

Chapter 20 In Brief

Drivers and impacts of changes in aquatic ecosystems



Pescadores vendem peixes frescos em suas canoas, no centro de Manaus (Foto: Bruno Kelly/Amazônia Real)



THE AMAZON WE WANT
Science Panel for the Amazon

Drivers and impacts of changes in aquatic ecosystems

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Key Messages & Recommendations

- 1) Over the last four decades, and especially over the last two, many Amazonian aquatic ecosystems have become less connected and more polluted. Urgent attention should be given to creating aquatic protected areas, as most existing protected areas were designed to safeguard terrestrial ecosystems and generally do little to conserve aquatic biota.
- 2) Prior to the massive impacts of dam construction over the past four decades, overexploitation of plant and animal species was the most significant driver of aquatic ecosystem degradation in the Amazon basin. This degradation continues to advance. Aquatic resources require cooperative arrangements to sustainably manage their use, including the exclusion of outside fishing vessels, and enforcement of restrictions on overharvesting.
- 3) Hydroelectric dams block fish migration and the transport of water, sediments and associated nutrients. They also alter river flows and oxygen levels. Dams with installed capacity greater than 10 MW should no longer be built. “Micro” dams, designed to power a single town or village, can be built with proper environmental licensing and risk-based approaches. In the meantime, energy policy should prioritize electricity conservation,

- halt exports of electricity-intensive products, and redirect investment to wind and solar generation.
- 4) Selected watersheds throughout the Amazon need to be preserved for research, long-term monitoring, and the protection of genetic and species diversity. These watersheds can also maintain ecological communities for recovery efforts.

Abstract Amazonian aquatic ecosystems are being destroyed and threats to their integrity are projected to grow in number and intensity. Here we present some of the main impacts on aquatic ecosystems triggered by infrastructure projects and predatory and illegal practices.

Introduction The Amazon River annually discharges 6.6 trillion m³ of fresh water to the oceans, along with 600-800 million tons of suspended sediments¹. The Amazon’s aquatic biodiversity is globally significant. So far, 2,406 fish species have been described² (see also Chapter 3), although the actual number is likely to be above 3,000 species³. Amazonian rivers and streams also connect distant parts of the vast Amazon basin, crucial for fish migration and sediment flow. However, these systems are fragile and impacts originating at any given location may be felt thousands of kilometers away. We list below some of the main threats faced by Amazonian

