Chapter 5
Biodiversity Sector: Risks of Temperature Increase to Biodiversity and Ecosystems

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5.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC, 2014) states that there is more abundant and comprehensive evidence of climate change impacts for natural systems than for human systems. Moreover, the report shows that the most vulnerable natural systems are those that lost a significant portion of their life-supporting mechanisms. In parallel, for human systems, the IPCC recognizes that the poor people are the most vulnerable to climate impacts (Fisher et al., 2014; Magrin et al., 2014). Indeed, one of the main conclusions of the Working Group II in the fifth assessment report of the IPCC (2014) is that practices that promote sustainable development in the present – by combining social justice, environmental health and economic productivity – reduce future risks imposed by climate change and are thus adaptive.

Since biodiversity is essential for the good flow of ecosystem services for people, which ensure vital water and food security, protection of cultural values and identity, among other services (McNeely et al., 2009), one can conclude that human and natural systems are coupled, although disciplinary science often treats them separately. Therefore, risks that climate change impose on biodiversity have direct and indirect consequences to human wellbeing and livelihoods.

Nevertheless, global biodiversity is declining. Estimates are that species extinction is at least one thousand times higher than historic rates (Mace et al., 2005). Diamond (1989) proposed that this is due to an "Evil Quartet" that comprises habitat loss, overkill, invasive species and extinction chains. Later, Thomas et al. (2004) argued that climate change turned the quartet into a quintet, although there is no

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doubt that at this point in time habitat destruction remains as the main causal factor behind species extinctions (Baillie et al., 2004). Indeed, it has been claimed that climate change and biosphere integrity are two core planetary boundaries that, once transgressed, may drive the Earth system into a new undesirable state for humankind (Steffen et al., 2015).

Brazil is the country with the largest number of species worldwide. From the 17 countries that host 70% of the species on the planet, it is the most diverse (Mittermeier et al., 1997). Furthermore, it holds the greatest proportion of superficial freshwater, and ranks among the top food producers in the world (Scarano et al., 2012). Thus, it is a key premise of this Chapter that if biodiversity and ecosystems in Brazil were at risk, the potential impacts that might derive from it would have planetary consequences. This Chapter revises the available literature on impacts and vulnerability of biodiversity and ecosystems in Brazil published since the latest reports from the IPCC (Magrin et al., 2014) and the Brazilian Panel on Climate Change – PBMC (Souza-Filho et al., 2014).

5.2 Vulnerability

The latest IPCC (Magrin et al., 2014) and PBMC reports (Souza-Filho et al., 2014) refer to climate change vulnerability in Brazil at three different organisation levels, based on the best science available at that moment: biomes, ecosystems and species. The literature published after the reports endorses these panels' findings and adds new discussion (Table 5.1).

In relation to biomes, there are more reports referring to climate change vulnerability in biodiversity hotspots (Atlantic Forest and Cerrado), in the Amazon, and in the Caatinga. The Atlantic Forest is one of the three hotspots most vulnerable to climate change in the world. This is due to a combination of high risk related to the emergence of new climate and the disappearance of the current one, as well as susceptibility to invasive species and expansion of pasture areas for cattle raising (Béllard et al., 2014). In the case of the Cerrado, high replacement rates of original vegetation cover and other land uses made the biome extremely vulnerable (Sawyer, 2008; Strassburg et al., 2017). For the Amazon, there is the potential for savannisation based on drought and rising temperatures brought about by deforestation and climate change, despite the existence of uncertainties around timing for a supposed tipping point to be reached (see review in Magrin et al., 2014). In the Caatinga, vulnerability refers to the low percentage of protected areas, persistence of poverty and desertification process due to extreme droughts (Oliveira et al., 2012; Tabarelli et al. 2017). In the most recent study on the subject, Seddon et al. (2016) propose that the Amazon and Caatinga are among the world's biomes that present intrinsic vulnerability to climate variations and would have low response or resilience to possible changes. In the case of the Amazon, sensitivity is related to changes in temperature and cloud cover, and in the case of the Caatinga, water is the pivotal component of sensitivity.

