Chapter 27

Science Panel for the Amazon (SPA)

Working Group 10

Conservation, Restoration, and Forest Transitions (Opportunities, Strategies and Challenges in Terrestrial and Aquatic systems

Lead Authors: Jos Barlow & Plinio Sist

Conservation measures to counter the main threats to Amazonian biodiversity

Lead authors: Barlow, Jos & Sist, Plinio

Contributing authors: Rafael Almeida, Caroline Arantes, Dolors Armenteras, Erika Berenguer, Patrick Caron, Francisco Cuesta, Carolina Doria, Joice Ferreira, Alexander Flecker, Sebastian Heilpern, Michelle Kalamandeen, Alexander C. Lees, Marielos Peña-Claros, Camille Piponiot, Paulo Santos Pompeu, Carlos Souza, Judson F. Valentim

Chapter 27

Conservation measures to counter the main threats to Amazonian biodiversity

Jos Barlow[1], *Plinio Sist*[2], *Rafael Almeida*[3], *Caroline Arantes*[4], *Dolors Armenteras*[5], *Erika Berenguer*[1,6], *Patrick Caron*[7], *Francisco Cuesta*[8], *Carolina Doria*[9], *Joice Ferreira*[10], *Alexander Flecker*[3], *Sebastian Heilpern*[11], *Michelle Kalamandeen*[12], *Alexander C. Lees*[13], *Marielos Peña-Claros*[14], *Camille Piponiot*[15], *Paulo Santos Pompeu*[16], *Carlos Souza*[17], *Judson F. Valentim*[18]

[1] Lancaster Environment Centre, Lancaster University, Lancaster, UK, jos.barlow@lancaster.ac.uk
[2] CIRAD, Université de Montpellier, UR Forests & Societies, Montpellier 34398, France, sist@cirad.fr

[3] Department of Ecology and Evolutionary Biology, Cornell University, 616 Thurston Ave., Ithaca NY 14853, USA
[4] Center for Global Change and Earth Observations, Michigan State University, East Lansing, USA
[5] Departamento de Biología, Facultad de Ciencias, Universidad Nacional de Colombia, Bogotá, Colombia.
[6] Environmental Change Institute, University of Oxford, Oxford, UK and Lancaster Environment Centre, Lancaster University, Lancaster,UK
[7] University of Montpellier, Cirad, Umr ART-DEV, Montpellier 34398, France, patrick.caron@cirad.fr
[8] Grupo de Investigación en Biodiversidad, Medio Ambiente y Salud - BIOMAS - Universidad de Las Américas (UDLA), Quito, Ecuador
[9] Laboratório de Ictiologia e Pesca, Departamento de Ciências Biológicas, Universidade Federal de Rondônia (UNIR), Porto Velho, Brazil
[10] Embrapa Amazonia Oriental, Trav. Eneas Pinheiro, Belém, Brazil
[11] Department of Natural Resources, Cornell University, USA
[12] School of Geography, University of Leeds, Leeds, UK
[13] Department of Natural Sciences, Manchester Metropolitan University, UK
[14] Forest Ecology and Forest Management Group, Wageningen University & Research, Wageningen, The Netherlands
[15] Smithsonian Conservation Biology Institute & Smithsonian Tropical Research Institute, Republic of Panama
[16] Departamento de Ecologia e Conservação, Instituto de Ciências Naturais, Universidade Federal de Lavras, Lavras, MG, Brazil.
[17] Instituto do Homem e Meio Ambiente da Amazônia—IMAZON, Belém, PA, Brazil.
[18] Agroforestry Research Center of Acre, Embrapa Acre, Rodovia BR-364, Km 14 (Rio Branco/Porto Velho), Rio Branco AC 69900-970, Brazil

INDEX

Chapter 27

WG 10 GENERAL INTRODUCTION

When the vast forests and river networks of the Amazon are observed from space, restoration may not seem key priorities when compared to avoiding deforestation and further loss. Yet, 20% of the forest has already been converted to other land uses, and at least a further 17% (or 1 million km^2) of the remaining forest has been disturbed and degraded since 1985 (Bullock *et al.* 2020). Outside of forested regions, transitional zones of old growth forests and old growth grasslands such as between the Amazon rainforest and the Cerrado in Brazil or Chiquitania in Bolivia have seen up to 50% conversion to pastures or croplands (Colli *et al.* 2020). Within the Amazon, estimates of disturbance often exceed the cumulative area of deforestation over the same time period (Aragão *et al.* 2018; Matricardi *et al.* 2020). Furthermore, much of the deforested land is either abandoned or locked into low productivity farming systems. Deforestation has not been random, and some regions are in greater need of restoration as they have very low levels of remaining forest cover - these include the Amazon/Andes transition (i.e. 500-1300 m asl) and the more seasonal regions of the "arc of deforestation" in Brazil. In these areas, restoration actions are opportunities to promote alternatives to deforestation and forest degradation as well as a tool to support forest transition.

In the aquatic realm, the longitudinal connectivity of many rivers and smaller streams has been fragmented by dams, and the vast informal road network has interrupted connectivity in countless small streams. These aquatic and terrestrial realms are intimately interlinked, and restoration will often be more effective if it considers these lateral linkages, aquatic connectivity and catchment-scale processes.

The Amazon contains some of the largest open mines in the world such as Carajas, Trombetas in Brazil while smaller-scale gold mining exists across Brazil and Peru, Venezuela and the Guianas. Coupled with urbanization, and oil and gas extraction, these activities have polluted many riverways and streams that are important food sources for many indigenous and local communities throughout Amazonia. In these highly polluted sites, remediation is essential because these areas will not recover on their own.

Chapters 27, 28 and 29 will explore the role conservation and restoration can play as solutions to the environmental issues outlined in **WG7. Chapter 27** outlines some of the conservation actions that are an urgent priority and must accompany restoration. **Chapter 28** will examine opportunities and approaches for restoration in terrestrial and aquatic systems, focusing on the local benefits. **Chapter 29** will examine issues regarding their implementation across landscapes and catchments, including their role in making the Amazon as a whole more resilient to climate change, helping avoid the dangerous tipping points outlined in Chapter 23. Restoration is only ever going to be part of the solution, as the prevention of habitat loss and degradation will always be less expensive and more ecologically rewarding.