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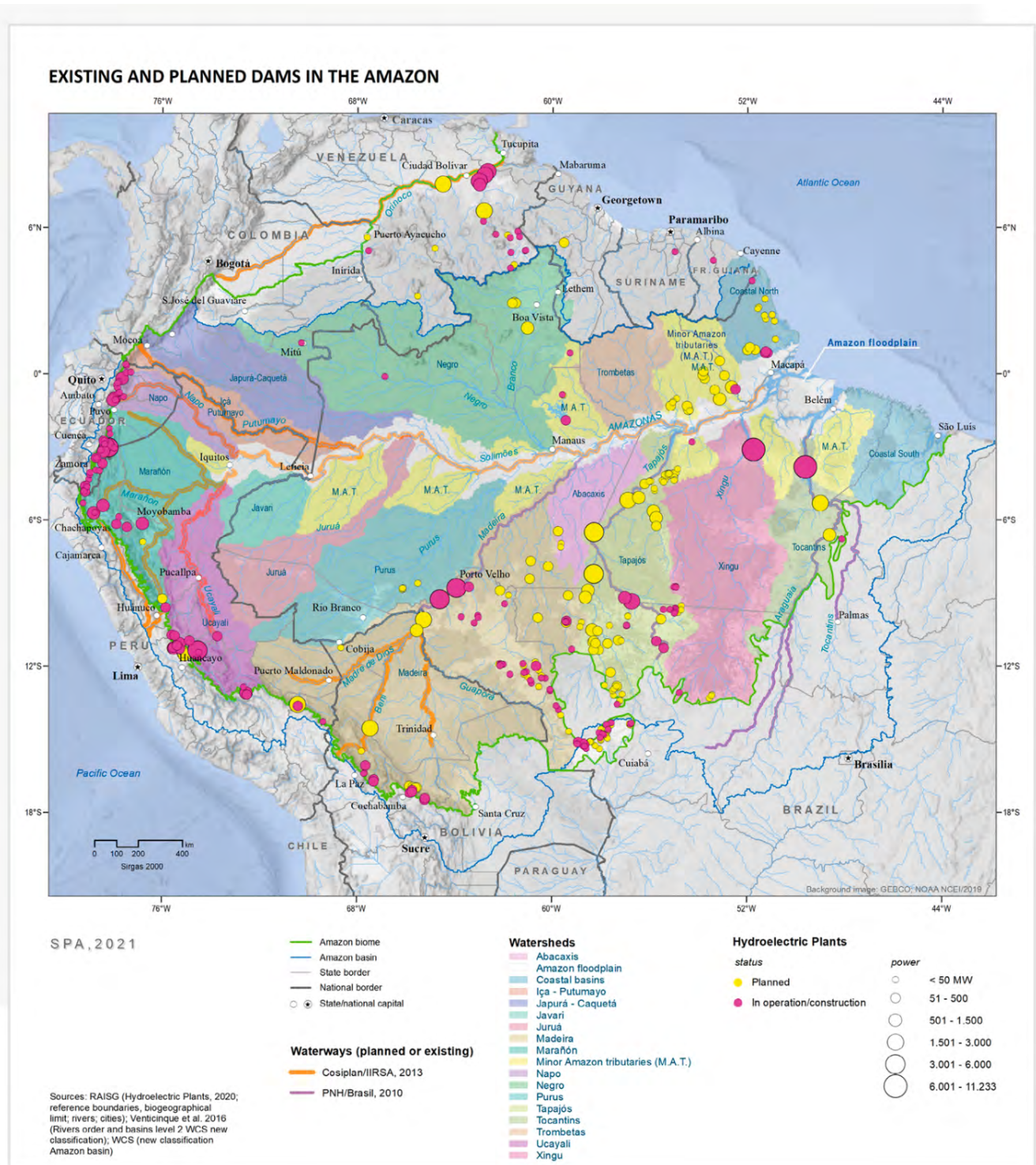


Figure 20. Existing and planned hydroelectric dams and waterways in Amazonia. Currently there are 307 dams existing or under construction; and 239 planned or projected (total = 546) ⁵.

aquatic ecosystems, along with their most important impacts. Across the Amazon there are 307 existing and 239 proposed hydroelectric dams, ranging from 1 MW installed capacity to some of the largest in the world, such as Belo Monte and Tucuruí (Figure 20.1)^{4,5}.

Fish communities Hydroelectric dams negatively impact fish communities, both above and below the reservoir, due to habitat loss and disconnection, and severe changes in the hydrological regimes of flooded forests^{6–9}. The conversion of a stretch of river from running water (lotic) to still water (lentic) eliminates or greatly reduces many species, few of which are adapted to the new environment¹⁰. Fish communities become structurally and functionally different from pre-dam baselines^{11–13}. Amazonian dams and their ineffective fish passes have already seriously disrupted the migration routes of many fish species, such as the “giant catfish” of the Madeira River (*Brachyplatystoma* spp.).

Aquatic mammals, reptiles and insects Dams can fragment populations of dolphins, amphibians, and reptiles. This disrupts gene flow and can result in small, vulnerable populations^{14,15}. A number of planned dams are particularly threatening to turtles¹⁶, because the beaches on which turtles lay their eggs are commonly flooded by reservoirs or when dams alter downstream flows¹⁷. Dam impacts on aquatic insects vary; species that depend on fast-moving water decrease in abundance, while others that breed in standing water, such as mosquitos, can undergo population explosions^{18,19}.

