SCIENCE PANEL FOR THE AMAZON

POLICY BRIEF

CONSERVING THE AMAZON'S FRESHWATER ECOSYSTEMS' HEALTH AND CONNECTIVITY

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KEY MESSAGES

(i) Safeguarding the Essential Biodiversity and Services of Amazonian Freshwater Ecosystems. The Amazon Basin plays a pivotal role in hydrological cycling, recycling 24% to 35% of its water annually and contributing significantly to continental rainfall through 'aerial rivers' that transport 6,400 km³ of water each year. This basin also discharges an average of 1,122 megatons (Mt) of suspended sediments annually, crucial for soil fertility and Atlantic Ocean ecosystem function and services, such as fisheries. Additionally, the region's freshwater ecosystems boast remarkable biodiversity, with approximately 2,700 fish species, from which 1,696 are endemic [1]. These ecosystems are vital for the livelihoods of Amazonian communities, where daily per-capita fish consumption can exceed 500 g, one of the highest rates globally.

(ii) Maintaining River Connectivity is Critical for Sustaining Amazonian Freshwater Ecosystems. Maintaining the multi-dimensional connectivity within Amazonian Freshwater Ecosystems is crucial for sustaining ecological processes, water recycling, biological and cultural diversity, and the resilience of the entire basin. This connectivity encompasses longitudinal, lateral, vertical, temporal, biocultural, and socio-bioeconomic dimensions. Numerous drivers of change in Amazon waters disrupt these vital connections. There is an urgent need for comprehensive management and proactive regional policies to protect the Amazonian Freshwater Ecosystems.

(iii) Rapid degradation of Amazonian Freshwater Ecosystems. Amazonian Freshwater Ecosystems are experiencing rapid degradation due to a confluence of factors, including water pollution, oil spills, informal and illegal mining, dam construction, water diversions, deforestation, overfishing, and climate change. These elements not only sever vital ecological connections within the Amazon's freshwater systems, but also drastically diminish their biodiversity, functionality, and ability to provide essential ecosystem services.

(iv) Prioritizing Free-Flowing Watershed Corridors Across the Entire Amazon Basin. Conservation, remediation, and restoration initiatives must be mapped and prioritized across the entire Amazon Basin. This includes developing specialized conservation frameworks that ensure connectivity between protected areas and new fluvial reserves on a basin-wide scale. Such frameworks must address a range of challenges, including monitoring fish populations and ensuring the sustainability of fisheries. Equally critical are restoration programs aimed at regenerating and reconnecting riparian vegetation and floodplain areas with rivers, streams, and wetlands. Moreover, the adoption of innovative technologies is crucial for developing more effective water treatment solutions, which are vital for maintaining water quality, ensuring ecological flows, and restoring the health of freshwater ecosystems.

(v) Pursuing Inclusive Engagement and Community-Based Management for Successful Conservation. Ending all deforestation (legal and illegal) and preventing forest degradation can restore the Amazonian carbon sink, even in the face of global climate change. Implementing large-scale forest protection measures would maintain the existing carbon stocks, while an advancing and ambitious program of forest restoration would capture and store an additional 15-30 billion tonnes of CO_2 in Amazonian forests by 2050.

(vi) Ensuring Freshwater Connectivity Through Transnational Collaboration and Support. Each Amazonian country must develop and implement national public policies for freshwater ecosystems, recognizing rivers, streams, riparian vegetation, and wetlands not merely as resources, but as unique ecosystems providing essential services. In addition, it is crucial to establish transnational agreements between Amazonian countries to preserve natural free-flowing watershed corridors.

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GRAPHICAL ABSTRACT

ECOSYSTEM SERVICES PROVIDED BY AMAZONIAN FRESHWATER ECOSYSTEMS

MAINTENANCE OF HYDROLOGICAL CYCLE

- Up 50% of rainfall recycling near tropical Andes.
- Aerial rivers transport 10 to 23 billion liter of water moisture per day southward.
- Largest aquifer systems of the world (2.7 million km^2)

MAINTENANCE OF HABITAT, SPECIES DIVERSITY AND LIFE CYCLE

- 30% of the Amazon consists of wetlands and land-water interfaces
- approx. 2,700 fish species, as well as a diversity of aquatic mammals, invertebrates, aquatic and semi-aquatic plants.
- 223 migrating fish species, sustaining fisheries across the basin.

