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Ecological restoration as a strategy for mitigating and adapting to climate change: lessons and challenges from Brazil

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Abstract

Climate change is a global phenomenon that affects biophysical systems and human well-being. The Paris Agreement of the United Nations Framework Convention on Climate Change entered into force in 2016 with the objective of strengthening the global response to climate change by keeping global temperature rise this century well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C. The agreement requires all Parties to submit their "nationally determined contributions" (NDCs) and to strengthen these efforts in the years ahead. Reducing carbon emissions from deforestation and forest degradation is an important strategy for mitigating climate change, particularly in developing countries with large forests. Extensive tropical forest loss and degradation have increased awareness at the international level of the need to undertake large-scale ecological restoration, highlighting the need to identify cases in which restoration strategies can contribute to mitigation and adaptation. Here we consider Brazil as a case study to evaluate the benefits and challenges of implementing large-scale restoration programs in developing countries. The Brazilian NDC included the target of restoring and reforesting 12 million hectares of forests for multiple uses by 2030. Restoration of native vegetation is one of the foundations of sustainable rural development in Brazil and should consider multiple purposes, from biodiversity and ecosystem services conservation to social and economic development. However, ecological restoration still presents substantial challenges for tropical and mega-diverse countries, including the need to develop plans that are technically and financially feasible, as well as public policies and monitoring instruments that can assess effectiveness. The planning, execution, and monitoring of restoration efforts strongly depend on the context and the diagnosis of the area with respect to reference ecosystems (e.g., forests, savannas, grasslands, wetlands). In addition, poor integration of climate change policies at the national and subnational levels and with other sectorial policies constrains the large-scale implementation of restoration programs. The case of Brazil shows that slowing deforestation is possible; however, this analysis highlights the need for increased national commitment and international support for actions that require large-scale transformations of the forest sector regarding ecosystem restoration efforts. Scaling up the ambitions and actions of the Paris Agreement implies the need for a global framework that recognizes landscape restoration as a cost-effective nature-based solution and that supports countries in addressing their remaining needs, challenges, and barriers.

Keywords Landscape degradation · Forestry sector · Brazilian NDC · Environmental monitoring · Environmental policy

1 Introduction

There are approximately 2 billion hectares (Bha) of degraded land around the world (Minnemeyer et al. 2011), for which the 2014 United Nations Climate Summit in New York set a restoration target of 350 Mha (WRI 2014; Latawiec et al. 2015). In addition to threatening the existence of many species and ecosystems, such wide-scale degradation poses serious obstacles to poverty elimination and sustainable development (Díaz et al. 2015; Isbell et al. 2015). Moreover, land use change influences the rate of human-induced climate change by altering the balance between terrestrial and atmospheric carbon pools (Bonan 2008). Increases in degraded land also affect regional climates through their impact on surface fluxes of radiation, heat, moisture, and momentum (Betts 2005). Thus, an effective integrated solution to global climate change must include action on land use policy and ecosystem restoration.

The importance of land use change was recognized by the United Nations Framework Convention on Climate Change (UNFCCC) 21st Conference of the Parties in Paris. The objective of the Paris Agreement was to hold the average global temperature below 2 °C above pre-industrial levels (UNFCCC 2015). By keeping to this target, signatory parties hope to prevent dangerous interference in the global climate system while ensuring sustainable food production and economic development (UNFCCC 1992; Knutti et al. 2016). Each party has an obligation to prepare, communicate, and maintain the successive nationally determined contributions (NDCs) that it intends to achieve through domestic mitigation measures (Article 4, Paragraph 2).

Rogelj et al. (2016) evaluated the predicted effect of post-2020 NDCs on the aggregate reduction of greenhouse gas emissions and achievement of the target temperature. They concluded that, if effectively implemented, the intended NDCs will collectively reduce greenhouse gas emissions compared with current policies but would nevertheless result in an average heating of 2.6 to 3.1 °C by 2100. Clearly, substantial improvement or over-delivery of NDCs is required to keep the increase well below the 2 °C target.

By providing a wide range of ecosystem services, well-managed ecosystems can help societies mitigate and adapt to current climate hazards, as well as future climate change (Turner et al. 2009). Forest degradation in developing countries, particularly those in tropical and subtropical latitudes, is perceived to be an important contributor to global greenhouse gas emissions. However, the largely international emission reduction programs have focused on deforestation, which is easier to detect and monitor (Pearson et al. 2017).

Given that many ecosystems are already degraded, ensuring the provision of essential ecosystem services requires not only the protection of native vegetation but also its restoration wherever necessary. Such restoration and regeneration can significantly increase carbon uptake. For example, second-growth forests in the Amazon can potentially accumulate a total aboveground carbon stock of 0.9 Mg C ha^{-1} $year^{-1}$ via low-cost natural regeneration or assisted regeneration, corresponding to a total CO_2 sequestration of 3.2 Mg CO_2 ha^{-1} $year^{-1}$ (Chazdon et al. 2016). In addition, regeneration provides the following ecological and socioeconomic benefits: expanding coverage and connectivity of the remaining native vegetation; increasing the flow of ecosystem goods and services (e.g., water, food, biological control, pollination, grazing livestock products, timber and non-timber forest products, climate regulation, control and mitigation of erosion and floods); and creation of social and economic development opportunities for rural communities (Suding 2011;

Suding et al. 2015; Chazdon and Uriarte 2016; Alexander et al. 2016; Alves-Pinto et al. 2017). Climate change funding initiatives can also be significant drivers for the implementation of vegetation and landscape restoration (Nelson et al. 2009). For example, an initiative to restore the productive bases of salinized lands in Senegal was among the first eight projects approved by the Green Climate Fund in November 2015 (GCF 2015).

Ecosystem restoration is particularly important but also uniquely challenging in mega-diverse tropical landscapes given the enormous extent of converted and degraded areas and the complexity of biotic interactions associated with these species-rich ecosystems. For example, Brazil has highly diverse forest and non-forest ecosystems that are subject to different drivers of degradation and conversion of native vegetation. The Brazilian NDC describes mitigation measures aimed at the agricultural, energy, industrial, transport, and forestry sectors with actions that specifically target land use changes. Specifically, Brazil plans to (i) *strengthen the Forest Code*; (ii) *reinforce policies and measures to achieve zero illegal net deforestation in the Brazilian Amazon by 2030*; (iii) *restore and reforest 12 Mha of forests by 2030 for multiple uses*; and (iv) *expand the range of sustainable management systems of native forests*. It is important to note that the Brazilian NDC does not specify the biomes in which reforestation and restoration actions will be targeted. However, approximately 40% of the country was originally covered by non-forest ecosystems, some of which are now highly converted or under strong pressure of conversion. It would therefore be relevant to include the full array of conservation and restoration options for non-forest ecosystems (Overbeck et al. 2013, 2015).

The feasibility of the Brazilian NDC depends largely on the definition of priority areas (biomes and ecosystems) to restore, restoration purposes and recommended methods (e.g., restoration by planting native species, natural regeneration, recovery by planting exotic species, or a combination of approaches), and identification of the main challenges and solutions in implementing these actions over the coming decades.

Some of challenges for large-scale restoration programs include clarifying the motivations driving the promotion of large-scale restoration, organizing the main stakeholders, defining goals, identifying both available and priority areas for restoration, determining science-based and field-validated methods including monitoring protocols, and developing strategies to promote public policies conducive to restoration (Brancalion et al. 2013; Chazdon and Uriarte 2016). To better understand the challenges of ecosystem restoration under the framework of biodiversity protection and climate change mitigation and adaptation, this paper uses Brazil as a case study to evaluate (i) the primary needs for effective and efficient restoration programs in developing countries; (ii) current ongoing approaches, with a focus on ecosystem services, especially those with the potential to mitigate climate change by reducing net greenhouse gas emissions; and (iii) demands for the development and implementation of public policies for the restoration of degraded landscapes.

We conducted a literature review to evaluate restoration policies and projects and to identify key knowledge gaps. These findings were cross-checked with focus groups consisting of a variety of stakeholders with experience in all Brazilian biomes (forest and non-forest ecosystems).

2 Degraded landscapes in Brazil and restoration demands

Between 2005 and 2010, forest degradation emissions were estimated across 74 developing countries covering 2.2 Bha of forests. The total estimated emissions was 2.1 billion tons of carbon dioxide per year, of which 53% was derived from timber harvest, 30% from woodfuel harvest, and 17% from forest fires, with these percentages differing by region (Pearson et al. 2017). Forest degradation accounted for 25% of the total emissions from deforestation and forest degradation, but for 28 of the 74 countries, emissions from forest degradation exceeded those from deforestation.

The area of Brazil covered by native vegetation is approximately 530 Mha, or 62% of the Brazilian territory. However, the distribution of native vegetation remnants is highly concentrated in the Amazon biome. Approximately 40% of the native vegetation in Brazil is located in public protected areas or indigenous territories, with 91% of this fraction in the Amazon biome. The remainder is in private properties or public lands still unassigned or under dispute (SAE 2013; Pitta and Mendonça 2015).

Large areas of forest and non-forest native ecosystems in Brazil have been degraded by agricultural use, although some agricultural lands were subsequently abandoned for political and economic reasons (Gibbs and Salmon 2015). Agricultural expansion and intensification has undoubtedly caused multiple environmental changes, such as (i) loss of nutrients and soil (Beutler et al. 2003); (ii) reduced water quality due to increased sediment inputs and changes in water production (Pinheiro et al. 2009; Coe et al. 2011; Pocewicz and Garcia 2016); and (iii) reduction in biodiversity and the supply of various ecosystem goods and services (Kaimowitz and Smith 2001; Foley et al. 2005; Spera et al. 2016).

