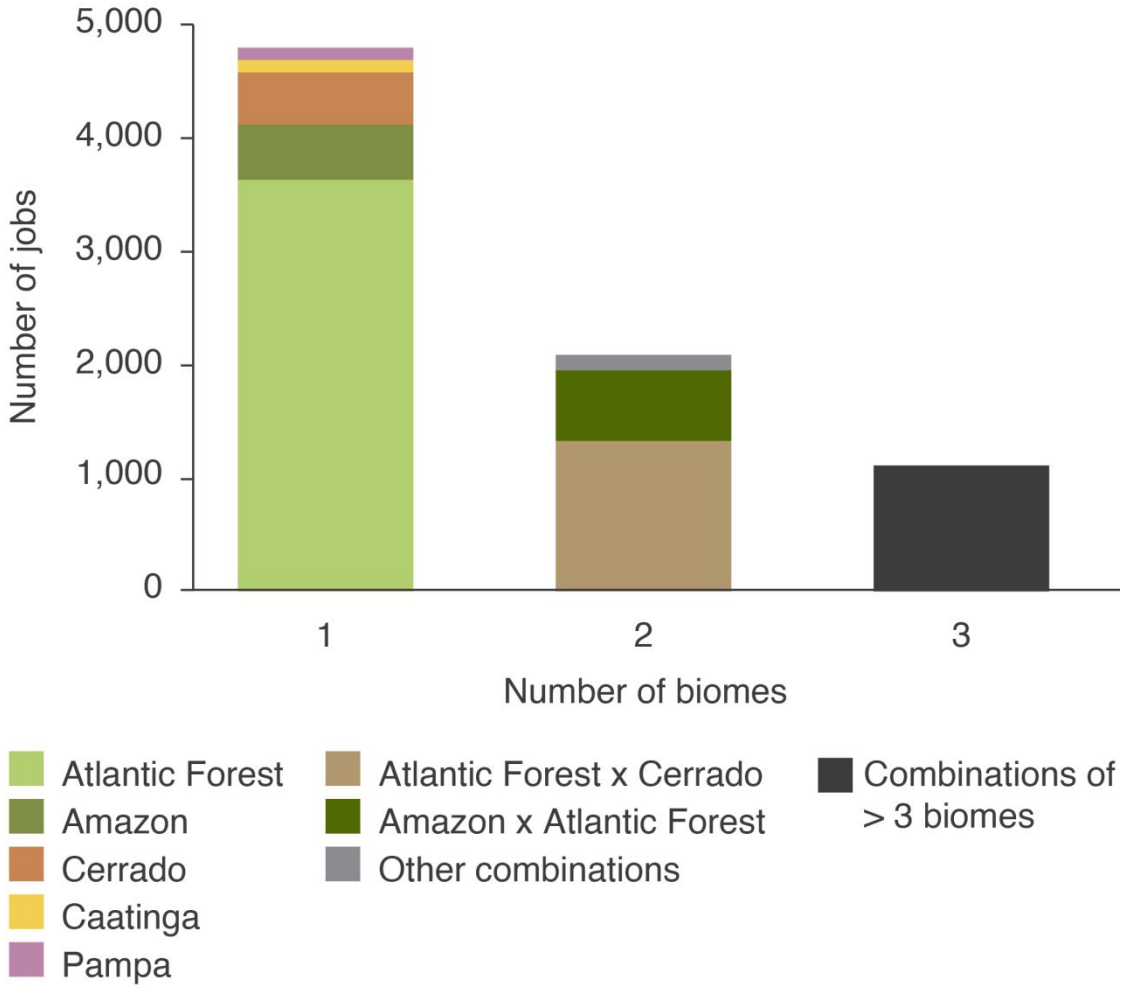


Figure 3. Distribution of restoration jobs across the Brazilian biomes. Bars represent the number of jobs generated by organizations that work (i) exclusively in one biome (colours represent the number of jobs per biome type), (ii) in two biomes (colour classes represent the number of jobs per different combinations of biomes), and (iii) three or more biomes.