Chapter 27

ABSTRACT

Human activities destroy biodiversity and disrupt the functioning of aquatic and terrestrial ecosystems at different levels. This chapter provides sustainable approaches to address some of the biggest threats to the Amazon's biodiversity and ecosystems, i.e., deforestation, damming of rivers, mining, hunting, illegal trade, drug production and trafficking, illegal logging, overfishing, and infrastructure expansion. The role of restoration is addressed in Chapters 28 and 29.

Chapter 27

KEY MESSAGES

- The Amazon's biodiversity and ecosystem functioning are threatened by a broad range of drivers originating within the basin and worldwide. These include cattle ranching, agricultural expansion, and land speculation; hunting and overfishing; climate change; inappropriate infrastructure; mining and energy generation; invasive species; war and unrest; pollution; and the fragmentation of watercourses by small dams and impoundments.
- Stressors often co-occur in the same regions, which can amplify their effects or create new problems.
- Given this complexity, there is no single or simple solution to solve the Amazon's socio-environmental problems. Instead, a broad set of initiatives need to be readopted, replicated, and scaled up, leveraging the Amazon's socioeconomic, cultural, and ecological complexity.
- Any restoration program must be accompanied by a much broader suite of conservation actions that maintain biodiversity and other desirable aspects of the existing ecosystem.
- Actions taken within the Amazon must be accompanied by changes in non-Amazonian countries and regions, to limit climate change and avoid exporting deforestation, river fragmentation, and other environmental harms.

1. INTRODUCTION

Restoration – the active or passive recovery of ecosystem or socio-economic condition – is important, but risks being undermined unless it is accompanied by a much broader suite of conservation actions that maintain biodiversity and other desirable aspects of the existing ecosystem. Here we outline the measures required to counter the most important threats to the Amazonian biodiversity, using the International Union for Conservation of Nature (IUCN) Threats Classification Scheme 3.2 as the framework for analysis of drivers of change (https://www.iucnredlist.org/resources/threat-classification-scheme). As this is a high-level review, it is important to clarify that not all threats are equally relevant across the basin, and conservation measures that may work in one country or setting may be ineffective or counter-productive elsewhere.

2.1. Habitat loss and ecosystem degradation resulting from cattle ranching, agricultural expansion, and land speculation

Deforestation, forest degradation, and the conversion of non-forest ecosystems threaten native biodiversity across Amazonia (Chapter 19). Where deforestation is the major threat, conservation actions can be developed around the adoption, replication, or return to interventions that were successful in the past or in other regions. These include (i) near-real-time monitoring of forest loss across the basin, (ii) effective on-the-ground enforcement actions, (iii) use of sanctions as allowed under environmental laws and credit restrictions for landholders in high deforestation zones, (iv) soy and cattle moratoria, (v) incentives for agricultural systems that avoid deforestation, (vi) the expansion and genuine protection of protected areas, including sustainable use reserves and Indigenous territories, and (vii) support for and recognition of grassroots actions including community led patrols and mapping.

Advancements in remote sensing can greatly support these interventions, allowing for real-time, finer scale, and higher-temporal resolution assessments of forest loss and an improved ability to track drivers of degradation such as fire and illegal logging. Remote sensing also needs to track the loss and degradation of non-forest ecosystems, which can be much harder to detect.

The success of interventions designed to prevent deforestation and degradation require better governance and reduced corruption at all scales (Cuneyt Koyuncu and Rasim Yilmaz 2008; Fischer *et al.* 2020). Evaluating the conservation of native vegetation on private lands requires up-to-date land registries (e.g., CAR in Brazil). Reducing the negative impact of commodities that are strongly associated with deforestation, such as beef, soy, and minerals, requires careful governance and transparency to track and remove deforestation from supply chains (Zu Ermgassen *et al.* 2020). This will require changes in governance and financial accountability in countries that import Amazonian products.

2.2. Ecosystem degradation resulting from biological resource use: overexploitation or resources by hunting, fishing and logging (IUCN #5)

Hunting

Illegal hunting of wildlife is widespread and culturally embedded in the Amazon, and represents a major threat to some Amazonian vertebrates and, ultimately, ecosystems. For species such as the Endangered Wattled Curassow *Crax globulosa* it is the preeminent threat, whilst for others like the Critically Endangered Black-winged Trumpeter *Psophia obscura* it acts in synergy with habitat loss, fragmentation and degradation. Effective enforcement of existing legal instruments to protect threatened species from hunting is crucial for the long-term persistence of such species. In some cases this may be a matter of effective outreach, with ignorance of the law often a driver of non-compliance with existing environmental regulations reinforced by high social acceptability (Winter and May 2001). However, conservation intervention strategies need to take into account potentially serious impacts on local people who are at risk of loss of culture, traditional knowledge, and dietary diversity leading to risks to food security (Ibarra *et al.* 2011). Although much hunting is for subsistence purposes and is tied to rural poverty, hunting does cross socio-economic boundaries (El Bizri *et al.* 2015) and may be facilitated by a lack of enforcement - encouraging non-compliance for economic gain or simply social enjoyment and/or prestige. Urban demand for bushmeat is high (Parry *et al.* 2014), and is an important driver of game species depletion, even in high forest cover landscape (Parry and Peres 2015).

Bragagnolo *et al.* (2019) drew up a series of recommendations to mitigate the impact of hunting while considering human well-being. They suggest that i) the process of registering to become a subsistence hunter needs to be simplified, ii) licensing schemes should be extended and iii) hunting needs to be linked to community-based wildlife management programmes. Management of harvested wildlife should ideally be based on quota systems which consider variation in life history attributes between game species such as reproductive rates and population density. Additionally, or alternatively the creation of ‘no-take zones’ which foster source-sink dynamics are another well-established strategy to avoid regional game depletion (Wilkie and Carpenter 1999). These no-take zones may be specific to certain habitats, for example restricting hunting to secondary forest zones embedded in primary forest matrices (Garcia-Frapolli *et al.* 2007). In circumstances where illegal hunting needs to be controlled and hunting pressure reduced then potential interventions include i) the provision for alternative livelihoods ii) modification of game supply chains through substitution and iii) utilising education and social marketing campaigns to target key demographics for behaviour change (Bragagnolo et al. 2019).