TRANSPORT AND CYCLING OF SEDIMENT AND NUTRIENT

- In the Amazon river estuary, river discharge is 220,000 m^3 per second
- Discharge of 1,122 megatons of suspended sediments annually, on avarege
- Riparian forests retain sediments, support successional processes, and act as natural filtration systems.


AERIAL RIVERS
WATER VAPOUR FROM THE OCEAN
RIVER MOUTH
AMAZON ESTUARY
MAJOR CITIES
MANGROVES AND COASTAL LAGOONS
RIVERINE COMMUNITIES
AGROFORESTRY
INDIGENOUS TERRITORIES
SAVANNAS
BIODIVERSITY

RECOMMENDATIONS

(i) Halt Construction of New Dams and Implement Alternative Sources of Renewable Energy

Adopt a moratorium on the construction of new dams and consider obsolete and inefficient dams for removal. Optimize existing hydroelectric schemes and carry out strategic environmental evaluations with other sources of renewable energy, such as solar, wind, hydrokinetic and biomass application.

(ii) Expand Water Treatment and Pollution Control

Urgently invest in water treatment infrastructure, enforce pollution control policies, reforest and regenerate riparian vegetation, as it serves as natural filtration systems, and strengthen monitoring efforts to reestablish water course connectivity.

(iii) Invest in Science, Technology, Innovation, and Water Literacy

Urgently invest in science, technology, and innovation to enhance mapping and monitoring of resources and ecosystems, providing crucial data to support cross-disciplinary research and local governance in addressing stressors and solutions on Amazonian Freshwater Ecosystems.

(iv) Align Deforestation and Degradation Reduction Strategies with Climate Policy

Integrate climate change mitigation and adaptation policies into regional development planning, aligning them with strategies to protect and reduce deforestation, including riparian and floodplain deforestation and the degradation of Amazon forests and other freshwater ecosystems.

(v) Empower IPLCs in Freshwater Management

Support the leadership of Indigenous Peoples and Local Communities in freshwater co-management initiatives and conservation, respect cultural diversity, and integrate Indigenous knowledge into governance structures, decision making processes, and scientific innovation.

(vi) Establish New Conservation Frameworks

Discuss and promote new conservation frameworks designed specifically for freshwater ecosystems (e.g., creation of Fluvial Community Reserves). Such a framework is more likely to succeed if it is developed through collaborative community-based partnerships.

(vii) Strengthen Transnational Governance and Coordination for River Protection

Develop and strengthen existing transnational governance agreements that allow protected free-flowing watershed corridors. National governments must unify policies to maintain and restore ecosystem connectivity, recognizing the importance of community-based conservation.

A. THE AMAZON BASIN: THE LARGEST AND MOST DIVERSE FRESHWATER NETWORK ON THE PLANET

Amazon Freshwater Characteristics, Functions, and Biodiversity

Covering 7.3 million km² throughout eight countries, the Amazon basin is rich in biodiversity shaped by millions of years of changes in lowland rivers and floodplains [2, 3 4]. At its estuary, the Amazon River discharges 220,000 m³ per second [5]. Its complex hydrological network includes about 15,000 catchments and various freshwater ecosystems such as tectonic lakes, swamps, wet meadows, Andean freshwater marshes, mangroves, meander lagoons, riparian wetlands, and expansive floodplains [6, 7, 8].

Approximately 30% of the Amazon region consists of wetlands, which include various ecosystems at the land-water interface, distinguished by factors like flood frequency and duration [9, 10], seasonal rainfall variability [11, 12, 13], depth of water, water chemistry, vegetation, and associated wildlife [14]. Floodplains of large rivers cover about 750,000 km², or 11% of the Amazon Basin [15]. These floodplains are crucial for nutrient cycling and sustaining biodiversity, with Andean sedimentary rivers creating fertile white-water várzeas and ancient shield-draining rivers forming nutrient-poor igapós [9, 10]. At the estuary, the river's discharge creates unique environments where river and sea waters mix, supplying abundant nutrients and sediments offshore and serving as a source of nursery, breeding grounds, and areas for the growth and development of freshwater, estuarine, and marine fish species [16]. Consequently, coastal wetlands, such as mangroves in Amapá, Pará, and Maranhão, demand urgent actions for biodiversity protection [14, 16].

