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Forests and Sustainable Development in the Brazilian Amazon: History, Trends, and Future Prospects

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Abstract

Ongoing deforestation in the Brazilian Amazon is the outcome of an explicit federal project to occupy, integrate, and "modernize" the region. Although there have been isolated periods of deforestation control, most recently between 2004 and 2012, the overall trajectory of the region since the colonial period has been one of forest loss and degradation. Addressing this challenge is especially urgent in the context of adverse climate-ecology feedbacks and tipping points. Here we describe the trends and outcomes of deforestation and degradation in the Amazon. We then highlight how historical development paradigms and policies have helped to cement the land use activities and structural lock-ins that underpin deforestation and degradation. We emphasize how the grounds for establishing a more sustainable economy in the Amazon were never consolidated, leading to a situation where forest conservation and development remain dependent on external programs—punitive measures against deforestation and fire and public social programs. This situation makes progress toward a forest transition

(arresting forest loss and degradation and restoring forest landscapes) highly vulnerable to changes in political leadership, private sector engagement, and global market signals. After summarizing these challenges, we present a suite of measures that collectively could be transformational to helping overcome destructive path dependencies in the region. These include innovations in agricultural management, improved forest governance through landscape approaches, developing a local forest economy, sustainable peri-urbanization, and the empowerment of women and youth. These initiatives must be inclusive and equitable, enabling the participation and empowerment of local communities, particularly indigenous groups who have faced numerous historical injustices and are increasingly under threat by current politics.

Contents

1. INTRODUCTION

The Brazilian Amazon biome is iconic for its expansive forests and biodiversity, which provide numerous ecosystem services to regulate and support our global climate. It is also a critical source

of rainfall to regions elsewhere in South America, with important teleconnections to climate throughout the world. The region is home to more than 28 million people, including both indigenous and traditional communities and migrants from elsewhere in Brazil and abroad (1). This diversity includes 256 peoples, speaking more than 150 different languages, that have been sustainably managing and shaping the environment over the past 12,000 years and domesticating native plants of global economic importance (e.g., cacao, coca) (2). The combination of bio- and cultural diversity supported by the Amazon has helped provide several of the world's most important inventions, from rubber to medicines, and could provide still many undiscovered solutions to global challenges.

The Brazilian Amazon (in particular the Legal Amazon region; see **Figure 1**) is also an important exporter of several food and mineral commodities to global markets, including beef, milk, soy, corn, cassava, rice, bauxite, and iron ore (3). The exploitation of these vast resources, as elsewhere in the tropics, has continued to contribute to the decline of the vast natural capital of the region without commensurate improvements in local wellbeing. Despite increasing international attention, the Amazon remains afflicted by forest loss and degradation (4), as well as poverty and high inequality (5). Without major improvements in human livelihoods and a forest transition in this region, neither Brazil nor the world will be able to meet sustainable development targets for poverty reduction, reduced inequality, biodiversity protection, and climate action.

This article synthesizes deforestation and degradation trends in the region and then contextualizes current forest loss and degradation within historical and contemporary institutional and cultural processes. In doing so, we aim to emphasize how existing power relations and path dependencies constrain sustainable development. We conclude by identifying a set of five opportunities (or leverage points) to change the direction of Amazonian development to improve ecological and human wellbeing in the region for the benefit of the whole planet. Each opportunity includes an example case where improvements in conservation and livelihoods have been simultaneously achieved. We conclude by recapping the challenges to seizing these opportunities.

2. DEFORESTATION AND FOREST DEGRADATION

2.1. Deforestation and Degradation Trends

The original forest cover of the Brazilian Amazon biome—estimated at 4.1 million km^2 prior to 1970—has been progressively decreasing due to ongoing deforestation (**Figure 1*a***), with approximately 84% (3.4 million km^2) remaining at present (4). Forest degradation caused by fires, logging, fragmentation, and hunting is also widespread, reaching 17% of the original forest area (**Figure 1*b***) (6). Deforestation rates have varied greatly since measurement began in 1988, with the highest rates between 1995 (29,059 km^2/year) and 2004 (27,777 km^2/year). The period between 2004 and 2012 was remarkable, as deforestation rates declined 84%, following improved governance measures. However, after reaching the lowest deforestation rate ever recorded in 2012 (4,571 km^2), deforestation levels have been increasing again and surpassed 10,000 km^2 in 2019 (4), and degradation has continued to increase even during periods of decreased deforestation (7).

The combination of deforestation and degradation has led to substantial losses of biodiversity, carbon stocks, and ecological processes and services. Degradation of primary forests halves biodiversity and carbon stocks (8, 9). Emissions from fires alone are substantial and largely unaccounted in carbon budgets (6). They more than double those from deforestation in drought years (10). These processes have contributed to turning the Amazon biome from a carbon sink to a carbon source during drought years (11). Positive feedbacks between deforestation, degradation, and climate change are expected to drive further degradation (12). State changes (Amazon dieback) have been predicted for the Amazon forest if these negative synergies persist, in particular a

Brazilian Amazon biome: an ecological designation pertaining to the humid tropical forest regions of the Amazon river basin that are located within Brazil

Legal Amazon: a political designation for the administrative region of the Amazon that extends beyond the biome boundaries, comprising nine states

Forest transition: the process of arresting forest loss and degradation while also regaining forest area and restoring forest landscapes

Sustainable development: improvements in the wellbeing of current generations that do not reduce overall wealth and opportunities for future generations

Deforestation: the process of completely removing (clear-cutting) a forest (here, referring to areas ≥0.5 ha with ≥10% canopy cover and trees ≥5 meters high)

Forest degradation: any disturbance to the forest ecosystem that does not involve a complete removal of tree cover but reduces ecosystem functions