Overfishing

Fishing in the Amazon embraces a gradient of intensity, from industrial to artisanal, and uses diverse gear and techniques, with impacts that vary spatiotemporally across different river ecosystems. This can lead to the depletion of stocks, but as with hunting, it disproportionately impacts some species more than others, with the greatest on large-bodied fish. Many large-bodied species are also migratory, posing transboundary management challenges. Many of the solutions to overharvesting of terrestrial vertebrates apply equally to fisheries with a focus on integrated fishery management that may include community-based planning, careful stock assessments which consider species life histories, the implementation of no-take areas and control of commercial activities. Enforcement of existing closed season limits and minimum size requirements would increase population productivity, limit overexploitation (Castello *et al.* 2011), and protect sexually immature individuals to guard against the collapse of fish stocks, even if fishing is curtailed (Myers and Mertz 1998). Diversification of the catch composition ought to reduce pressure on overexploited species; this is particularly the case for migratory species like *Salminus brasiliensis*, *Colossoma macropomum*, *Brachyplatystoma capapretum* and *Pseudoplatystoma* sp. which need effective management at large spatial scales. Other ‘fishing’ activities, for example the catch of the Amazonian freshwater dolphins *Inia geoffrensis* and *Sotalia fluviatilis* which are now caught as bait for the scavenging catfish *Calophysus* *macropterus* and consequently driving population declines in the dolphin species - which are also widely impacted by bycatch need to be ended immediately (da Silva et al. 2018).

Illegal wildlife trade

Although the prevalence may have declined from historical highs, trafficking remains the main driver of decline for aquatic species such as ornamental fish (see WG7) and terrestrial species such as songbirds. The population of the Great-billed Seed-Finch *Sporophila maximiliani* is Critically Endangered in Brazil but it is still encountered in trade (do Nascimento *et al.* 2015; Machado *et al.* 2019). These measures require international actions, such as the foundation of pedigree-controlled captive lineages from the last wild birds or from wild birds confiscated by environmental authorities to ensure the species genetic integrity (Ubaid *et al.* 2018). This in addition to efforts to stop wild birds entering the trade and measures to increase the sustainability of bird-keeping through emphasizing the importance of captive-bred birds (Marshall *et al.* 2020).

Illegal logging

In the absence of strict regulation and monitoring, selective logging can be a major driver of forest degradation, weakening forest resilience to fires (Alencar *et al.* 2004), increasing the risk of commercial extinction of the most valuable timber species (Blundell and Gullison 2003; Branch *et al.* 2013; Richardson and Peres 2016), and reducing the richness and altering the composition of forest fauna (e.g. Mason 1996, Barlow et al. 2006, Franca et al. 2018). There is a wealth of evidence on the regulatory solutions, such as timber harvesting guidelines that set offtake limits, avoid logging in ecologically sensitive areas such as on steep slopes or adjacent to watercourses, and aim to mitigate impacts of tree felling, yarding, and hauling; these are collectively known as "reduced-impact logging" (RIL) techniques (ITTO/IUCN 2009; ITTO 2015). While these are undoubtedly preferable to conventional (unplanned) approaches to logging in reducing losses of carbon and biodiversity (West *et al.* 2014; Chaudhary *et al.* 2016), there are still important concerns about the long-term sustainability of harvest rates that have been set (Sist *et al.* 2021) – these need to be revisited using species and region specific data from repeated harvests and modeling studies (Sist and Ferreira 2007; Piponiot *et al.* 2019). The greatest and most immediate challenge relates to the high prevalence of illegal activities, which even permeate legal concessions (Finer *et al.* 2014; Brancalion *et al.* 2018). This illegal logging has two main effects. First, sustainable forest management practices will not be followed in the areas where the timber is illegally extracted (Vidal *et al.* 2020) causing significant and long-lasting reductions in forest carbon stocks (Berenguer *et al.* 2014) and biodiversity. Second, the availability of illegal timber suppresses market prices, reducing incentives for others to follow RIL methods (Santos de Lima *et al.* 2018).

Addressing these issues will require improved public systems governing logging and more transparent supply chains so that the origin of timber can be clearly traced and verified (Brancalion et al. 2018). Big data, use of unmanned aerial vehicles (UAV) (Figueiredo *et al.* 2016) and DNA technologies could support the verification process (Degen *et al.* 2013). Improvements can also be made by creating stronger forest-related partnerships between multiple actors, including local community involvement (Ros-Tonen *et al.* 2008), that can help ensure both compliance with environmental laws and land tenure rights. In the longer term, reducing Amazonia's economic reliance on timber from native forests will provide the best approach (see Chapter 29).

2.3. Ecosystem degradation resulting from climate change & severe weather

Climate change and climate extremes are a major driver of ecosystem degradation. Impacts can be direct and immediate through droughts that cause widespread mortality of trees and aquatic life (Phillips *et al.* 2009; Lennox *et al.* 2019) or due to damaging floods (Marengo and Espinoza 2016; Barichivich *et al.* 2018). Extreme climatic events alter the availability of keystone resources such as fruiting trees (Wright *et al.* 1999) and bring about major shifts in wildlife populations (Bodmer *et al.* 2018). Climate change can also act slowly, over long time periods, altering temperature and rainfall patterns, increasing dry season length (Fu *et al.* 2013). These more gradual changes are associated with changes in tree species composition observed in long-term plot networks (Esquivel-Muelbert *et al.* 2019). Climate change and extremes can also act in concert with other disturbances to increase the likelihood of large scale megafires (e.g. Aragao et al. 2018, Withey et al. 2018) and forest dieback (Nobre *et al.* 2016) (See Chapters 22 and 24).

Addressing pervasive climatic drivers is challenging, requiring action to reduce greenhouse gas emissions, including in non-Amazonian countries that have historically emitted the most carbon dioxide. However, actions within the Amazon are also key. First, the Amazon is in itself a critically important global carbon store and potential sink (Chapter 19 and 20), and land-use change contributes the majority of emissions from Amazonian nations. Local management to avoid deforestation and degradation and encourages restoration, will therefore play a key role in mitigating global climate change if conducted in concert with emission reductions elsewhere. Second, local management may be key to enable ecosystems to retain their innate resilience to climatic stress (e.g. França *et al.* 2020). For example, avoiding logging and buffering forest edges with regenerating forests could all help retain humid forest microclimates (Uhl and Kauffman 1990), reducing the risk of forest fires. Stems in intact forests may also be more resilient to drought and fire stress, with lower levels of tree mortality (Berenguer et al. 2021). Local management that encourages free flowing rivers could also make aquatic systems more resilient to climate change and climatic extremes, as extreme weather exacerbates the impacts that large dams have on ecosystem functioning in downstream forests (Moser *et al.* 2019).