Connectivity among these river systems and wetlands is essential for the Amazon's ecological integrity and resilience, as it regulates hydrological pulses, ensures the distribution of rainfall and seed dispersal, and guarantees fisheries and feeding [8]. Ultimately, the essence of the Amazon hinges upon the interconnectedness of its waterways, facilitating the exchange of water, nutrients, sediments, and biodiversity [17].

The Multidimensional Connections of the Amazon

We can identify distinct dimensions of water connectivity within the basin. For the purposes of this policy brief, we consider six dimensions of connectivity through the basin, taking into consideration ecological, seasonal, and socio-economic aspects:

1. Longitudinal Dimension: *linking the Andes with the rest of Amazon and with the Atlantic Ocean.* The Andes-Amazon-Atlantic transition is a crucial zone of hydrological connection [18] (Figure 1). The region at the Andes feet experiences high rainfall rates (up 6,000 and 7,000 mm.yr^{-1}) due to interactions between regional atmospheric circulation and temperature and moisture contrasts [19, 20, 21, 22]. These rains result in erosion, providing nearly all of the suspended sediment load observed in the Amazon Basin. It is estimated that the Amazon River exports between 550 and 1500 Mt.yr^{-1} of sediment load to the Atlantic Ocean [23], with 90% of total originating in the Andes [24]. Also, many species depend on this transition zone for their life cycles, including long migration journeys related to fish reproduction that sustain fisheries throughout the basin [25].

FIGURE 1. The Sangay Volcano, located in the Ecuadorian Andes, and the Upano River, a tributary of the Marañon basin within the Amazon Watershed, exemplify four critical hydrological connections between the Andes and the lowland Amazon: longitudinal, lateral, vertical, and temporal (Photo: Jorge Juan Anhalzer).

2. Lateral Dimension: *connecting rivers, forests, and wetlands to provide conditions for numerous species to strive*. Seasonal fluctuations of the water table (Figure 2) create interconnected corridors during high-water periods that facilitate species migration and seed dispersal between rivers and lakes with the floodplain. These corridors also serve as a refuge during low-water periods [26], allowing organisms such as fish and aquatic mammals to seek optimal conditions for survival [27, 28, 29]. Moreover, floodplains store and transport water, sediments, and nutrients during high water periods, thus sustaining fishery resources [26]. Lastly, the evolutionary interaction between fish-tree fruits in the Amazon highlights the critical role of river-floodplain connectivity for plant recruitment dynamics and diversity [30, 31].

3. Vertical Dimension: *encompassing interactions between wetlands, aerial rivers, and groundwater*. Approximately 25-50% of the total annual rainfall observed in the tropical Andes originates from Amazon tree transpiration [32]. Part of the produced

FIGURE 2. Seasonal cycles of river discharges ($m^3 s^{-1}$). Fluctuations in river discharge drive pronounced seasonal changes in the water level of large Amazon rivers, causing them to overflow their banks into adjacent floodplains [103, 104, 105].

moisture reaching east of the Andes — 10 to 23 billion liters per day [33] — is transported southward by winds flowing in low altitudes, known as "aerial rivers", reaching as far as Argentina and supplying water to other major river basins on the continent, thus supporting agriculture and providing drinking water [5]. Moreover, rainfall infiltrates the ground and contributes to the formation of large aquifers like the Alter do Chão-Içá system, with a recharge amount estimated to be at least 236,400 and 350,000 $m^3.yr^{-1}$ [4, 34].

4. Temporal Dimension: *linking rivers responses over time in which past events shape current and future river function and diversity.* In the Amazon, temporal connectivity is fundamentally linked to the region's complex hydrological cycle (Figure 2). The lowlands, for instance, are subject to a yearly flood pulse, marked by pronounced low and high-water periods, while the Andean-Amazon experiences variable flows that can change on a daily basis [35]. This flood regime not only shapes the river morphology, such as the formation of oxbow lakes and main river channels, but it also influences organismal behaviors like migrations and mast seeding, and affects people's livelihoods through activities such as floodplain agriculture and navigation [36]. Therefore, the timing and predictability of the flood pulse are intimately connected with other dimensions of connectivity.