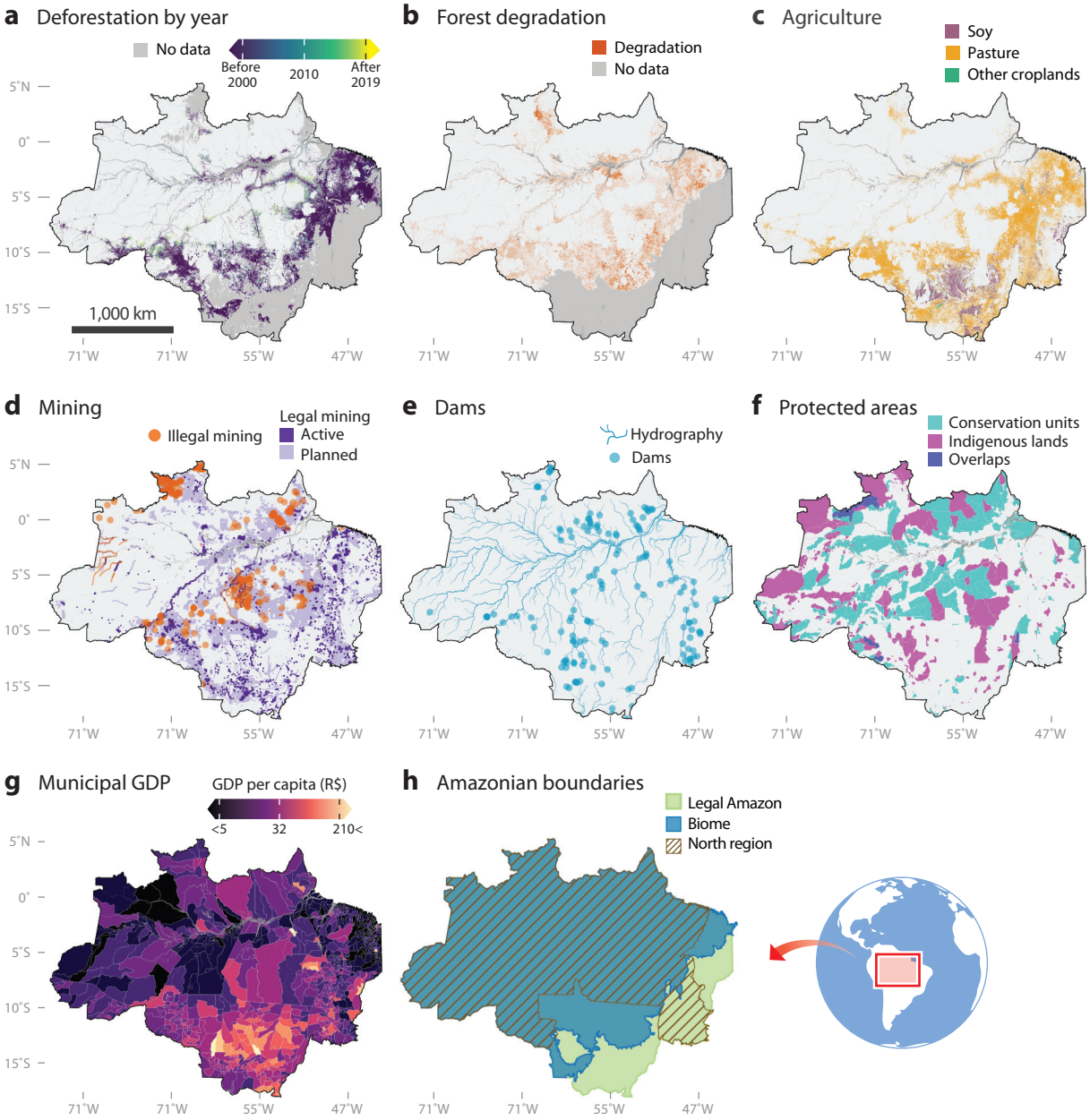

Figure 1

Drivers of forest change and development in the Brazilian Legal Amazon. (*a*) Deforestation by year from 2000 to 2019 according to the National Institute for Space Research [*Instituto Nacional de Pesquisas Espaciais* (INPE)] PRODES satellite monitoring program (4); (*b*) forest degradation as of 2017 according to Bullock et al. (6); (*c*) soy, pasture, and other croplands according to MapBiomas V5 (26); (*d*) legal and illegal mining sites as of 2019 according to the National Mining Agency database (SIGMINI) (**https://www.gov.br/anm**) and the Amazon Geo-Referenced Socio-Environmental Information Network [*Rede Amazônica de Informação Socioambiental Georreferenciada* (RAISG)] (48); (*e*) hydrography according to the National Water Agency [*Agência Nacional de Águas e Saneamento Básico* (ANA)] (**https://www.gov.br/ana/pt-br**) and dams as of 2014, courtesy of Arias et al. (151); (*f*) protected areas according to the World Database on Protected Areas (WDPA) (**https://www.protectedplanet.net/**); (*g*) municipal gross domestic product (GDP) per capita estimate from the Brazilian Institute of Geography and Statistics [*Instituto Brasileiro de Geografia e Estatística* (IBGE)] (**https://sidra.ibge.gov.br/**); and (*h*) Amazonian boundaries.

collapse of the Eastern, Southern, and Central Amazon, turning it into drought-prone vegetation, including savannas (13). These tipping points have been predicted at 20–25% deforestation of the Amazon forest (13).

The recovery of Amazonian forests is highly variable and depends on climatic conditions, landscape configurations, and the type and intensity of disturbances (14, 15). Forests naturally recovering after clear-cutting account for ~130,000 km^2 of the Brazilian Amazon biome and correspond to ~23% of previously deforested areas (16). These secondary forests in the Amazon can recover large amounts of carbon and forest species but normally do not regain the biomass and biodiversity typical of an undisturbed primary forest even after multiple decades (17). To date, secondary recovery in the Brazilian Amazon biome has only compensated around 10% of the original emissions from clearing primary forests (15).

Amazon dieback: the process of humid forests turning into drought-prone vegetation due to reductions in rainfall from climate change and ongoing deforestation

Pasture degradation: the process of deteriorating soil quality (structure and nutrient stock) and declining pasture productivity over time

Pasture reformation: the recuperation of degraded pastures and other nonforested landscapes for use as pasture

2.2. Interactions Between Forest Disturbances and Human Health

The loss and degradation of Amazonian forests not only drive climate change but also contribute directly to losses in social welfare through their impacts on human health (18) and rural and indigenous livelihoods (13). Fires create haze comprised of dangerous pollutants (PM2.5) that is carried by the wind throughout Latin America, causing 16,800 premature deaths every year (19). In 2019 alone, it was estimated that there was a total of 2,195 hospitalizations due to respiratory diseases linked with ambient air pollution from deforestation-related fires in the Brazilian Amazon biome and a total cost of 1.4 million US dollars (20). Escaped fires also create direct risks to the livelihoods of rural households through health hazards from fighting fires without adequate means or training (21), by directly damaging property, and by discouraging investments (22).

Deforestation in the Amazon is linked to several infectious diseases, including malaria, leishmaniasis, rabies, hantavirus, paracoccidioidomycosis, and Chagas disease (23). The mechanisms underpinning these outbreaks include (*a*) habitat loss leading to pathogen spillover, (*b*) flooding and water contamination from changes to the hydrological cycle, and (*c*) increased human and animal hosts and transport for infections via increased human and livestock intensity (23).

2.3. Drivers of Large-Scale Land Clearing

Large-scale land clearing (i.e., deforestation) in the Amazon is influenced by a variety of economic, demographic, and institutional processes. Below we describe the three major direct drivers of land clearing in the region: agricultural expansion, urbanization and infrastructure expansion (i.e., roads and hydroelectric dams), and mining. In Sections 3 to 5 we provide more background about the broader structural context influencing these proximate drivers of land change.

2.3.1. Agriculture. Commercial agriculture remains the largest driver of deforestation in the Legal Amazon (as elsewhere in the tropics), with the majority of this deforestation being directly driven by cattle ranching (24). Deforestation for cattle ranching is used as a means to secure de facto possession over the land (25). Cattle pastures, which in 2019 occupied 53.4 (Mha) (**Figure 1*c***) (26), accounted for 62% of all forests and woodlands cleared between 2001 and 2013 (24).

The primary form of pasture management is extensive, meaning it is continuously grazed with almost no inputs (i.e., lime, fertilizer, or new seeds). Extensive ranching practices result in widespread pasture degradation, currently estimated at 30 Mha in the Legal Brazilian Amazon (27). Because this degradation requires substantial investments to reverse, it is largely undesirable or economically infeasible for ranchers to reform their lands (28). Pasture reformation is especially unlikely in the many areas where forested land is still cheap and where ranchers lack capital and/or are averse to taking on debt.

During the early 2000s, deforestation for soy accelerated, bolstered by rapidly growing demand for chicken and pork in China (29). However, deforestation for soy remained well below pasture-driven deforestation, and after improvements in both public and private sector deforestation governance, direct deforestation for soy declined to low levels—approximately 2% of the deforested area (30). Soy continues to contribute to deforestation in the Amazon indirectly (especially in the Legal Amazon), by displacing cattle pastures (31), and is a direct driver of deforestation in the Cerrado (30). Corn is increasingly planted as a second crop following soy, leading to two crop harvests in the same year. Corn is commonly used as a feed for the growing chicken and pork production sectors.

The availability of undesignated public forest lands and land tenure uncertainty incentivizes speculators to illegally "grab" land by clearing it, sowing large extensions of pastures and grazing cattle, in the hopes that land prices will rise and they will be granted amnesty for their illegal actions (32). The expectation of rising land prices is fueled by the advancing crop frontier, particularly soy (33). Although large clearings and commodity-driven deforestation are by far the largest drivers of land clearing in the Brazilian Amazon biome (24), since 2004, coinciding with greater enforcement of deforestation regulations (see Section 4), there has been an increase in smaller and more remote clearings (34). However, a recent analysis also suggests that just 2% of rural properties are responsible for 62% of all illegal deforestation (35).

2.3.2. Urbanization and large infrastructure. Urbanization has led to a growth in local demand for food and energy, as well as greater migration to the Brazilian Amazon. To meet the growing regional and national demand for energy to fuel economic development over the past five decades, the Brazilian government implemented an ambitious program to install new hydroelectric dams (**Figure 1*e***) (36). Although hydropower could theoretically provide a low-cost and fossil fuel–free energy source for the Brazilian Amazon, most energy is exported out of the region. Large dams have a massive environmental and social footprint, including flooding large areas of forest, emitting high quantities of methane, displacing communities, blocking fish migration, harming freshwater biodiversity, and contaminating groundwater (37, 38). Smaller run-of-the-river dams have fewer negative impacts but also provide only marginal electricity generation (39).