~~the second bar represent the number of jobs generated in two biomes where the organization operates simultaneously, and the third bar the few cases where a given organization operates in three or more biomes.~~

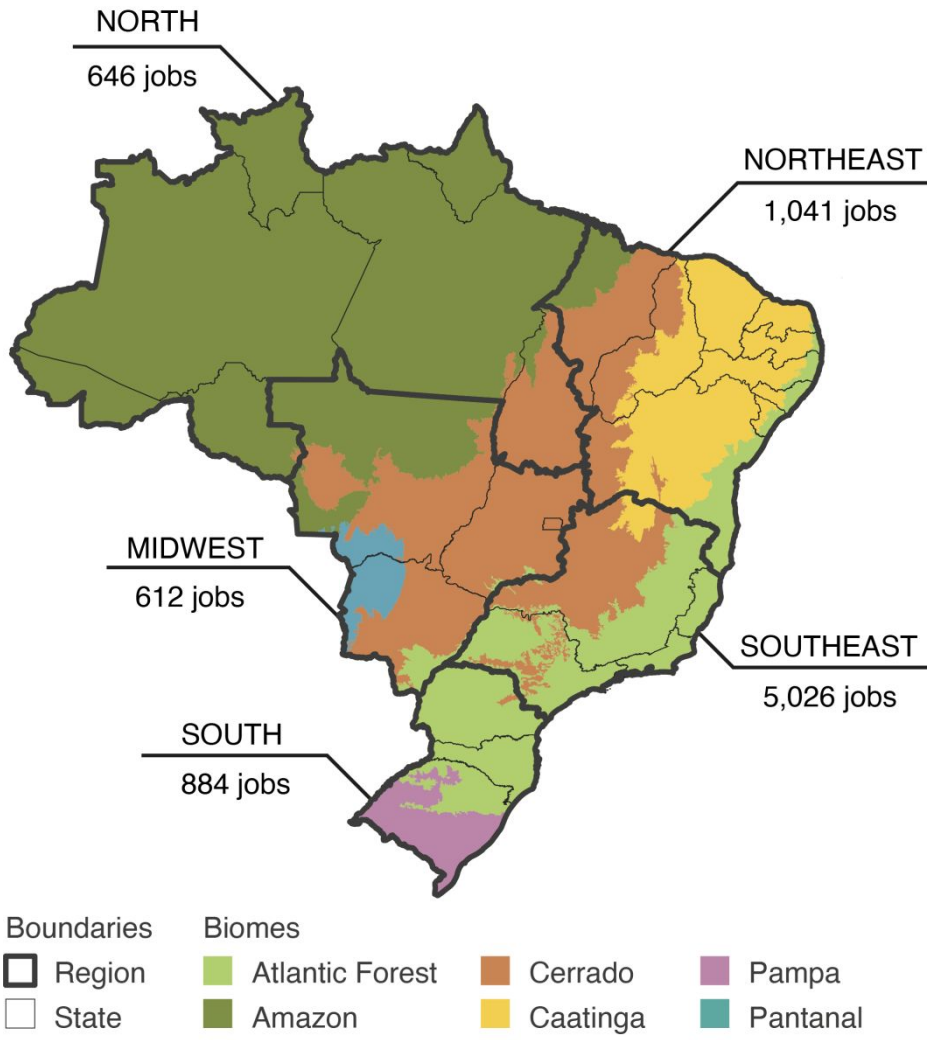
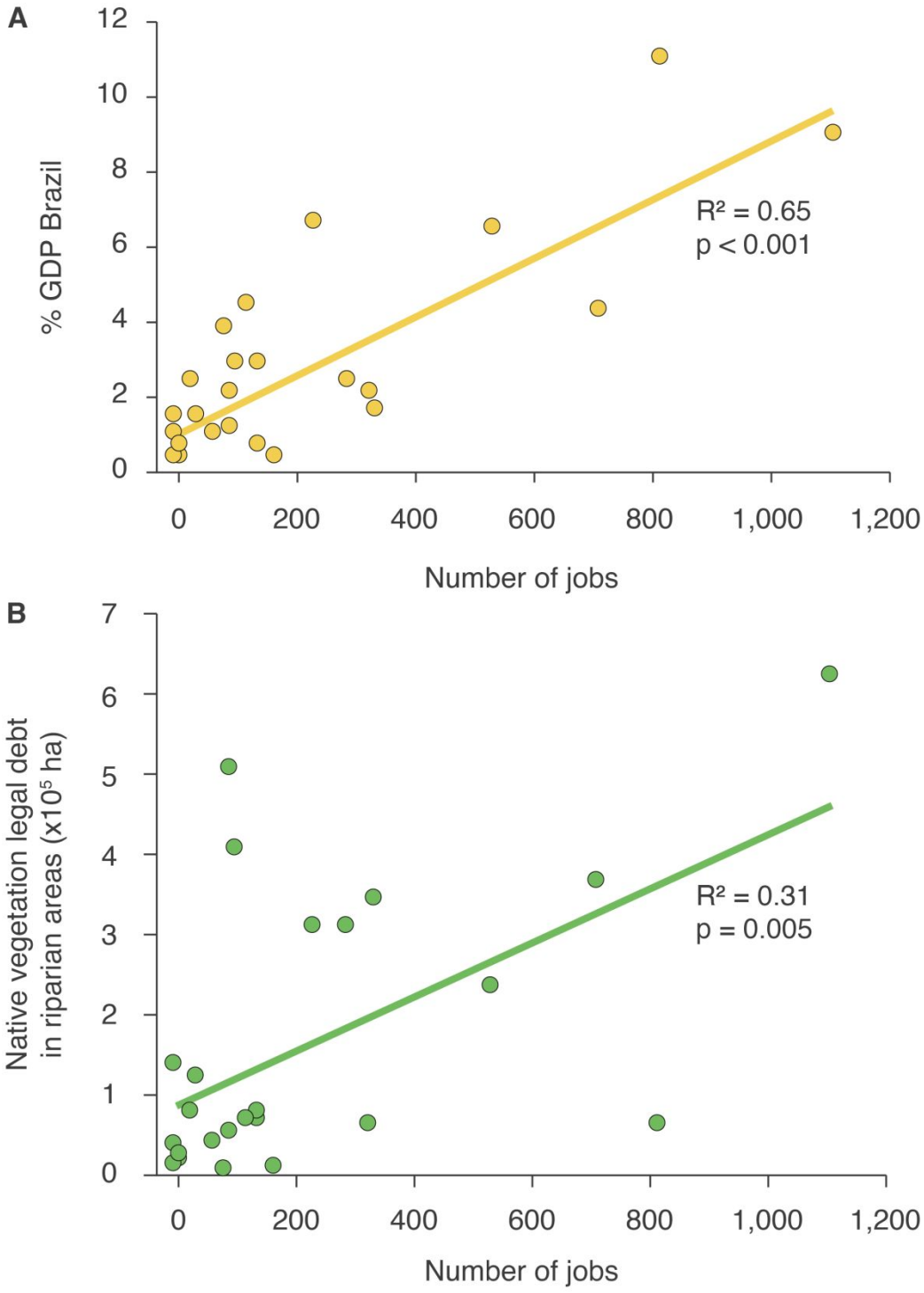


