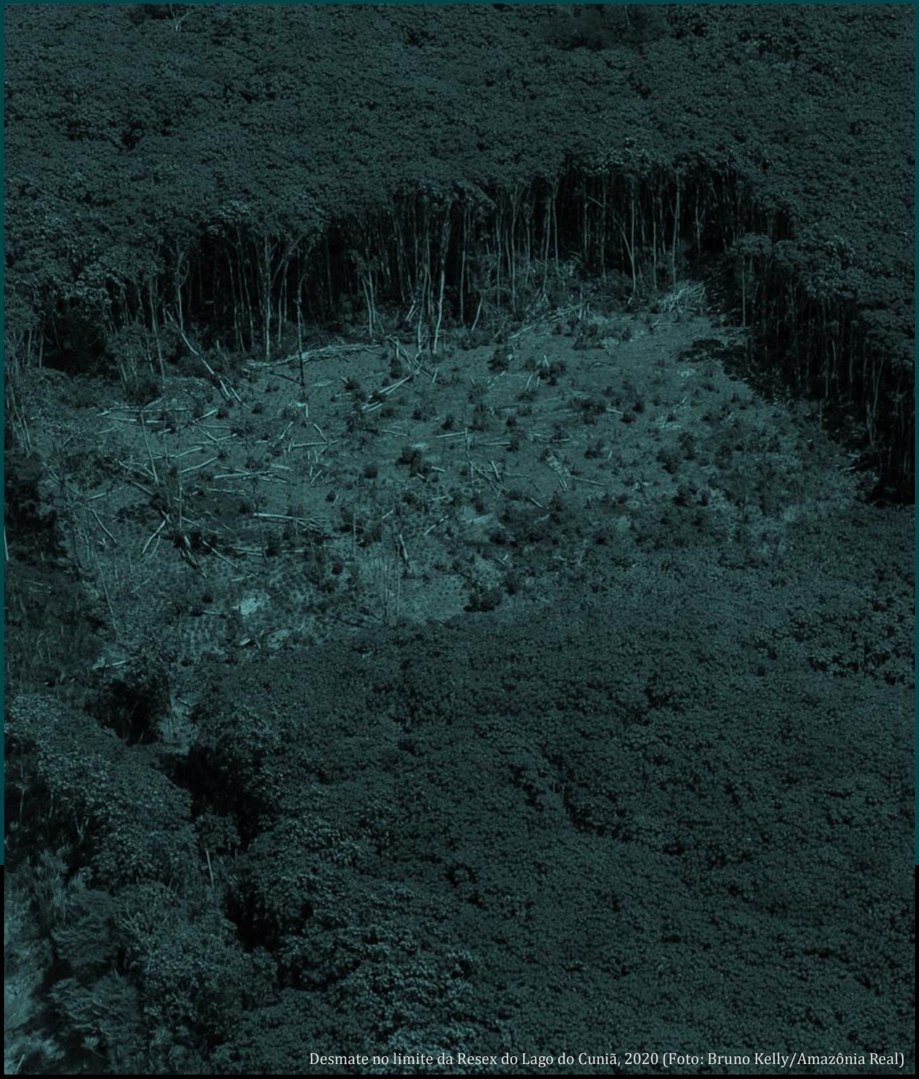
Chapter 23 In Brief

Impacts of deforestation and climate change on biodiversity, ecological processes, and environmental adaptation



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THE AMAZON WE WANT
Science Panel for the Amazon

Impacts of deforestation and climate change on biodiversity, ecological processes, and environmental adaptation

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Key Messages & Recommendations