Road infrastructure is also a key driver of migration and human encroachment into forests and indigenous areas. Infrastructure growth also contributes to deforestation by fueling land conflict and speculation (40). At least 12,000 km of new roads are planned for the next years (41), and the paving of existing roads is still planned across many regions, including pristine areas of Amazonas (42).

2.3.3. Mining. Large- and small-scale mines cover nearly 100 Mha of land in the Brazilian Amazon, leading both directly and indirectly to deforestation (**Figure 1*d***) (43). Deforestation within concessions occurs for extraction, processing, and infrastructure and beyond concession borders as the local population and demand for charcoal (to fuel iron furnaces) grow (43). Large-scale mining and other infrastructure projects increasingly threaten protected areas and indigenous lands (44). Industrial mining has been regularly responsible for environmental disasters when the dams that store toxic wastes rupture. These ruptures endanger local subsistence livelihoods and, more broadly, the health of nearby communities.

Gold mining occurs in both large- and small-scale processes and within Brazil is linked to deforestation (45) and threatens people's health and ecosystems through use of mercury and other toxic substances (46). Effects on freshwater food webs are particularly harmful, and at times fatal, to riverine and indigenous populations who depend heavily on fish in their diet (47). More than

120 illegal mining sites (mostly gold) were operating in the Brazilian Amazon in 2020, with high prices driving expansion into previously unexplored areas (48).

2.4. Drivers of Forest Degradation

Logging and fires are the primary, direct causes of forest degradation, alongside isolation and edge effects from fragmentation (49). Selective logging is the process of cutting a limited number of marketable tree species, rather than clearing all trees (i.e., deforestation or clear-cutting). It occurs through both legal and illegal processes. Legal processes include the extraction of trees on private properties and sustainable use areas through official Forest Management Plans, whereas illegal logging occurs within protected areas (indigenous lands and conservation units), undesignated public lands, and individual properties without permission (50). The timber industry is difficult to regulate, as sawmills source logs from a range of formal and informal actors, including many individual landowners or illegal extractors. These logs are purchased directly at the sawmill, making traceability difficult. Furthermore, the rights to extraction can be sold without the land, making it difficult to link logging activities to individual property owners. Selective logging causes damage to the surrounding forest, by damaging other trees, subcanopy vegetation, and soils in the process of creating access roads and extracting logs (51). Even 15 years after logging has occurred, forest biomass is not fully recovered (52).

Extractive: used here in the Portuguese sense to describe the use of nontimber forest products (not including deforestation-related resource extraction)

Riparian areas: the terrestrial areas immediately surrounding rivers or streams

There are many types of fires in the Amazon, including agricultural fires to clear fallow vegetation, escaped fires from agricultural properties (which harm nearby forests and properties), fires used to burn slashed vegetation and stumps after various stages of forest clearing, and fires used during land conflict to secure land and drive others out (53). Fire intensive agricultural practices are popular among farmers given resource and capital constraints but on average generate lower returns than other practices (22). Fire control measures (e.g., clearing firebreaks, carrying water on-site, keeping the intensity of the burn low) are relatively expensive and can be jeopardized by fires from neighboring properties (21). Due to this high external fire risk, many farmers continue to use fire-intensive land uses without any fire control (22).

Fires were partially decoupled from deforestation in the past two decades (7), with an increasing proportion of fires deriving from land management and escaped fires rather than new land clearing (7, 54). However, since 2019 fires associated with deforestation have increased (53), most likely driven by the illegal seizure of land. Fires are increasing in intensity and extent due to droughts and prior forest degradation (55). Small farmers, traditional and indigenous people, who lack barriers and fire breaks, are often the first to experience property and physical losses from fires in the Brazilian Amazon.

Finally, although less emphasized and more difficult to measure, overhunting by Amazonian households also contributes to forest degradation by creating empty forests. Forest loss and fragmentation not only reduces habitat of game species but also increases access to game (56). The extent of this form of degradation may rival or exceed that of logging and fire damage (by one 2006 estimate; see 57). Hunting plays an important role in the subsistence and food security of many households, alongside other extractive activities (gathering of nuts and fruits) (58). However, the extirpation of large mammals causes reduced seed dispersal and herbivory, leading to biomass (and therefore carbon) losses and other substantial alterations to ecosystem processes and further threatening the livelihoods of poor households (59).

2.5. Drivers and Challenges to Forest Landscape Restoration

The Brazilian Amazon contains vast areas that are out of compliance with the legal requirements for conservation in both riparian areas and at the broader property level, as well as within

protected areas (see Section 4) (60). The restoration of riparian areas, in particular, is critical to supporting freshwater biodiversity (61), although restoring whole watersheds has wider benefits (62). The concept of forest landscape restoration (FLR) refers to the intentional process of regaining ecological functionality and enhancing human wellbeing in deforested and degraded forest landscapes, which can occur through passive (i.e., spontaneous regrowth) and active (e.g., planting seeds, assisted natural regeneration, and agroforestry) techniques (63). Barriers to successful restoration include the broader failings of environmental governance outlined in Section 4, lack of regulations (to protect naturally regenerating forests) (64), financial constraints to implement active techniques, and ongoing pressures for clearing fallows. Conversely, restoration efforts have been successful when indigenous groups, smallholders, large-scale agribusinesses, project developers, NGOs, and the government have come together to organize and facilitate the process, for example, as has happened with the development of a restoration seed network in the Xingu River Basin in Mato Grosso (65).

Forest landscape restoration (FLR): the process of regaining ecological functionality and enhancing human wellbeing in deforested and degraded forest landscapes

Modernization theory: a development paradigm common in the 1950s and 1960s contending that "traditional" countries should adopt the "modern" practices of "developed" nations

3. "DEVELOPMENT" OF THE AMAZON FOREST: A HISTORICAL PERSPECTIVE

3.1. State-Led Colonization

The specific drivers of deforestation and degradation described in Sections 2.3 and 2.4 are merely the outcome of a broader Brazilian development paradigm that took hold in the 1950s and 1960s that advocates for the conversion of forests to achieve economic growth and national security (66). This paradigm has its roots in modernization theory, which seeks to replicate development processes in already industrialized nations, by eliminating traditional practices in favor of more "modern" commercial economic activities. Early colonization of the Amazon was focused on wild rubber extraction, of which Brazil had a monopoly, as well as cattle, which allowed for large areas of land to be cheaply and easily occupied. During the 1970s, the federal government intensified its occupation of the Amazon as part of the National Integration Program. Agrarian reform policies established by the federal and state governments resulted in the settlement of more than 1.25 million households (mostly from the South, Southeast, and Northeast) in more than 9,100 settlements all over Brazil by 2013. The Legal Amazon alone hosts 55% of these households, occupying 77 Mha (67, 68). This initiative was intended to help secure the region from outside interests ("integrate or lose it"), as well as to offset growing population pressure ("land without men to men without land"), particularly in Northeast Brazil, where ecological conditions and frequent droughts made farming challenging (66).

This historical development agenda gave rise to powerful physical, institutional, cultural, and political rigidities against forest conservation (**Figure 2**). Physically, the replacement of forest with pastures and other "modern" land uses drastically reduces the range of services that the landscape can provide, locking land users into a narrow range of commercial transactions and reducing self-sufficiency. From an institutional perspective, the rhetoric of modernization underpinned the varied and unclear land tenure structures that allow public forest lands to be appropriated into private property regimes. In particular, entitling ownership through the "productive use" of lands has threatened and devalued indigenous land uses and has been invoked to justify the privileges, inequalities, and inefficiencies of the cattle ranching system (69). These land tenure policies have enabled the accumulation of large financial reserves among a relatively narrow subset of actors within the cattle and broader agricultural sectors. These actors continue to leverage this financial power to strengthen their power over political agendas and promote the modernist narrative (70).