Figure 4. Distribution of restoration jobs across Brazilian regions (see Figure S1 for distribution among states).

298



299

300 Figure 5. Association between the number of restoration jobs and state GDP and the legal

301 deficit of native vegetation in riparian areas. Lines represent linear regressions without São

302 Paulo state data, an outlier.

303

304 We estimated that the restoration supply chain can generate 0.42 jobs per hectare (19,426 ha
305 of restoration implementation created 8,223 jobs), which could potentially create 1.0 to 2.5
306 million jobs based on the scenarios of 20 to 50% of Brazil´s restoration target, respectively,
307 being implemented through active restoration.
308
309 **Discussion**
310 Our assessment of the ecosystem restoration supply chain in Brazil highlighted restoration as
311 a complex, multistakeholder, and both geographically and ecologically biased activity. We
312 showed several idiosyncrasies of restoration as an economic activity that must be addressed
313 to evaluate the economic impact of restoration. Our estimates that each hectare of restoration
314 creates 0.42 jobs is nearly the double of previous estimates of restoration jobs in Brazil (e.g.,
315 Calmon *et al.* 2011; Costa 2016; Brasil 2017), and indicates the potential to create 1.0 to 2.5
316 million direct jobs through the implementation of the national restoration target of 12 million
317 hectares. Considering the estimate of BenDor *et al.* (2015a) for the United States that each
318 direct restoration job was associated with 0.76 indirect jobs, the total number of jobs created
319 by restoration in Brazil could reach 1.76-4.40 million.
320
321 Previous studies have demonstrated that restoration activities can be important for job
322 creation in the United States (Edwards, Sutton-Grier & Coyle 2013), South Africa (van
323 Wilgen & Wannenburgh 2016), and the United Kingdom (GreenAlliance 2021), and
324 particularly for sectors of society with high unemployment. However, these studies were
325 based on different methodologies and contexts, and for the most part did not conduct detailed
326 analyses by region and restoration activity, so it is challenging to compare their results with
327 ours. Despite the uniqueness of our study, we draw some general lessons that could
328 potentially be extrapolated to other contexts and improve future surveys.