Greenhouse-gas emissions Amazonian dams contribute to greenhouse gas emissions in two main ways; (1) methane is produced in stratified reservoirs, and (2) CO₂ is released by decaying trees killed by flooding^{20–23}. The large amount of initial biomass lost when a reservoir is flooded (which is especially high in tropical forests), in addition to the presence of easily oxidized labile carbon in the soil, leads to young reservoirs being larger emitters than older ones²⁴. Furthermore, trees near the edges of reservoirs suffer stress from higher water tables, causing additional mortality and CO₂ emissions^{25–27}.

Alteration of sediment flows Dams reduce sediment flows by trapping sediments in reservoirs²⁸ and by changing the natural hydrologic cycle. Downstream of dams, the reduced sediment load results in scouring, or increased erosion of riverbanks and bottoms^{29,30}. Sediment reduction also deprives the river of nutrients downstream. In the Madeira River, sediment transport downstream of the Santo Antônio and Jirau Dams decreased by 20% compared to pre-dam quantities³¹, which may have contributed to observed sharp declines in fish catches downstream of the dams^{30,32}. Sediments, including suspended organic matter, form the base of aquatic food chains in the lower Amazon³³; therefore, reductions in sediment loads below Andean dams are likely to have far-reaching consequences for fish along the entire length of the Madeira and Amazon Rivers³⁴.

Alteration of streamflow Dams can impact four hydrological parameters downstream; 1) the frequency and 2) duration of high and low water levels (flood pulses), and 3) the rate and 4) frequency of changes in water levels³⁵. Other impacts on streamflow occur when the reservoir is filling, such that downstream river stretches dry out during all or part of the filling period. The Belo Monte Dam illustrates this effect; water flow is greatly reduced in a 130-km stretch known as the “big bend of the Xingu River” (*Volta Grande do Rio Xingu*), as 80% of the river’s annual flow is diverted. Modifications in the hydrological regime directly impact aquatic biodiversity. Fish behavior, especially migration and reproduction, is attuned to changes in flow, and false signals caused by dams can induce fish to behave in ways that jeopardize their reproductive success^{36–41}.

Roads Dams are not the only type of infrastructure that degrade, or even destroy, aquatic systems in the Amazon; roads are also an important threat to these ecosystems. Amazonian roads are often built without adequate passages for water, such as culverts or bridges, fragmenting small tributaries and seasonal streams. Roads can act as dams, and their impact on seasonal streams is especially strong, causing ponding, blocking the passage of aquatic life, and disrupting stream connectivity.

Navigational waterways and river diversions The maintenance of navigational waterways can have severe impacts on aquatic ecosystems. Many endemic fish species could go extinct when rocky habitats are removed by dynamiting to allow barges to pass unimpeded⁴². In addition to removing rocky outcrops, the dredging of river channels deepens shallow zones and removes woody debris⁴³, destroying rich habitats for specific endemic fish fauna⁴⁴. These populations are unlikely to recover. In the Peruvian Amazon, the recently contracted ~2,700-km *Hidrovia Amazónica*^{45,46} could significantly alter river-channel morphology, impacting fish diversity and productivity on which local economies depend.

Fish harvested for human consumption Most large, high-valued fish species, such as the giant *pirarucu* or *paiche* (*Arapaima spp.*) and the large fruit-eating *tambaqui* or *gamitana*, are considered overfished in their natural ranges^{47–50}. The same applies to several of the smaller Characiformes species, such as *Prochilodus nigricans* and *Psectrogaster spp.*^{51–53}. Migratory fish are the most at risk from overfishing, accounting for over 90% of landings in the Amazon basin and generating over USD 400 million in income⁵⁴.

