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Brazilian Atlantic forest: impact, vulnerability, and adaptation to climate change

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Abstract Biodiversity hotspots are among some of the habitats most threatened by climate change, and the Brazilian Atlantic forest is no exception. Only 11.6 % of the natural vegetation cover remains in an intensely fragmented state, which results in high vulnerability of this biome to climate change. Since >60 % of the Brazilian people live within the Atlantic forest domain, societies both in rural and urban areas are also highly vulnerable to climate change. This review examines the vulnerabilities of biodiversity and society in the Atlantic forest to climate change, as well as impacts of land use and climate change, particularly on recent biological evidence of strong synergies and feedback between them. We then discuss the crucial role ecosystem-based adaptation to climate change might play in increasing the resilience of local society to future climate scenarios and provide some ongoing examples of good adaptive practices, especially related to ecosystem restoration and conservation incentive schemes such as payment for ecosystem services. Finally, we list a set of arguments about why we trust that the Atlantic forest can turn from a "shrinking biodiversity hotspot" to a climate adaptation "hope spot" whereby society's vulnerability to climate change is reduced by protecting and restoring nature and improving human life standards.

Keywords Atlantic forest · Climate change · Ecosystem-based adaptation · Vulnerability

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Introduction

The domain of the Brazilian Atlantic Forest biome is home to more than 100 million Brazilians and is the economic engine of the country. It contributes to 70 % of the gross domestic product (GDP) and 2/3 of the industrial economy (Martinelli et al. 2013). Therefore, some of the largest Brazilian urban concentrations are within the Atlantic forest territory, such as the metropolis of Rio de Janeiro and São Paulo. Although 90 % of the Atlantic forest population lives in urban centres, at the same time more than half of the national land dedicated to horticulture is within the biome (Pinto et al. 2012). Urbanization, industrialization, and agriculture expansion meant loss of natural habitats and, even though they led to economic growth, they did not translate into a fair distribution of wealth and human wellbeing is often challenged. Social inequality remains a major issue, although there has been a reduction in poverty levels which afflicted some twenty-five percent of the people that lived in the Atlantic forest domain until the end of the last century (Galindo-Leal and Câmara 2003). For instance, a decade ago mean Human Development Index of Atlantic Forest municipalities in the Brazilian northeast was 0.630, against 0.744 from southeastern municipalities and 0.767 from southern municipalities (IPEA et al. 2003).

Poverty and major loss of natural vegetation cover, as seen in the Atlantic forest domain, interact with climatic changes in perverse ways. Societies that are experiencing shortage of natural resources are the least resilient to climate change; and poor people are the most vulnerable to climate impacts (Fisher et al. 2014; Magrin et al. 2014). Therefore, due to the combination of natural resource decline and low human wellbeing standards, it is not surprising that parts of the Brazilian northeast and the metropolitan areas of Rio de Janeiro, São Paulo and Belo Horizonte are pointed as socio-climatic hotspots (Torres et al. 2012) and the Atlantic forest is classified as one of the 3 biodiversity hotspots most vulnerable to climate change (Béllard et al. 2014).

In this context, and according to the definition of the Intergovernmental Panel on Climate Change (IPCC), vulnerability to climate change is the propensity or predisposition of a given system to be adversely affected by climate change, including climate variability, extremes and hazards (Burkett et al. 2014). It therefore applies to social systems, natural systems, or both. Vulnerable systems are subject to impact. "Impact", according to the IPCC (Agard and Schipper 2014), refers to "effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period". Evidence of climate-change impacts is strongest and most comprehensive for natural systems (IPCC 2014). In order to reduce vulnerability and minimize impact, adaptation strategies are needed. In view of the high predisposition of the Brazilian Atlantic forest to the adverse effects of climate change (Béllard et al. 2014; Jantz et al. 2015), in this paper we review vulnerability, reported and projected impacts on biodiversity, and we examine adaptation strategies based on ecosystems for the local society to become more resilient to climate change. Societal adaptation to climate change within the Atlantic forest domain, we propose, will rely heavily on ecosystem-based practices, which simultaneously reduce poverty and enhance natural vegetation cover.

Vulnerability and impact

Biodiversity

Conversion of natural ecosystems is the main cause of biodiversity and ecosystem loss in Brazil and South America as a whole, and is also a driver of anthropogenic climate change, as native vegetation removal generates the release of greenhouse gases (Magrin et al. 2014). Landscape conversion started off even before the arrival of the Portuguese colonizers at the Brazilian coast in 1500, when native Brazilians living in the Atlantic forest biome intensely used forest resources for their livelihoods (Gaspar et al. 2008). Portuguese colonization of Brazil began at the Atlantic forest domain (Dean 1996) and today more than 60 % of the Brazilian population lives in this biome. The replacement of native forests by agriculture or by urban centers intensified in the nineteenth and twentieth centuries. For example, more than 1 million hectares of forest were lost between 1985 and 1996 (Young 2003). Despite a national legislation from 2008 that protects the biome, 23,948 ha of remnant vegetation were still deforested between 2012 and 2013, 92 % of which were in the states of Minas Gerais, Bahia, Piauí and Paraná (SOS Mata Atlântica and INPE 2014). As a result, the Atlantic forest is a biodiversity hotspot, one of the 35 places in the world where high biodiversity thrives although large portions of the habitats were lost (Mittermeier et al. 2005; Williams et al. 2011). This biome became an archipelago of small forest islands surrounded by a matrix that can be agriculture, pasture, artificial forests (eucalypts or pine-trees) or urban (Joly et al. 2014). Only 11.6 % of the natural vegetation cover of the Atlantic forest remains (Ribeiro et al. 2009) and in an intensely fragmented state: 83.4 % of the fragments are less than 50 ha (Ribeiro et al. 2011).