1) A comprehensive network of Amazonian environmental observatories and a system for sharing comparable data is needed to diagnose ongoing changes.
2) Knowledge gaps on carbon (C) balance are significant. Remote sensing of CO_2 measurements, ground-based tower flux data, aircraft measurements, and modeling tools need to be integrated to close these gaps.
3) Reducing emissions from biomass burning is critical to minimize negative impacts on ecosystems and human health.
4) More integrated studies on biodiversity loss and climate change, for example on species resilience, are needed.
5) More studies on the feedbacks between climate change and Amazonian ecosystem functioning are vital and must be better known and quantified, especially for carbon and water vapor.
6) Basin-wide water balance studies integrating all aspects of the hydrologic cycle are needed.
7) Paleoclimate studies are essential to understanding natural climate variability and the historical role of humans in shaping the landscape over several timescales.
8) Studies are needed on ecosystem and species resilience to increased temperatures and reduced water supplies.
9) In addition to reducing deforestation is also essential to reduce the burning of fossil fuels which is the main cause of global warming.

Abstract This chapter presents observed and predicted impacts of climate change on Amazonian ecosystems, focusing on biodiversity, ecosystem services, carbon cycling, fisheries, and emissions from biomass burning. It also considers climate and land-use change feedbacks and highlights knowledge gaps to better understand these complex interactions.

Deforestation- and climate change-driven changes in biodiversity and ecosystem services Climate change and deforestation combined could cause a decline of up to 58% in Amazon tree species richness by 2050, and species may lose an average of 65% of their original environmentally suitable area[1]. The regions most likely to be affected are the eastern, southwestern, and southern Amazon. Figure 23.1 illustrates the complex links between the impacts of climate, deforestation, forest degradation, and fire on the Amazon ecosystem.

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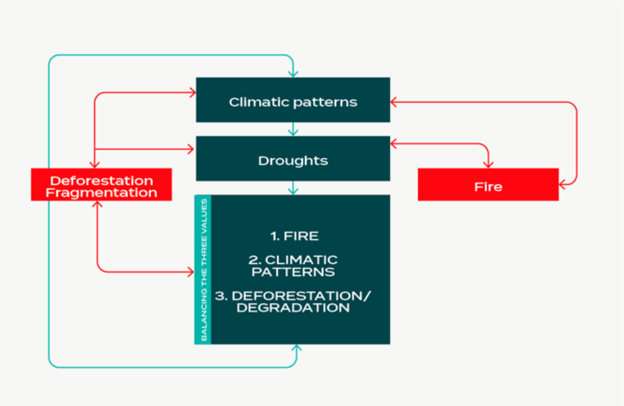

Figure 23.1 Links between the impacts of climate, deforestation, forest degradation, and fire on the Amazon ecosystem.

Over the past 30 years, tree communities have become increasingly dominated by large-statured taxa and drought-tolerant genera[2]. While climate change affects biodiversity, plant trait diversity may enable Amazon forests to adjust to new climate conditions, protecting the Amazon's ecosystem functions[3] (see Chapter 24). However, under the RCP 8.5 scenario of the Intergovernmental Panel on Climate Change (IPCC), abrupt disruption of ecological assemblages might simultaneously expose most species to climates beyond their realized niche limits, affecting tropical forests by 2050. Little historical climate variability and shallow thermal gradients mean that many species in the region are already living close to their upper realized thermal limits throughout their geographic range. The Amazon is one of the world's most at risk regions, with a possibility that over 90% of species could be exposed to unprecedented temperatures by 2100[4].

Migration towards wetter and colder habitats, with the Andes representing a potential refuge for many species, could result in a net loss of species in lowland forests[5]. However, increases in species richness in the Andes may be offset by other threats to biodiversity, such as habitat loss. Protecting lowlands' connectivity to the cooler highlands may provide an escape route for many species.

Aquatic biodiversity, ecosystems, and services Climate change effects on Amazonian fish remain to be fully understood, although they seem to be significant when exposed to different IPCC scenarios for temperature, CO_2, and humidity for the year 2100. A significant effect on the function and biodiversity of aquatic ecosystems is the disruption of the natural hydrological cycle due to unusually low and high peaks in water levels during extreme drought and flood events[6] (see Chapter 22). These events can lead to changes in size, reproduction, abundance, and community composition of several species, including fish, wading birds, and river dolphins[7].