Table 5.1 Brazilian biomes, ecosystems and species more vulnerable to climate change

Level of organisation	Types	Case	References
Biomes	Atlantic forest	Biodiversity hotspot	Béllard et al. (2014); Joly et al. (2014); Scarano and Ceotto (2015)
	Cerrado	Biodiversity hotspot	Sawyer (2008), Strassburg et al. (2017)
	Caatinga	Desertification	Seddon et al. (2016); Oliveira et al. (2012)
	Amazon	Savannisation	Anadón et al. (2014); Balch et al. (2015); Seddon et al. (2016)
Ecosystems	High altitude	High thermal sensitivity	Laurance (2015)
	Coastal and marine	Rising sea level	Godoy and Lacerda (2015)
	Urban	Heat waves	Lucena et al. (2012); Rosenzweig et al. (2015)
Species	Endangered species	High ecological sensitivity	Keith et al. (2015); Urban (2015)
	Amphibians	High ecological sensitivity	Loyola et al. (2014)
	Corals	High ecological sensitivity	Descombes et al. (2015)
	Invertebrates	High ecological sensitivity and diminishing abundance	Faleiro et al. (2018); Ferro et al. (2014); Giannini et al. (2015)
	Plants, mammals, birds	Moving south	Giannini et al. (2015); Hoffmann et al. (2015); Oliveira et al. (2015)

In relation to ecosystems, the ones at high altitudes, on the coast and in urban areas are particularly vulnerable. The IPCC reports (Magrin et al., 2014) at the global level and the one produced by PBMC (Souza-Filho et al., 2014) for Brazil, already pointed out this trend and subsequent studies confirmed it. Laurance (2015) argues that high altitude ecosystems are made up of species with high thermal specialisation, making them vulnerable to climate change. The effects of climate change on coastal ecosystems, include impacts on coastal dynamics like floods and erosion. In Brazil, a recent example is the reported increase of the mangrove area in the state of Ceará by 24 hectares inland, which happened between 1992 and 2003 (Godoy and Lacerda, 2015). Urban ecosystems are among the most vulnerable to the general reduction in natural cover (Rosenzweig et al., 2015), both inside urban centers and in their periphery, and the recent water supply related impacts in big cities like São Paulo and Rio de Janeiro, are possibly related to a synergy between land use change and climate change (Cunningham et al., 2017). In the case of the Rio de Janeiro metropolitan region, the increase of heat islands in the last few decades also reflects this vulnerability (Lucena et al., 2012).

Recent studies on taxonomic groups and species also reinforce patterns already described in IPCC and PBMC about the vulnerability of corals (Descombes et al., 2015), invertebrates (i.e. moths and bees, Faleiro et al., 2018, Ferro et al., 2014, Giannini et al., 2015) amphibians (Loyola et al., 2014), mammals (Ribeiro et al., 2016), and endangered species in general (Keith et al., 2015; Urban, 2015). They also predict that mammals, birds and plants will migrate south due to the increase in temperature (Giannini et al., 2015; Hoffmann et al., 2015; Oliveira et al., 2015).

5.3 Risk Assessment for Temperature Limits Exceeding 2–4 °C

Specific projections for biomes, ecosystems and Brazilian species in a warmer world, from 2 to 4 °C temperature rise, or over 4 °C are still hard to find in the literature, particularly using the IPCC (2013)'s RCP scenarios. However, the general patterns of the studies reviewed here are similar to the general vulnerability patterns described in Table 5.1.

By 2070, there is a 90% probability of temperature rise between 2 to 3 °C in scenario RCP 8.5 in Brazil (Figs. 2.4d and 2.5d in Chap. 2 of this book). In this case, Anadón et al. (2014) predict impoverishment and reduction of the Atlantic Forest and the Amazon. They also predict the expansion of the savanna (including the Caatinga, and in the direction of the Amazon) and of forest in the Pampas, all together with changes in species distribution and impoverishment. This projection is similar to the one provided by Yu et al., (2014), who also used scenario RCP 8.5, as well as Leadley et al. (2014), predicting a 3 °C rise for 2075, leading to the savannisation of Brazilian tropical forests and impoverishment of the Cerrado, in IPCC scenario A2 (2007). More recently, Zanin et al., (2017) found similar projections of forest contraction, expansion of open vegetation, and overall vegetation impoverishment.