Most successful large-scale restoration programs around the world have focused on native forest regeneration. For example, South Korea, which suffered heavy losses of its forests during the Japanese occupation in the nineteenth century, deemed reforestation a national priority (Lamb and Gilmour 2003). Consequently, forest cover increased from approximately 3.5 million hectares (Mha) in the mid-1950s to 6.5 Mha in 2007. While forest cover increased from 35 to 64% of its territory, the country's population has doubled, and the economy has grown 300-fold (Buckingham and Hanson 2015; Bae et al. 2012; KFS 2010). In 2013, the estimated monetary value of ecosystem services was approximately US$ 92 billion, which is equivalent to 9% of the national gross domestic product (GDP) (Table 1). This example of forest transition in South Korea has been used in analyses involving comparisons of different world regions and conditions, and provides a starting point for other developing countries to develop forest recovery strategies (Liu et al. 2017; Park and Youn 2017; Andoh and Lee 2018).

Costa Rica provides another example of successful forest restoration in a tropical country. In this country, forest cover decreased about 77% in the 1940s to only 21% by 1987 (Sader and Joyce 1988; GOCR 2011). A series of actions aimed at environmental conservation and recovery led to an increase in forest cover to 52% by 2010—a gain of approximately 1.6 Mha (GOCR 2011).

Table 1 The monetary benefits from ecosystem services provided by restored forests in South Korea

Benefit	Amount (US$)
Carbon sequestration and air purification	18.7 billion
Water benefits	22.7 billion
Prevention of soil erosion	12.2 billion
Landslide prevention	5.6 billion
Biodiversity conservation	6.5 billion
Forest therapy	1.4 billion
Other benefits	12.5 billion

Source: (KFS 2013)

The USA is another country with successful forest recovery, through natural and human-induced processes. Approximately 13 Mha of forests in the eastern USA were recovered between 1910 and 1960 (USDA Forest Service n.d.; Hanson et al. 2010).

In Brazil, the best-known restoration project is probably the Tijuca Forest, a federal conservation unit located in Rio de Janeiro City (in the Atlantic Forest biome). In the early nineteenth century, city authorities became concerned about the water supply after major droughts in 1829, 1833, and 1844. They responded with Decree 577/1861, which provided instructions for the planting and conservation of the Tijuca and Paineiras Forests. The imperial government then began expropriating private land around the headwaters for reforestation (Santana 2002; Maya 1966). It should be noted that the Tijuca Forest was not entirely replanted; 3200 ha were planted, but its current size is largely the result of natural regeneration. However, this fact does not diminish the importance of the social pressures of that time or the conservation and reforestation measures taken (Dean 1996).

Although there are many negative impacts associated with hydroelectric power plants, as exemplified by the Belo Monte Dam in the Amazon (Jiang et al. 2018), the Itaipu Hydroelectric Power Plant provides a global example of a large successful reforestation program. The Itaipu Dam is located on the border between Brazil and Paraguay, between Foz do Iguaçu, Brazil and Ciudad del Este, Paraguay, ranging from Guaíra, Brazil in the south and Salto del Guairá, Paraguay in the north. Completed in 1984, the dam occupies an area of 1350 km^2, with a length of 170 km^2 and an average width of 7 km^2. Since 1979, approximately 60,000 ha has been reforested in Itaipu to protect the reservoir from erosion and silting. Although both exotic and native species were planted, the target coverage was fully reached, and colonization by native species has been observed in these areas (Durigan and Melo 2011). In the Atlantic Forest biome of Brazil, a multi-stakeholder coalition (Atlantic Forest Restoration Pact) of more than 270 members representing the private sector, governments, nongovernmental organizations, and research organizations joined efforts to transform the way large-scale restoration is governed and implemented (Calmon et al. 2011; Melo et al. 2013; Brancalion et al. 2016). Established in 2009, this coalition aims to restore 15 Mha of the Atlantic Forest by 2050, doubling native forest cover from approximately 15 to 30% (Brancalion et al. 2013).

In addition to the external commitment with the UNFCCC, Brazil has also an internal commitment to meet the requirements of the Native Vegetation Protection Law (Law 12651/2012, which replaced the former Brazilian Forest Code). The law requires that every property conserve or restore the native vegetation located in permanent preservation areas (known by the Portuguese acronym APPs) and in legal reserves (LRs). APPs represent areas at risk of generating erosion, storm water runoff, or deterioration of the protective role of the headwaters and the edges of water bodies, whereas LRs represent the proportion of every landholding that must be maintained with native vegetation cover (the LR proportion depends on the biome and the specific area of the property). If a property does not have enough land with native vegetation to comply with the LR requirement, native vegetation must be restored. However, compensation within the same biome is allowed by means of market mechanisms such as the environmental reserve quota of native vegetation, which may further incentivize restoration. Brazil has an estimated deficit of approximately 21 Mha of APPs and LRs in private properties (Soares-Filho et al. 2014). The National Plan for Recovery of Native Vegetation (PLANAVEG) has recently been devised by the Brazilian Ministry of Environment to address this demand. The PLANAVEG aims to expand and strengthen public policies, financial incentives, private markets, agricultural practices, and other actions that allow the recovery of a minimum of 12.5 Mha of native vegetation over the next 20 years (this represents 62.5%

of the APP and LR deficit in rural properties). The plan recognizes the need to integrate different sectoral and cross-sectoral policies such as those addressing climate change, sustainable agriculture, water resources, and energy (MMA 2017).

Although command-and-control policy instruments to reduce conversion of native vegetation have generated significant results in Brazil, especially for the Amazon region (Godar et al. 2014), these instruments have not been demonstrably effective in balancing the ever-present conflicts between economic growth and environmental conservation in the country. Although the 2012 Native Vegetation Protection Law has the potential to curb land use conversion, it has not been fully enforced by state environmental agencies. Moreover, when applied in isolation, command-and-control policies have not resulted in the large-scale restoration needed to establish connectivity between landscapes or ensure a reasonable provision of ecosystem services needed to maintain quality of life and economic development (Rizek 2013).

Vegetation restoration can mitigate the consequences of environmental degradation (Bullock et al. 2011; Blignaut and Aronson 2008; Mansourian 2016). Activities that enhance the ecological health of a system can also create or increase buffering capacity against the negative impacts of climate change (Biringer and Hansen 2005). The basic principles of restoration for adaptation include working on a large scale to increase available options, including environmental corridors, buffer zones, protection of freshwater resources, and promoting heterogeneity within the restoration approach (Biringer 2003; Noss 2001).

Forest and non-forest vegetation types vary across the Brazilian biomes, which therefore require different strategies for restoration. Practice demands detailed diagnoses, considering the history of disturbance and land degradation, ecosystem resilience, and surrounding landscape to plan and optimize recovery (Rodrigues et al. 2009). Restoration efforts, however, should focus not only on recovering species diversity but also on habitat diversity and the complex interactions involved in ecosystem functions that ultimately allow reconstruction and perpetuation (SER 2004; Roberts et al. 2009; Devoto et al. 2012).

3 Factors for success in restoration programs

3.1 Technical feasibility

Restoration is a process with multiple objectives, integrating biodiversity conservation and ecosystem services with the prevailing social and economic agenda. Restoration planning depends on the specific context and ecosystem diagnosis (original vegetation, history of use, physical environment, and socioeconomic factors), and restoration targets must therefore take into account the reference ecosystems (e.g., forests, savannas, grasslands, wetlands). Future biophysical conditions due to climate change must also be considered for the broader practice of ecological restoration (Harris et al. 2006).

Restoration of native vegetation is essential for sustainable rural development; therefore, it must extend it to all degraded areas, not only APPs and LRs, whose restoration is regulated by the Native Vegetation Protection Law. According to Chazdon (2008), restoring native vegetation can recover several ecosystem functions and components of the original biodiversity, demonstrating the importance of ecological restoration for sustainable rural development.

The short time-scale that the Brazilian Government has proposed (until 2030) in its NDC to recover 12 Mha of forest may be an obstacle to the success of the program. In addition, the use of exotic species to restore LRs, an exception allowed by the Native Vegetation Protection Law in the case of small farms (property size of up to 4 rural modules, units that depend on the region), may compromise the effectiveness of restoration initiatives. This ambitious commitment increases the risk of widespread use of exotic and fast-growing species. According to the Brazilian Association of Forest Plantation Producers (ABRAF 2013), *Eucalyptus* and *Pinus* are the predominant genera in silvicultural areas in Brazil, representing 77 and 23% of these plantations, respectively. Planting exotic *Eucalyptus* and *Pinus* species could increase CO_2 sequestration but at the cost of losing other ecosystem processes and services (see section 7 on Afforestation risks), as well as species and genetic diversity (Fernandes et al. 2016).

The sheer scale of the Brazilian NDC goals—12 Mha by 2030 compared with the approximately 0.3 Mha of vegetation currently restored across the country (IUCN 2016)—poses an enormous challenge. Logistical barriers include insufficient production and supply of seeds and seedlings (Silva et al. 2017) and lack of a qualified labor force. Currently, the Brazilian silviculture sector has an annual planting capacity of approximately 0.7 Mha, suggesting the need to adopt a gradual restoration schedule with an annual growth rate of 22% per year to achieve full recovery by 2030 (Instituto Escolhas 2016). This would allow forest restoration, mostly with exotics, to meet the NDC goal. This planting capacity does not consider the use of native species from regions other than those where restoration initiatives will be developed. Currently no data exist for planning the restoration of non-forest ecosystems.