It has been estimated that this fragmentation means—over a 10-year period—a total carbon loss of 69 Tg C (±14 Tg C) in addition to the loss due to deforestation (Pütz et al. 2014). In other words, deforestation is the largest contribution to carbon emission due to land use (Ciais et al. 2013), but fragmentation significantly adds to that by a reduction in biomass: diverse, old-growth flora is replaced by early successional plant species in highly fragmented landscapes (Joly et al. 2014). Moreover, it has also been shown that Atlantic forest fragmentation leads to a biotic homogenization. For instance, tree species with large fleshy seeds or fruits, species pollinated by specialized vectors or emergent species are becoming rarer in small fragments and pioneer and early successional species begin to dominate (Lôbo et al. 2011; Leão et al. 2014).

Indeed, the forest fragments that remain in the Atlantic Forest are often too small to allow for the persistence of many species. It is therefore not surprising that 1544 plant species of the Atlantic forest are threatened with extinction, or 60 % of the entire list of threatened species of the Brazilian flora (Martinelli et al. 2013). For the fauna, the situation is similar: 380 threatened species or 60 % of the official list of Brazilian threatened species (Paglia et al. 2008). Moreover, vertebrate loss has been intense (Canale et al. 2012) and 9 % of all terrestrial vertebrate known to the biome are threatened with extinction and, among the endemic, one in each four species is threatened (Paglia et al. 2008).

The historic impact of land use change by deforestation on biodiversity turns the Atlantic forest all the more vulnerable to climate change. Projections of future climate scenarios indicate a reduction in the distribution range of many important plant species such as the palm-heart (*Euterpe edulis*) and the legume tree known as "ingá" (*Inga sessilis*), and also a distribution shift towards the south (Colombo and Joly 2010). For vertebrates, there are also projections of local extinction for birds (Anciães and Peterson

2006; Souza et al. 2011) and of amphibians (Loyola et al. 2014). Considering the high rates of endemism in the biome (Mittermeier et al. 2005), such projections are indicative of major future impacts if climate change and deforestation proceed business as usual (Brook et al. 2008; Joly et al. 2014).

Furthermore, there are biological evidences of a process of "secondarization" and even "savannization" in the Atlantic forest sites. Joly et al. (2014) reviewed several studies that indicate a process of biotic reorganization especially of fragmented Atlantic forest where land use changes and incidence of fire replace mature forests by early successional ones. This process they call secondarization is very much related to the biotic homogenization already described. A recent thesis (Sansevero 2013), still unpublished, has found however an Atlantic forest site affected by fire and possibly climate change that is remarkably similar to the Brazilian savanna (Cerrado) in traits related to vegetation structure, species composition and plant functionality. Burned communities exhibited more C_4 grass cover, trees with thicker bark, and a lower canopy cover compared to old growth forests, and 81 % of the plant species observed in the burned communities presents a widespread distribution and also occur in the Cerrado. This stands out as a biological evidence for savannization of the rainforest, probably resulting from the synergy between land use change (fragmentation, deforestation, fire) and climate change, resulting in a warmer and drier climate. This is in harmony with some of the climate projections available for the savannization of another rainforest, the Amazon (Salazar et al. 2007).

Finally, the marginal habitats in the rainforest periphery of this biome—the high altitude vegetation above the tree line (or "campos de altitude") and also the coastal vegetation in sandy coastal plains (or "restingas") and mangroves (Scarano 2002, 2009)—are also vulnerable to climate change. High altitude ecosystems' vulnerability is due mostly to the sensitivity of such species to higher temperatures, whereas coastal habitats such as restingas and mangroves are potentially threatened by sea-level rise (Magrin et al. 2014). Since such habitats are well recognized for being important carbon sinks and storages (Dias et al. 2006; Scarano 2007), habitat loss might mean a strong synergy with climate change.

Ecosystem services and society

Since biodiversity underpins the ecosystem services that are essential both for survival and wellbeing of human societies, food production, climate stability, water security and even cultural services are highly vulnerable to further land-use change and climate change in the Atlantic forest (e.g., Ferraz et al. 2014; Joly et al. 2014). Historic and ongoing impacts on key ecosystem services expose residents of cities and rural areas in the Atlantic forest domain to extreme events, along with freshwater and food insecurity. Magrin et al. (2014) have recently described an increase in the occurrence of extreme events (heavy rains, landslides, heat waves, floodings and droughts) in Central and South America as a whole, and particularly in the southeast of South America, where much of Atlantic forest lies (Nobre et al. 2010). Rainfall distribution pattern in the biome plays an important role in climate regulation. The relative balance of this system controls the stability of soils on mountain slopes, as well as the level of rivers and reservoirs. When this balance is impaired by climate variability it often results in extreme events leading to floodings and landslides as seen in recent years in the states of São Paulo, Rio de Janeiro and Santa Catarina (see also Joly et al. 2014). On the other hand, there is also evidence indicating a positive relationship between tree cover and number of rainy days in the Atlantic forest. Webb et al.

(2005) have found that more fragmented and patchier forests are associated with fewer rainy days.