In addition to the vulnerability of biomes, South America is the continent with the highest risk of species extinction (23%) that may be attributed to climate change. Extinction risk goes from 5.2% at 2 °C to 15.7% when temperatures reach over 4 °C (Urban, 2015). Visconti et al. (2015) proposed that in 2050, for a business as usual scenario with temperature increase higher than 2 °C (A1B, IPCC, 2007), species richness will decline rather sharply, particularly for mammals. In the Atlantic Forest, the endemic species from the top of the mountain in Brazil's east, the grey-backed tachuri bird (*Polystictus superciliaris*) would be endangered by 2080 (Hoffmann et al., 2015), following the IPCC A2 and B2 scenarios (2007). In the Cerrado, Aguiar et al., (2016) predicted that bat species would move south in scenario RCP 4.5 for 2050, when there is an 80% probability of temperature rising above 2 °C. Under these types of future scenarios, there is already evidence that usual conservation instruments, such as protected areas, may become inefficient for given species and ecosystems (Ferro et al., 2014; Feeley & Silman, 2016).

Two projections for Brazilian species under different climate change scenarios draw attention due to the impact on socio-economics. Oliveira et al. (2015) predicted the occurrence and distribution of 16 edible plant species in the Cerrado, which are important for local and traditional communities – among them the souari nut (*Caryocar brasiliense* Camb.), mouriche palm (*Mauritia flexuosa* L.f.) and locust berries (*Byrsonima verbascifolia* L.DC.). The projection was based on RCP 8.5 for 2080, when there is a 75% chance of temperatures rising above 4.5 °C in the Brazilian territory. The results point to the extinction of several of these species and a shift in the distribution of some of them to the south, in the direction of what is the Atlantic Forest today. The study suggests that the southeast area of the Cerrado needs conservation measures, as for these 16 species it is the most irreplaceable region. In another example, Giannini et al. (2015) predicted a shift in the distribution of *Meliponina quadrifasciata* – a stingless bee, native of the Atlantic Forest and key pollinator of native species and farming plants – from the north to the south, and from the coast to inland areas. However, the scenario used was A1B for 2030, 2050 and 2080. Results point to a deficit in coffee pollinators in the states of São Paulo and Minas Gerais in 2030 already, with potential impacts on the economy.

Another worrying and less known component of the effect of climate change on biodiversity refers to the impacts on plant growth. This component is important because plant productivity affects the functioning of ecosystems, food chains, oxygen supply, food, fibres and fuel for humanity. Mora et al. (2015) found that tropical areas, amongst them Brazil, may lose up to 200 good plant growing days a year by 2100, in a RCP 8.5 scenario (over 4.5 °C). The impact on the human population and economy would be devastating. In scenarios RCP 2.6 and 4.5, the impact would be much smaller. In evergreen perennial forests like the Amazon and Atlantic Forest, the impact on plant growth would be higher for all plant groups in scenario RCP 8.5 (Mora et al., 2015).

Segan et al. (2016) analysed the interaction between habitat loss and fragmentation with climate change. They argue that in order to avoid a bigger impact in Brazilian biomes and ecosystems by 2090, in a RCP 8.5 scenario (over 4.5 °C), the western part of the Amazon and the Pantanal should be protected, in addition to prioritising the restoration of areas in the Caatinga, Cerrado, Atlantic Forest and Pampa. Another recommendation is to develop schemes to account for climate change in spatial prioritisation studies for conservation (e.g., Faleiro et al., 2013; Jones et al., 2016; Lemes and Loyola, 2013; Zwiener et al., 2017).

The marine panorama is also reason for concern, especially in more severe climate change scenarios (RCP 6.0 and 8.5). Beaugrand et al., (2015) state that changes of this magnitude will affect the marine pelagic biodiversity more than changes in temperature that took place between the last glacial maximum and current times, 50% (RCP 6.0) and 70% (RCP 8.5) of the global ocean surface by 2100. Species loss will be particularly severe in the tropics, including the Brazilian coast.

5.4 Adaptation

The projections of the impacts of future climate trends on Brazilian biodiversity and ecosystems call for immediate action. Carbon mitigation alone will continue to be relevant and must speed up, but alone will not suffice to halt or circumvent ongoing climate trends. Thus, adaptation strategies are needed to boost resilience of vulnerable socio-ecological systems, always bearing in mind that there are limits for adaptation (Scarano, 2017), as the planetary boundaries framework suggests (Steffen et al., 2015). Whenever adaptation avoids or reduces climate risks without negatively impacting coupled human-natural systems, it becomes key to the sustainable development agenda (Juhola et al., 2016; Pant et al., 2015; Scarano, 2017). Therefore, although adaptation and sustainable development are not synonyms, an alignment between policy actions on these two fronts is desirable (Kasecker et al., 2017).