2.4. Infrastructure as a driver of change: Roads and Railways

Past experience suggests that, without dramatic changes in governance, increasing access to new regions via road building or paving will result in an inevitable increase in deforestation and environmental degradation (see Chapters 14 and 19). Given changes in governance are unlikely in the short term, and have not yet proven to be effective on smaller scales, maintaining Amazonia's integrity requires a halt to new road construction and a very cautious approach to improving existing roads. This is especially important when road building or improvement schemes cross previously inaccessible regions – such as the IIRSA, the road planned in the 'Calha Norte' of the Brazilian Amazon, or the paving of highways such as the BR319 between Manaus and Porto Velho. There needs to be greater consideration of what are good roads (i.e., those important for the local economy and people) and bad roads (i.e., those which open up forest frontiers, encourage land grabbing and a wide range of illegal activities, and are motivated by geopolitical reasons or land speculation). While many unofficial roads are associated with deforestation, these are both symptoms of unplanned governance and land speculation as well as potential drivers of deforestation *per se*. Railways in the region are almost all tied to moving soy/mining products (Chapter 19). While railways may have less indirect impacts on surrounding forests as roads, they nonetheless act to fragment the region and hasten deforestation alongside the tracks (Chapter 19). Finally, large infrastructure developments must avoid protected areas and Indigenous territories.

2.5. Energy and mining as a driver of change

Instead of constructing major dams, alternative sources of renewable energy should be harnessed in the Amazon, including off-grid solar(Sánchez *et al.* 2015), biomass, and wind. Where dams are essential, the focus should be on smaller headwater hydropower stations along tertiary tributaries that minimise impacts on biodiversity, and should avoid the lower reaches of Amazonian rivers where impacts on socio-biodiversity are most pervasive. These smaller hydropower dams will still require full river catchment environmental analyses to understand and mitigate cumulative environmental impacts. They will require the removal of vegetation prior to flooding to minimize methane emissions, and there is a need to maintain dam-free river stretches containing representative sections of the original landscape (Lees *et al.* 2016). Approval of new dams should also be accompanied by trade-off analysis including realistic estimates of future energy production under different climate scenarios (Winemiller *et al.* 2016). Efforts to modernize older hydropower plants will result in considerable cost and time saving and lead to fewer ecological and social impacts – although decommissioning and a switch to alternative forms of renewable energy will likely provide the greatest environmental benefits. The indirect effects of dams and mining are significant and extend tens of kilometers into the surrounding forests (Chapter 17, Sonter *et al.* 2017) and the full social and ecological costs and greenhouse gas emissions footprint of these projects must be included in the decision making process when they are being planned.

Gold mining is a source of mercury in river waters. It accumulates throughout the food chain up to humans, especially in populations that rely heavily on fish consumption, leading to severe neurological and motor damage, even in populations living kilometers away from pollution sources (Chapter 21). These predominantly illegal activities need to be curbed immediately. Although regulated, large-scale mining must consider its indirect impacts – i.e. the increase in deforestation up to 70 km away from the concession are due to human migration (Chapter 19).

2.6. Invasive species and diseases (IUCN #8)

Invasive species are widespread in Amazonia's aquatic ecosystems (Chapter 20). However, knowledge of their impacts in the Amazon is limited. To date, most impacts have been demonstrated in riparian systems that experience higher propagule pressure of invasive non-native species (Doria *et al.* 2021). Many fish introductions e.g. of carp and tilapia are deliberate and a perceived means of developing aquaculture and the economy. Such measures have recently received political endorsement by legal measures facilitating "naturalisation by decree" of such invasive fish species (Pelicice *et al.* 2014; Alves *et al.* 2018). This trend towards legalization of non-native species for aquaculture needs to be rolled back and instead aquaculture producers should seek to develop new technologies for the production of native fish species - of which Amazonia has the most diverse reservoir of options globally.

Beyond introduced fish, aquatic ecosystems are also under threat from the invasive grass *Urochloa arrecta* (African Signalgrass) which competes with native macrophyte communities, leading to local extinctions which impoverish ecosystem services (Fares *et al.* 2020). Invasives like *Urochloa arrecta* are associated with altered environments and a breakdown in ecosystem integrity, especially increased canopy openness which increases invisibility so measures taken to restore riparian buffers should help to restrict its spread. Enhanced biosecurity is needed to stop the spread of other aquatic species into Amazonia, the golden mussel *Limnoperna fortunei* for example represents a major threat, and its establishment in the basin would not only result in far-reaching negative impacts to biodiversity but also causing huge economic losses in blocking pipelines of hydroelectric power plants and water-supply company infrastructure (Uliano-Silva *et al.* 2013). Monitoring can help ensure early detection, but needs to be accompanied by effective biosecurity protocols that prevent transport of invasive species into the Amazon. This requires coordinated management at various scales and the close cooperation of state and local governments.

Terrestrial systems are seemingly less threatened by invasive species in Amazonia, but there are examples – including the escape of the acacia *Acacia mangium* from large-scale commercial plantations which is invasive surrounding Amazonian savannas (Aguiar et al. 2014). Silvicultural initiatives should carry out risk assessments for the invasion potential of their forestry projects and contribute to controlling biological invasions should they occur, or risk losing their environmental certification. Disease surveillance efforts are needed to track prevalence of diseases like yellow fever in primates (Ramos-Fernández and Wallace 2008) and chytridiomycosis in amphibians which may be largely asymptomatic in the basin (Russell *et al.* 2019). Although these may not be major problems at present, they may represent serious threats for small, fragmented populations of Critically Endangered species in future.

2.7. Human intrusions: War and unrest

The negative environmental impacts of within-country conflicts with non-state actors have been documented around the world (McNeely 2003). Among drivers of deforestation, war and violent conflicts in tropical areas have affected forests and biodiversity of many countries in Latin America (McNeely 2003; Fjeldså *et al.* 2005). The impacts of violence on tropical deforestation are mixed. In some cases, conflict increases rates of deforestation (McNeely 2003; Hanson *et al.* 2009), due mainly to shifts in land tenure and changes of agricultural practices including the expansion of illicit crops (Negret *et al.* 2019). In other cases, by limiting the access to the forest, armed groups have inadvertently reduced forest exploitation (Dávalos 2001), prevented infrastructure and agriculture development (Reardon 2018) and even facilitated recovery (McSweeney *et al.* 2014).