Many fish species in the Amazon are susceptible to small temperature increases, and the maximum critical temperature of some fish groups is already very near the average maximum[8]. Increases in the metabolism of warm-water species in lowland habitats can trigger greater food intake and cause unforeseen consequences in local food webs. Andean Amazonian fish species are highly susceptible to contractions in their distribution range, which will eventually to extinction[9]. In addition, low water levels during extreme drought events can lead to temporal river fragmentation, blockage of fish migrations, and local extinctions[10]. Fishes of the Amazon are adapted to extreme conditions such as low pH, variable dissolved oxygen, variable types of water and dissolved organic carbon, and different pHs. However, we are still far from understanding how the complex network of recent anthropogenic impacts will modify aquatic biota.

Calculating the economic losses due to reductions in fisheries yields induced by climate change is challenging because of the sparse knowledge on fisheries yields per habitat type[11–13].

Forest dynamics in a changing climate Anthropogenic climate change is severely altering forest dynamics across the basin, exacerbating chronic drivers of forest change and the extent, frequency, and intensity of single and compounding disturbance events, including wildfire, drought, windthrow, and biotic attack[14]. An outstanding question is whether such interactions between stressors and disturbances will be large enough to surpass tropical forests' capacity to resist and respond to such changes, especially as they interact with land-use change and fire (see Chapter 24).

While forests have evolved resilience to some level of disturbance, these novel regimes can cause severe and prolonged forest degradation, reducing forest species richness and carbon storage capacity, and causing significant shifts in species composition towards a more generalist, less diverse plant community. The forests most susceptible to these disturbances grow along the driest southern and eastern margins of the Amazon, where drought, wildfires, and fragmentation already interact synergistically[15,16]. Lowland forests are also particularly vulnerable[17]. Despite the extensive degradation caused by drought-fire interactions in the Amazon, it is still unclear how much of this is caused by climate change itself, given complex interactions involving land-use change.

Although forests disturbed by compounding extreme events may eventually recover, the timeframe is unclear. A single disturbance event may kill the most susceptible species and select those more resistant, which can potentially reduce tree mortality in successive events. Furthermore, even severely disturbed forests might recover some pre-disturbance characteristics within decades[18]. However, climate change is expected to increase the risks of new disturbances, perhaps with subsequent disturbances precluding recovery. More frequent disturbances would result in chronic impoverishment of biomass and biodiversity, especially in fragmented landscapes. As regional climate changes, forest resilience is expected to decrease[19]. Improving our understanding of the potential impacts of climate change in the near future requires long-term monitoring from the scale of individual trees to the entire continent and improving the current dynamic global vegetation models.

Pollination and seed dispersal Birds are good biological indicators of climate change impacts on ecosystem services. In a study by Miranda et al.[21], the authors compiled extensive species occurrence data representative of the southeastern Amazon to assess the potential impact of climate change on avian assemblages. They estimated that 4-19% of the species would find no suitable habitat. Inside currently established protected areas (PAs) species loss could be over 70%. Frugivores would be the most sensitive, with consequences for seed dispersal and natural regeneration. Western and northern parts of the study area were considered climatically stable.

Costa et al.[22] found that 57% of 83 bat species would not find suitable locations in the Carajás National Park (Brazil) under studied climate change scenarios. Pollinators, seed dispersers, and omnivorous bats would potentially be the most affected, suffering a 28–36% decrease in suitable areas under the 2070 scenario, affecting plant-bat interactions. Climate change would also affect the distribution of bees and, consequently, crop pollination. Analysis and projections of the distribution of 216 species in Carajás National Forest showed that 95% of bee species would face a decline in total occurrence area[23].

Projections also indicated that Brazil nuts' pollinators would lose nearly 50% of their suitable distribution in the future, leading to an almost 80% reduction in co-occurrence potential[24] and generating negative impacts on human economies and well-being. Another study examined the loss of seed dispersal services by primates, indicating average contractions of 56% on the studied primates' suitable areas[24].