Therefore, water scarcity recently became a major issue for cities in the Atlantic forest, although Brazil has some 20 % of global water resources (Freitas 2003). Within the Atlantic forest, the Brazilian northeast suffers from water scarcity during the dry season and the relationship between water consumption and availability in some portions of the biome is considered critical (ANA 2013). The situation may be worsened with time, since water resources are poorly protected and managed: Nogueira et al. (2010) have shown that 29 % of the countrýs microbasins lost more than 70 % of their vegetation cover and only 26 % have a significant overlap with protected areas or indigenous territories. Moreover, 40 % of the Brazilian microbasins overlap with hydroenergy plants and have high rates of habitat loss. Among degraded and threatened microbasins, a majority is found in the Atlantic Forest biome. These numbers are reason for concern given that Brazil is one of the eight nations that altogether respond for 50 % of the water footprint of the planet (Hoekstra and Chapagain 2007) and irrigation for agriculture is responsible for 72 % of the water consumption in the country (ANA 2013). Since Brazilian economy is very much centered in agriculture, there is a tendency of water competition with other sectors, such as energy or sanitation: 83 % of Brazilian energy is generated by hydros (Lucena et al. 2009) and sanitation is still a major issue in the country. The population in the Atlantic forest domain responds for 70 % of the Brazilian GDP, and as the region develops it will demand an even greater use of water. The ongoing political conflicts between the governments of the states of Rio de Janeiro and São Paulo for the water of the much deforested Paraíba do Sul river is a symptom of the vulnerability of the biome regarding water security (see http://exame.abril.com.br/brasil/noticias/guerra-por-agua-revela-crise-de-governanca). Vitule et al. (2015) argue that biodiversity conservation and restoration should be the main tactics to revert the water shortage scenario in São Paulo.

Food security is also vulnerable to climate change. Globally, 800 million people live in hunger and to feed these people—and also make sure that the 9–10 billion people expected to be on the planet by 2050 are fed—agriculture will need pollinators. Brazil is currently one of the most important agricultural producers of the planet and, therefore, if things go wrong with Brazilian agriculture the whole planet will be seriously affected. Insect pollination is needed for 70 % of cultivated crops in the world, and bees are particularly relevant. Only in Brazil, the export value of eight cultivated crops that are dependent on pollinators is estimated at 9.3 billion dollars (Freitas and Imperatriz-Fonseca 2004). The relevance of Atlantic forest fragments for pollination of cultivated plants is exemplified by a study that shows coffee plantation close to such fragments produce in average more than 15 % of plantations further away from forests, precisely because of the presence of pollinators in these native remnants (De Marco and Coelho 2004; Freitas and Nunes-Silva 2012). Indeed, recent projections are that coffee plantations within some areas in the Atlantic forest domain may suffer pollination deficit in the near future (Giannini et al. 2015).

Of course, high population densities and low human development (low access to education, health and poor income generation) can magnify vulnerability of societies to natural disasters and food and freshwater insecurity (Cardona et al. 2012). Indeed, Torres et al. (2012) estimated that while the Atlantic forest is not as highly exposed to climate change as to other Brazilian biomes such as the semi-arid Caatinga, the Socio-Climatic Vulnerability Index assessed for some cities located in the Atlantic Forest is quite high, which is explained—to a great extent—by the high population densities found in cities like Rio de Janeiro and São Paulo. Further evidence of the perverse effect of high population densities on biodiversity conservation and consequently climate has been described by Specht et al. (2015): fuelwood harvesting is a chronic source of forest degradation and fragmentation in densely populated landscapes in poor areas in the Atlantic forest of the Brazilian northeast.

Ecosystem-based adaptation: building resilience to nature and society

Even in the most optimistic carbon emission scenarios mean planet temperature is likely to increase at least by 2 °C until the year 2100 (IPCC 2013). Thus, carbon mitigation alone will not suffice to halt or circumvent ongoing climate trends. Society therefore has entered the "adaptation era". IPCC (2014) defines adaptation as "the process of adjustment to actual or expected climate and its effects" and understands that "in human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities" and that "in some natural systems, human intervention may facilitate adjustment to expected climate and its effects". To increase resilience and reduce vulnerability of the part of the Brazilian society living within the Atlantic forest domain, poverty has to be reduced and nature has to be protected and restored. The type of adaptation that seems to combine these two goals and is therefore applicable to the case of the Atlantic forest is the so-called "ecosystem-based adaptation". The term refers to policies and practices that are based on the premise that ecosystem services protected or restored reduce the vulnerability of society to climate change (Vignola et al. 2009) and that, in the process of doing so, might further reduce poverty (Magrin et al. 2014). Recent optimism with ecosystem-based adaptation to climate change has led to recommendation of immediate inclusion of such practices in National Adaptation Plans (Munang et al. 2013). In South America ecosystem-based adaptation practices are increasingly common and include the effective management and establishment of protected areas, conservation agreements and payment for ecosystem services, community management of natural areas, and forest restoration (Magrin et al. 2014).