On the other hand, the use of natural regeneration as a restoration strategy is also risky and may require research to identify and model the ecological and economic conditions where this process is a viable option. Moreover, protocols would need to be developed to allow local communities to monitor the natural regeneration. Finally, specific incentives and regulatory conditions would be needed to ensure the success of this strategy (Chazdon and Guariguata 2016).

The effectiveness of restoration initiatives requires a better understanding of the perspectives and contributions of different stakeholders, which include scientists, policy makers, extension agents, local communities, and the private sector (agriculture, livestock, and forestry sectors). Identifying priority sites for restoration is also a complex task. Planning large-scale systematic restoration must consider the multiple and often disparate objectives associated with landscape restoration, and projects aiming to meet more than one objective tend to be viewed more positively by funding agencies and communities. Trade-offs between desired goals, such as carbon sequestration and water supply (Jackson et al. 2005), are crucial for decision makers but are seldomly explicitly considered. In particular, the existence of ecological limits to restoration has important implications for decision-making, both at the project and regional levels (Maron and Cockfield 2008). For example, a recent study by Li et al. (2018) highlighted the critical role of precipitation feedback from afforestation on the regional hydrological balance (e.g., increased soil moisture). The authors pointed out the need to include precipitation feedback in models evaluating afforestation projects because of the important policy implications for the use of large-scale afforestation projects as a mitigation option (Li et al. 2018).

3.2 Economic and financial viability

Brazil's commitment to forest restoration as a contribution to the Paris agreement would involve an investment of approximately US$ 1 billion[1] annually over a period of 14 years if this were to involve only forest restoration, which is not the case. Implementation of this

[1] Exchange rate on Aug/08/2018 (1 dollar = R$ 3.71)
Source: Banco Central do Brasil. http://www.bcb.gov.br

project would create 215,000 jobs and raise US$ 1.7 billion[1] in taxes (Instituto Escolhas 2016). Another study estimated the total cost for recovery of 12 Mha of forest as approximately US$ 15.3 billion[1] (Young 2016); however, both estimates ignore non-forest ecosystems. It is important to emphasize that the development of a modern forestry economy in Brazil would mitigate environmental liabilities related to forest conversion for agriculture. The resources for these actions may come from the general budget of the federal government, states, and municipalities; multilateral development banks, investors, and the private sector; programs such as Brazilian Development Bank (BNDES) Florestal, BNDES Environment, Pronaf Floresta, Pronaf Eco[2]; constitutional funds (FNO-biodiversity,[3] FNE-green,[4] FCO-green[5]); the National Climate Change Fund and the Amazon Fund; and the promotion of green bonds (MMA 2016).

The PLANAVEG estimates that implementing eight strategic initiatives (increase awareness, provision of seeds and seedlings, markets, institutions, financial mechanisms, rural extension, spatial planning and monitoring, research and development) in the first 5 years of the plan will cost about US$ 48.5 million,[1] with funding from a range of sources such as government budgets, national and multilateral financial institutions, bilateral agreements between governments, donations, and the private sector (MMA 2017). Economic, social, and environmental benefits would include the following: poverty reduction by direct creation of 112,000 to 191,000 rural jobs; diversification of farming income by creating new sources of income from restored areas and payment for ecosystem services such as carbon sequestration and water provisioning; increased access to financial resources and ecosystem services markets for farmers; increased supply of drinking water to urban centers; reduction of risks associated with natural disasters and extreme weather events such as floods and landslides; lower costs to comply with the Native Vegetation Protection Law; and improved biodiversity conservation and climate change mitigation (Strassburg et al. 2016).

In North Brazil, farmers can also access benefits in the Degraded Areas Recovery Program in the Amazon (PRADAM) in partnership with the Ministry of Agriculture, with funding provided in part by the Constitutional Fund for the North Region and the Development Program for the Amazon (Almeida et al. 2006). This program promotes sustainable agriculture projects with subsidized loans and training courses. In its first year (2016), the program mobilized 1113 producers for 11 events on sustainable technologies for the Amazon biome including Planted Forests and Agroforestry Systems (http://www.senar.org.br/abcsenar/pradam/).

Other sources of funding for the recovery of degraded areas are derived from federal, state, and municipality programs and donations; fees for water use; fines from environmental law violations; funds from oil and mineral extraction royalties; compensation for the use of natural resources; resources under agreements; private investments; carbon credits; resources from vehicle pollution control; loans; funds from payments for products; environmental services; and revenues from protected areas (Young 2016).

Payment for ecosystem services (PES) is one of the instruments mentioned in the National Policy on Climate Change, as well as the Native Vegetation Protection Law (article 41), which authorizes compensation (monetary or non-monetary) or incentives for ecosystem services including the following: (a) sequestration, conservation, maintenance and stock increase, and

[2] Financing to farmers and family farmers to invest in the use of environmental technologies.
[3] Funding Program for the Maintenance and Recovery of Amazonian Biodiversity.
[4] Northeast Environmental Sustainability Financing Program
[5] Midwest Environmental Sustainability Financing Program

decrease in carbon flux; (b) conservation of natural scenic beauty; (c) biodiversity conservation; (d) conservation of water and water services; (e) climate regulation; (f) cultural appreciation and traditional ecosystem knowledge; (g) soil conservation and improvement; and (h) maintenance of APPs, LRs, and areas of restricted use (MMA 2011).

Fifteen of the 26 Brazilian states have specific laws regarding the establishment of policies and programs for PES (Young 2016). Regulation is fundamental to develop a market for ecosystem services. Brazil does not have a federal regulatory standard for PES, although discussions are ongoing in the federal legislature under the draft bill 792/2007. Harmonization between federal and state regulations is essential to avoid conflicts and legal insecurity and to take advantage of the synergies between these laws. For example, Richards et al. (2015) evaluated a case in the Brazilian Atlantic Forest and showed that strong municipal organizations and socioeconomic pressures were not the only tools for recruiting landowner enrollment in PES contracts; legal institutions such as the federal Forest Code were also effective.

Restoration is a costly activity, and its perceived benefits are often based on incomplete data. According to Young (2016), the average cost for ecological restoration and fencing of areas in Brazil is approximately US$ 2340. In many cases, the cost-benefit analysis is based solely on financial costs and benefits, ignoring a larger set of factors that more accurately reflect the benefits of restoration (De Groot et al. 2013; Barbier 2007). To understand how markets provide support for ecological restoration efforts, it is necessary to develop consistent methodologies for the economic evaluation and risk analysis of these projects (Crookes et al. 2013).

Economic feasibility is a key factor for the success of restoring degraded areas through re-vegetation. This feasibility involves, above all, technological advances to increase vegetation productivity, incorporating externalities in the revenue stream, economic modeling that takes into account major economic factors, mitigating financial risks, and clarification of laws (e.g., what is accepted as productive activity in LRs).

A financial return from environmental restoration would encourage landowners to accept the conservation practices needed for ecosystem health. Thus, decision makers and restoration scientists must include financial opportunities when demonstrating the range of possibilities that environmental restoration can offer. For example, households near restorable sites would be willing to pay an average of US$ 252 per year for improved environmental services (Loomis et al. 2000). Studies quantifying and monetizing ecosystem services in restored wetlands found that the value of social welfare ranges from US$ 1435 to US$ 1486 ha^{-1} year^{-1}, greenhouse gas mitigation ranges from US$ 171 to US$ 222, nitrogen mitigation is estimated at US$ 1248, and recreation for waterfowl hunters is estimated at US$ 16 (Jenkins et al. 2010).

The structure of markets and production chains for the products and services generated by restored ecosystems is critical to the viability of restoration programs. In Brazil, it is particularly important to reduce costs, improve efficiency, and reduce bureaucracy to increase business opportunities and human well-being. The engagement of stakeholders (e.g., farmers) depends on the ease and efficiency of these processes and on sharing costs with society as a whole, given that everyone benefits from restoration. Another important consideration is capacity building for all stages of the restoration processes.

Restoration of vegetation on a large scale requires national and international financial resources, both public and private, which in turn rely on legal security. In addition to refundable investments, non-refundable investments are essential to achieve restoration goals. A legal and institutional framework that provides legal security and appropriate economic instruments is essential for the environmental and economic sustainability of restoration programs at the planned scale and is needed to attract investments from the private sector.

In 2014, the GDP of the Brazilian forestry sector (including wood, pulp and paper, furniture, non-timber, and forest products) represented about 1.2% of the wealth generated in the country (Ibá 2014), which may be an important economic incentive for restoration. It is important to note that most marketing of non-timber and forest products is informal and therefore not captured in official statistics (Afonso and Ângelo 2009). Although silviculture has demonstrated great efficiency in carbon sequestration (Cunningham et al. 2015), this economic activity should also aim to achieve other goals, especially those related to maintaining biodiversity and ecosystem services.