Post-conflict situations require careful management. In Colombia, after decades of unrest, the recent 2016 peace agreement expanded unsustainable development practices, resulting in an increase in deforestation in some frontier areas. A disproportionate increase in fires was the first signal indicating large-scale forest degradation (Armenteras *et al.* 2019) and transformation at the heart of the key protected areas in the Colombian Amazon (Murillo-Sandoval *et al.* 2020). In Colombia, as in Brazil, cattle ranching are used by land owners to claim ownership over newly cleared forests coupled with the lack of clarity of ownership of land property titles (Armenteras *et al.* 2019) . Establishing legitimate government control and governance in former Amazonian conflict zones in Peru and Colombia is critical to ensure that deforestation rates do not increase during periods of transition. In Colombia this necessitates working with communities in Indigenous reserves and Afro-Colombian collective lands in order to set conservation objectives within a broader context of local development aspirations (Negret *et al.* 2019). Conservation and sustainable use also require the involvement of communities displaced by warfare, but this is being undermined by the mass killings and murders of social community leaders in Colombia (UN, 2021) and a rise in area of illicit crops (Murillo-Sandoval et al., 2020). Further, access to and distribution of land is still highly unequal in countries such as Brazil, Peru and Colombia and in the later this has been a major source of violent conflict for decades (Krause 2020); curbing land speculation and land grabbing is essential to protect forests (Armenteras et al., 2019). Political, technical and financial support for small farmers to ensure the transition from coca culture to other legal land use is needed and must be promoted. Some of the solutions lie outside of the Amazon countries. For example, deregulation and the legalization of drugs in the developed world would reduce gangs' income and open up opportunities for sustainable development and conservation in regions affected by growing and trafficking (McSweeney *et al.* 2014).

2.8. Agricultural, aquacultural, and industrial waste; plastic waste; heavy metals and mercury

The Amazon needs a water quality monitoring network that extends across the many different river basins, providing a way of linking changes in quality with changes in biodiversity and ecosystem conditions. This is also key for human communities, given that rivers are the region's chief source of drinking water, and that it is consumed untreated in many areas(Fenzl and Mathis 2004). Although water is treated for consumption in Amazonian cities, wastewater treatment is often inexistent or ineffective and requires urgent investment. Monitoring also needs to cover industrial and mining zones, such as Manaus (Amazonas) and Barcarena (Pará), respectively, where industrial waste tailing basins pose a major risk to human and ecosystem health (Medeiros *et al.* 2017). Pollution from these and other mining activities – especially gold mining (see Chapter 21) - needs to be tackled with effective command and control activities. Urgent research is needed to understand the impact of pesticides on biodiversity and ecosystem servicesin both aquatic and terrestrial ecosystems (Chapter 20). Solutions involve more rigorous screening and licensing of chemicals, and better training for farmers in their use to reduce usage and impacts arising from poor application techniques. These issues are especially pertinent in the south of the basin (Lathuillière *et al.* 2018). Plastic pollution is a growing issue and country-specific actions (see Chapter 28) need to be supported by basin-wide regulation.

2.9. Small dams not for energy (IUCN #7) as included in agriculture and road infrastructure

Watercourse fragmentation in Amazon is also associated with inappropriate road crossings and culverts. Although these barriers are small, they have landscape-scale consequences for species assemblages (Schiesari *et al.* 2020); the small reservoirs upstream of the road are an important component of instream habitat change (Leal *et al.* 2016). Inappropriate road crossings also isolate aquatic populations by interrupting dispersal pathways (Perkin and Gido 2012), potentially hindering recolonization opportunities following stochastic and human induced extinction events (Schumann *et al.* 2019; Wilkes *et al.* 2019), and shifting distributions due to climate changes (Comte *et al.* 2014). Despite growing awareness of the benefits that can be gained from adapting the small but pervasive barriers created by road crossings (O'Shaughnessy *et al.* 2016), there is little incentive to currently do so: these crossings are considered as low environmental impacts by the Brazilian Environmental Council (CONAMA 2006); resolution #369), discouraging restoration practices. However, even relatively minor changes to regulations could make an important difference. Many road crossings in the Amazon require annual repairs, and replacing them with less-damaging structures (bridges) could have an attractive benefit-cost ratio.

2.10. Ecosystem degradation resulting from interactions between stressors

Many of the aforementioned stressors co-occur, and one set of stressors can amplify both the prevalence and impact of other stressors, or create new problems. Forest fires are a key example of such an interaction, as they are encouraged by a combination of local and climatic stressors (Chapter 19). Global climate change is a key driver of fire prevalence, increasing both dry season lengths and temperatures (Brando *et al.* 2019). Maintaining the climate change mitigation potential of the Amazon is therefore itself dependent on reducing greenhouse gas emissions across the world. But while tackling climate change remains a global priority, this is a slow process and preventing forest fires in the coming decades will require conservation and prevention measures that address their local causes (Barlow *et al.* 2020). Tackling deforestation is fundamental, as forest clearance is a major source of ignition, and augments the flammability of remaining forests by increasing edge density, raising regional temperatures and reducing rainfall (WG 7). But deforestation is not the only source of ignition in the landscape. Many forest fires start when fires in cattle pastures 'escape' (Chapter 19); this risk can be reduced by encouraging fire-free cattle ranching, which could also bring about multiple other benefits (Chapter 28). Traditional fire-dependent agriculture, such as farm-fallow systems using slash and burn (e.g. Padoch and Pinedo-Vasquez 2010) are more difficult to replace, as actions could have undesirable outcomes for sustainable land use, regional food security and social justice. In these cases, conservation policies need to help farmers adapt existing farming practices, and must consider local perspectives (Carmenta *et al.* 2013). Fires could also be reduced by preventing illegal logging and any other actions provoking forest degradation, as the high offtake rates and lack of pre-cut planning or follow-up management make illegally logged forests especially vulnerable to fire, due changes in the microclimate (Uhl and Kauffman 1990). Finally, forest fires can be reduced by near-real-time monitoring and forecasting of drought intensity and fire risk, especially if linked to responsive, resourced and capable local fire brigades. Fire brigades are fundamental to effective park management in the Bolivian and Brazilian Amazon, but remain chronically under-resourced (Nóbrega Spínola *et al.* 2020).