329

330 ***Profile of restoration jobs***

331 We found a predominance of temporary, seasonal jobs in the restoration supply chain, with
332 work concentrated in periods of peaking demand (i.e., during the rainy season in Brazil) and
333 reduced offers for stable, longer-term job opportunities. Indeed, the seasonal nature of
334 restoration jobs is a concern for growing the global restoration economy (Baker & Quinn-
335 Davidson 2011; BenDor *et al.* 2015a). Our results show that many restoration organizations
336 focus on one or two primary activities, whereas diversifying the restoration activities that
337 organizations perform can be a valuable strategy to increase the permanence of restoration
338 jobs, since seed collection, seedling production, some maintenance activities, and project
339 planning and monitoring require labor throughout the year. The quantity and quality of
340 restoration jobs could then be expanded, and the chances of restoration failure reduced, if the
341 maintenance period is increased and monitoring and adaptive management become integral
342 components of projects (Holl 2020). At the same time diversification may enhance the overall
343 management of restoration projects, it may reduce the efficiency of individual restoration
344 activities as compared to specialization.

345

346 ***Restoration employers***

347 The high proportion of non-specialized, multitask restoration organizations may also reflect
348 the high level of instability of the restoration market. The lack of stable and predictable
349 demand for restoration inputs and services over time may force restoration organizations to
350 diversify their activities into different directions, either to activities not directly associated
351 with restoration or different types of restoration activities within the supply chain. For
352 instance, 71% of the nurseries in Brazil that produce native tree seedlings also commercialize
353 exotic species as a way to diversify their income and be financially viable (Silva *et al.* 2017).

354 Conversely, this result may suggest that organizations not previously dedicated to restoration
355 are progressively including it as part of their portfolio of products and services, and can
356 expand their participation in this sector if supportive market and policy instruments are
357 established (Brancalion *et al.* 2017).
358
359 The prominent role the non-profit and private sectors play in restoration shows that it is an
360 entrepreneurial activity. Although government regulations and policy interventions play a
361 central role in restoration, and EMBRAPA (the Brazilian Agricultural Research Corporation,
362 a federal government agency) has contributed to the creation of restoration jobs in different
363 Brazilian regions, our findings suggest that more jobs could be created if the market demand
364 for restoration inputs and services increased. Conversely, many jobs can be terminated
365 abruptly if market demand is reduced and environmental policies are weakened (BenDor *et*
366 *al.* 2015b), as potentially occurred during the COVID-19 pandemic when nearly 20% of
367 restoration jobs were terminated. The restoration sectors with higher proportion of terminated
368 jobs during the COVID-19 pandemic were those with lower levels of capital and higher
369 dependency from external financial support, as farmers (46% of restoration jobs terminated),
370 medium-sized private companies (42%), cooperatives, associations, and seed networks
371 (41%), and local/municipal NGOs (28%).
372
373 Cooperatives, seed networks, NGOs operating at the regional/state level, and small private
374 companies provide nearly half of all jobs, and were also some of the most impacted
375 organizations by the COVID-19 pandemic, so these local, grassroots organizations require
376 special financial aid to recover after the pandemic. In addition to providing a larger share of
377 restoration jobs, local and community-based organizations can maximize the social benefits
378 of those jobs and opportunities, improving local livelihoods while involving indigenous

participation and promoting environmental justice throughout targeted territories (Urzedo *et al.* 2021). Brazil, like a number of Latin American countries, has been going through a long and intense process of rural outmigration, followed by a concentration of jobs in urban centers and reduction of jobs in the rural area due to agriculture mechanization (Aide & Grau 2004; Baptista & Rudel 2006; García-Barrios *et al.* 2009). Ecosystem restoration can become a powerful alternative to generate green jobs in rural areas, contributing to economic development and alleviating social problems in urban centers, as well as providing environmental benefits to society and the planet (Mansuy 2020; GreenAlliance 2021).