Ornamental fish The aquarium fish trade is a growing, multi-billion dollar industry^{55,56}. Fish are one of the most popular pets in the world⁵⁷, and harvesting wild specimens for international trade is a major conservation issue^{55,58,59}. The Amazon basin accounts for ~10% of the global trade in freshwater ornamental fish, with Brazil, Colombia, and Peru as the major exporters; in 2007, the total declared (greatly underestimated) export value from these three countries was about USD 17 million⁶⁰. However, the effects of the ornamental fish trade on natural populations are poorly studied. Anecdotal information suggests population collapses or declines at some locations in the Rio Negro, such as for discus (*Symphysodon discus*)⁶¹ and cardinal tetra (*Paracheirodon axelrodi*)^{55,62}. In the Peruvian Amazon, exploitation has led to reductions of over 50% in ornamental species at study locations in terms of abundance, diversity, and biomass⁶³.

Invasive species In the Amazon, invasive species are used for farming, cultivation of ornamental species, and recreational fishing⁶⁴. Fish introduced to lakes and reservoirs are often predatory species (*Cichla spp.*, *Astronotus spp.* or *Pygocentrus nattereri*), feeding on and reducing the abundance of native species, with whole-ecosystem consequences including habitat loss, interruption of the life span of native fish (many invasive species eat the eggs of native fish), and competition for food, leading to changes in species composition and entire food-webs^{65–69}. In the Andean waters of Bolivia and Peru, the introduction of predatory rainbow trout (*Oncorhynchus mykiss*) resulted in local extirpation or greatly reduced abundance of native *Astroblepus spp.*^{70,71}.

Deforestation Forest loss usually results in increased rainfall runoff and discharge. For example, deforestation induced a 25% increase in discharge in large river systems such as the Tocantins and Araguaia Rivers, with little change in precipitation⁷². Increased water runoff and sediment loads alters geomorphological and biochemical processes downstream, with consequences for soil erosion and the biological productivity of aquatic ecosystems^{72–76}. Forest cover loss also results in direct sun exposure, reducing evapotranspirative cooling and sensible heat flux over land, leading to changes in the temperature, oxygen, and chemical content of watercourses, greatly affecting aquatic fauna⁷⁷. For example, increased water temperatures and reduced oxygen during the dry period can be lethal for fish such as cardinal tetras^{78,79}.

Pollution

Agricultural chemicals Pesticides, herbicides, medicines, and other drugs are released into the environment, and their residence time is undetermined. Transition metals and other pollutants present in agricultural chemicals may affect local fish species differentially depending on their respiration, reproduction, trophic position, and metabolic characteristics^{80,81}. The herbicide glyphosate (Roundup®) and the pesticide malathion have been shown to cause metabolic and cellular damage in fish exposed to

concentrations lower than their 50% lethal concentrations (LC_{50})^{82,83}. The presence of pesticides has also been detected in Amazonian river dolphins^{84,85} and turtles⁸⁶. Expansion of soybean production in the southern Amazon is of particular concern to aquatic ecosystems due to the heavy use of herbicides, including glyphosate. Laboratory experiments on fish have shown that this and other herbicides cause damage to the liver and gills, as well as DNA breakage and increased risk of cancer^{82,83,87}.

Oil spills and toxic waste Contamination from crude oil and untreated toxic wastes from oil and gas exploitation are notorious in the Amazonian portions of Ecuador⁸⁸ and Peru^{89,90}. In the Ecuadorian Amazon between 1972 and 1992, 73 billion liters of crude oil was discharged into the environment, nearly twice the amount released by the Exxon Valdez oil tanker in Alaska^{91,92}. Over this period 43 billion liters of produced water (oilfield brine) was also released, containing salts that disrupt fish migrations⁹². Oil is toxic to fish⁹³, and oil-associated contamination can have far-reaching impacts on Amazonian aquatic communities because it can disperse widely, affecting the entire downstream network^{90,94}. Hydrocarbon-related toxins have been found in Ecuadorian streams at concentrations up to 500 times higher than those allowed by European regulations⁹¹.