Although this Chapter examines the potential impacts of climate change, especially temperature rise, on biodiversity and ecosystems, the other side of the same coin is that biodiversity and ecosystems can be adaptive to climate change. In developing countries such as Brazil, reduction of the climate change vulnerability of local societies and its associated risks requires a combination of policy instruments related to biodiversity and ecosystem services conservation (e.g., establishment and effective management of protected areas, community management of natural areas, and ecological restoration) and socio-economic policies that foster livelihood diversification, income generation and poverty reduction. We call this type of action 'ecosystem-based adaptation to climate change' (EbA; Jones et al., 2012; Scarano, 2017).

Kasecker et al. (2017) found 397 Brazilian municipalities that combine high natural vegetation cover, high human poverty, and high exposure to climate change. These municipalities are mainly located in the Amazon, the Cerrado and the Caatinga biomes. This paper proposes that an EbA approach that conciliates biodiversity and ecosystem conservation actions with improvement of socioeconomic conditions is essential to reducing climate vulnerability in these municipalities. In parallel, Brazil also has municipalities that have lost a significant part of their vegetation cover and have high human poverty, as seen by examples in the Atlantic forest (Pires et al., 2017; Rezende et al., 2018) and in the Amazon (Silva and Prasad, 2017). This restoration gap is echoed by Brazil's commitment to the Paris Agreement of the climate convention to restore 12 million hectares by 2030, and backed up by national environmental legislation that turn mandatory the restoration of existing environmental debts within private rural properties (Scarano, 2017). However, restoration is often expensive. Both for conservation and for restoration, incentive mechanisms will be necessary to reach the necessary scale and to cover some of the implementation costs (Kasecker et al., 2017; Strassburg et al., 2017; Vieira et al., 2017).

5.5 Conclusions and Recommendations

Based on the reduced literature on the impact of an increase of 4°C or above in the average temperature, it is clear that in this scenario the effects would significantly amplify projections already made for settings with a 2 °C rise. The following projections stand out:

(a) Savannisation and vegetation impoverishment will be likely seen in an above 2 °C rise in 2070, which might be aggravated with the increase in temperature;
(b) Species' extinction risk may increase from 5.2% at 2 °C, to 15.7%, if the 4 °C barrier is broken - South America will be the continent most susceptible to species extinction;
(c) Extinction and changes in the distribution pattern of native species with edible and cultural value in the Cerrado would lead to socio-economic issues by 2080, when the temperature could break the 4 °C barrier;
(d) Impact on biodiversity might also negatively affect agriculture, such as in the case of the reduction in the native bee species in the Atlantic Forest that are important for coffee pollination. This reduction would be seen in 2030 and would get worse until extinction in 2050 and 2080, with temperature rising between 2 and 4 °C;
(e) In 2100, with an increase above 4.5 °C, Brazil would lose 200 days a year in suitable plant growing days, causing great impacts on biodiversity, productivity of ecosystems and the economy. For forest species in the Amazon and Atlantic Forest, the scenario would be particularly severe;
(f) In 2100, with a likely increase above 4.5 °C, biodiversity loss on tropical coasts, including Brazil's, would have a significant negative impact on food and economy.

The main practical recommendation found in this review are:

(a) To prioritise conservation (especially in the western Amazon, Pantanal and Cerrado) and restoration areas (particularly in the Caatinga, Cerrado, Atlantic Forest and Pampa), considering climate change scenarios, in order to promote ecosystem-based adaptation to climate change;
(b) To design and implement biodiversity and ecosystem conservation and restoration in a way that these actions foster livelihood improvement and poverty reduction in areas vulnerable to climate change to increase local adaptive capacity and resilience.

The main recommendations from the scientific point of view are:

(a) Due to the shortage of literature with predicted scenarios for Brazilian biodiversity in temperatures over 4 °C, it is critical for research to be encouraged in this area;

(b) Prioritisation schemes for conservation and restoration areas (used to guide public policies such as SNUC, Planaveg and the New Forest Code[1]) should incorporate the climate component to their analyses, considering scenarios with temperature increase.

In conclusion, while climate change poses obvious risks to biodiversity and the socioecological systems dependent on it in Brazil, the country's natural wealth, its biodiversity and ecosystems, are simultaneously the main source of alternatives for mitigation and adaptation (Scarano, 2017). To bring biodiversity and ecosystems to the centre of the development process of the country, rather than treating them as an obstacle to this process, will be strategic both to fight climate change and to promote a sustainable and inclusive development.

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[1] SNUC = National Conservation Units System; Planaveg = National Native Vegetation Restoration Plan; New Forest Code = Native Vegetation Protection Law.

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