Spatial distribution of restoration jobs

The high concentration of restoration jobs and overall investment in restoration in Brazil (Brancalion et al. 2019a) in the southeastern region and in the Atlantic Forest biome is a result of multiple, intertwined factors that are difficult to disentangle. First, it likely reflects the economic inequalities among Brazilian states and suggests that restoration has been a "luxury" environmental intervention promoted for those that can pay for it. Rather than concentrating restoration where it is most needed in terms of legal compliance, restoration jobs have been mostly promoted where the GDP is higher and organizations can afford to pay for it (Figure 5). Conversely, given that more than 40 and 60% of Brazil's population lives within the Southeast region and the Atlantic Forest biome, one could argue that restoration jobs are concentrated where they have the potential to supply ecosystem services to the most people, and potentially where environmental agencies and policies are more efficient.

Second, this geographic pattern of restoration may reflect historical legacies, as the restoration movement in Brazil originated in the Atlantic Forest (Rodrigues *et al.* 2009) and currently restoration research is concentrated in this region (Guerra *et al.* 2020). More

404 funding needs to be invested in restoration of other biomes in Brazil. This geographical bias
405 may be progressively reduced over time as the implementation of the 2012 Native Vegetation
406 Protection Law advances (Brancalion *et al.* 2016). This revised law established a more
407 efficient governance system than the previous 1965 Forest Code, including the creation of a
408 national system for registering the legal native vegetation deficit, a program to foster legal
409 compliance, economic incentives for restoration, and a national policy for native vegetation
410 recovery (Brancalion *et al.* 2016). Once this program is fully operational, the number of jobs
411 should increase substantially and be more equitably distributed across the country. However,
412 there is a great deal of uncertainty regarding the impact of this law, as initial studies have not
413 found clear evidence that the national registry has changed landowners' willingness to protect
414 and a restore native ecosystems (Rasmussen *et al.* 2016; Jung *et al.* 2017), and the current
415 presidential administration has promoted a massive deregulation of environmental policies
416 (Vale *et al.* 2021).
417
418 ***Survey limitations***
419 We acknowledge a slight geographic bias of our survey responses, as most of the leaders of
420 the survey work in the Atlantic Forest and are based in the southeast region, despite the fact
421 that it was an online, national survey and we received responses from nearly all states.
422 Further, on-line surveys may underrepresent important restoration stakeholder groups, such
423 as indigenous and traditional communities, small farmers, and local NGOs and companies,
424 who have less access to internet and may prefer to be contacted through in-person meetings.
425 We recommend that future surveys census restoration jobs in targeted regions, which could
426 yield estimates less biased by sampling. Finally, we note that the assumptions we used to
427 estimate job creation by achieving Brazil's restoration plan are simplistic and necessarily
428 subject to the uncertainty regarding the extent of its implementation.

Conclusion

We and other (e.g. BenDor *et al.* 2015a; van Wilgen & Wannenburgh 2016; GreenAlliance 2021) demonstrate that ecosystem restoration is an emerging economic activity with relevant potential to generate jobs, especially through local organizations. In Brazil, this potential mostly has been leveraged by the financial capacity of states to pay for restoration activities, which highlight the critical role of financial incentives, appropriate policies, and the development of markets for restoration goods and services to create new jobs, especially in less economically developed regions. We conclude by reinforcing the potential value of ecosystem restoration to promote economic development and the creation of jobs, which can be crucial for the effective engagement of countries in the U.N. Decade on Ecosystem Restoration (Aronson *et al.* 2020; Edwards *et al.* 2021), and highlighting the critical role of grassroots organizations to maximize restoration opportunities for the socioeconomic development in times of post-pandemic economic recovery. However, to realize these potential outcomes requires that successful restoration have a funding commitment longer than 1-2 years (Iftekhar *et al.* 2017), and that restoration funding, particularly from national and international players, should be expanded and more equitably distributed across regions and biomes (Brancalion & Holl 2020).

Conflict of Interest: We have no conflicts of interest to declare.