Another legacy of this development program is that as of 2019, there were still 70 Mha of public forestlands (15% of the region) lacking permanent designation under clear zoning rules.

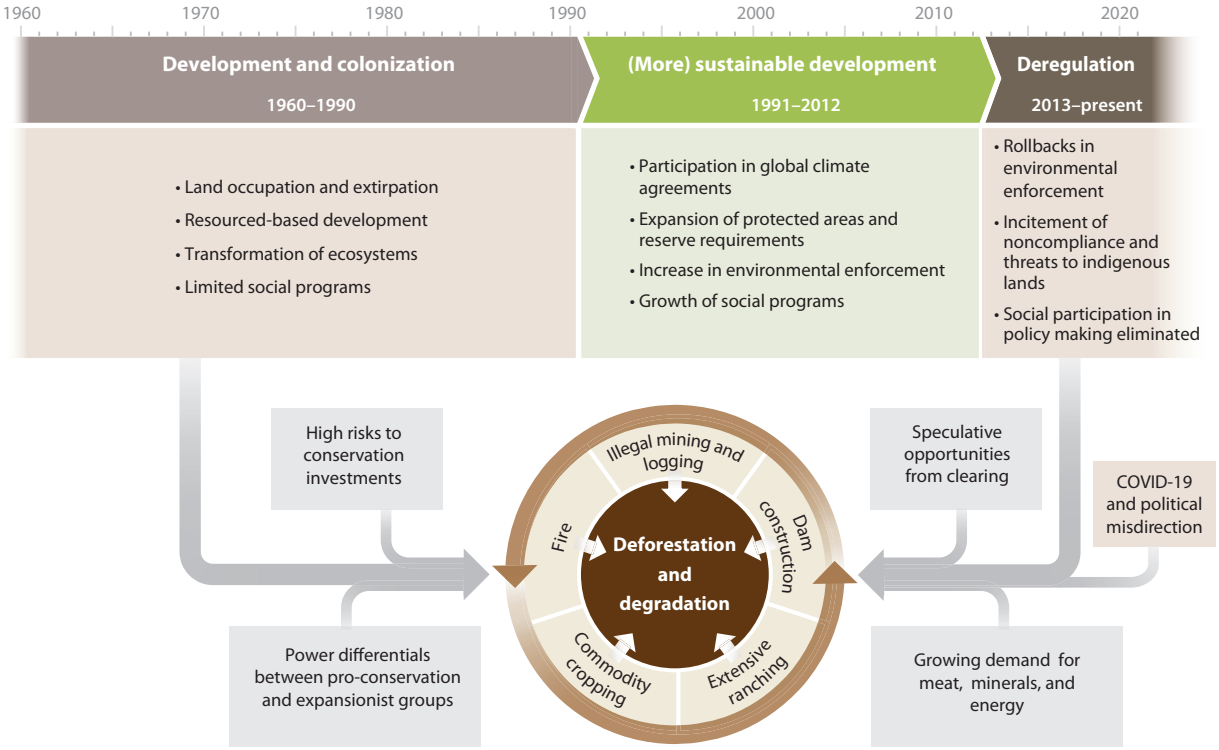

Figure 2

Policy periods and feedbacks leadinig to land use lock-ins in the Brazilian Amazon. Policy periods refer to changes in the overarching paradigm or motivation guiding more specific policy actions and politics at the federal level. Details within each policy period box reflect general overarching changes in policies and politics within each period. Brown boxes indicate periods of more destructive, pro-expansion, modernization policies, whereas the green box indicates the interlude of policies focused more on sustainable development, although still accompanied by resource-based expansion. The gray arrows represent external structural pressures driving deforestation and degradation from the broad policy paradigms (*brown boxes*) or more proximate economic and political factors (*gray boxes*). The brown loops represent how deforestation and degradation themselves contribute to the lock-ins in the system, i.e., how past deforestation and degradation can exacerbate power differentials and help create economic expectations that promote deforestation and degradation. Direct drivers of deforestation and degradation are listed in the outer circle. The long initial period aimed at development and colonization of the region focused on land occupation, resource-based development, and transformation of the natural ecosystems. This trajectory, in combination with growing demand for meat, minerals, and energy worldwide, has led to a situation where environmentally degrading land uses have persisted even despite a period of strong public policy emphasis on sustainable development. Since 1991, the country pivoted toward more sustainable development narratives, and in the period between 2004 and 2012, especially, Brazil showed that it was possible to reduce deforestation while increasing agriculture production. However, recent deregulation and power consolidation by the agricultural lobby have fostered additional rollbacks in enforcement and social conflict that have further exacerbated the lock-ins. Abbreviation, COVID-19, coronavirus disease 2019.

This uncertainty fuels speculative activities and accounted for 25% of deforestation between 2010 and 2015 (71). In 2009, the federal government launched the Terra Legal program aimed at land regularization across 67 Mha of public land or 13% of the Brazilian Legal Amazon area. Despite its claims, the Terra Legal program has not significantly reduced deforestation (72).

Land regularization: the process of using legal, environmental, and social measures for the purpose of integrating irregular settlements into the legal context

3.2. Globalization and the Increasing Role of the Private Sector

During the 1990s and 2000s, like elsewhere in the world, export agriculture and large-scale infrastructure projects became the major drivers of in-migration and urbanization in the region.

Legal Reserve: an area within private properties that must be set aside for conservation according to the Native Vegetation Legislation (Forest Code)

These processes were stimulated by public support for road building, the establishment of a stable and predictable investment climate for agriculture (73), and various financial incentives to attract new firms (e.g., tax breaks, subsidized loans) (74). They were further fueled by globalization and increasing global demand for food (i.e., soy) and minerals (e.g., iron, niobium, bauxite, gold), particularly in China (75), which became Brazil's largest trade partner in 2009 (76).

The returns to agriculture and its comparative advantage in global markets influenced multinational agribusiness investment (73). Given the increasing orientation of Brazilian agricultural production toward export markets, the siting decisions and governance structure of these supply chain actors have become increasingly important for agricultural production. In the Amazon, the soy industry is heavily concentrated, with five traders (Archer Daniels Midland, Amaggi, Bunge, Cargill, Louis Dreyfus) controlling 58% of its soy exports (77). The Brazilian beef sector is similarly concentrated, with just three slaughterhouses handling 66–71% of all production (78). The high concentration of power in both sectors raises substantial equity concerns; however, it also serves as a potential leverage for deforestation control, as described in Section 4.2, below.

4. DEFORESTATION CONTROL AND COMMITMENTS TO RESTORATION: AN INTERLUDE

4.1. Increasing Areas Designated for Conservation and the Enforcement of Forest Policies

The clearing of forests on private lands is regulated by the Native Vegetation Protection Law (Forest Code), established in 1934 (Lei 23,793) and reformed in 1965 and 2012. Since 1965, this law prohibits landowners from removing native vegetation from areas along the margins of rivers and other water bodies (permanent preservation areas), as well as hilltops and steep slopes. Landowners are also required to maintain a certain proportion of the native forest on their land as a Legal Reserve. In 1996, the Legal Reserve size in the Amazon biome was increased from 50% to 80% via Provisional Measure 1511. This provisional measure was renovated several times in the following years, until it was definitively consolidated in the new Forest Code in 2012.

Historically, the Forest Code was not well enforced, especially in the Amazon biome. However, in 1998 the Environmental Crimes Law (Lei 9,605) was signed, establishing penalties and sanctions for environmental crimes, including Forest Code violations. Another critical step for conservation was the establishment of the National System of Conservation Units (Lei 9,985 in 2000). The new matrix of protected areas established by this law includes areas with strict protection (International Union for the Conservation of Nature (IUCN) categories I–IV), where only nonconsumptive use is allowed (i.e., recreation), as well as "sustainable use" areas (IUCN categories IV–VI), where varying levels of extractivism and agriculture are allowed. Brazil currently has 2,446 conservation units in different categories, covering an area of 120 Mha in the Amazon biome (**Figure 1*f***) (79).