In the case of the Atlantic forest biome, a number of adaptive strategies are also taking place. Perhaps the most ambitious one is the so-called "Atlantic Forest Restoration Pact". This is a multisectoral initiative with more than 200 institutions involved that was launched in 2009 (Calmon et al. 2009) to restore 15 million hectares of Atlantic Forest until 2050. Success would more than double the current natural cover and would ensure 30 % vegetation cover in relation to the original extension (Melo et al. 2013; Pinto et al. 2014). This ambitious goal is equivalent to what would be necessary for farmers to fulfill the Brazilian environmental legislation (the Forest Code) that requires a given percentage of land inside private properties to be protected (Melo et al. 2013)—and currently many such properties do not abide to the law. Indeed, Strassburg et al. (2014) have shown that up to 18 million hectares of low productive pasture lands could be restored in the Atlantic forest without halting national agriculture expansion. Additional bonuses, these authors argue, would be slowing down species extinction and sequestering 7.5 billion tons of CO_2eq. This logic has been transformed in an actual plan for large scale restoration for the Atlantic forest state of Espírito Santo, southeast Brazil (Latawiec et al. 2015).

However, there are currently only 58,000 ha (or 0.03 % of the goal) in process of restoration under the guidelines of the Pact (Melo et al. 2013), which indicates a clear need for scaling up. Although costs of forest restoration are normally high in Brazil (USD 5000–8000 per hectare; Soares-Filho et al. 2014), Banks-Leite et al. (2014) give a more optimist perspective and demonstrate that proportionally such values may not be so high and that full implementation of an initiative such as the Pact might be equivalent to 6.5 % of what Brazil spends in agricultural subsidies annually, or 0.0092 % of Brazil's annual GDP. Moreover, recent evidence of fast spontaneous regeneration of forests cleared in the past increases the perspective of cost reduction of restoration (Rezende et al. 2015, in this issue). Of course, forest restoration also plays an important role in mitigation, through carbon sequestration and storage. Shimamoto et al. (2014) have found in a modeling exercise the exponential increase of the carbon sink service of restored Atlantic forest over a 60-year period.

The effective implementation of the Pact will require projects that generate legal, environmental and socioeconomic benefits to landowners and other stakeholders. The possibility to promote livelihoods and businesses from, for instance, production and plantation of seedlings or seed collection will often demand training and capacitating local actors. Such types of initiatives simultaneously enhance carbon sequestration, promote community organization, economic activities and human wellbeing in rural areas (Chazdon 2008), as already seen in some areas of the Atlantic forest biome (Calmon et al. 2011; Rodrigues et al. 2011). Moreover, recent evidence of a highly positive perception by local communities of cultural services (aesthetic improvements, tourism, recreational, spiritual and educational) provided by restoration efforts in the Atlantic forest suggest popular adherence to such initiatives (Brancalion et al. 2014).

Another important adaptive mechanism is the set of initiatives generally called payment for ecosystem services, which is becoming widespread in South America (Balvanera et al. 2012; Magrin et al. 2014) and in the Brazilian Atlantic forest. Such schemes ensure the flow of a given environmental service (or the type of land use capable of ensuring it) through conditional payments or compensations to voluntary providers. Ecosystem services subjected to these agreements include freshwater flow, carbon storage or sequestration, and habitat provision for biodiversity (Tacconi 2012; Magrin et al. 2014). Since ecosystems that provide such services often times are found inside private lands, as in the case of the Atlantic Forest, such incentives are designed to support landowners to maintain the offer of such services in time. Until 2012, six states of the Brazilian federation within the Atlantic forest domain had created some legal mechanism related to ecosystem services, as well as investments and programs, while three other states were defining policies along those lines (Mesquita et al. 2010). More than 40 initiatives of payment for ecosystem services are in phase of planning, implementation or operation at the Atlantic forest, which are related to either water or carbon (Pinto et al. 2012; Young and Bakker 2014). The amounting evidence of potential co-benefits between carbon and biodiversity in protected forest fragments indicate the opportunity for REDD+ (reducing emissions from deforestation and forest degradation) to contribute not only with mitigation but also with adaptation to climate change (Strassburg et al. 2010; Magnago et al. 2015).

While perspectives with forest restoration and payment for ecosystem services are reason for optimism, there remains a still unrealized adaptive potential related to protected areas. Protected areas that exclude human activities add up to only 2 % of the Atlantic Forest territory and have a mean average size of 10,000 ha. Privately owned protected areas have in average only 200 ha (Pinto et al. 2012). Only 1 % of the threatened plant species (Martinelli et al. 2013) and 15 % of the threatened animal species occur inside protected areas (Paglia et al. 2004). Furthermore, protected areas in the Atlantic forest and in Brazil as a whole have a highly unrealized ecotouristic potential (Da Riva et al. 2014).

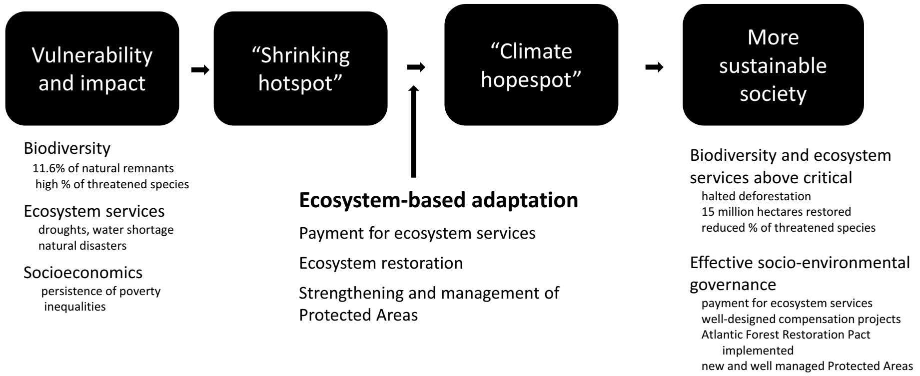

Fig. 1 Atlantic forest's theory of change: a history of impacts turns the biome and the local society vulnerable to climate change. Ecosystem-based adaptation can help turn the biome from a "shrinking hotspot" to "climate hope spot", whereby society is increasingly resistant and resilient to climate change