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453 **Research ethics:** This research was carried out by the NGOs Atlantic Forest Restoration
454 Pact, The Nature Conservancy, and World Resources Institute, which have internal ethical
455 procedure that this survey was signed off against. Participants of the online survey signed a
456 consent term of participation.
457
458 **Figure captions**
459 Figure 1. Distribution of restoration jobs according to the number of activities performed by
460 organizations. The colour(s) of the bars (except for the blue bar – total) represent the
461 composition of activities.
462
463 Figure 2. Distribution of restoration jobs according to stakeholder groups and number of jobs
464 terminated during the COVID-19 pandemic in 2020.
465
466 Figure 3. Distribution of restoration jobs across the Brazilian biomes. Bars represent the
467 number of jobs generated by organizations that work (i) exclusively in one biome (colours
468 represent the number of jobs per biome type), (ii) in two biomes (colour classes represent the
469 number of jobs per different combinations of biomes), and (iii) three or more biomes.
470
471 Figure 4. Distribution of restoration jobs across Brazilian regions (see Figure S1 for
472 distribution among states).
473
474 Figure 5. Association between the number of restoration jobs and state GDP and the legal
475 deficit of native vegetation in riparian areas. Lines represent linear regressions without São
476 Paulo state data, an outlier.
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Supplementary material

Ecosystem restoration supply chain and jobs in Brazil

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People and Nature

Appendix S1. Questionnaire for the assessment of the ecosystem restoration chain in Brazil. This is an extract of the complete questionnaire that specifically refers to the data discussed in this paper.

1. **Full name of the person responding to the survey:**

2. **Identification of your organization (Write your company name or your first name, if informal).**

3. **Which of the restoration products or services does your organization offer?**

You can check more than one option.

Answer all next questions including/summing up all products and services offered.

- Collection and/or commercialization of native seeds
- Production and/or commercialization of native seedlings
- Implementation services
- Maintenance services
- Technical services (surveys, planning, *CAR*, *PRA,* and monitoring)
- I do not offer restoration products or services

4. **Which was your organization's restoration-related production in 2019?**

You can list more than one product or service.

Ex: 50 kg of seeds; 100,000 native seedlings; 40 hectares implanted; 20 hectares of maintained; 5 projects; etc

(non-mandatory response for those who do not offer restoration products or services)

5. **In which biome(s) does your organization operate restoration activities?**

You can check more than one option.

- Amazon
- Caatinga
- Cerrado
- Atlantic Forest
- Pampa
- Pantanal

6. **In which state (federative unit) is your organization headquartered?**

If the headquarter is outside Brazil, inform the state of work/residence of a representative in Brazil.

7. **In which municipality is your organization's headquarter located?**

If the headquarters is outside Brazil, inform the municipality of work /residence of a representative in Brazil.

8. **What is the legal nature of the organization?**

- Individual or family producer (informal)

- Rural producer receipt (*NFP*)
- Individual Micro Entrepreneur (*MEI*)
- Microenterprise (*ME*)
- Small company (EPP) - Annual gross revenue greater than R$ 360,000 and less than or equal to R$ 4.8 million
- Medium-sized company - Annual gross revenue greater than R$ 4.8 million and less than or equal to R$ 300 million
- Large company - Annual gross revenue greater than R$ 300 million
- 3rd sector: Cooperatives, Associations or Seed Networks (=> 8.1)
- 3rd sector: other organizations - local or municipal activities
- 3rd sector: other organizations - regional or state performance
- 3rd sector: other organizations - national or international performance
- Municipal government
- State government
- Federal government
- Other (Specify)

8.1. How many associates/coops/seed collectors did your organization have at the end of 2019?

If it is a network, count only the number of associations/cooperatives that make up the network (do not include in your response the number of associates/seed collection workers that belong to those other associations).

Please, when you have finished replying, forward the survey so that these associations also respond about their associates/coops/seed collectors.

9. What is the relative importance of restoration for your organization's activities?

Restoration = seeds, seedlings, implantation, maintenance, and technical and scientific services, and not just planting

- 100% - Exclusive/the only activity
- Approx. 75% - Main activity
- Approx. 50% - Secondary activity
- Approx. 25% - Marginal activity

10. What was the year with the largest amount of restoration-related work in your organization's history?

Restoration = seeds, seedlings, implantation, maintenance, and technical and scientific services, and not just planting

From now on, whenever we ask about the year with the largest amount of work, answer thinking about this year informed here.

Jobs

Count only the jobs of individuals hired by your organization (e.g. *CLT*, *RPA,* and also *MEI*), including also owners and business partners.

Please do not count outsourced workers and after completing the survey forward the survey to the head of the outsourced company so that they can respond and these workers can be counted only once.

11. How many TEMPORARY/SEASONAL workers (e.g. daily workers, etc.) did your organization hire in restoration activities in 2019?