Given that land use changes are the major source of greenhouse gas emissions in Brazil, deforestation control and restoration took on a new emphasis in the era of international climate agreements. In 2002, Brazil signed the Kyoto Protocol, pledging national reductions in greenhouse gas emissions. Restoration is supported by the clean development mechanism of the Kyoto Protocol, which facilitates payments and credits for restoration activities by generating protocols for monitoring and determining its additional impacts on carbon budgets beyond business as usual (65). Brazil has since adopted several commitments to mitigate climate change in the scope of the 2015 Paris Agreement, with pledges to cut its emissions by 37% in 2025 and 43% in 2030, relative to 2005 emissions (80). Brazilian commitments associated with the Paris Agreement include

better enforcement of the Forest Code and new measures to achieve zero illegal deforestation in the Amazon and to restore 12 Mha of forests by 2030 (65).

A critical program in the deforestation control efforts was the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon [*Plano de Ação para a Prevenção e Controle do Desmatamento na Amazônia* (PPCDAm)], launched by the Lula government in 2004. PPCDAm led to the addition of 20 Mha of conservation units and 10 Mha to the protected areas system (81). This accounted for 37% deforestation reduction in the Brazilian Amazon between 2005 and 2007 (82). PPCDAm also increased enforcement of existing restrictions on forest clearing in private properties, which contain almost 60% of the remaining native vegetation in Brazil (83). Using increasingly advanced satellite monitoring capacities, the government pursued more integrated action to combat illegal deforestation and was highly successful in significantly lowering the rates of deforestation (84). PPCDAm results have also allowed Brazil to access results-based climate mitigation financing from international actors, including REDD+ funding (see Section 7.2), which can also be used for restoration.

Despite an extensive policy regime to protect forests within private properties and committing to ending illegal deforestation by 2030, huge numbers of rural properties are currently not in compliance with Brazil's forest legislation (25). To monitor and combat this problem, Brazil established a new system for property registration [*Cadastro Ambiental Rural* (CAR)] in 2012. However, out of 362,000 properties identified in this rural property cadaster in 2018, 45% were not in compliance with the Forest Code. Among the CAR properties, 10% were found to have deforested illegally (i.e., clearing in ways that violate the Forest Code after 2008) (35).

Forest degradation processes are less well regulated, and there is no integrated plan to address simultaneous degradation from fires, logging, and hunting. The Forest Code (article 38) forbids all fires, with the exception of agricultural fires, which are allowed with a license and fire control measures. However, licensing is rare, and enforcement of control measures is often absent (85). Fire brigades are grossly underfunded, forcing them to focus on protecting parks and indigenous lands, leaving smallholders unattended. Bans on trading endangered species, such as mahogany, have not been enforced and have been associated with a surge in local violence (86). Hunting is generally prohibited but is also part of the subsistence rights of local populations. The lack of a clear legal framework inhibits progress toward reducing overhunting (87).

Timber extraction on both public and private property is allowed with permits under certain conditions, although governance of this process is largely ineffective. However, it is estimated that 44% of logging sites in the Eastern Amazon are illegal, and 25% to 95% of the extracted volume of timber from Brazil is illegal, resulting in increased pressure on undesignated lands and parks (88, 89). Timber from newly deforested private land cannot be sold (Decreto 6.514 in 2008), but circumventing this is easy, by inflating timber density in legal concessions or by using ghost timber merchants' names (90). To combat this issue, the government tries to match legally sanctioned timber volumes at origin with volumes at destination under a Document of Forest Origin system (91). In recent years, the Brazilian Institute of the Environment and Renewable Natural Resources [*Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis* (IBAMA)] has intensified activities to counteract illegal logging through initiatives called the Green Wave, activated in 2013 and again in 2019, focusing on regions with the highest concentration of illicit activity (91).

4.2. Private Sector Initiatives

In the 2000s, increasing knowledge of the role that a handful of large multinational companies had in the sourcing products linked to deforestation in the Brazilian Amazon led to a series of highly

publicized civil society campaigns against individual companies, most notably by Greenpeace (for soy in 2006 and cattle in 2009). Following this civil society pressure, several private sector initiatives were created with the aim of decoupling the production of soy and cattle from deforestation in the Amazon biome, as well as avoiding reputational damage.

In the soy sector, the primary initiative is the Soy Moratorium, signed in 2006, including all members of the Brazilian Association of Vegetable Oil Industries and the National Grain Exporters Association, the two largest soy producer associations in Brazil, collectively accounting for approximately 90% of the soy market in the Brazilian Amazon (92). The Moratorium committed soy buyers to not buy, trade, or finance soy produced in areas of the Amazon biome cleared after July 2006, later moved to July 2008 (92). Since the policy began, direct deforestation for soy in the Brazilian Amazon has dramatically decreased with the rate of soy expansion via deforestation going from 30% in the two years preceding the Soy Moratorium to only approximately 1% of all soy expansion in the Amazon biome by 2014 (30). It is estimated that the Moratorium contributed to $18{,}000 \pm 9{,}000$ km^2 of avoided deforestation, equivalent to 35% reduction of deforestation rates in the biome (93). Despite these positive findings, there has been concern that the Soy Moratorium may have encouraged leakage of deforestation or a redirection of soy expansion from Amazonian forests to natural vegetation in the Cerrado biome, outside the Moratorium's coverage (30), but there is little evidence of this (93).

Since 2009, the cattle sector of the Brazilian Amazon has had a parallel policy, the G4 Cattle Agreement. This initiative was signed between Greenpeace and the four largest cattle companies in the Brazilian Amazon at the time (JBS, Marfrig, Minerva, and Bertin). Subsequently, the signatories expanded to include the largest three supermarket groups in Brazil—Carrefour, Walmart, and GPA/Casino—thereby becoming the G6 Agreement (with Bertin being merged with JBS). As with the Soy Moratorium, this policy requires signatories to monitor the deforestation of potential suppliers and to not purchase cattle from those who deforested any new areas since 2009. However, research investigating the effectiveness of the G4/G6 Agreement has been mixed. Alix-Garcia & Gibbs (94) found no net impact to the G4 agreements in Mato Grosso or Pará states, attributing this lack of impact to the leakage associated with the loopholes present in the G4 Agreement. Specifically, the initiative only monitors direct suppliers and not producers further upstream. Furthermore, there is increasing evidence that existing programs favor larger farmers and exacerbate inequality (95). In 2020, JBS committed to monitoring these indirect suppliers by 2025. Even if this is accomplished, another weakness is that G4 companies control only ∼50% of the Amazonian cattle market in many regions (S. Levy, R. Garrett, F. Cammelli, P. Vale, R. Vale & H. Gibbs H, manuscript under review). Deforestation control in beef supply chains are further supported by the Terms of Adjustment of Conduct, agreements between the Federal Prosecutor's office and individual slaughterhouses, to help enforce legal compliance with public policy. Given that most cattle properties are in a deficit with respect to their Legal Reserves, this translates to enforcing a zero-deforestation policy among suppliers to the committed slaughterhouses.

Sustainability in timber supply chains is governed by various private sector certification initiatives, as well as several more narrowly defined legality efforts (91). Certification programs include the Forest Stewardship Council (FSC) and the Program for the Endorsement of Forest Certification Schemes, the latter of which includes the Brazilian Forest Certification Program (Cerflor). Whereas FSC includes management of natural forests, Cerflor has largely certified plantation systems. Despite most importing countries requiring some form of certification, only a small share of Brazilian timber production is exported, and existing certification programs cover relatively little of the potential timber base (91). Community-managed and smallholder timber production systems are rarely certified under these schemes (96).

In addition to these two market exclusion mechanisms for zero deforestation, there are numerous other public and private initiatives governing sustainable agriculture more broadly. The Brazilian Agricultural Research Corporation [*Empresa Brasileira de Pesquisa Agropecuária* (Embrapa)] launched a Carbon Neutral Beef concept in 2015, which aims to certify the beef produced in silvopastoral (tree-livestock) or agrosilvipastoral (crop-tree-livestock) type integration systems. Additional certification systems include the Rainforest Alliance Sustainable Agriculture standard for various crop and livestock products and the Round Table for Responsible Soy (RTRS). Both certification schemes aim to accredit socially and environmentally sustainable producers (although not necessarily deforestation-free ones) and provide preferential markets for their produce. However, these policies have failed to mainstream, with only a handful of cattle farms certified by Rainforest Alliance as of 2016 (97); similarly, very few soy producers had become certified except in Maranhão, where 20% of producers have RTRS certification (98).