Despite available financing, efficient existing technologies, and specialized labor and legal security, the capacity of the sector (0.7 Mha planted per year) cannot be dedicated entirely to the 12 Mha of land that Brazilian government intends to recover by 2030. Moreover, it is unlikely that these reclaimed areas would generate a profit that justifies such an investment, which highlights the need for public investment, as foreseen in the government's plans. However, Brazil's economic situation has deteriorated significantly in recent years. The economy entered a recession in 2014, and the situation continued to worsen until 2016, with real GDP declining by 3.6%. The use of public funds for restoration is therefore limited by the current financial crisis, with unknown consequences for restoration targets.

4 Public policies and monitoring instruments

Environmental policies in Brazil have promulgated a series of legal instruments to support the sustainable use of natural areas throughout the twentieth century. This legal framework has become stronger, forcing landowners to protect key areas for the provisioning of ecosystem services, and companies to compensate for environmental damages caused by the implementation or operation of their activities (Table 2). Compensation for environmental damage is currently one of the main drivers for restoration in Brazil; however, the criteria for identifying which areas to

Table 2 Evolution of environmental policy framework in Brazil

Year	Law	Characteristics
1934	Decree No. 23793 Forest Code	All native forests were of public interest and no more than 3/4 of the native vegetation existing in a farm could be exploited.
1965	Law No. 4771 Forest Code (Update)	Insisted that public authorities could carry out, if necessary, afforestation or reforestation of permanent preservation.
1981	Law No. 6938 National Environmental Policy	Introduced the restoration of degraded areas as compensation for the environmental impacts.
1998	Law No. 9605 Environmental Crimes Act	Established administrative, civil, and criminal penalties for environmental crimes, and fostered forest restoration initiatives.
2009	Law No. 12187 National Policy on Climate Change	One of the objectives was to consolidate and expand the legally protected areas and encourage reforestation and restoration of vegetation in degraded areas.
2012	Law No. 12651 Native Vegetation Protection	Brought important setbacks to environment protections such as the amnesty of fines for illegal deforestation committed prior to 2008.
2017	Decree No. 8972 National Plan for Recovery of Native Vegetation	Established the National Plan for Native Vegetation Recovery.

restore are insufficient, and the sole goal is to fulfill legal requirements. Better use of these resources, identification of priority areas, and the definition of environmental and social goals for restoration efforts may improve biodiversity conservation and ecosystem services provision.

Between 2003 and 2008, several policy instruments for environmental conservation were implemented, including the Inter-Ministerial Working Group (GPTI), which was charged with proposing and coordinating actions to reduce illegal deforestation. The main set of policies—Action Plan for Prevention and Control of Deforestation in the Legal Amazon (PPCDAm)—led to a significant reduction in annual deforestation rates in the Brazilian Amazon (Assunção et al. 2015). Other environmental policy instruments and monitoring systems were also launched to assist the development and implementation of policies focusing on the maintenance and restoration of forests and other natural ecosystems (Table 3). Civil society initiatives have also contributed to the reduction of deforestation in the Amazon region through actions such as the Soy Moratorium launched in 2006, which was a pact among representatives of the soybean sector, nongovernmental organizations, and the government (Gibbs et al. 2015).

Table 3 Main environmental policy instruments and monitoring systems in Brazil

Environmental policy instrument	Description
Action Plan to Prevent and Control Deforestation in the Cerrado Biome (PPCerrado)	Aims to mitigate the effects on climate change and improve the management of natural resources in the Cerrado biome by means of rural environmental regularization and the prevention and combat of forest fires.
Action Plan to Prevent and Control Deforestation in the Caatinga Biome (PPCaatinga)	Integration and articulation of initiatives of the various federal and state government agencies to implement actions to combat and control deforestation and the promotion of sustainable activities
Rural Environmental Registry (CAR)	Instrument of environmental regularization of rural properties and possessions
National Strategy for Reducing Emissions from Deforestation and Forest Degradation ($ENREDD^+$)	National strategy for structuring and improving coordinated actions to prevent and control deforestation and forest degradation, promote forest recovery and promote sustainable development.
Monitoring system	Description
Satellite monitoring program for clear-cut deforestation in the Legal Amazon (PRODES)	Conducts satellite monitoring of clear-cut deforestation in the Legal Amazon and produces annual deforestation rates that are used by the Brazilian government to establish public policies
Real-time deforestation detection system (DETER)	System that makes in real time a quick survey of alerts of evidence of alteration of the forest cover with area greater than 25 ha in the Amazon
Mapping System of Forest Degradation in the Brazilian Amazon (DEGRAD)	System to map areas in the process of deforestation where the forest cover has not yet been completely removed in the Brazilian Amazon
Deforestation Monitoring Project in the Brazilian Biomes by Satellite (PMDBBS)	A program that aims to quantify deforestation of areas with native vegetation, through satellites, to support actions to control and combat illegal deforestation in Brazilian biomes
Selective Logging Detection System (DETEX)	System to detect the selective logging of wood by means of satellite images
Deforestation classification system in the Brazilian Legal Amazon (TerraClass)	System that aims to produce systemic maps of the use and coverage of the deforested lands of the Brazilian Legal Amazon
National Forest Inventory	Reports information about Brazilian forest resources every 5 years

Although Brazil has a strong legal apparatus and instruments for the protection of the environment, it is still necessary to strengthen implementation of the law. Penalties are not always enforced (Araújo 2017), which discourages compliance, especially in the case of restoration demands. In addition, systematic actions for native vegetation restoration are not implemented in ways that take into account the extent of altered and degraded areas, and policies have focused primarily on forest restoration, neglecting other types of vegetation (Overbeck et al. 2013). This situation has motivated a proposal to convert fines to environmental services through restoration projects (Araújo 2017).

The implementation of large-scale restoration programs also requires robust mechanisms and additional funding for monitoring (Rodrigues et al. 2009; Méndez-Toribio et al. 2017). In an extensive survey to identify the underlying motivations for restoration in Australia, Hagger et al. (2017) reported that rigorous monitoring designs (e.g., quantitative, repeatable surveys, and use of performance indicators) were rarely used in restoration projects, other than those motivated by scientific research. Such monitoring should recognize the importance of landscape mosaics (including the integration of terrestrial and aquatic ecosystems) and the interactions between vegetation cover and configuration, and between vegetation cover and biodiversity in other trophic levels, using appropriate conceptual landscape models to maintain ecosystem resilience. This requires a clear vision for landscape conservation and quantifiable objectives to measure progress (Lindenmayer et al. 2008; Fengler et al. 2017; Gatica-Saavedra et al. 2017). Ecosystem functions should also be evaluated when monitoring ecological restoration to better understand the restored ecosystems (Kollmann et al. 2016).

Despite the enormous commitments of Brazil, the restoration initiatives are only beginning, except for large restoration programs of the Atlantic forests, mostly in the states of São Paulo and Paraná (Rodrigues et al. 2011; Durigan and Melo 2011). Ecological restoration has increased slightly in response to the environmental regulation of production activities, environmental compensation of infrastructure projects, and restoration for water quality and stream flow regulation. Several restoration methods have been used, but monitoring, evaluation, and documentation are insufficient, and it is therefore not clear whether the restoration objectives of a particular site are being achieved or whether resources are effectively allocated (Lamb and Gilmour 2003). Monitoring is needed to assess compliance with legal requirements and PES, verify the provided services, and carry out scientific and technological research. In addition, monitoring provides information on whether action is needed to keep the restored area on a successional trajectory (Walker and del Moral 2003). Monitoring ecological restoration also provides an opportunity to test ecological and restoration concepts, contributing to adaptive management and maintenance protocols (Palmer et al. 2006; Hobbs et al. 2007; Prack et al. 2007). Without adequate monitoring, there is no precise measure of whether actions have succeeded or failed.

Thus, ecological restoration should be monitored and continuously adapted on the basis of ecological, economic, and social indicators and in accordance with the project's objectives. This continuous assessment of past initiatives allows methods to be adjusted and improved (Barbosa et al. 2003). The monitoring of areas restored with native species is limited (Suganuma and Durigan 2015) but is essential to assess the effectiveness of restoration actions and refine methods.

For a successful outcome, vegetation restoration initiatives must take into account the high costs of monitoring, including the evaluation of social engagement, participatory decisions, and governance (Lestrelin et al. 2007; Xu et al. 2012; Durigan et al. 2013; Richards et al. 2015; Heikkila and Gerlak 2016). This investigation of social, economic, and ecological components of the system (Reed et al. 2011) provides learning experiences at different scales. The range of national commitments now emerging in the international climate regime further increases the need for robust monitoring, reporting, and verification (MRV) systems, which can assess the global impact of diverse and segmented national policies and lower costs to ensure net benefits and attract the participation of key stakeholders (Wiener 2015).

5 Governance capacity

Poor implementation of environmental regulations may be due to poor planning and insufficient management capacity by the responsible environmental agencies. Political interference and lack of effective monitoring and mitigation strategies are also common factors undermining environmental management by the public sector (Sousa 2005). Strategies to overcome these shortcomings include multi-stakeholder coalitions and participatory planning (Brancalion et al. 2016; Meli and Brancalion 2017).

Environmental legislation will become more effective as it is transversally integrated into different economic sectors and decision-making processes. However, only modest efforts have been made to address environmental issues using a policy framework that integrates economic, social, and infrastructure aspects. Both horizontal collaborations (between ministries or sectors) and vertical collaborations (between levels) are important to improve efficiency (Lenschow 2002).