Feedbacks of climate and land-use change Feedbacks between climate and land-use change may amplify their negative impacts[25]. A key question is whether a general long-term trend exists toward drought conditions and, if so, to what degree it is associated with greenhouse gas (GHG) emissions and deforestation. Answering this question requires analyses of the causes of interannual and interdecadal variability in rainfall.

Carbon cycling and storage The spatial variability of carbon uptake and productivity of Amazonian forests strongly relate to climatic gradients across

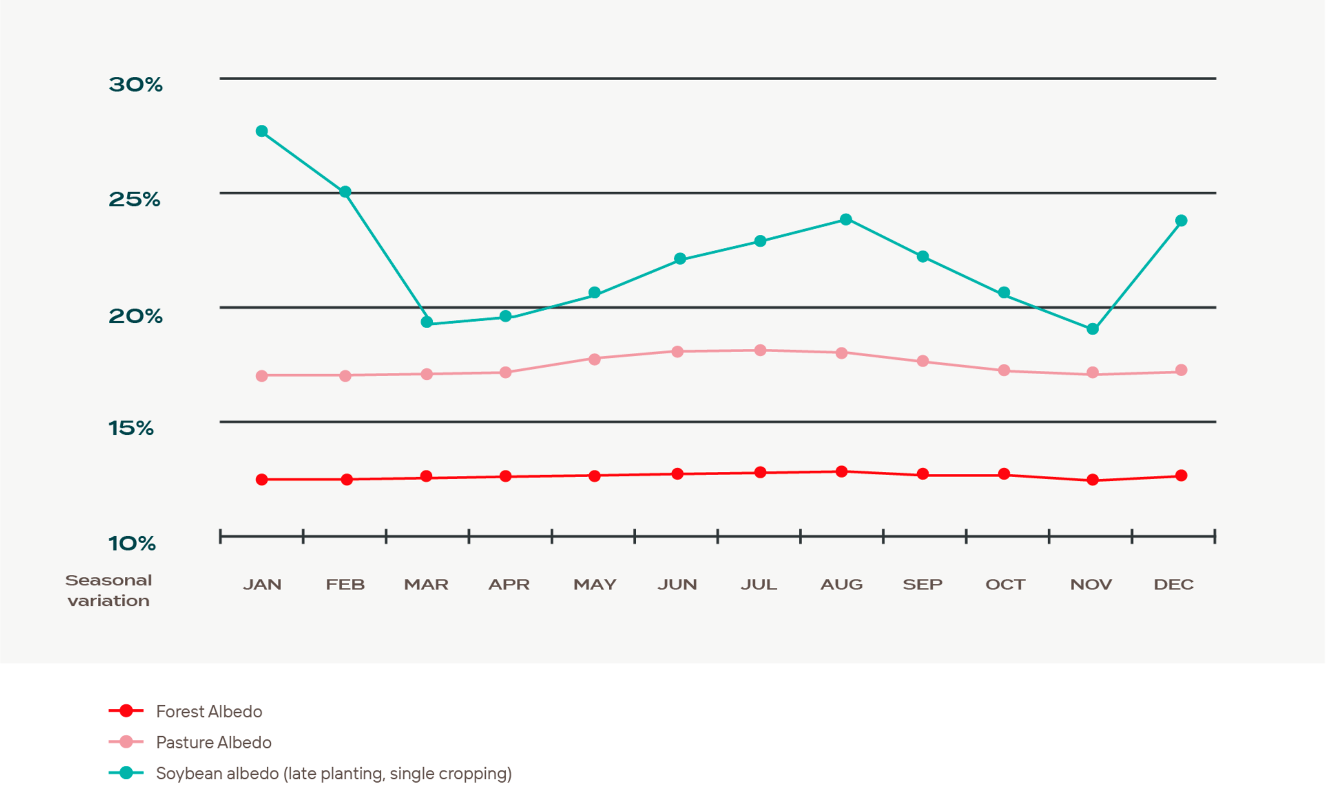

Figure 23.2 Seasonal variation of forest, pasture, and soybean albedo. A substantial increase in surface albedo can be observed when the forest is changed to pasture or soybean. Albedo increases from 13% (forest) to 17% (pasture). Adapted from Costa (2007)[20].