5. RETRACTION OF DEFORESTATION CONTROL EFFORTS

Forest protections began unraveling under Dilma Rouseff when the increasingly powerful agricultural lobby group (the "ruralistas") pressured legislators to revise the Forest Code in 2012 (99), and other measures related to decreasing public protected areas. Changes included a reduction in riparian buffer sizes, allowing Permanent Preservation Areas to count toward the Legal Reserve, and created amnesties for illegal deforestation that had already taken place, reducing the environmental debt among landowners and their obligation to restore areas (60). When Michel Temer took over the government in 2016, after the impeachment of President Dilma, he cut the budget of the Ministry of Environment (responsible for environmental policing through IBAMA) by the equivalent of $100 million. He then approved Constitutional Amendment Proposal PEC 241, freezing the Ministry of the Environment budget for 20 years. PEC 65 was also passed under President Temer, which relaxes the environmental controls on construction and has been linked to increased land speculation and land grabbing (100).

In 2018, Jair Bolsonaro was elected with an extremely antienvironmental discourse (101). Since the beginning of his administration, President Bolsonaro's agenda has been to concentrate power and dismantle central environmental structures and legislation without replacements (102). Key examples include an increase in nominated public servants over permanent ones and a reduction of important functions of the Ministry of the Environment, including leaving vacant—or being slow to replace—key positions required for environmental enforcement. The administration has also limited the participatory rights of civil society and has taken a hostile approach to the Amazon Fund, resulting in a loss of $1 billion dollars in funds to help conserve the Amazon (35, 103). Aggressive discourses in relation to indigenous peoples and traditional communities, in general, have been inciting illegal activities such as land grabbing, mining, and logging (104, 105).

The changes made by the Temer and Bolsonaro administrations led to accelerated rates of deforestation and degradation (4, 53) and increasing violence and human rights violations in the Amazon (104, 105). Although dissonance was present between the discourse of previous Brazilian governments and their environmental policies in recent decades (106), the current period (Temer and Bolsonaro) is unprecedented in the democratic period of Brazilian history.

The interactions between deregulation and agribusiness growth and power consolidation lead to a positive feedback loop that is difficult to reverse—as the cattle sector expands, a portion of the profits generated can be directed back to lobbying and parliamentary seats to support further deregulation (70). The reductions of Amazonian protections have further accelerated with the advent of the global coronavirus disease 2019 (COVID-19) pandemic in March 2020, reducing international attention to Brazil's environmental governance. Between March and May 2020, 195

infralegal acts (ordinances, decrees, normative instructions, etc.) were published, up from 16 in the same period in 2019 (107). These publications come after the Minister of Environment, Ricardo Salles, publicly stated that the pandemic can be used as an opportunity to "simplify" environmental regulations (108).

Nontimber forest product (NTFP): any product that is naturally produced in forests and can be harvested for human use without cutting trees

North region: another administrative proxy for the Brazilian Amazon region that includes seven of the nine states in the Legal Amazon

6. DEVELOPMENT FOR WHOM?

6.1. Diversity of Rural Livelihood Experiences

The Brazilian Amazon landscape is one of high cultural and social heterogeneity, as well as high economic inequality. Humans have been present in the Amazon over the past 12,000 years and have influenced the region's ecology and environmental conditions by managing and domesticating hundreds of plant species for use as food and medicine and creating high-quality soils called Amazonian Dark Earths (109). Indigenous communities rely heavily on the gathering of nontimber forest products (NTFPs), fishing, and hunting to sustain their families, making them highly vulnerable to ongoing deforestation and degradation.

Outside of indigenous areas, farming is the primary economic activity. Cattle ranching and slash-and-burn agriculture have long been the primary land use activities in private lands (in terms of total area affected). Other core agricultural activities include mechanized annual production (including soy and grains), perennials (namely, fruits and pepper), and horticulture. Smallholders with varying degrees of market integration live alongside larger commercial properties, many of which started as family operations. Smallholders historically focused on manioc, rice, and corn production, with some rearing of beef cattle. In regions with good road access, some smallholders now engage in dairy production, which can be processed into powdered milk and transported long distances (110). Cow-calf operations by small farmers have been increasingly economically attractive due to the impacts of COVID-19 on the supply of meat within Brazil and the sharp increase in demand for meat from China due to African swine fever outbreaks (111).

Riverine communities (communities residing immediately along the banks of the Amazon and its tributaries or in seasonally flooded forests called "Varzeas") often combine small-scale swidden agriculture, agroforestry, forest management for timber and NTFPs, fishing and shrimping, cattle and buffalo ranching, and hunting (112). Among other crops, many agroforestry systems grow açaí, cocoa, banana, oil palm, and coffee (113). Agroforestry systems are also present even within smallholders' settlements along major highways. One notable example is the Japanese community in Tomé-Açu, Pará, which has become a basin-wide example of how successful agroforestry systems can be developed and commercialized through locally driven efforts (114). Agroforestry constitutes only a small proportion of the land use in the Amazon but remains critically important to the wellbeing of the most vulnerable groups within the Amazon and to the broader development of local economies through processing and distribution of various agricultural and forest products.

Rural to urban migration accelerated during the second half of the twentieth century in Brazil (116) as well as in the Amazon. However, the absolute rural population is still on the rise due to frontier migration (117). In 2010, of the 449 municipalities of the North region of Brazil, 85.7% (comprising 76% of the territory and 36.5% of the population) were considered rural (<50,000 inhabitants) (118). However, people living in rural and peri-urban areas increasingly rely on cities as a part of their multi-sited lives, to access education, health care, wage labor, and government benefits (112).

Many of the fastest growing economies and cities in the Amazon are driven by the exports of commodities, including soybeans in Mato Grosso and bauxite and iron-ore in Pará (see areas of high municipal GDP per capita in **Figure 1*g***). However, economic growth in Manaus, the largest

Table 1 Wellbeing and development indicators in the Brazilian Amazon over time

Indicator	1996	2006 (or nearest year)	2017 (or nearest year)	Average annual change (earliest to latest year) %	Source
Per capita GDP (Brazilian Real-2019 prices)[a]	15,232	17,872	21,237	1.9	IBGE: national accounts
Poverty (%)[b]	38.23	31.02	17.50 (2014)	−3.0	Ipea: macroeconomic social indicators
Literacy (%)[c]	86.7	85.1	88.6 (2015)	0.1	IBGE: continuous household survey; INEP
Infant mortality (%)	36.1	24.3	17.6	−2.4	IBGE: sustainable development indexes
Life expectancy at birth (years)	68.4	69.7	72.2 (2016)	0.3	IBGE: sustainable development indexes
Food security (%)	NA	53.4	57	0.3	IBGE: household consumption survey
Energy access (%)[d]	NA	93.7 (2010)	98.1 (2013)	1.6	IBGE: household census; national survey of health
Income inequality (Gini coefficient)	0.58	0.52	0.54	−0.3	Ipea: macroeconomic social indicators
GDP inequality (Gini coefficient)	NA	0.82	0.79	−0.3	IBGE: national accounts

[a]The per capita value estimated uses population data from the IBGE Demographic Census.
[b]The poverty rate is the proportion of the whole population.
[c]The literacy rate here includes the proportion of the population older than 15.
[d]The energy access rate includes the proportion of households with a permanent home.
Abbreviations: GDP, gross domestic product; IBGE, *Instituto Brasileiro de Geografia e Estatíistica* (Brazilian Institute of Geography and Statistics); Ipea, *Instituto de Pesquisa Econômica Aplicada* (Institute for Applied Economic Research); INEP, *Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira* (National Institute of Educational Studies and Research Anísio Teixeira); NA, not applicable.

city in the Amazon, was driven by its establishment as an Industrial Pole (since 1967), which incentivized foreign direct investment and manufacturing via tax exemptions and other fiscal measures. Both urban economic models are highly vulnerable to economic cycles, and neither takes advantage of potential economic opportunities that can be derived from the standing forest (as outlined in Section 7).