Governance, transparency, and policy coordination are key elements for a successful restoration program at the scale of Brazil's commitments. Faggin and Behagel (2017) described how translating sustainable forest management-related rules, norms, and discourses from the global to the domestic level in Brazil is shaped by domestic policy and social-ecological systems. Therefore, mapping restoration opportunities that meet several goals should be carried out with the participation of local and regional actors and at different levels of governance, incorporating traditional and local knowledge (Chazdon et al. 2017; Holl 2017).

The approval and implementation of PLANAVEG should be integrated into other policies and activities of states, municipalities, nongovernmental organizations, and the private sector to stimulate synergies and the exchange of experiences, and to enhance the development of initiatives and restoration actions (Freire et al. 2017; Silva et al. 2017). A national restoration program must be accompanied by the elimination of illegal removal of native vegetation, with appropriate criteria to authorize legal removal in all biomes.

Rochedo et al. (2018) used integrated assessment models developed for Brazil to explore 2 °C-compliant CO_2 emission scenarios. Their results indicated that weakening deforestation control policies would rely on other economic sectors to use advanced technologies before they are fully mature or readily available to compensate for the higher emissions. This scenario would make it impossible for Brazil to meet its contribution to the 2 °C garget.

The creation and implementation of a National Policy for Restoration of Native Vegetation should be integrated with the existing inter-related policies and instruments (Brancalion et al. 2016). This policy must act on a broad scale, accomplishing the multiple objectives of landscape restoration (productive, functional, and biodiversity) through dialogue with all other forms of land use planning and adaptation to the local realities and stakeholders. For example, the Rural Environmental Registry is a mandatory registry for all rural properties in Brazil that requires owners to provide information on the status of their productive areas and legally protected areas (APPs and LRs). Large-scale integration of APP and LR data can support restoration strategies and efforts at the landscape level (Silva et al. 2011). It can also indicate environmental liabilities in the different biomes and vegetation types, reinforcing the need to also restore non-forest ecosystems. Public disclosure of such data can assist command-and-control actions and monitor compliance with the Native Vegetation Protection Law to improve large-scale land governance.

6 Research, development, and innovation

The restoration of complex and diverse landscapes that are under different pressures is a challenge that demands new approaches of environmental governance. It also demands additional investment for the development of restoration science and technologies, and continued actions for training and technical assistance in environmental compliance and sustainable use of the landscape. Furthermore, there are numerous Brazilian species that have high potential for sustainable use (e.g., energy, timber, non-timber products, medicinal uses) but are still understudied. Including landscape restoration in technical school curricula, higher education courses, and scientific and technological research agendas in Brazil and simplifying bureaucratic processes would facilitate the development and dissemination of knowledge on native vegetation restoration and ecological intensification of production systems.

7 Environmental trade-offs: restoration of non-forested ecosystems and afforestation risks

Soil degradation is a global environmental problem, with many countries adopting afforestation to reduce soil erosion. Afforestation is also a strategy for climate change mitigation; however, there are also concerns about planting forest species in non-forest systems (Cao et al. 2010; Veldman et al. 2015a, b; Fernandes et al. 2016). In China, afforestation was carried out in arid and semi-arid environments to prevent sandstorms, but it proved to be costly and environmentally unsustainable (Xu et al. 2006) with severe impacts on water resources (Cao et al. 2011; Deng et al. 2016). The water consumption of the exotic trees used was 20 to 40% higher than that of native tree species, leading to increased tree mortality (Zhenghu et al. 2004). A global analysis of the effect of afforestation on water yield (26 catchments data sets with 504 observations, including annual and low flow) found that afforestation may cause or aggravate water shortage in many places, a trade-off that should be explicitly addressed in carbon sequestration programs (Farley et al. 2005). In a Chinese large-scale afforestation program in the Tibetan Plateau (the source of the major Asian rivers), tree plantations consume 1.7×10^9 m^3 more water per year than the equivalent area of natural vegetation. The shrinking of glaciers by global warming is exacerbating the water shortages produced by these plantations (Cao and Zhang 2015). The authors therefore recommend that mitigation efforts focus on preserving natural vegetation. Indigenous and local communities in the Cerrado region, who meet their fundamental needs and earn income from subsistence farming and harvesting of wild products (Scariot 2013), also experience the negative consequences of afforestation with industrial monocultures (Cardinale et al. 2012; Pacheco 2012). Afforestation of grass or shrubland (especially with *Eucalyptus*) severely decreases water yield (Brown et al. 2005; Nosetto et al. 2005), which may endanger water security in some regions of the Cerrado, Caatinga, and Pampa biomes. The Cerrado in the north of Minas Gerais State is experiencing a critical water shortage due to historical low precipitation and large-scale afforestation on tablelands in the last decades (Leite and Fujaco 2010). Impacts of afforestation on biodiversity were also reported. For example, changes in the composition of bird communities related to afforestation in temperate pastures in southern Brazil decrease the conservation value of these areas (Dias et al. 2013).

8 Concluding remarks

Two relevant challenges emerge from analyses of the formulation and implementation of climate change policies in Brazil. The first is related to the engagement of subnational governments as international and national policies are developed and in fact implemented at the subnational level. In the case of Brazil, responsibilities for environmental policies and legislation are divided among the three levels of government (federal, state, and municipal), requiring the coordination of 27 federal government units and more than 5500 municipalities, which complicates the implementation of climate change policies (de Oliveira 2009). The second is related to the gap between the objectives of the National Policy for Climate Change and sectoral/regional planning (do Nascimento Nadruz et al. 2018), which hinders successful implementation of climate change-related policies and requires good government coordination and innovation in policymaking and implementation (Di Gregorio et al. 2017).

Restoration success will depend on social participation. Programs must allow participants to take action, permit governance sharing, and identify potential outcomes from actions, as well as the associated costs and benefits (Ostrom and Cox 2010; Hill et al. 2012). Restoration technologies will be more attractive if they improve productivity or include economic compensation for landowners (Shiferaw et al. 2009). Once land conservation and restoration are inextricably linked to livelihoods, any intervention for social action should integrate the production chain, labor, food, and water security. Furthermore, incorporating local knowledge often provides opportunities to innovate with local and low-cost resources, making technologies less expensive and better adapted to the specific problem (Shiferaw et al. 2009; Xu et al. 2012). Projects must be flexible and offer a range of options that acknowledge and embrace the social and biophysical heterogeneity (Shiferaw et al. 2009). Funders should establish flexible goals that consider variations and adaptations throughout the project. Executor’s contracts could be scaled, including diagnosis, adherence, implementation, monitoring, and management. Finally, demystifying environmental laws, especially with respect to the farmer’s legal obligations and flexibility of the legislation, would also encourage compliance.

Globally, deforestation and forest degradation, together with agriculture, account for about a quarter of total emissions. Protecting tropical ecosystems and reversing the impacts of deforestation and forest degradation through effective restoration and sustainable management of forests is crucial to achieve the adaptation and mitigation goals of the Paris Agreement. Additionally, standing tropical forests contribute to the achievement of Sustainable Development Goals related to food, water, health, energy, human safety, and biological diversity. The case of Brazil shows that slowing deforestation is possible; however, this analysis highlights the need for increased national commitment and international support for actions that require large-scale transformations of the forest sector regarding ecosystem restoration efforts. Scaling up the ambitions and actions of the Paris Agreement implies the need for a global framework that recognizes landscape restoration as a cost-effective nature-based solution and that supports countries in addressing their remaining needs, challenges, and barriers.

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References

ABRAF (2013) Anuário estatístico ABRAF 2013 ano base 2012/ABRAF, Brasília

Afonso SR, Ângelo H (2009) Market of non-wood forest products from Brazilian savanna. Ciência Florestal 19(3):317–328. https://doi.org/10.5902/19805098887

Alexander S, Aronson J, Whaley O, Lamb D (2016) The relationship between ecological restoration and the ecosystem services concept. Ecol Soc 21(1):34

Almeida E, Sabogal C, Júnior SB (2006) Recuperação de Áreas Alteradas na Amazônia Brasileira: Experiências locais, lições aprendidas e implicações para políticas públicas. CIFOR, Belém

Alves-Pinto HN, Latawiec AE, Strassburg BB et al (2017) Reconciling rural development and ecological restoration: strategies and policy recommendations for the Brazilian Atlantic Forest. Land Use Policy 60:419–426

Andoh J, Lee Y (2018) Forest transition through reforestation policy integration: a comparative study between Ghana and the Republic of Korea. Forest Policy Econ 90:12–21

Araújo SMVG (2017) Desafios do Ibama para a gestão ambiental no Brasil. http://repositorio.ipea.gov.br/handle/11058/7944. Accessed 17 Dec 2018

Assunção J, Gandour C, Rocha R (2015) Deforestation slowdown in the Brazilian Amazon: prices or policies? Environ Dev Econ 20(6):697–722

Bae JS, Joo RW, Kim Y-S (2012) Forest transition in South Korea: reality, path and drivers. Land Use Policy 29(1):198–207

Barbier E (2007) Valuing ecosystem services as productive inputs. Econ Policy 22(49):178–229

Barbosa LM, Barbosa JM, Barbosa KC et al (2003) Recuperação florestal com espécies nativas no estado de São Paulo: pesquisas apontam mudanças necessárias. Florestar Estatístico 6(1):28–34

Betts RA (2005) Integrated approaches to climate–crop modelling: needs and challenges. Philos Trans R Soc Lond B Biol Sci 360(1463):2049–2065