Conclusion

As science advances, it will need to further improve its dialogue and communication with policy-making (see Scarano and Martinelli 2010) in a time span that is most likely short given the climatic changes the planet is already facing (IPCC 2014). In Brazil, the effectiveness of this dialogue and its translation into practical action varies greatly according to a myriad of interests that are often at stake. This political hesitation has for now stopped Brazil from establishing itself as a true global leader in sustainability and in the fight against climate change (Scarano et al. 2012a; Ferreira et al. 2014; Loyola 2014), but there is still some time to reverse that trend especially during this year of 2015, as the planet fast approach its decision on Sustainable Development Goals (Griggs et al. 2013) and pressure increase for significant commitments and agreements at the climate convention in Paris (Geden 2015). Societal adaptation to climate change will demand a lot of basic biological sciences, but will also demand more solution-driven interdisciplinary approaches in the realm of sustainability science (Scarano et al. 2012b; Liu et al. 2015).

We believe the Atlantic forest can turn from a "shrinking biodiversity hotspot" (Ribeiro et al. 2011) to a climate adaptation "hope spot" (sensu Sylvia Earle; see McKenna 2010) where societýs vulnerability to climate change is eradicated by protecting and restoring nature and improving human life standards (Fig. 1). There are at least three reasons for optimism:

1. Natural resilience of the biome: this is apparent from the growing body of literature showing the high ecological plasticity and adaptive capacity of many Atlantic forest species (see Scarano 2009; Lüttge et al. 2013; Scarano and Garbin 2013; Rezende et al. 2015), especially plants. This natural resilience is probably related to the fact that so much diversity still thrives within so few forest remnants left, and also a handicap for ecosystem-based adaptation.
2. Increasing production of papers that are solution-driven: most papers cited in this review are solution-driven, interdisciplinary, and indicate the growing concern of Atlantic forest scientists to communicate with policy-making; and

3. Some policies and agreements are already in place (e.g., payment for ecosystem services in many states, strong environmental legislation, a protected area network, the restoration Pact), so achieving large scale will be a matter of funding and of time.

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References

Agard J, Schipper ELF (2014) Glossary. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 1757–1776

ANA—Agência Nacional de Águas (2013) Conjuntura dos recursos hídricos no Brasil. http://arquivos.ana.gov.br/institucional/spr/conjuntura/webSite_relatorioConjuntura/projeto/index.html

Anciães M, Peterson AT (2006) Climate change effects on neotropical manakin diversity based on ecological niche modeling. Condor 108:778–791

Balvanera P, Uriarte M, Almeida-Leñero L, Altesor A, DeClerck F, Gardner T, Hall J, Lara A, Laterra P, Peña-Claros M, Silva Matos DM, Vogl AL, Romero-Duque LP, Arreola LF, Caro- Borrero ÁP, Gallego F, Jain M, Little C, de Oliveira Xavier R, Paruelo JM, Peinado JE, Poorter L, Ascarrunz N, Correa F, Cunha-Santino MB, Hernández-Sánchez AP, Vallejos M (2012) Ecosystem services research in Latin America: the state of the art. Ecosyst Serv 2:56–70

Banks-Leite C, Pardini R, Tambosi LR, Pearse WD, Bueno AA, Bruscagin RT, Condez TH, Dixo M, Igari AT, Martensen AC, Metzger JP (2014) Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot. Science 345:1041–1044

Béllard C, Leclerc C, Leroy B, Bakkenes M, Veloz S, Thuiller W, Courchamp F (2014) Vulnerability of biodiversity hotspots to global change. Glob Ecol Biogeogr 23:1376–1386

Brancalion PHS, Cardozo IV, Camatta A, Aronson J, Rodrigues RR (2014) Cultural ecosystem services and popular perceptions of the benefits of an ecological restoration project in the Brazilian Atlantic forest. Restor Ecol 22:65–71

Brook BW, Sodhi NS, Bradshaw CJA (2008) Synergies among extinction drivers under global change. Trends Ecol Evol 23:453–460

Burkett VR, Suarez AG, Bindi M, Conde C, Mukerji R, Prather MJ, St. Clair AL, Yohe GW (2014) Point of departure. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 169–194

Calmon M, Lino CF, Nave AG, Pinto LP, Rodrigues RR (2009) Pacto pela Restauração da Mata Atlântica: um movimento pela valorização da floresta. In: Fujihara MA, Cavalcanti R, Guimarães A, Garlipp R (eds) O valor das florestas. Terra das Artes Editora, São Paulo, pp 330–335

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

Canale GR, Peres CA, Guidorizzi CE, Gatto CAF, Kierulff MCM (2012) Pervasive defaunation of forest remnants in a tropical biodiversity hotspot. PLoS One 7:e41671

Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, Sinh BT (2012) Determinants of risk: exposure and vulnerability. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds) Managing the risks of extreme events and disasters to advance climate change adaptation: a special report of working groups I and II of the intergovernmental panel on climate change (IPCC). Cambridge University Press, Cambridge, pp 65–108

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

Ciais P, Sabine C, Bala G, Bopp L, Brovkin V, Canadell J, Chhabra A, DeFries R, Galloway J, Heimann M, Jones C, Le Quéré C, Myneni RB, Piao S, Thornton P (2013) Carbon and other biogeochemical cycles. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 465–570