6.2. Socioeconomic Development Trends

Despite producing ecosystem services and financial wealth for much of the country, in terms of "objective" development metrics (rather than self-reported wellbeing), many people in the Brazilian Amazon still suffer from poverty and lack access to critical services (**Table 1**). As of 2018, only 57.1% of the population in the North had access to clean water, 10.5% to sanitation, and 11.1% to household waste collection (119). The early exposure of children to insufficient or inadequate dietary practices has led to significant height-for-age, weight-for-age, and weight-for-height deficits (120).

Historical gains in material wellbeing have been largely ephemeral and have come at the expense of natural capital or traditional livelihoods. Inequality remains high and many small farmers have been displaced from their land, either forcibly or through large financial incentives to

sell their properties (121). Indigenous reserves are increasingly threatened by encroachment. Deforestation and forest degradation have also disproportionately negatively impacted women, by reducing opportunities for gathering of medicinal plants and NTFPs (122). Large-scale infrastructure and mining programs have displaced tens of thousands of families (123), and more than 300 people have been killed during the past decade as a result of land and resource conflicts in the Amazon—many involving illegal logging and deforestation (105).

Urbanization writ large has not brought many objective improvements in welfare. Migrants to urban areas tend to have high unemployment and poor access to piped water, sanitation services, electricity, garbage disposal, education, health care, and housing (124). Urban industrial development processes have also generated substantial externalities, including defaunation of major fish species. This defaunation harms downstream terrestrial ecosystems through reduced seed dispersal and harms fish-dependent communities by reducing food security and income (125).

Despite this grim picture, reductions in poverty and inequality and improvements in health and food security have been achieved in the region (**Table 1**) through the expansive federal poverty reduction program "Brazil Sem Miséria" (Brazil Without Extreme Poverty), which includes the "Bolsa Familia" (conditional cash transfer program) as well as more targeted programs "Fome Zero" (Zero Hunger), "Luz Para Todos" (Light for All), and "Bolsa Verde" (reward program for conservation behavior) (126, 127). The government has also supported local food systems by establishing programs that buy agricultural products from family farmers for use as meals at schools via the National School Meal Program and for state institutions via the Food Procurement Program. These programs have been instrumental to encourage diversified production, improving local economies and human health (128).

7. LEVERAGE POINTS FOR SUSTAINABLE DEVELOPMENT AND FOREST TRANSITIONS IN THE BRAZILIAN AMAZON

7.1. Innovations in Agricultural Management

Given that 53.4 Mha of the deforested areas in the Amazon biome are associated with pastures used predominantly to support extensive cattle ranching (see Section 2.3) (26), sustainable intensification of these areas, including the reformation of degraded pastures, will play an important role in helping to meet growing demand for food fiber and fuel (129). Promising examples include mixed grass-legume pastures and improved pasture management with rotational grazing (130, 131), as well as integrated crop and livestock systems (132). These management innovations are all supported by the federal Low Carbon Agriculture Plan, which provides subsidized credit and research and development to support such systems (28). The growth of soy and corn production in the region has increased incentives to intensify cattle production through the adoption of crop-pasture rotations (i.e., integrated crop and livestock systems) and through supplementary feeding (i.e., semi-confinement systems) (133). These more intensive systems can have substantially higher profits and shorter payback periods (132).

Ideally, this process of intensification could help reduce deforestation pressure and help free up land for FLR and compliance with the Forest Code. Recent empirical evidence from Latin America, however, indicates that past improvements in technical efficiency have largely increased, rather than decreased agricultural expansion and deforestation (134). To date, no study has assessed whether cattle intensification in the Amazon has spared land or encouraged expansion, largely due to challenges measuring intensification and the endogeneity of deforestation and intensification processes (133). Nevertheless, models based on experimental research data have shown that in Mato Grosso, the adoption of more intensive cattle production systems can substantially improve

climate resilience and reduce the amount of greenhouse gas emissions and water use per unit of protein produced (132).

Forest economy: activities that generate financial and other benefits from the standing forest

7.2. Improved Forest Governance Through Landscape Approaches

To address the shortcomings of both public and private sector deforestation control efforts (see Section 4), recent calls for improved socio-ecological governance in the Brazilian Amazon and elsewhere in the tropics support the adoption of integrated landscape approaches. These approaches engage multiple stakeholders across the public, private, and civil society spheres, in attempts to reconcile societal and environmental objectives at the landscape scale to identify trade-offs and synergies for more sustainable and equitable land (135). Existing efforts in the Amazon include (*a*) Jurisdictional REDD+—a form of payments for environmental services that aim to catalyze reduced deforestation and degradation through carbon finance and incentives for sustainable development at a subnational jurisdictional level; (*b*) Verified Sourcing Areas (VSAs)—a program developed by The Sustainable Trade Initiative to stimulate demand for commodities from regions where all production has been verified as sustainable according to their criteria; and (*c*) locally driven approaches including Mato Grosso's Produce, Conserve and Include (PCI) and the "Municípios Verdes" (Green Municipality) Program in Pará. REDD+ initiatives exist in the states of Acre, Amazonas (Bolsa Floresta), Amapá, Pará, and Mato Grosso (136), and VSA pilots exist in selected municipalities of Mato Grosso and Pará State in Brazil, focused on zero-deforestation soy farming and cattle ranching. PCI was initiated by the Governor of Mato Grosso in 2016 with a goal to cut deforestation by 90%, enhance agricultural production, rehabilitate 2.9 Mha of vegetation, and involve smallholders and indigenous communities in low-emission rural development (137). The Municípios Verdes Program was initiated by the municipal government and rural producer syndicate in Paragominas, with participation from two major NGOs (Imazon and The Nature Conservancy) with the goal of exiting the federal government's Red List (a list of counties blocked from receiving credit due to high deforestation). This effort committed the municipality to zero illegal deforestation georeferencing and environmental licensing of all properties under the Rural Environmental Registry (CAR) (95).

Such approaches have the potential to bypass an unwilling federal government and leverage state- or municipal-level support to improve the equity and legitimacy of forest governance in the Brazilian Amazon. By making trade-offs between different policy options more explicit and reaching consensus among different stakeholders, such approaches might be able to develop more locally appropriate and effective incentive and monitoring systems. Acre's State System of Incentives for Environmental Services—the world's first jurisdictional REDD+ program—for example, has demonstrated some long-term success in combination with other conservation and development measures at the state level. Nevertheless, jurisdictional programs rely heavily on the financial and political will of external donors and local government officials, which may change over time (138) and should be considered within a broader policy mix including federal policies and supply chain initiatives. There are many issues that jurisdictional programs cannot solve, such as the need for land regularization support from the federal government.

7.3. Developing New Models for a Local Forest Economy

Large areas in the Amazon, particularly those designated for indigenous peoples and traditional communities in conservation units for sustainable use (see Sections 4.1 and 6.1), hold extraordinary potential for the development of sustainable biodiversity productive chains in the context of a local forest economy. The North region is responsible for 45% of nontimber forest production

in Brazil, with açaí (*Euterpe oleracea* Mart.) as one of the main products, followed by Brazil nuts (*Bertholletia excelsa* Bonpl.). Extractive forms of production generated 4.3 billion Brazilian Reals, of which 1.6 billion comes from nontimber forest production (139); however, these official numbers are likely a large underestimation of the potential benefits. Another valuable resource is the generation of biopharmaceuticals, such as jaborandi (*Pilocarpus microphyllus* Stapf ex. Wardl), which is used to cure glaucoma. For example, Natura, the largest Brazilian cosmetics company, has sourced seeds, fruits, and oils for lotions and shampoos from 33 extractive communities in the Amazon and Northeast Brazil, comprising more than 5,000 families (140).