Beutler JF, Bertol I, Veiga M, Wildner LP (2003) Perdas de solo e água num Latossolo Vermelho aluminoférrico submetido a diferentes sistemas de preparo e cultivo sob chuva natural. Rev Bras Ciênc Solo 27:509–517

Biringer J (2003) Forest ecosystems threatened by climate change: promoting long-term forest resilience. In: Hansen LJ, Biringer JL, Hoffman JR (eds) Buying time: a user's manual for building resistance and resilience to climate change in natural systems. WWF, Washington, pp 41–69

Biringer J, Hansen LJ (2005) Restoring forest landscapes in the face of climate change. In: Mansourian S, Vallauri D, Dudley N (eds) Forest restoration in landscapes: beyond planting trees. Springer, New York, pp 31–37

Blignaut JN, Aronson J (2008) Getting serious about maintaining biodiversity. Conserv Lett 1:12–17

Bonan GB (2008) Forests and climate change: forcings, feedbacks and the climate benefit of forests. Science 320(5882):1444–1449

Brancalion PHS, Viani RA, Calmon M et al (2013) How to organize a large-scale ecological restoration program? The framework developed by the Atlantic Forest Restoration Pact in Brazil. J Sustain For 32(7):728–744

Brancalion PHS, Garcia LC, Loyola C et al (2016) A critical analysis of the Native Vegetation Protection Law of Brazil (2012): updates and ongoing initiatives. Natureza Conservação 14(1):1–15

Brown AE, Zhang L, McMahon TA et al (2005) A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. J Hydrol 310:28–61

Buckingham K, Hanson C (2015) The restoration diagnostic case example: South Korea. World Resources Institute. 8 pp. https://www.wri.org/sites/default/files/WRI_Restoration_Diagnostic_Case_Example_SouthKorea.pdf. Accessed 12 Dec 2017

Bullock JM, Aronson J, Newton AC, Pywell RF, Rey-Benayas JM (2011) Restoration of ecosystem services and biodiversity. Trends Ecol Evol 26:541–549

Calmon M, Brancalion PHS, Paese A, Aronson J, Castro P, da Silva SC, Rodrigues RR (2011) Emerging threats and opportunities for large-scale ecological restoration in the Atlantic Forest of Brazil. Restor Ecol 19(2):154–158

Cao S, Zhang J (2015) Political risks arising from the impacts of large-scale afforestation on water resources of the Tibetan Plateau. Gondwana Res 28(2):898–903

Cao S, Tian T, Chen L, Dong X, Yu X, Wang G (2010) Damage caused to the environment by reforestation policies in arid and semi-arid areas of China. Ambio 39:279–283

Cao S, Chen L, Shankman D, Wang C, Wang X, Zhang H (2011) Excessive reliance on afforestation in China's arid and semi-arid regions: lessons in ecological restoration. Earth-Sci Rev 104:240–245

Cardinale BJ, Duffy JE, Gonzalez AG, Hooper DU, Perrings C, Venail P, Narwani A, Mace GM, Tilman D, Wardle DA, Kinzig AP, Daily GC, Loreau M, Grace JB, Larigauderie A, Srivastava DS, Naeem S (2012) Corrigendum: biodiversity loss and its impact on humanity. Nature 486:59–67

Chazdon RL (2008) Beyond deforestation: restoring forests and ecosystem services on degraded lands. Science 320(5882):1458–1460

Chazdon RL, Guariguata MR (2016) Natural regeneration as a tool for large-scale forest restoration in the tropics: prospects and challenges. Biotropica 48(6):716–730

Chazdon RL, Uriarte M (2016) Natural regeneration in the context of large-scale forest and landscape restoration in the tropics. Biotropica 48(6):707–715

Chazdon RL, Broadbent EN, Rozendaal DMA et al (2016) Carbon sequestration potential of second-growth forest regeneration in the Latin American tropics. Sci Adv 2(5):1–10

Chazdon RL, Brancalion PHS, Lamb D, Laestadius L, Calmon M, Kumar C (2017) A policy-driven knowledge agenda for global forest and landscape restoration. Conserv Lett 10(1):125–132

Coe MT, Latrubesse EM, Ferreira ME, Amsler ML (2011) The effects of deforestation and climate variability on the streamflow of the Araguaia River, Brazil. Biogeochemistry 105(1–3):119–131

Crookes DJ, Blignautb JN, de Witc MP et al (2013) System dynamic modelling to assess economic viability and risk trade-offs for ecological restoration in South Africa. J Environ Manag 120:138–147

Cunningham SC, Mac Nallyb R, Bakerc PJ et al (2015) Balancing the environmental benefits of reforestation in agricultural regions. Perspect Plant Ecol Evol Syst 17:301–317

De Groot R, Blignaut J, van der Ploeg S et al (2013) Benefits of investing in ecosystem restoration. Conserv Biol 27(6):1286–1293

de Oliveira JAP (2009) The implementation of climate change related policies at the subnational level: an analysis of three countries. Habitat Int 33(3):253–259

Dean W (1996) A ferro e fogo: a história e a devastação da Mata Atlântica brasileira. Cia. das Letras, São Paulo

Deng L, Yana W, Zhangb Y, Shangguan Z (2016) Severe depletion of soil moisture following land-use changes for ecological restoration: evidence from northern China. For Ecol Manag 366:1–10

Devoto M, Bailey S, Craze P, Memmott J (2012) Understanding and planning ecological restoration of plant-pollinator networks. Ecol Lett 15:319–328

Di Gregorio M, Nurrochmat DR, Paavola J, Sari IM et al (2017) Climate policy integration in the land use sector: mitigation, adaptation and sustainable development linkages. Environ Sci Pol 67:35–43

Dias RA, Bastazini VAG, Gonçalves MSS, Bonow FC, Müller SC (2013) Shifts in composition of avian communities related to temperate-grassland afforestation in southeastern South America. Iheringia Sér Zool 103(1):12–19

Díaz S, Demissew S, Carabias J, Joly C, Lonsdale M, Ash N, Larigauderie A, Adhikari JR, Arico S, Báldi A, Bartuska A, Baste IA, Bilgin A, Brondizio E, Chan KMA, Figueroa VE, Duraiappah A, Fischer M, Hill R, Koetz T, Leadley P, Lyver P, Mace GM, Martin-Lopez B, Okumura M, Pacheco D, Pascual U, Pérez ES, Reyers B, Roth E, Saito O, Scholes RJ, Sharma N, Tallis H, Thaman R, Watson R, Yahara T, Hamid ZA, Akosim C, al-Hafedh Y, Allahverdiyev R, Amankwah E, Asah ST, Asfaw Z, Bartus G, Brooks LA, Caillaux J, Dalle G, Darnaedi D, Driver A, Erpul G, Escobar-Eyzaguirre P, Failler P, Fouda AMM, Fu B, Gundimeda H, Hashimoto S, Homer F, Lavorel S, Lichtenstein G, Mala WA, Mandivenyi W, Matczak P, Mbizvo C, Mehrdadi M, Metzger JP, Mikissa JB, Moller H, Mooney HA, Mumby P, Nagendra H, Nesshover C, Oteng-Yeboah AA, Pataki G, Roué M, Rubis J, Schultz M, Smith P, Sumaila R, Takeuchi K, Thomas S, Verma M, Yeo-Chang Y, Zlatanova D (2015) The IPBES Conceptual Framework—connecting nature and people. Curr Opin Environ Sustain 14:1–16

do Nascimento Nadruz V, Gallardo ALCF, Montaño M et al (2018) Identifying the missing link between climate change policies and sectoral/regional planning supported by Strategic Environmental Assessment in emergent economies: lessons from Brazil. Renew Sust Energ Rev 88:46–53

Durigan G, Melo ACG (2011) An overview of public policies and research on ecological restoration in the state of São Paulo, Brazil. In: Figueiroa EB (ed) Biodiversity conservation in the Americas: lessons and policy recommendations. Editorial FEN-Universidad de Chile, Santiago, pp 320–355

Durigan G, Guerin N, da Costa JN (2013) Ecological restoration of Xingu Basin headwaters: motivations, engagement, challenges and perspectives. Philos Trans R Soc Lond Ser B Biol Sci 368(1619):1–9

Faggin JM, Behagel JH (2017) Translating sustainable forest management from the global to the domestic sphere: the case of Brazil. Forest Policy Econ 85(1):22–31