3. CONCLUSIONS

Amazonia's enormous size means that relatively few of its endemic species are classified as having restricted ranges or are currently regarded as being globally threatened. Yet there is no room for complacency, and a broad suite of conservation measures are urgently needed to prevent further ecosystem degradation and habitat loss. These measures are most urgent in some of the most deforested regions, especially in the south and east of the basin where several species are now critically endangered. But concrete and urgent measures are also needed across the entire region, to allow Amazonia's ecosystems to continue to provide the many local, regional and global benefits. Finally, it is important to note that conservation assessments are inherently conservative. Many species, especially invertebrates, are yet to be described – and ongoing taxonomic revisions are uncovering a large shortfall in our current understanding of Amazonian diversity, with many widespread species complexes being split into multiple restricted range species with much smaller distributions. The more we look at the Amazon's biota, the more reasons we will find to conserve it.

Chapter 27

REFERENCES

Alencar AAC, Solórzano LA, and Nepstad DC. 2004. Modeling forest understory fires in an eastern Amazonian landscape. *Ecol Appl* **14**: 139–49.

Alves GHZ, Tófoli RM, Lima-Júnior DP, *et al.* 2018. New decree promotes fish invasion in Amazon and Pantanal. *Biodivers Conserv* **27**: 2449–50.

Aragão LEOC, Anderson LO, Fonseca MG, *et al.* 2018. 21st Century drought-related fires counteract the decline of Amazon deforestation carbon emissions. *Nat Commun* **9**: 536.

Armenteras D, Negret P, Melgarejo LF, *et al.* 2019. Curb land grabbing to save the Amazon. *Nat Ecol Evol* **3**: 1497–1497.

Barichivich J, Gloor E, Peylin P, *et al.* 2018. Recent intensification of Amazon flooding extremes driven by strengthened Walker circulation. *Sci Adv* **4**: eaat8785.

Barlow J, Berenguer E, Carmenta R, and França F. 2020. Clarifying Amazonia's burning crisis. *Glob Chang Biol* **26**: 319–21.

Berenguer E, Ferreira J, Gardner TA, *et al.* 2014. A large-scale field assessment of carbon stocks in human-modified tropical forests. *Glob Chang Biol* **20**: 3713–26.

Bizri HR El, Morcatty TQ, Lima JJS, and Valsecchi J. 2015. The thrill of the chase: uncovering illegal sport hunting in Brazil through YouTube™ posts. *Ecol Soc* **20**.

Blundell AG and Gullison RE. 2003. Poor regulatory capacity limits the ability of science to influence the management of mahogany. In: Forest Policy and Economics. Elsevier.

Bodmer R, Mayor P, Antunez M, *et al.* 2018. Major shifts in Amazon wildlife populations from recent intensification of floods and drought. *Conserv Biol* **32**: 333–44.

Bragagnolo C, Gama GM, Vieira FAS, *et al.* 2019. Hunting in Brazil: What are the options? *Perspect Ecol Conserv* **17**: 71–9.

Brancalion PHS, Almeida DRA de, Vidal E, *et al.* 2018. Fake legal logging in the Brazilian

Amazon. *Sci Adv* **4**: eaat1192.

Branch TA, Lobo AS, and Purcell SW. 2013. Opportunistic exploitation: An overlooked pathway to extinction. *Trends Ecol Evol* **28**: 409–13.

Brando PM, Silvério D, Maracahipes‐Santos L, *et al.* 2019. Prolonged tropical forest degradation due to compounding disturbances: Implications for CO 2 and H 2 O fluxes. *Glob Chang Biol* **25**: 2855–68.

Bullock EL, Woodcock CE, Souza C, and Olofsson P. 2020. Satellite‐based estimates reveal widespread forest degradation in the Amazon. *Glob Chang Biol* **26**: 2956–69.

Carmenta R, Vermeylen S, Parry L, and Barlow J. 2013. Shifting Cultivation and Fire Policy: Insights from the Brazilian Amazon. *Hum Ecol* **41**: 603–14.

Castello L, McGrath DG, and Beck PSA. 2011. Resource sustainability in small-scale fisheries in the Lower Amazon floodplains. *Fish Res* **110**: 356–64.

Chaudhary A, Burivalova Z, Koh LP, and Hellweg S. 2016. Impact of Forest Management on Species Richness: Global Meta-Analysis and Economic Trade-Offs. *Sci Rep* **6**: 1–10.

Colli GR, Vieira CR, and Dianese JC. 2020. Biodiversity and conservation of the Cerrado: recent advances and old challenges. *Biodivers Conserv* **29**: 1465–75.

Comte L, Murienne J, and Grenouillet G. 2014. Species traits and phylogenetic conservatism of climate-induced range shifts in stream fishes. *Nat Commun* **5**: 1–9.

CONAMA. 2006. Resolução Conama Nº 369, de 28 de março de 2006. Brazil.

Cuneyt Koyuncu and Rasim Yilmaz. 2008. The Impact of Corruption on Deforestation: A Cross-Country Evidence. *J Dev Areas* **42**: 213–22.

Dávalos LM. 2001. The San Lucas mountain range in Colombia: how much conservation is owed to the violence? *Biodivers Conserv* **10**: 69–78.

Degen B, Ward SE, Lemes MR, *et al.* 2013. Verifying the geographic origin of mahogany

(Swietenia macrophylla King) with DNA-fingerprints. *Forensic Sci Int Genet* **7**: 55–62.

Doria CR da C, Agudelo E, Akama A, *et al.* 2021. The Silent Threat of Non-native Fish in the Amazon: ANNF Database and Review. *Front Ecol Evol* **0**: 316.

Esquivel‐Muelbert A, Baker TR, Dexter KG, *et al.* 2019. Compositional response of Amazon forests to climate change. *Glob Chang Biol* **25**: 39–56.

Fares ALB, Calvão LB, Torres NR, *et al.* 2020. Environmental factors affect macrophyte diversity on Amazonian aquatic ecosystems inserted in an anthropogenic landscape. *Ecol Indic* **113**: 106231.