Colombo AF, Joly CA (2010) Brazilian Atlantic Forest lato sensu: the most ancient Brazilian forest, and a biodiversity hotspot, is highly threatened by climate change. Braz J Biol 70:697–708

Da Riva AL, Aidar F, Toledo C, Pages M, Laes M, Dutra V (2014) Unidades de conservação no Brasil: a contribuição do uso público para o desenvolvimento socioeconômico. Instituto Semeia, São Paulo

De Marco P, Jr Coelho FM (2004) Services performed by the ecosystem: forest remnants influence agricultural cultures' pollination and production. Biodivers Conserv 13:1245–1255

Dean WJ (1996) A ferro e fogo: a história e a devastação da Mata Atlântica brasileira. Companhia das Letras, Rio de Janeiro

Dias ATC, de Mattos EA, Vieira SA, Azeredo JV, Scarano FR (2006) Aboveground biomass stock of native woodland on a Brazilian sandy coastal plain: estimates based on the dominant tree species. For Ecol Manag 226:364–367

Ferraz SFB, Ferraz KMPMB, Cassiano CC, Brancalion PHS, Luz DTA, Azevedo TN, Tambosi LR, Metzger JP (2014) How good are tropical forest patches for ecosystem services provisioning? Landsc Ecol 29:187–200

Ferreira J, Aragão LEOC, Barlow J, Barreto P, Berenguer E, Bustamante M, Gardner TA, Lees AC, Lima A, Louzada J, Parry L, Peres CA, Pardini R, Pompeu PS, Tabarelli M, Zuanon J (2014) Brazil's environmental leadership at risk. Science 343:706–707

Fisher JA, Patenaude G, Kalpana G, Meir P, Pinho P, Rounsevell MDA, Williams M (2014) Understanding the relationships between ecosystem services and poverty alleviation: a conceptual framework. Ecosyst Serv 7:34–45

Freitas MAV (ed) (2003) Estado das águas no Brasil, 2001–2002. Agência Nacional de Águas, Ministério do Meio Ambiente, Brasília

Freitas BM, Imperatriz-Fonseca VL (2004). Economic value of Brazilian cash crops and estimates of their pollination constraints. In: FAO (ed) Economic value of pollination and pollinators. Food and Agriculture Organization, Universidade de São Paulo, São Paulo

Freitas BM, Nunes-Silva P (2012) Polinização agrícola e sua importância no Brasil. In: Imperatriz-Fonseca VL, Canhos DAL, Alves DA, Saraiva AM (eds) Polinizadores no Brasil. Edusp, São Paulo, pp 103–118

Galindo-Leal C, Câmara IG (2003) The Atlantic forest of South America: biodiversity status, threat and outlook. Island Press, Conservation International, Washington

Gaspar MD, Deblasis P, Fish SK, Fish PR (2008) Sambaqui (shell mound) societies of coastal Brazil. In: Silverman E, Isbell WH (eds) Handbook of South American archaeology. Springer, New York, pp 319–338

Geden O (2015) Climate advisers must maintain integrity. Nature 521:27–28

Giannini TC, Tambosi LR, Acosta AL, Jaffé R, Saraiva AM, Imperatriz-Fonseca VL, Metzger JP (2015) Safeguarding ecosystem services: a methodological framework to buffer the joint effect of habitat configuration and climate change. PLoS One. doi:10.1371/journal.pone.0129225

Griggs D, Stafford-Smith M, Gaffney O, Rockström J, Öhman MC, Shyamsundar P, Steffen W, Glaser G, Kanie N, Noble I (2013) Sustainable development goals for people and planet. Nature 495:305–307

Hoekstra AY, Chapagain AK (2007) Water footprints of nations: water use by people as a function of their consumption pattern. Water Resour Manag 21:35–48

IPCC (2013) Summary for policymakers. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 3–29

IPCC (2014) Summary for policymakers. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge (in press)

IPEA, FJP, PNUD (2003) Atlas do Desenvolvimento Humano no Brasil. www.ipeadata.gov.br

Jantz SM, Barker B, Brooks TM, Chini LP, Huang Q, Moore RM, Noel J, Hurtt GC (2015) Future habitat loss and extinctions driven by land-use change in biodiversity hotspots under four scenarios of climate-change mitigation. Conserv Biol. doi:10.1111/cobi.12549

Joly C, Metzger JP, Tabarelli M (2014) Experiences from the Brazilian Atlantic Forest: ecological findings and conservation initiatives. New Phytol 204:459–473

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

Leão TCC, Fonseca CR, Peres CA, Tabarelli M (2014) Predicting extinction risk of Brazilian Atlantic Forest angiosperms. Conserv Biol 28:1349–1359

Liu J, Mooney H, Hull V, Davis SJ, Gaskell J, Hertel T, Lubchenco J, Seto KC, Gleick P, Kremen C, Li S (2015) Systems integration for global sustainability. Science 347:1258832. doi:10.1126/science.1258832

Lôbo D, Leão TCC, Melo FPL, Santos AMM, Tabarelli M (2011) Forest fragmentation drives Atlantic forest of northeastern Brazil to biotic homogenization. Divers Distrib 17:287–296

Loyola RD (2014) Brazil cannot risk its environmental leadership. Divers Distrib 20:1365–1367

Loyola RD, Lemes P, Brum FT, Provete DB, Duarte LDS (2014) Clade-specific consequences of climate change to amphibians in Atlantic Forest protected areas. Ecography 37:65–72