Farley KA, Jobbágy EG, Jackson RB (2005) Effects of afforestation on water yield: a global synthesis with implications for policy. Glob Chang Biol 11:1565–1576
Fengler FH, Bressane A, Carvalho MM, Longo RM, de Medeiros GA, de Melo WJ, Jakovac CC, Ribeiro AI (2017) Forest restoration assessment in Brazilian Amazonia: a new clustering-based methodology considering the reference ecosystem. Ecol Eng 108:93–99
Fernandes GW, Coelho MS, Machado RB, Ferreira ME, Aguiar LMS, Dirzo R, Scariot A, Lopes CR (2016) Afforestation of savannas: an impending ecological disaster. Natureza Conservação 14(2):146–151
Foley JA, DeFries R, Asner GP et al (2005) Global consequences of land use. Science 309(5734):570–574
Freire JM, Urzedo DI, Piña-Rodrigues FC (2017) A realidade das sementes nativas no Brasil: desafios e oportunidades para a produção em larga escala. Seed News 21(5):24–28
Gatica-Saavedra P, Echeverría C, Nelson CR (2017) Ecological indicators for assessing ecological success of forest restoration: a world review. Restor Ecol 25(6):850–857
Gibbs HK, Salmon JM (2015) Mapping the world's degraded lands. Appl Geogr 57:12–21
Gibbs HK, Rausch L, Munger J, Schelly I, Morton DC, Noojipady P, Soares-Filho B, Barreto P, Micol L, Walker NF (2015) Brazil's Soy Moratorium. Science 347(6220):377–378
Godar J, Gardner TA, Tizado EJ, Pacheco P (2014) Actor-specific contributions to the deforestation slowdown in the Brazilian Amazon. Proceedings of the National Academy of Sciences 111(43):15591–96. https://doi.org/10.1073/pnas.1322825111
Government of Costa Rica—GOCR (2011) Propuesta para la Preparación de Readiness R-PP. Submitted to FCPF April 2011. San José, Costa Rica 1-150pp. https://www.forestcarbonpartnership.org/sites/forestcarbonpartnership.org/files/Documents/PDF/Jan2013/R-PPCostaRica%20(2a).pdf. Accessed 12 Dec 2017
Green Climate Fund - GCF (2015) Consideration of funding proposals—Addendum Funding proposal package for FP003. http://www.greenclimate.fund/-/resilience-increase-of-ecosystems-and-communities-through-restoration-of-the-productive-bases-of-salinized-lands?inheritRedirect=true&redirect=%2Fprojects%2Fbrowse-projects
Hagger V, Dwyer J, Wilson K (2017) What motivates ecological restoration? Restor Ecol 25(5):832–843
Hanson C, Yonavjak L, Clarke C et al (2010) Southern forests for the future. World Resources Institute, Washington. http://wriorg.s3.amazonaws.com/s3fs-public/pdf/southern_forests_for_the_future.pdf. Accessed 12 Dec 2017
Harris JA, Hobbs RJ, Higgs E, Aronson J (2006) Ecological restoration and global climate change. Restor Ecol 14(2):170–176. https://doi.org/10.1111/j.1526-100X.2006.00136.x
Heikkila T, Gerlak AK (2016) Investigating collaborative processes over time: a 10-year study of the South Florida Ecosystem Restoration Task Force. Am Rev Public Adm 46:180–200
Hill R, Grant C, George M (2012) A typology of indigenous engagement in Australian environmental management: implications for knowledge integration and social-ecological system sustainability. Ecol Soc 17:1–17
Hobbs RJ, Walker LR, Walker J (2007) Integrating restoration and succession. In: Walker LR, Walker J, Hobbs RJ (eds) Linking restoration and ecological succession. Springer, New York, pp 168–179
Holl KD (2017) Research directions in tropical forest restoration. Ann Mo Bot Gard 102(2):237–250
Indústria Brasileira de Árvores—Ibá (2014) Anuário da Indústria Brasileira de Árvores. http://www.ipef.br/estatisticas/relatorios/anuario-iba_2014.pdf. Accessed 12 Dec 2017
Instituto Escolhas (2016) Quanto Custa Reflorestar 12 Milhões de Hectares? Instituto Escolhas, São Paulo
International Union for Conservation of Nature and Natural Resources—IUCN (2016) In: Moraes MA (ed) Forest landscape restoration in Brazil. UICN, Brasília
Isbell F, Craven D, Connolly J (2015) Biodiversity increases the resistance of ecosystem productivity to climate extremes. Nature 526:574–577
Jackson RB, Jobbágy EG, Avissar R (2005) Trading water for carbon with biological carbon sequestration. Science 30:1944–1947
Jenkins A, Murray B et al (2010) Valuing ecosystem services from wetlands restoration in the Mississippi Alluvial Valley. Ecol Econ 69:1051–1061
Jiang X, Lu D, Moran E, Calvi MF, Dutra LV, Li G (2018) Examining impacts of the Belo Monte hydroelectric dam construction on land-cover changes using multitemporal Landsat imagery. Appl Geogr 97:35–47
Kaimowitz D, Smith J (2001) Soybean technology and the loss of natural vegetation in Brazil and Bolivia. In: Angelsen A, Kaimowitz D (eds) Agricultural technologies and tropical deforestation. CABI Publishing, Wallingford, Oxon, pp 195–211
Knutti R, Rogelj J, Sedláček J, Fischer EM (2016) A scientific critique of the two-degree climate change target. Nat Geosci 9:13–18
Kollmann J, Meyer ST, Bateman R (2016) Integrating ecosystem functions into restoration ecology-recent advances and future directions. Restor Ecol 24(6):722–730

Korean Forest Service—KFS (2010) Current status of forests. http://english.forest.go.kr/newkfsweb/html/EngHtmlPage.do?pg=/english/korea/korea_020_010.html&mn=ENG_02_02. Accessed 12 Dec 2017

Korean Forest Service—KFS (2013) Korean forests at a glance 2013. http://english.forest.go.kr/newkfsweb/html/EngHtmlPage.do?pg=/esh/koforest/UI_0101_030000.html&mn=ENG_01_03. Accessed 12 Dec 2017

Lamb D, Gilmour D (2003) Rehabilitation and restoration of degraded forests. IUCN and WWF, Gland, Cambridge, and Gland

Latawiec AE, Strassburg BBN, Brancalion PHS, Rodrigues RR, Gardner T (2015) Creating space for large-scale restoration in tropical agricultural landscapes. Front Ecol Environ 13(4):211–218

Leite MGP, Fujaco MAG (2010) A long-term annual water balance analysis of the Aracuai River basin, Brazil. J Geogr Syst 20:938–946

Lenschow A (2002) "Greening" the European Union: are there lessons to be learned for international environmental policy? Glob Environ Chang 12:241–245

Lestrelin G, Pelletreau A, Valentin C (2007) Local knowledge and land degradation: a participatory case study in the uplands of the Lao PDR. In: Gebbie L, Glendinning A, Lefroy-Braun R, Victor M (eds) Proceedings of the 2nd international conference on sustainable sloping lands and watershed management: linking research to strengthen upland policies and practices, pp 270-286

Li Y, Piao S, Li LZ, Chen A et al (2018) Divergent hydrological response to large-scale afforestation and vegetation greening in China. Sci Adv 4(5):eaar4182

Lindenmayer D, Hobbs RJ, Montague-Drake R et al (2008) A checklist for ecological management of landscapes for conservation. Ecol Lett 11(1):78–91

Liu J, Liang M, Li L, Long H, de Jong W (2017) Comparative study of the forest transition pathways of nine Asia-Pacific countries. Forest Policy Econ 76:25–34

Loomis J, Kent P, Strange L, Fausch K, Covich A (2000) Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecol Econ 33:103–117

Mansourian S (2016) Understanding the relationship between governance and forest landscape restoration. Conserv Soc 14(3):267–278

Maron M, Cockfield G (2008) Managing trade-offs in landscape restoration and revegetation projects. Ecol Appl 18(8):2041–2049

Maya ROC (1966) A Floresta da Tijuca. Centro de conservação da Natureza. Ed. Estado da Guanabara, Rio de Janeiro

Meli P, Brancalion PHS (2017) Contrasting regulatory frameworks to govern riparian forest restoration in Mexico and Brazil: current status and needs for advances. World Dev Perspect 5:60–62

Melo FPL, Pinto SRR, Brancalion PHS, Castro PS, Rodrigues RR, Aronson J, Tabarelli M (2013) Priority setting for scaling-up tropical forest restoration projects: early lessons from the Atlantic Forest Restoration Pact. Environ Sci Pol 33:395–404. https://doi.org/10.1016/j.envsci.2013.07.013

Méndez-Toribio M, Martínez-Garza C, Cecconc E, Guariguata MR (2017) Current ecological restoration plans in Latin America: progress and omissions. Ciencias Ambientales 51(2):1–30

Ministério do Meio Ambiente—MMA (2011) Pagamentos por Serviços Ambientais na Mata Atlântica: lições aprendidas e desafios. Série Biodiversidade, 42. Guedes FB and Seehusen SE (eds), Brasília

Ministério do Meio Ambiente—MMA (2016) Documento-base para subsidiar os diálogos estruturados sobre a elaboração de uma estratégia de implementação e financiamento da Contribuição Nacionalmente Determinada do Brasil ao Acordo de Paris. http://www.mma.gov.br/images/arquivos/clima/ndc/NDCDocBase.pdf. Accessed 12 Dec 2017

Ministério do Meio Ambiente—MMA (2017) Plano Nacional de Recuperação da Vegetação Nativa. MMA, Brasília

Minnemeyer S, Laestadius L, Sizer N et al (2011) A world of opportunity. World Resources Institute, Washington, DC. http://www.wri.org/sites/default/files/world_of_opportunity_brochure_2011-09.pdf. Accessed 12 Dec 2017

Nelson E, Mendoza G, Regetz J, Polasky S, Tallis H, Cameron DR, Chan KMA, Daily GC, Goldstein J, Kareiva PM, Lonsdorf E, Naidoo R, Ricketts TH, Shaw MR (2009) Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Front Ecol Environ 7(1):4–11

Nosetto MD, Jobbágy EG, Paruelo JM (2005) Land-use change and water losses: the case of grassland afforestation across a soil textural gradient in central Argentina. Glob Chang Biol 11:1101–1117

Noss R (2001) Beyond Kyoto: forest management in a time of rapid climate change. Conserv Biol 15(3):578–590

Ostrom E, Cox M (2010) Moving beyond panaceas: a multi-tiered diagnostic approach for social-ecological analysis. Environ Conserv 37:451–463