Fenzl N and Mathis A. 2004. Pollution of natural water resources in Amazonia: Sources, risks and consequences. *Issues local Glob use water from Amaz Montevideo, UNESCO*: 57–76.

Figueiredo EO, D'Oliveira MVN, Locks CJ, and Papa D de A. 2016. Estimativa do Volume de Madeira em Pátios de Estocagem de Toras por meio de Câmeras RGB Instaladas em Aeronaves Remotamente Pilotadas (ARP). *Bol Pesqui Número 9 - Embrapa* **d**: 1–59.

Finer M, Jenkins CN, Sky MAB, and Pine J. 2014. Logging concessions enable illegal logging crisis in the peruvian amazon. *Sci Rep* **4**: 1–6.

Fischer R, Giessen L, and Günter S. 2020. Governance effects on deforestation in the tropics: A review of the evidence. *Environ Sci Policy* **105**: 84–101.

Fjeldså J, Álvarez MD, Lazcano JM, and León B. 2005. Illicit Crops and Armed Conflict as Constraints on Biodiversity Conservation in the Andes Region. *AMBIO A J Hum Environ* **34**: 205–11.

França FM, Benkwitt CE, Peralta G, *et al.* 2020. Climatic and local stressor interactions threaten tropical forests and coral reefs. *Philos Trans R Soc B Biol Sci* **375**.

Fu R, Yin L, Li W, *et al.* 2013. Increased dry-season length over southern Amazonia in recent decades and its implication for future climate projection. *Proc Natl Acad Sci* **110**: 18110–5.

Garcia-Frapolli E, Ayala-Orozco B, Bonilla-Moheno M, *et al.* 2007. Biodiversity conservation, traditional agriculture and ecotourism: Land cover/land use change projections for a natural protected area in the northeastern Yucatan Peninsula, Mexico. *Landsc Urban Plan* **83**: 137–53.

Hanson T, Brooks TM, Fonseca GAB Da, *et al.* 2009. Warfare in Biodiversity Hotspots. *Conserv Biol* **23**: 578–87.

Ibarra JT, Barreau A, Campo C Del, *et al.* 2011. When formal and market-based conservation mechanisms disrupt food sovereignty: impacts of community conservation and payments for environmental services on an indigenous community of Oaxaca, Mexico. *Int For Rev* **13**: 318–37.

ITTO/IUCN. 2009. Guidelines for the conservation and sustainable use of biodiversity in tropical timber production forests. ITTO Policy Development Series No 17 ITTO/IUCN.

ITTO. 2015. Guidelines for the sustainable management of natural tropical forests. ITTO Policy Development Series (IITT Organization, Ed). Yokohama, Japan.

Krause T. 2020. Reducing deforestation in Colombia while building peace and pursuing business as usual extractivism? *J Polit Ecol* **27**: 401–18.

Lathuillière MJ, Coe MT, Castanho A, *et al.* 2018. Evaluating water use for agricultural intensification in Southern Amazonia using the Water Footprint Sustainability Assessment. *Water* **10**: 349.

Leal CG, Pompeu PS, Gardner TA, *et al.* 2016. Multi-scale assessment of human-induced changes to Amazonian instream habitats. *Landsc Ecol* **31**: 1725–45.

Lees AC, Peres CA, Fearnside PM, *et al.* 2016. Hydropower and the future of Amazonian biodiversity. *Biodivers Conserv* **25**: 451–66.

Lennox RJ, Crook DA, Moyle PB, *et al.* 2019. Toward a better understanding of freshwater fish responses to an increasingly drought-stricken world. *Rev Fish Biol Fish* **29**: 71–92.

Machado RB, Silveira LF, Silva MISG da, *et al.* 2019. Reintroduction of songbirds from captivity: the case of the Great-billed Seed-finch (Sporophila maximiliani) in Brazil. *Biodivers Conserv*: 1–24.

Marengo JA and Espinoza JC. 2016. Extreme seasonal droughts and floods in Amazonia: Causes, trends and impacts. *Int J Climatol* **36**: 1033–50.

Marshall H, Collar NJ, Lees AC, *et al.* 2020. Characterizing bird-keeping user-groups on Java reveals distinct behaviours, profiles and potential for change. *People Nat* **2**: 877–88.

Matricardi EAT, Skole DL, Costa OB, *et al.* 2020. Long-term forest degradation surpasses deforestation in the Brazilian Amazon. *Science (80-)* **369**: 1378–82.

McNeely JA. 2003. Conserving forest biodiversity in times of violent conflict. *Oryx* **37**: 142–52.

McSweeney K, Nielsen EA, Taylor MJ, *et al.* 2014. Drug Policy as Conservation Policy: Narco-Deforestation. *Science (80-)* **343**: 489–90.

Medeiros AC, Faial KRF, Faial K do CF, *et al.* 2017. Quality index of the surface water of Amazonian rivers in industrial areas in Pará, Brazil. *Mar Pollut Bull* **123**: 156–64.

Moser P, Simon MF, Medeiros MB, *et al.* 2019. Interaction between extreme weather events and mega-dams increases tree mortality and alters functional status of Amazonian forests. *J Appl Ecol* **56**: 2641–51.

Murillo-Sandoval PJ, Dexter K Van, Hoek J Van Den, *et al.* 2020. The end of gunpoint conservation: forest disturbance after the Colombian peace agreement. *Environ Res Lett* **15**: 34033.

Myers RA and Mertz G. 1998. The limits of exploitation: a precautionary approach. *Ecol Appl* **8**: S165--S169.

Nascimento CAR do, Czaban RE, and Alves RRN. 2015. Trends in illegal trade of wild birds in Amazonas state, Brazil. *Trop Conserv Sci* **8**: 1098–113.

Negret PJ, Sonter L, Watson JEM, *et al.* 2019. Emerging evidence that armed conflict and coca cultivation influence deforestation patterns. *Biol Conserv* **239**: 108176.

Chapter 27

Nobre CA, Sampaio G, Borma LS, *et al.* 2016. Land-use and climate change risks in the Amazon and the need of a novel sustainable development paradigm. *Proc Natl Acad Sci* **113**: 10759–68.