Restoration = seeds, seedlings, implantation, maintenance, and technical and scientific services, and not just planting

If you have not had any workers, type the number zero: 0

12. How many were women?

If you have not had any workers, type the number zero: 0

13. Was there a reduction in TEMPORARY/SEASONAL jobs in 2020 because of the pandemic?

- Yes
- No

14. How many TEMPORARY/SEASONAL jobs have been closed because of the pandemic?

(Note: Do not count jobs lost for other reasons)

15. How many TEMPORARY/SEASONAL workers did your organization employed in restoration activities in the year with the largest amount of restoration work?

Restoration = seeds, seedlings, implantation, maintenance, and technical and scientific services, and not just planting

If you have not had any workers, type the numeral zero: 0

16. How many FIXED/PERMANENT workers did your organization employed in catering activities in 2019?

Restoration = seeds, seedlings, implantation, maintenance, and technical and scientific services, and not just planting

If you have not had any workers, type the number zero: 0

17. How many were women?

If you have not had any workers, type the number zero: 0

18. Was there a reduction in PERMANENT jobs in 2020 because of the pandemic?

- Yes
- No

19. How many PERMANENT jobs were closed in 2020 because of the pandemic?

(Note: Do not write down lost jobs for other reasons)

20. How many PERMANENT workers did your organization employed in restoration activities in the year with the greatest amount of restoration work?

Restoration = seeds, seedlings, implantation, maintenance, and technical and scientific services, and not just planting

If you have not had any workers, type the number zero: 0

Appendix S2. Engagement and outreach strategies used in the study.

Activities	**Description**
Mapping of institutions in the value chain classified per type of player and biome	Initially, we mapped 259 organizations/contact persons in the ecological restoration value chain in Brazil based on contributions from the authors of this study, partners, and supporters of the research.
Construction of the questionnaire	We then prepared an online questionnaire, aimed at all biomes and links composing the ecological restoration value chain.
Test of the questionnaire	We counted on key partners including NGOs, nurseries, private companies, and researchers to test the first version of the questionnaire. After the tests and feedback, we adapted and validated the questionnaire for the final data collection.
Data collection	We collected data via an online questionnaire open for the participation of respondents between August 11th and September 30th, 2020.

Outreach strategies	As our main engagement strategy, we created the "Restoration Glassdoor" (*Vitrine da Restauração*, in Brazilian Portuguese), a free online platform, organized by biomes, location (states/municipalities), and the role played in the value chain, where all players part of the ecological restoration chain in Brazil could be found upon their participation in our study. The communication strategy was divided into waves. In the first wave, we invited players through emails and social media to take part in the study. In the second wave, we created cards informing statistics of responses by type of player and biome and counted on different partners to publicize the invitation in their networks in a coordinated and synchronized way. In the third wave, we released the beta version of the "Restoration Hub" (*Vitrine da Restauração*), before the end of the data collection period to motivate more respondents to take part in the study. Throughout the data collection period, we strategically used several available platforms and tools (by voice, text messages, and video calls) to communicate with respondents and key-partners and organizations both to solve specific doubts concerning how to fill the questionnaire as well as to engage them to collaborate them to publicize the initiative throughout their networks in the entire country.