Lucena AFP, Szklo AS, Schaeffer R, Souza RR, Borba BSMC, Costa IVL, Pereira AO Jr, Cunha SHF (2009) The vulnerability of renewable energy to climate change in Brazil. Energy Policy 37:879–889

Lüttge U, Garbin MA, Scarano FR (2013) Evo–Devo–Eco and ecological stem species: potential repair systems in the planetary biosphere crisis. Prog Bot 74:191–212

Magnago LFS, Magrach A, Laurance WF, Martins SV, Meira-Neto AA, Simonelli M, Edwards DP (2015) Would protecting tropical forest fragments provide carbon and biodiversity cobenefits under REDD+? Glob Change Biol. doi:10.1111/gcb.12937

Magrin GO, Marengo JA, Boulanger J-P, Buckeridge MS, Castellanos E, Poveda G, Scarano FR, Vicuña S (2014) Central and South America. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge (in press)

Martinelli G, Valente ASM, Maurenza D, Kutschenko C, Judice DM, Silva DS, Fernandez EP, Martins EM, Barros FSM, Sfair JC, Santos Filho LAF, Abreu MB, Moraes MA, Monteiro NP, Pietro PV, Fernandes RA, Hering RLO, Messina T, Penedo TSA (2013) Avaliação de risco de extinção de espécies da flora brasileira. In: Martinelli G, Moraes MA (eds) Livro vermelho da flora do Brasil. CNC Flora, Jardim Botânico do Rio de Janeiro, Andrea Jakobsson Estúdio, Rio de Janeiro, pp 60–84

McKenna P (2010) Sylvia Earle: how not to clean up an oil spill. New Sci 207:26–27

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 Policy 33:395–404

Mesquita CAB, Veiga F, Belote T, Calmon M, Guimarães A (2010) Pagando a conta do almoço: compensação pelos serviços ambientais na Mata Atlântica. In: Marone E, Riet D, Melo T (eds) Brasil Atlântico: um país com a raiz na mata. Mar de Ideias, Instituto Bioatlântica, Rio de Janeiro, pp 262–299

Mittermeier RA, Gil PR, Hoffmann M, Pilgrim J, Brooks T, Mittermeier CG, Lamoreux J, Fonseca GAB (2005) Hotspots revisited: earth's biologically richest and most endangered terrestrial ecoregions, 2nd edn. CEMEX, Mexico City

Munang R, Thiaw I, Alverson K, Mumba M, Liu J, Rivington M (2013) Climate change and ecosystem-based adaptation: a new pragmatic approach to buffering climate change impacts. Curr Opin Environ Sustainabil 5:67–71

Nobre CA, Young, AF, Saldiva, P, Marengo, JA, Nobre, AD, Alves Júnior, SP, Silva, GCM, Lombardo, M (2010) Vulnerabilidades das megacidades brasileiras às mudanças climáticas: região metropolitana de São Paulo. http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/publicacoes/2010/SumarioExecutivo_megacidades.pdf

Nogueira C, Buckup PA, Menezes NA, Oyakawa OT, Kasecker TP, Ramos Neto MB, Silva JMC (2010) Restricted-range fishes and the conservation of Brazilian freshwaters. PLoS One 5:e11390

Paglia AP, Paese A, Bedê L, Fonseca M, Pinto LP, Machado R (2004) Lacunas de conservação e áreas insubstituíveis para vertebrados ameaçados da Mata Atlântica. Em Anais do IV Congresso Brasileiro de Unidades de Conservação—17 a 21 de outubro de 2004. Seminário, vol. II. Fundação O Boticário de Proteção à Natureza e Rede Pró-Unidades de Conservação, Curitiba, pp 39–50

Paglia AP, Fonseca GAF, Silva JMC (2008) A fauna brasileira ameaçada de extinção: síntese taxonômica e geográfica. In: Machado ABM, Drummond GM, Paglia AP (eds) Livro Vermelho da Fauna Brasileira Ameaçada de Extinção. Ministério do Meio Ambiente, Brasília, pp 63–70

Pinto LP, Bede LC, Fonseca M, Lamas I, Mesquita CA, Paglia A, Cisalpino TP (2012) Mata Atlântica. In: Scarano FR, Santos I, Martins ACI, Silva JMC, Guimarães A, Mittermeier RA (eds) Biomas Brasileiros: Retratos de um País Plural. Casa da Palavra, Conservação Internacional, Rio de Janeiro, pp 16–55

Pinto SR, Melo F, Tabarelli M, Padovesi A, Mesquita CA, Scaramuzza CAM, Castro P, Carrascosa H, Calmon M, Rodrigues R, César RG, Brancalion PHS (2014) Governing and delivering a biome-wide restoration initiative: the case of Atlantic Forest Restoration Pact in Brazil. Forests 5:2212–2229

Pütz S, Groeneveld J, Henle K, Knogge C, Martensen AC, Metz M, Metzger JP, Ribeiro MC, de Paula MD, Huth A (2014) Long-term carbon loss in fragmented neotropical forests. Nat Commun. doi:10.1038/ncomms6037

Rezende CL, Uezu A, Scarano FR, Araujo DSD (2015) Atlantic forest spontaneous regeneration at landscape scale. Biodiv Conserv. doi:10.1007/s10531-015-0980-y

Ribeiro MC, Metzger JP, Martensen AC, Ponzoni FJ, Hirota MM (2009) The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. Biol Conserv 142:1141–1153