Mining Gold mining is especially prevalent in Brazil and Peru, and the scale and impacts of this activity is projected to increase substantially if urgent action is not taken (Figure 20.2)^{4,5,95}. It is estimated that the mercury shed by gold mining in the Brazilian Amazon totals more than 200,000 tons since the late 19th Century⁹⁶. Gold mining has been estimated to account for 64% of the mercury entering Amazonian aquatic systems^{97–100}. The remaining amount comes from natural deposits that are eroded by deforestation (33%) and from atmospheric deposition, with the original source being deforestation and forest fires (3%)^{99,101}. At the basin scale, the dynamics of mercury involve abiotic physical processes (i.e., downstream transport of sediments). Elemental mercury can then be turned into toxic methylmercury by specific bacteria in anoxic environments,

such as those created at the bottom of reservoirs or in thermally stratified natural lakes and rivers.

Methylmercury (MeHg) enters aquatic food webs and bio-accumulates with trophic levels^{102,103}. Wildlife is exposed to MeHg through diet^{103–105}. Mercury bioaccumulation causes concentrations to increase greatly in top predators such as large catfish, black caimans, otters, and dolphins^{106–112}. Through fish consumption, humans also bioaccumulate mercury; Amazonian populations show some of the world's highest recorded mercury levels in human hair, along with associated health issues¹¹³.

Urban sewage and plastic waste Urban sewage greatly affects aquatic invertebrates, reducing both abundance and species richness^{114–118}. Large amounts of plastic are discarded in Amazonian rivers and streams and microplastics have been detected in river sediments¹¹⁹ and in the sand of coastal beaches near the mouth of the Amazon¹²⁰. Microplastics have also been found in fish species at all trophic levels, including 13 species from the Xingu River¹²¹, and 14 from the Amazon estuary¹²². Micro- and nano-plastics affect aquatic ecosystems, and further serve as carriers for persistent organic pollutants (POPs)¹²³ and other chemicals that can provoke hepatic stress in fish¹²⁴.

Interactions among drivers The text above discusses drivers of degradation separately; however, several are highly correlated and often interacting, and aquatic organisms will have to cope with combinations of these drivers. For example, hydroelectric dams induce road construction, which in turn leads to increased deforestation and agriculture^{34,45,125–127}. As already explained, interruptions to the hydrological cycle by dams isolates large portions of floodplains, which will likely then be exploited for agriculture, further increasing deforestation³⁴.

Similarly, the waterway in the Tapajós sub-basin is likely to encourage further deforestation directly through increased soy production in Mato Grosso. Runoff from soy plantations delivers fertilizers, herbicides, pesticides, and sediments from soil erosion to aquatic ecosystems. Waterways reduce transportation costs and encourage the transition