the basin. Currently, around 110 Pg of carbon is stored in Amazonian forests aboveground[26], equivalent to 10 years of all global fossil fuel burning. Amazonian primary forests remove carbon from the atmosphere at a rate of about $50g/m^{-2}/y^{-1}$ [27–29]. Still, this rate has sharply declined over the past two decades due to reductions in tree growth and increases in tree mortality, associated with droughts[30,31], and possibly increased atmospheric CO_2, promoting higher forest turnover rates[32]. Furthermore, many Amazonian trees operate close to their bioclimatic limit. It is estimated that carbon accumulation in Amazonian forests decreases nearly 9 MgC/ha for every one degree Celsius increase in termperature[33]. Extreme daytime temperatures and droughts are critical in depressing tree growth rates. As a result, the carbon accumulation capacity of undisturbed Amazonian forests is getting weaker, with the possibility of forests becoming global carbon sources in a few years[30,33].

Deforestation has also been an essential driver of carbon storage reductions. In 2019, deforestation in the Brazilian Amazonia released about 559 $MtCO_2$[34]. More than half of all CO_2 emissions from Amazonian nations result from deforestation and degradation. The net emissions from 2003 to 2016 alone were estimated at 4.7 Gt CO_2[35]. The remaining forest edges have become much more flammable and prone to burning[36]. Once forests burn, they tend to be more severely disturbed by windstorms than primary forests, explaining why forest carbon stocks can decline by 90% when impacted by these disturbances[37].

Energy and water balance Tropical forests have a lower albedo, higher evapotranspiration (ET), and higher roughness than the croplands and pastures that often replace them (see Chapter 7). Low albedo results in a significant fraction of incoming solar radiation being absorbed, depositing energy in the foliar system. Much of that energy is used in the cooling process of evapotranspiration, which is generally high throughout the year because of relatively abundant sunshine and rainfall or stored soil moisture. The relatively high surface roughness increases the atmospheric mixing of ET and releases energy into the troposphere[38]. These conditions provide atmospheric moisture that increase rainfall, particularly at the onset of the rainy season[39]. As a result, more than 60% of all rainfall is transpired back to the atmosphere. This has the immediate effect of cooling the land surface by 2-5°C[40,41]. Deforestation and degradation reduce evapotranspiration by 30% or more, increase the surface temperature[41], and if large enough, reduce rainfall regionally[42–44]. The type of land use that follows deforestation has a lesser but still significant impact, with crops having a relatively greater impact on energy balance than pasture[41]. Despite many variable seasonal curve details, crop albedo is typically much higher than pasture albedo and forest albedo (Figure 23.2).

Relative to the forests they replace, crops and pasture grasses have reduced root density and depth and a lower leaf area index. This decreases water demand and lowers evapotranspiration[45–53], which tends to increase water runoff. Conversion of the native vegetation results in a decrease in mean annual ET of about 30%, with much greater dry season decreases[50,54–56]. The changes to ET directly impact other variables that influence the surface water balance; soil moisture and groundwater storage increase by as much as 30% locally, while streamflow can rise 3- to 4-fold in small headwater streams and as much as 20% in very large rivers (e.g., Tocantins/Araguaia)[57–61]. Crops and pastures in the southern Amazon evapotranspire at rates equivalent to forests, but only for 2 to 3 months per year at the peak of the growing season[62].