Ribeiro MC, Martensen AC, Metzger JP, Tabarelli M, Scarano FR, Fortin MJ (2011) The Brazilian Atlantic Forest: a shrinking biodiversity hotspot. In: Zachos FE, Habel JC (eds) Biodiversity hotspots. Springer, Heidelberg, pp 405–434

Rodrigues RR, Gandolfi S, Nave AG, Aronson J, Barreto TE, Vidal CY, Brancalion PHS (2011) Large-scale ecological restoration of high-diversity tropical forests in SE Brazil. For Ecol Manag 261:1605–1613

Salazar LF, Nobre CA, Oyama MD (2007) Climate change consequences on the biome distribution in tropical South America. Geophys Res Lett 34:L09708. doi:10.1029/2007GL029695

Sansevero JBB (2013) Classificação de grupos funcionais e caracterização de trajetórias sucessionais na Floresta Atlântica. Ph.D. Thesis, Escola Nacional de Botânica Tropical, Jardim Botânico do Rio de Janeiro, Rio de Janeiro

Scarano FR (2002) Structure, function and floristic relationships of plant communities in stressful habitats marginal to the Brazilian Atlantic rain forest. Ann Bot 90:517–524

Scarano FR (2007) Rock outcrop vegetation in Brazil: a brief overview. Rev Brasil Bot 30:561–568

Scarano FR (2009) Plant communities at the periphery of the Atlantic rain forest: rare-species bias and its risks for conservation. Biol Conserv 142:1201–1208

Scarano FR, Garbin ML (2013) Stem species: plant species that function as regenerating cells of Gaia. Nova Acta Leopoldina NF 114:317–324

Scarano FR, Martinelli G (2010) Brazilian list of threatened plant species: reconciling scientific uncertainty and political decision making. Natureza & Conservação 8:13–18

Scarano FR, Guimarães AL, Silva JMC (2012a) Lead by example. Nature 486:25–26

Scarano FR, Silva JMC, Guimarães AL, Raik D, Boltz F (2012b) Brazil on the spot: Rio+ 20, sustainability and a role for science. Braz J Bot 35:233–239

Shimamoto CY, Botosso PC, Marques MCM (2014) How much carbon is sequestered during the restoration of tropical forests? Estimates from tree species in the Brazilian Atlantic forest. For Ecol Manag 329:1–9

Soares-Filho B, Rajão R, Macedo M, Carneiro A, Costa W, Coe M, Rodrigues H, Alencar A (2014) Cracking Brazil's forest code. Science 344:363–364

SOS Mata Atlântica/INPE-Instituto Nacional de Pesquisas Espaciais (2014). Atlas de remascentes florestais da Mata Atlântica, 2014. http://www.sosma.org.br/17811/divulgados-novos-dados-sobre-o-desmatamento-da-mata-atlantica/

Souza TV, Lorini ML, Alves MAS, Cordeiro P, Vale MM (2011) Redistribution of threatened and endemic Atlantic forest birds under climate change. Natureza e Conservação 9:214–218

Specht MJ, Pinto SRR, Albuquerque UP, Tabarelli M, Melo FPL (2015) Burning biodiversity: fuelwood harvesting causes forest degradation in human-dominated tropical landscapes. Glob Ecol Conserv 3:200–209

Strassburg BBN, Kelly A, Balmford A, Davies RG, Gibbs HK, Lovett A, Miles L, Orme CDL, Price J, Turner RK, Rodrigues ASL (2010) Global congruence of carbon storage and biodiversity in terrestrial ecosystems. Conserv Lett 3:98–105

Strassburg BBN, Latawiec AE, Barioni LG, Nobre CA, Silva VP, Valentim JF, Vianna M, Assad ED (2014) When enough should be enough: improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. Glob Environ Change 28:84–97

Tacconi L (2012) Redefining payments for environmental services. Ecological Economics 73:29–36

Torres RR, Lapola DM, Marengo JA, Lombardo MA (2012) Socio-climatic hotspots in Brazil. Clim Change 115:597–609

Vignola R, Locatelli B, Martinez C, Imbach P (2009) Ecosystem-based adaptation to climate change: what role for policy-makers, society and scientists? Mitig Adapt Strat Glob Change 14:691–696

Vitule JRS, Azevedo-Santos VM, Daga VS, Lima-Junior DP, Magalhães ALB, Orsi ML, Pelicice FM, Agostinho AA (2015) Brazil's drought: protect biodiversity. Science 347:1427–1428

Webb TJ, Woodward FI, Hannah L, Gaston KJ (2005) Forest cover-rainfall relationships in a biodiversity hotspot: the Atlantic forest of Brazil. Ecol Appl 15:1968–1983

Williams KJ, Ford A, Rosauer DF, De Silva N, Mittermeier R, Bruce C, Larsen FW, Margules C (2011) Forests of East Australia: the 35th biodiversity hotspot. In: Zachos FE, Habel JC (eds) Biodiversity hotspots. Springer, Heidelberg, pp 295–310

Young CEF (2003) Socioeconomic causes of deforestation in the Atlantic forest of Brazil. In: Galindo-Leal C, Câmara IG (eds) The Atlantic forest of South America: biodiversity status, threat and outlook. Island Press, Conservation International, Washington, pp 103–117

Young CEF, Bakker LB (2014) Payments for ecosystem services from watershed protection: a methodological assessment of the Oasis Project in Brazil. Natureza e Conservação 12:71–78