Nóbrega Spínola J, Soares da Silva MJ, Assis da Silva JR, *et al.* 2020. A shared perspective on managing Amazonian sustainable‐use reserves in an era of megafires (AB Leverkus, Ed). *J Appl Ecol* **57**: 2132–8.

O'Shaughnessy E, Landi M, Januchowski-Hartley SR, and Diebel M. 2016. Conservation leverage: Ecological design culverts also return fiscal benefits. *Fisheries* **41**: 750–7.

Padoch C and Pinedo-Vasquez M. 2010. Saving Slash-and-Burn to Save Biodiversity. *Biotropica* **42**: 550–2.

Parry L, Barlow J, and Pereira H. 2014. Wildlife harvest and consumption in Amazonia's urbanized wilderness. *Conserv Lett* **7**: 565–74.

Parry L and Peres CA. 2015. Evaluating the use of local ecological knowledge to monitor hunted tropical-forest wildlife over large spatial scales. **20**.

Pelicice FM, Vitule JRS, Lima Junior DP, *et al.* 2014. A serious new threat to Brazilian freshwater ecosystems: the naturalization of nonnative fish by decree. *Conserv Lett* **7**: 55–60.

Perkin JS and Gido KB. 2012. Fragmentation alters stream fish community structure in dendritic ecological networks. *Ecol Appl* **22**: 2176–87.

Phillips OL, Aragão LEOC, Lewis SL, *et al.* 2009. Drought sensitivity of the Amazon rainforest. *Science (80-)* **323**: 1344–7.

Piponiot C, Rödig E, Putz FE, *et al.* 2019. Can timber provision from Amazonian production forests be sustainable? *Environ Res Lett* **14**: 064014.

Ramos-Fernández G and Wallace RB. 2008. Spider monkey conservation in the twenty-first century: recognizing risks and opportunities. *Spider monkeys Behav Ecol Evol genus Ateles*:

351–76.

Reardon S. 2018. FARC and the forest: Peace is destroying Colombia's jungle - and opening it to science. *Nature* **558**: 169–70.

Richardson VA and Peres CA. 2016. Temporal Decay in Timber Species Composition and Value in Amazonian Logging Concessions (A Zia, Ed). *PLoS One* **11**: e0159035.

Ros-Tonen MAF, Andel T Van, Morsello C, *et al.* 2008. Forest-related partnerships in Brazilian Amazonia: there is more to sustainable forest management than reduced impact logging. *For Ecol Manage* **256**: 1482–97.

Russell ID, Larson JG, May R von, *et al.* 2019. Widespread chytrid infection across frogs in the Peruvian Amazon suggests critical role for low elevation in pathogen spread and persistence. *PLoS One* **14**: e0222718.

Sánchez AS, Torres EA, and Kalid RA. 2015. Renewable energy generation for the rural electrification of isolated communities in the Amazon Region. *Renew Sustain Energy Rev* **49**: 278–90.

Santos de Lima L, Merry F, Soares-Filho B, *et al.* 2018. Illegal logging as a disincentive to the establishment of a sustainable forest sector in the Amazon (B Heinze, Ed). *PLoS One* **13**: e0207855.

Schiesari L, Ilha PR, Negri DDB, *et al.* 2020. Ponds, puddles, floodplains and dams in the Upper Xingu Basin: could we be witnessing the 'lentification'of deforested Amazonia? *Perspect Ecol Conserv*.

Schumann DA, Haag JM, Ellensohn PC, *et al.* 2019. Restricted movement of prairie fishes in fragmented riverscapes risks ecosystem structure being ratcheted downstream. *Aquat Conserv Mar Freshw Ecosyst* **29**: 235–44.

Sist P and Ferreira FN. 2007. Sustainability of reduced-impact logging in the Eastern Amazon. *For Ecol Manage* **243**: 199–209.

Sist P, Piponiot C, Kanashiro M, *et al.* 2021. Sustainability of Brazilian forest concessions. *For Ecol Manage* **496**: 119440.

Sonter LJ, Herrera D, Barrett DJ, *et al.* 2017. Mining drives extensive deforestation in the Brazilian Amazon. *Nat Commun* **8**: 1013.

Ubaid FK, Silveira LF, Medolago CAB, *et al.* 2018. Taxonomy, natural history, and conservation of the Great-billed Seed-Finch Sporophila maximiliani (Cabanis, 1851)(Thraupidae, Sporophilinae). *Zootaxa* **4442**: 551–71.

Uhl C and Kauffman JB. 1990. Deforestation, fire susceptibility, and potential tree responses to fire in the eastern Amazon. *Ecology* **71**: 437–49.

Uliano-Silva M, Fernandes F, Holanda IBB de, and Rebelo MF. 2013. Invasive species as a threat to biodiversity: the golden mussel Limnoperna fortunei approaching the Amazon River basin. *Explor Themes Aquat Toxicol Res Signpost, India*.

Vidal E, West TAP, Lentini M, *et al.* 2020. Sustainable forest management (SFM) of tropical moist forests: the case of the Brazilian Amazon. In: Achieving Sustainable Management of Tropical Forests.

West TAP, Vidal E, and Putz FE. 2014. Forest biomass recovery after conventional and reduced-impact logging in Amazonian Brazil. *For Ecol Manage* **314**: 59–63.

Wilkes MA, Webb JA, Pompeu PS, *et al.* 2019. Not just a migration problem: Metapopulations, habitat shifts, and gene flow are also important for fishway science and management. In: River Research and Applications. John Wiley and Sons Ltd.

Wilkie DS and Carpenter JF. 1999. Bushmeat hunting in the Congo Basin: an assessment of impacts and options for mitigation. *Biodivers Conserv* **8**: 927–55.

Winemiller KO, McIntyre PB, Castello L, *et al.* 2016. Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. *Science (80-)* **351**: 128–9.

Winter SC and May PJ. 2001. Motivation for compliance with environmental regulations. *J*

Policy Anal Manag J Assoc Public Policy Anal Manag **20**: 675–98.

Wright SJ, Carrasco C, Calderon O, and Paton S. 1999. The El Nino Southern Oscillation, Variable Fruit Production, and Famine in a Tropical Forest. *Ecology* **80**: 1632.

Zu Ermgassen EKHJ, Godar J, Lathuillière MJ, *et al.* 2020. The origin, supply chain, and deforestation risk of Brazil's beef exports. *Proc Natl Acad Sci U S A* **117**: 31770–9.