Much of the precipitation in the Amazon is the result of moisture recycled by the forest[63,64] (see Chapter 5). Thus, the decreased ET that results from deforestation directly impacts the amount, location, and timing of rainfall. Numerous studies have shown a clear link between deforestation and the delayed onset of the rainy season, which is also shorter (i.e., ending earlier)[42,65,66]. In numerical modeling studies, Wright et al.[39] showed that

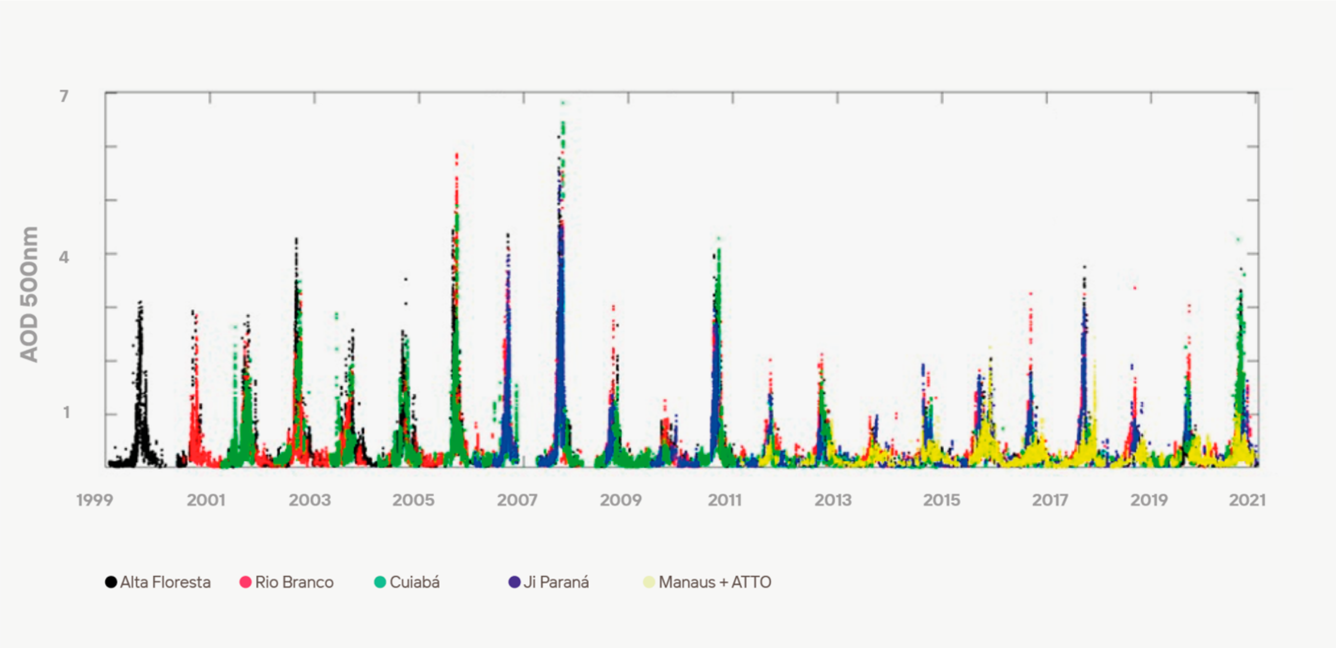

Figure 23.3 Time series (2000-2020) of aerosol optical depth over five sites in the Brazilian Amazonia. Significant year-to-year variability is driven by climate as well as public policies leading to deforestation and emissions from biomass burning.

evapotranspiration increases humidity throughout the atmosphere during the late dry season, and that this is crucial to initiate rainfall, with initiation being hastened by 2-3 months compared to simulations without forest ET. Evidence indicates that dry season humidity in the Amazon is decreasing, making the dry season more severe[67]. In an analysis of rain gauge data in the southern Amazon, Leite-Filho et al.[44] estimate that for every 1% increase in deforestation the onset of the rainy season is delayed by 0.12-0.17 days, which has amounted to a delay of 11 to 18 days in Rondônia, Brazil[42].