Overbeck GE, Hermann J-M, Andrade BO, Boldrini II, Kiehl K, Kirmer A, Koch C, Kollmann J, Meyer ST, Müller SC, Nabinger C, Pilger GE, Trindade JPP, Vélez-Martin E, Walker EA, Zimmermann DG, Pillar VD (2013) Restoration ecology in Brazil—time to step out of the forest. Nat Conservação 11:92–95

Overbeck GE, Vélez-Martin E, Scarano FR et al (2015) Conservation in Brazil needs to include non-forest ecosystems. Divers Distrib 21:1455–1460
Pacheco P (2012) Soybean and oil palm expansion in South America: a review of main trends and implications. CIFOR Working Paper 90, CIFOR, Indonesia
Palmer MA, Ambrose RF, LeRoy PN (2006) Ecological theory and restoration ecology. In: Falk DA, Palmer MA, Zedler JB (eds) Foundations of restoration ecology. Island Press, Washington, pp 1–10
Park MS, Youn YC (2017) Reforestation policy integration by the multiple sectors toward forest transition in the Republic of Korea. Forest Policy Econ 76:45–55
Pearson TR, Brown S, Murray L, Sidman G (2017) Greenhouse gas emissions from tropical forest degradation: an underestimated source. Carbon Balance Manag 12(3):1–11
Pinheiro A, Teixeira LP, Kaufmann V (2009) Capacidade de infiltração de água em solos sob diferentes usos e práticas de manejo agrícola. Rev Ambient Água 4:188–199
Pitta TP, Mendonça ML (2015) A empresa Radar S/A e a especulação com terras no Brasil. Outras Expressões, São Paulo
Pocewicz A, Garcia E (2016) Deforestation facilitates widespread stream habitat and flow alteration in Brazilian Amazon. Biol Conserv 203:252–259
Prack K, Marrs R et al (2007) Manipulation of succession. In: Walker LR, Walker J, Hobbs RJ (eds) Linking restoration and ecological succession. Springer, New York, pp 121–149
Reed MS, Buenemann M, Atlhopheng J (2011) Cross-scale monitoring and assessment of land degradation and sustainable land management: a methodological framework for knowledge management. Land Degrad Dev 22:261–271
Richards RC, Rerolle J, Aronson J, Pereira PH, Gonçalves H, Brancalion PHS (2015) Governing a pioneer program on payment for watershed services: stakeholder involvement, legal frameworks and early lessons from the Atlantic forest of Brazil. Ecosyst Serv 16:23–32
Rizek R (2013) Fomentos a projetos de restauração ecológica. In: Políticas Públicas para a Restauração Ecológica e Conservação da Biodiversidade. Instituto de Botânica—SMA, São Paulo
Roberts L, Stone R, Sugden A (2009) The rise of ecological restoration. Science 325(5940):555
Rochedo PR, Soares-Filho B, Schaeffer R et al (2018) The threat of political bargaining to climate mitigation in Brazil. Nat Clim Chang 8:695–698
Rodrigues RR, Lima RAF, Gandolfi S, Nave AG (2009) On the restoration of high diversity forests: 30 years of experience in the Brazilian Atlantic Forest. Biol Conserv 142:1242–1251
Rodrigues RR, Gandolfi S, Nave AG (2011) Large-scale ecological restoration of high-diversity tropical forests in SE Brazil. For Ecol Manag 261:1605–1613
Rogelj J, den Elzen M, Höhne N, Fransen T, Fekete H, Winkler H, Schaeffer R, Sha F, Riahi K, Meinshausen M (2016) Paris Agreement climate proposals need a boost to keep warming well below 2 °C. Nature 534:631–639
Sader AS, Joyce AT (1988) Deforestation. Rates and Trends in Costa Rica, 1940 to 1983 Biotropica 20(1):11–19
Santana CAA (2002) Estrutura e florística de fragmentos de florestas secundárias de encosta no Município do Rio de Janeiro. Dissertation, Universidade Federal Rural do Rio de Janeiro
Scariot A (2013) Land sparing or land sharing: the missing link. Front Ecol Environ 11:177–178
Secretaria de Assuntos Estratégicos—SAE (2013) Impacto da revisão do código florestal: como viabilizar o grande desafio adiante? https://www.socioambiental.org/sites/blog.socioambiental.org/files/nsa/arquivos/artigo-codigo-florestal_britaldo_soares_sae_2013pdf.pdf. Accessed 12 Dec 2017
Shiferaw BA, Okello J, Reddy RV (2009) Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices. Environ Dev Sustain 11:601–619
Silva JA, Nobre AD, Manzatto CV (2011) O código florestal e a ciência: contribuições para o diálogo. Sociedade Brasileira para o Progresso da. Ciência: Academia Brasileira de Ciência, São Paulo
Silva APM, Schweizer D, Marques HR (2017) Can current native tree seedling production and infrastructure meet an increasing forest restoration demand in Brazil? Restor Ecol 25(4):509–515
Soares-Filho B, Rajão R, Macedo M (2014) Cracking Brazil's forest code. Science 344:363–364
Society for Ecological Restoration International—SER (2004) Science and policy working group the SER International Primer on ecological restoration. Society for Ecological Restoration International. Tucson, Arizona
Sousa PM (2005) Análise do licenciamento ambiental como instrumento de política do meio ambiente no Rio Grande do Norte—Período 1992–2003. Dissertation, Universidade Federal do Rio Grande do Norte
Spera SA, Galford GL, Coe MT, Macedo MN, Mustard JF (2016) Land-use change affects water recycling in Brazil's last agricultural frontier. Glob Chang Biol 22:3405–3413
Strassburg BBN, Barros FSM, Crouzeilles R, Iribarrem A, Santos JS, Silva D, Sansevero JBB, Alves-Pinto HN, Feltran-Barbieri R, Latawiec AE (2016) The role of natural regeneration to ecosystem services provision and habitat availability: a case study in the Brazilian Atlantic Forest. Biotropica 48(6):890–899
Suding KN (2011) Toward an era of restoration in ecology: successes, failures, and opportunities ahead. Annu Rev Ecol Evol Syst 42(42):465–487
Suding K, Higgs E, Palmer M, Callicott JB, Anderson CB, Baker M, Gutrich JJ, Hondula KL, LaFevor MC, Larson BMH, Randall A, Ruhl JB, Schwartz KZS (2015) Committing to ecological restoration. Science 348:638–640

Suganuma MS, Durigan G (2015) Indicators of restoration success in riparian tropical forests using multiple reference ecosystems. Restor Ecol 23(3):238–251
Turner WR, Oppenheimer M, Wilcove DS (2009) A force to fight global warming. Nature 462:278–279
United Nations Framework Convention on Climate Change—UNFCCC (1992) Report No. FCCC/INFORMAL/84 https://unfccc.int/resource/docs/convkp/conveng.pdf. Accessed 12 Dec 2017
United Nations Framework Convention on Climate Change—UNFCCC (2015) Adoption of the Paris Agreement. Report n° FCCC/CP/2015/L.9/Rev.1 http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf
USDA Forest Service (n.d.) https://www.fia.fs.fed.us/slides/Trend-data/Web%20Historic%20Spreadsheets/1630_2000_US_pop_and_forestarea.xls. Accessed 12 Dec 2017
Veldman JW, Overbeck GE, Negreiros D, Mahy G, le Stradic S, Fernandes GW, Durigan G, Buisson E, Putz FE, Bond WJ (2015a) Tyranny of trees in grassy biomes. Science 347:484–485
Veldman JW, Overbeck GE, Negreiros D, Mahy G, le Stradic S, Fernandes GW, Durigan G, Buisson E, Putz FE, Bond WJ (2015b) Where tree planting and forest expansion are bad for biodiversity and ecosystem services. Bioscience 65(10):1011–1018
Walker LR, del Moral R (2003) Primary succession and ecosystem rehabilitation. Cambridge University Press, Cambridge
Wiener JB (2015) Towards an effective system of monitoring, reporting, and verification. In: Barrett S, Carraro C, de Melo J (eds) Towards a workable and effective climate regime. Centre for Economic Policy Research
World Resources Institute—WRI (2014) The role of natural regeneration in large-scale forest and landscape restoration: challenge and opportunity building the foundation for a global natural regeneration partnership. In: Org. União Internacional para a Conservação da Natureza—UICN, International Institute for Sustainability—IIS, People and Reforestation in the Tropics—PARTNERS (eds) 56 pp
Xu J, Yin R, Li Z, Liu C (2006) China's ecological rehabilitation: unprecedented efforts, dramatic impacts, and requisite policies. Ecol Econ 57:595–607
Xu J, van Noordwijk M, He J, Kim KJ, Jo RS, Pak KG, Kye UH, Kim JS, Kim KM, Sim YN, Pak JU, Song KU, Jong YS, Kim KC, Pang CJ, Ho MH (2012) Participatory agroforestry development for restoring degraded sloping land in DPR Korea. Agrofor Syst 85:291–303
Young CEF (2016) Estudos e produção de subsídios técnicos para a construção de uma Política Nacional de Pagamento por Serviços. Final Report. Rio de Janeiro, Instituto de Economia, UFRJ, 93pp
Zhenghu D, Honglang X, Xinrong L, Zhibao D, Gang W (2004) Evolution of soil properties on stabilized sands in the Tengger Desert, China. Geomorphology 59:237–246

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