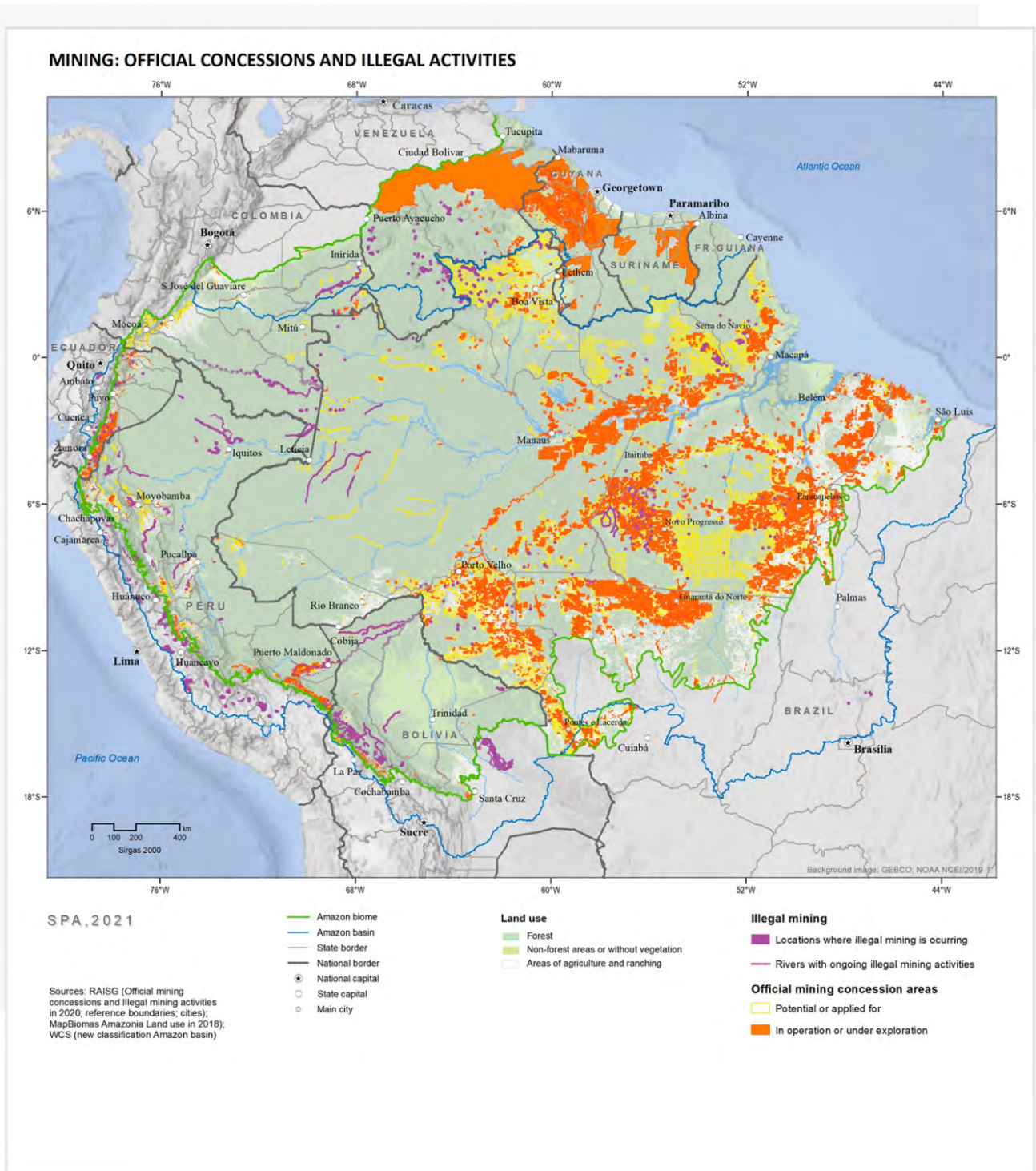


Figure 20.2 Official mining concessions and illegal activities⁵.

from livestock to soy, resulting in indirect land-use change, as cattle ranchers sell their land to soy farmers and clear new parts of the Amazon for pasture^{128,129}.

One impact of waterways is that they justify hydroelectric dams regardless of how severe the negative impacts may be. Without a complete set of dams and locks on a river, barges cannot pass. They rely on reservoirs to eliminate rapids and waterfalls. The Tocantins/Araguaia waterway¹³⁰ and the Tapajós waterway¹²⁸ both serve as examples. In the case of the Madeira River, a plan for 4,000 km of waterways in the Amazonian portion of Bolivia, intended to transport soybeans, was used as an argument to support the viability of Brazil's Santo Antônio and Jirau Dams^{131,132}.

Exploitation of new sources of energy, such as oil, usually require road construction, hence deforestation^{45,133}. Oil exploitation also has strong combined effects with dams, devastating aquatic biota where these drivers intersect¹³⁴. In the Peruvian Amazon, the Interoceanic highway has had a dual impact on the rivers and associated terrestrial ecosystems; this road has promoted land-use change due to agriculture expansion in the north, while at the same time contributing to gold extraction in the Malinowsky and Inambari Rivers^{135,136}.

Conclusions The Amazon's aquatic ecosystems are impacted by human actions, especially infrastructure such as hydroelectric dams, roads, and oil and gas exploitation. These impacts have been intensified by increases in deforestation, pollution by agrochemicals, urban and industrial waste, and illegal mining. The synergistic effects of these impacts can compromise the functioning of ecosystems, leading to imbalances in food chains, decreases in species abundance, and extinction; this, in turn, has important effects on human health and ways of life.

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