Still concerning evapotranspiration, GHG emissions and deforestation have opposite effects. Increased emissions and associated increased atmospheric temperatures tend to increase ET, while deforestation and associated land conversion to agriculture decrease ET. A large amount of carbon emissions from Amazon deforestation contribute to increases in the atmospheric GHG and temperature globally, which are also expected to increase forest water use efficiency through CO_2 fertilization, and reduce the amount of water vapor recycled to the atmosphere. Recent studies show an increased vapor deficit throughout the Amazon, but it is unknown if this is a transient or permanent trend or how this will affect the forest and drive feedback over the long term. The reduced ET can impact precipitation, but changes in response to deforestation depend on how much and where deforestation occurs. Therefore, the impact of deforestation and climate change on hydrology in any location will be a complex function of competing factors[45]. The eastern Amazon region remains particularly vulnerable to feedback from ongoing land-use conversion to agriculture[46]. In summary, the initial significant decrease in ET initiated by deforestation has already impacted much of the Amazon, particularly the south. It has the potential through large-scale feedback to alter the region's climate.

Biogenic and fire aerosol emissions and their impacts in and outside the region The Amazonian atmosphere is dominated by two clear seasons. In the wet season, the atmosphere is dominated by natural primary biogenic aerosol particles emitted directly by the vegetation[68–70].

In the dry season, biomass burning emissions substantially change atmospheric composition and properties, impacting the hydrological cycle, radiation balance, and overall functioning of the ecosystem. [14,71–73]. Significant emissions of carbon monoxide, ozone precursors, nitrogen oxides, aerosol particles, and other compounds alter the atmospheric composition significantly over large areas of South America, and particles can travel for thousands of kilometers[74–76]. Black carbon emissions from Amazonian biomass burning change the snow and ice albedo, impacting the melting of Andean glaciers. Critical components of natural forest emissions, such as biogenic volatile organic compounds (VOCs), are changing, possibly associated with higher temperatures[77]. These emissions significantly impact the ecosystem, including the radiation balance, atmospheric chemistry, and human health[78–81]. Fire emissions are calculated based on the fire burned area derived from remote sensing data and emission factors measured in field experiments[82,83]. Future climate variability is expected to enhance the risk and severity of fires in tropical rainforests. In Amazonia, most if not all fires are human-driven. A way to assess the aerosol column in the atmosphere is by looking at the so-called aerosol optical depth that expresses the total amount of particles in the whole aerosol column, as expressed in Figure 23.3.

Conclusions The impacts of climate change and deforestation in the Amazon are strong, diverse, and well documented. Wherever we look, climate and anthropogenic land-use change already have a substantial impact on Amazonian ecosystems. Moreover, the reverse is also true, with the Amazon affecting global climate change, especially in terms of carbon emissions due to deforestation. Tropical deforestation is responsible for about 13% of global CO_2 emissions[84], and Brazil, Colombia, Bolivia, and Peru are among the 10 top tropical deforestation countries. Reducing tropical deforestation is the fastest and cheapest way to mitigate GHG emissions, and has many co-benefits. Climactic changes, particularly increases in temperature, climate extremes, and altered hydrological cycles, are significantly stressing tropical forests. Reducing biomass burning is essential to minimize several negative aspects associated with high concentrations of aerosols, ozone, carbon monoxide, and nitrogen oxides over large areas of South America. Three main effects of climate change on aquatic systems (both marine and freshwater) are the warming of rivers and hydrographic basins, acidification, and oxygen loss. If we consider only these effects, we can preview habitat loss, changes in fish migration, disturbances in fish assemblages, and changes in spatial fish species distribution. Biodiversity loss is expected not only from direct deforestation but also from different sensitivities of plant species to increased temperature and reduced precipitation. It is important to emphasize that, in addition to reducing deforestation, it is also essential to reduce fossil fuel burning, which is the leading cause of global warming.

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