Unlike past development models, these types of productive chains generate income from the standing forest. When retail companies source directly from communities, the prices paid to extractivist communities can be quite high and coupled with substantial capacity building investments. However, despite the large potential linked to its enormous socio-biodiversity, successful examples of forest-based value chains are still rare. Investments in science and technology, training and education, and infrastructural projects (e.g., transportation, Internet connection, and water treatment) related to the forest economy are critically needed.

A critical fairness issue in the development of these biopharmaceutical and biocosmetic chains is the protection of indigenous and traditional intellectual property and the creation of benefit sharing mechanisms. The introduction of greater market integration with powerful multinational firms also raises concern about the inequality in power relationships between bio-entrepreneurs and local populations (141). In August 2020, Brazil launched a national decree (Decreto 136) that approved the text of the Nagoya Protocol on access to genetic resources and fair benefits sharing. This may be an important step toward regulating benefit sharing with indigenous communities and traditional populations.

7.4. Sustainable Peri-Urbanization

As outlined in Section 6.2, semi-extractive and manufacturing models of urban development have failed to generate sustainable economic models for the Amazon. However, interesting models of more sustainable trajectories appear to be self-generating at the peri-urban fringe. People increasingly seek out peri-urban regions to maintain the "segurança" (security) of a rural lifestyle with greater access to markets and services (142). Peri-urban communities also have better conditions for higher value agricultural production systems, including perennial and horticulture production, which are highly perishable and require immediate consumption unless processed (143).

Peri-urban home garden and agroforestry projects are particularly suited to the needs of small farmers migrating from extractive forest areas and governmental settlements. They are leaving these areas due to declining prices of rubber, the paucity of other nontimber income-earning alternatives and in search of better conditions of access to health services for their families and schools for the younger generation (124, 144). The Agroforestry Poles in the peri-urban areas of Rio Branco, Acre, in the western Brazilian Amazon are illustrative of this potential. These initiatives were implemented by the municipal government in the second half of the 1990s to reallocate low-income families with some farming expertise to already deforested areas ranging from 2.5 to 11 ha, consisting mostly of degraded pastures and secondary vegetation. The poles have fulfilled their goal of diversifying production, ensuring food security, and improving income and income distribution among the 296 families, out-performing urban low-income housing initiatives (124). Additionally, they have shown some success in conserving existing forests and enhancing recovery of degraded areas (145).

7.5. Empowerment of Women and Youth

Achieving social justice and equity requires inclusion and empowerment of the most vulnerable and underrepresented actors in society. Numerous social movements now exist across different vulnerable groups, including indigenous, riverine, and former slave communities, among others. But even within these communities, the voices of women and the youth are particularly hidden, despite their unique potential to contribute to a forest transition.

Women are crucial to the collection and sale of medicinal plants and other NTFPs, activities that are large contributors to household resilience (146). As a challenge to traditional gender structures, women are now increasingly engaging in formal markets for agricultural and forest products (147), as well as collective organization and social movements. The growth of women's collective microenterprises aims to improve not only material outcomes for women but also their self-confidence, visibility, and environmental and political awareness (122).

Younger generations play a crucial role in advocating for environmental justice and cultural preservation in the Brazilian Amazon due to their greater engagement with social media, film, and photography (148). Several indigenous youth movements exist in the Brazilian Amazon, such as the Movimento Mebengokre Nyre (Kayapó youth movement) in Pará. Intercultural education and community-based cultural revitalization projects are key to supporting such movements (149).

8. CONCLUSION

As a result of decades of explicit colonization initiatives and little focus on sustainable use strategies, the forests of the Brazilian Amazon continue to decline and degrade. Ongoing logging, mining, and agricultural activities contribute to greenhouse gas emissions, biodiversity loss, infectious disease outbreaks, and social conflicts, with little financial benefit to a majority of the people who live there. Some traditional practices, such as NTFP extraction and agroforestry, and nascent social movements, such as women's extractive collectives and indigenous youth groups, are a promising reservoir for building a more sustainable local forest economy toward a forest transition. However, they are practiced by largely invisible and increasingly threatened groups, who remain backstage in internal political discussions about Amazonian conservation and sustainable development.

Existing public-private policy mixes have had success in curbing deforestation rates and have made incremental progress in helping to spur some innovations in the agricultural sector that can bring sustainability benefits, but they have failed to tackle the broader underlying power dynamics promoting deforestation. Instead, the enforcement capacities underpinning the public forest protections have been vastly rolled back in recent administrations. This process has been exacerbated by COVID-19, which has reduced field enforcement operations and has been intentionally used to draw attention away from deforestation and deregulation activities (4). The pandemic has also underscored the vast inequalities (150) in the region and helped to increase the visibility of a broader range of development and health concerns in the region, which perhaps could help to catalyze broader sustainability improvements.

The sheer scale of cattle ranching and its high contributions to climate change and household livelihood portfolios makes focusing on improving cattle management a necessary short-term strategy to improve sustainable development in the Amazon. However, efforts to tackle deforestation only through innovation and intensification in the agricultural sector may further strengthen and legitimize the agribusiness lobby, which could ultimately derail existing anti-deforestation protections. Increasing international pressure to reduce deforestation, via withholding financing for agriculture and conservation or refusing to sign trade agreements, appears to be a somewhat successful lever for moderating pro-clearing behaviors in the modern political climate. These

pressure points are greatly aided by increasing transparency of deforestation impacts (92). However, a problem remains for how to keep the pressure constant long enough to consolidate the cultural, social, and economic changes necessary to decouple the economic development process in the Amazon from deforestation.

To achieve lasting sustainable development and a forest transition in the Amazon, it will be necessary to reduce incentives for deforestation and forest degradation, while creating new, long-lasting opportunities for restoration and improved rural and urban livelihoods. Such efforts need to build on, but go further than, the progress made during 2004 to the early 2010s, a period of increased deforestation control—marking a radical structural shift from overtly counterproductive historical colonization regimes and modernization paradigms. This structural transformation, which includes strengthening the forest economy and empowering local people, is extremely urgent given the potential tipping points for a forest Amazon dieback and feedbacks to other economic sectors and regions within Brazil. It is also urgent from a justice perspective, as the people most harmed by the status quo are those that are already teetering on the edge of existence. Emerging landscape-scale initiatives may help leverage financing opportunities from abroad, but ultimately the most important solution will be a change in the domestic politics to favor autonomy by local communities and a new sustainable development paradigm.

SUMMARY POINTS

1. Ongoing deforestation has reduced the original Brazilian Amazon forest extent by 16%, and forest degradation has impacted another 17% of the remaining area.
2. The underlying driver of Amazonian forest loss is a historical development agenda that gave rise to powerful physical, institutional, cultural, and political structures that drive mining, logging, and agriculture and create rigidities against forest conservation.
3. Deforestation activities continue to cause substantial damages to human health, alongside broader ecological harms, and do not provide a robust or sustainable economic development model for the region.
4. To support sustainable development and a forest transition in the Brazilian Amazon, we draw attention to the following five particularly promising opportunities: (*a*) innovations in agricultural management, (*b*) improved forest governance through landscape approaches, (*c*) developing new models for a forest economy, (*d*) sustainable peri-urbanization, and (*e*) empowerment of women and youth.
5. The forest transition is extremely urgent given the potential ecological tipping points on the horizon and ongoing harm to the vulnerable indigenous and traditional communities.

FUTURE ISSUES

1. Existing research has substantially advanced our understanding of the quantity, drivers, and impacts of deforestation and the role of agricultural expansion; however, the extent and drivers of forest degradation remain less well understood.
2. More studies of the drivers of degradation and fire use, their impacts on ecosystems and people, and the effectiveness of different programs and policy interventions for tackling degradation and fire are urgently needed.

3. Political ecology approaches must be deepened to identify and quantify financial flows and other levers of influence that connect actors engaged in deforestation-related activities to government actors and decisions.
4. More research is needed on the effectiveness of agricultural innovations, landscape governance approaches, value chains for forest products, socioeconomic processes in periurban regions, and the social movements supporting the empowerment of women and youth.
5. New research should focus on the conditions that favor entrepreneurship and innovation in the new sustainable forest economy, both at a micro level as well as at a scale that allows for an economic structural change.

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