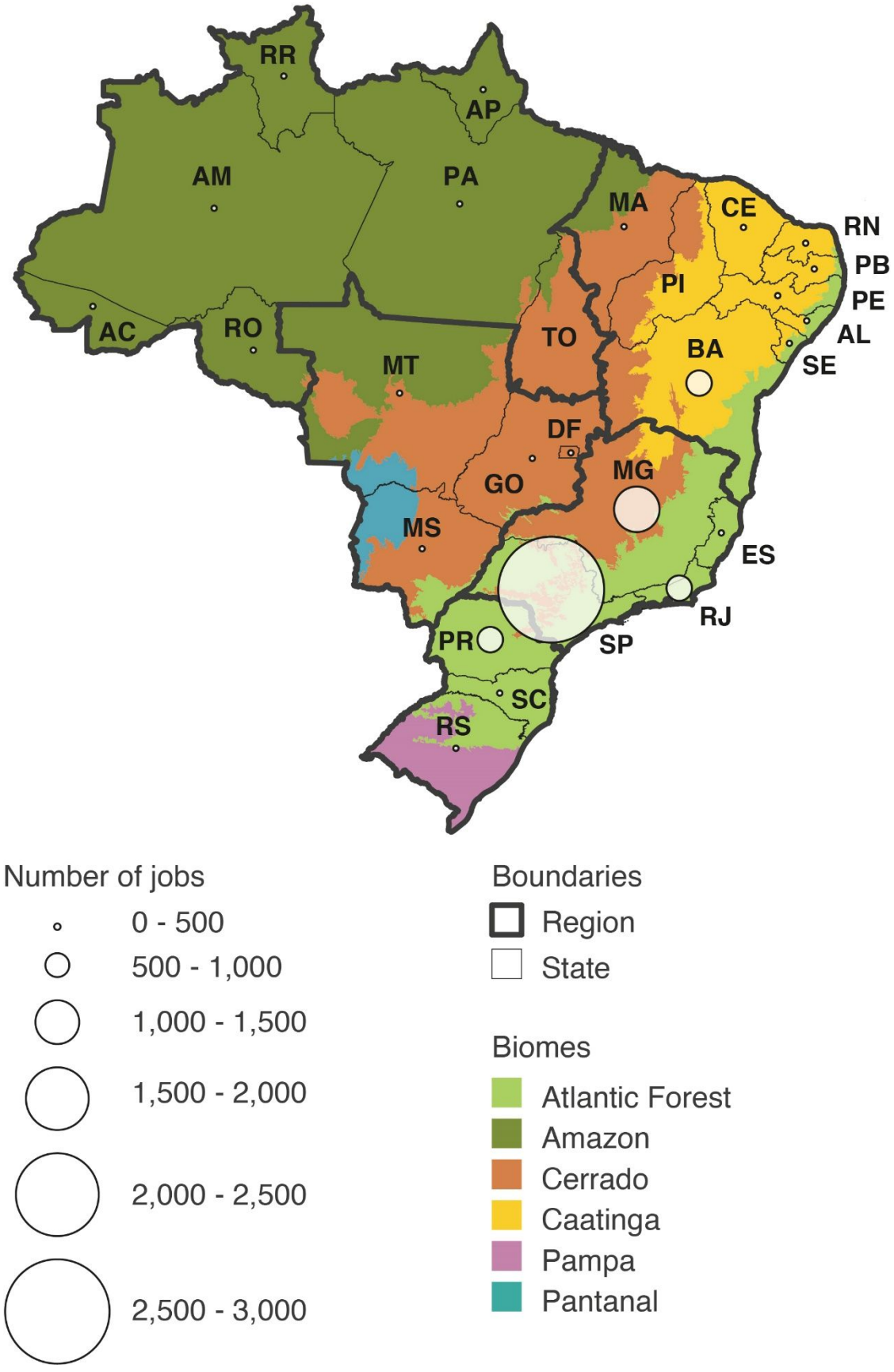

Figure S1. Distribution of restoration jobs according to Brazilian states.

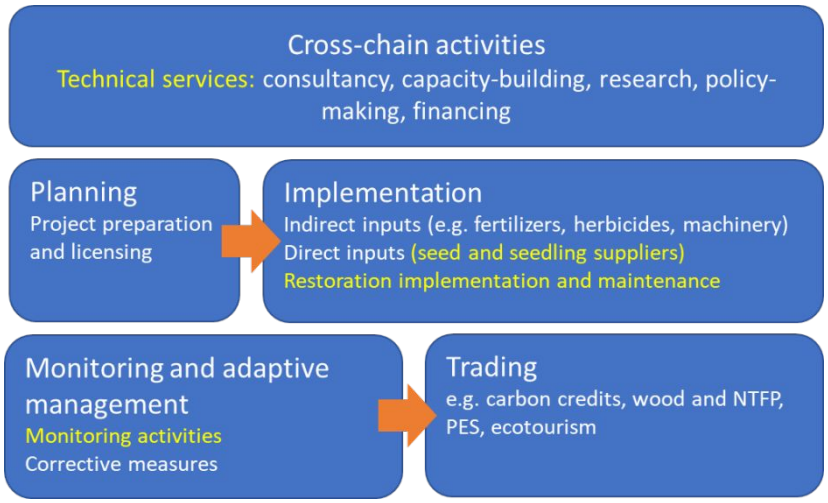

Figure S2. An overview of the ecosystem restoration supply chain. Activities highlighted in yellow were surveyed in this study.