5. Biocultural Dimension: *incorporating the relationships between human populations and rivers, and wetlands and their aquatic biodiversity, which are observed in cultural traditions and beliefs.* Indigenous populations hold worldviews (Box 1), linguistic conceptualizations, spiritual connections and experiential knowledge of Amazonian Freshwater Ecosystems gained over many years [37, 38]. Recently, Indigenous and local knowledge systems have been combined with scientific knowledge and technology to protect and restore freshwaters and headwaters through co-management experiences and fisheries agreements, including cases in which Indigenous people have been meaningfully involved in decision-making processes [30, 39].

6. Bioeconomic Dimension: *acknowledging the provision of food, transportation, drinking water, and economic activities by freshwater ecosystems.* Fish are the main providers of protein, micronutrients, and income for both rural and urban households across the Amazon Basin [40]. The estimated total extraction of fish in the Amazon basin is between 422,000 and 473,000 tons per year [41]. There is also a great significance of freshwater ecosystems for Amazonian agro-forestry crops and resources of great economic importance, such as cacao, açaí palm, and many others, which have been domesticated or semi-domesticated by Indigenous people and local communities [42]. Also, fluvial transport plays a crucial role in accessing remote areas, enabling services such as public health to meet the demands of rural areas [43]. And lastly, outdoor recreation and tourism allow visitors to share these relationships with the watershed resources.

These different dimensions of water connectivity are facing significant challenges due to human action that promotes the fragmentation of aquatic habitats, thus pushing the biome rapidly to a point of no return. We strongly advocate for conservation initiatives that ensure open connectivity within the basin, considering all dimensions, while ensuring equity and inclusion in conversation planning, policies, and practices.

BOX 1: INTEGRATING TRADITIONAL KNOWLEDGE IN FRESHWATER ECOSYSTEM CONSERVATION

Traditional knowledge provides invaluable insights into the conservation of freshwater ecosystems, guiding sustainable management practices and fostering respect for the services these ecosystems offer. This approach stems from the worldview of many Indigenous peoples, who perceive natural resources not as possessions but as entities inhabited by spirits or guardians, whether in plants, animals, minerals, or rocks [97].

For the Munduruku people, interacting with forests and rivers also involves engaging with the spirits that reside within them. Such interactions necessitate negotiating harmonious relationships and respectful exchanges with all beings, enabling the articulation of multiple coexisting worlds.

Traditional knowledge is crucial for comprehending complex ecological processes that might otherwise remain unexplained, passed down through generations. A pertinent example is the identification of a spawning area in the Beni basin, derived from fishermen's observations of dorado pairs near the Altamirani community. This localized knowledge facilitated the characterization of the area, leading to the identification of at least 22 other potential dorado spawning zones [98]. Such insights are vital for management decisions in these regions and underscore the significance of integrating protected areas with traditional ecological knowledge.

B. MAIN DRIVERS OF FRAGMENTATION OF FRESHWATER ECOSYSTEMS

Fragmentation within the Amazonian Freshwater Ecosystems is one of main reasons behind loss of surface water area, habitats, biodiversity, and consequently, of ecosystem services essential to the well-being of human populations. This fragmentation occurs due to human activities that either lead to physical barriers that alter the rivers courses, or through chemical barriers [44] that degrade the quality of the water.

Physical Fragmentation

The primary threat to freshwater connectivity is river fragmentation due to **hydropower development and construction of dams** [45], which currently impacts rivers ranging from the Andes to large basins like the Marañon, Madeira, Napo, Tapajós, Tocantins, and Ucayali [28, 46, 47, 48] (Figure 3). Dams alter riverine habitats by blocking the movements of organisms and changing hydrological patterns, sediment discharge [28, 48, 49, 50], temperature, and nutrient balance [51], affecting biodiversity, causing declines in migratory species [28, 52] and massive tree mortality [53]. Additionally, studies show that some lowland dams in the Amazon may have a considerable contribution in greenhouse gas emissions per unit of electricity generated (median = 133 kg CO_2eq MWh−1) [54].

Road construction has similar impacts to dams, as it alters seasonal streams, thus disrupting connectivity, blocking the passage of aquatic life [55] and influencing sediment deposition in aquatic systems [56]. Additionally, the land-cover change related to roads contributes to CO_2 emissions [57]. The loss of freshwater and its biodiversity in Amazonian ecosystems is also strongly related to environmental degradation,

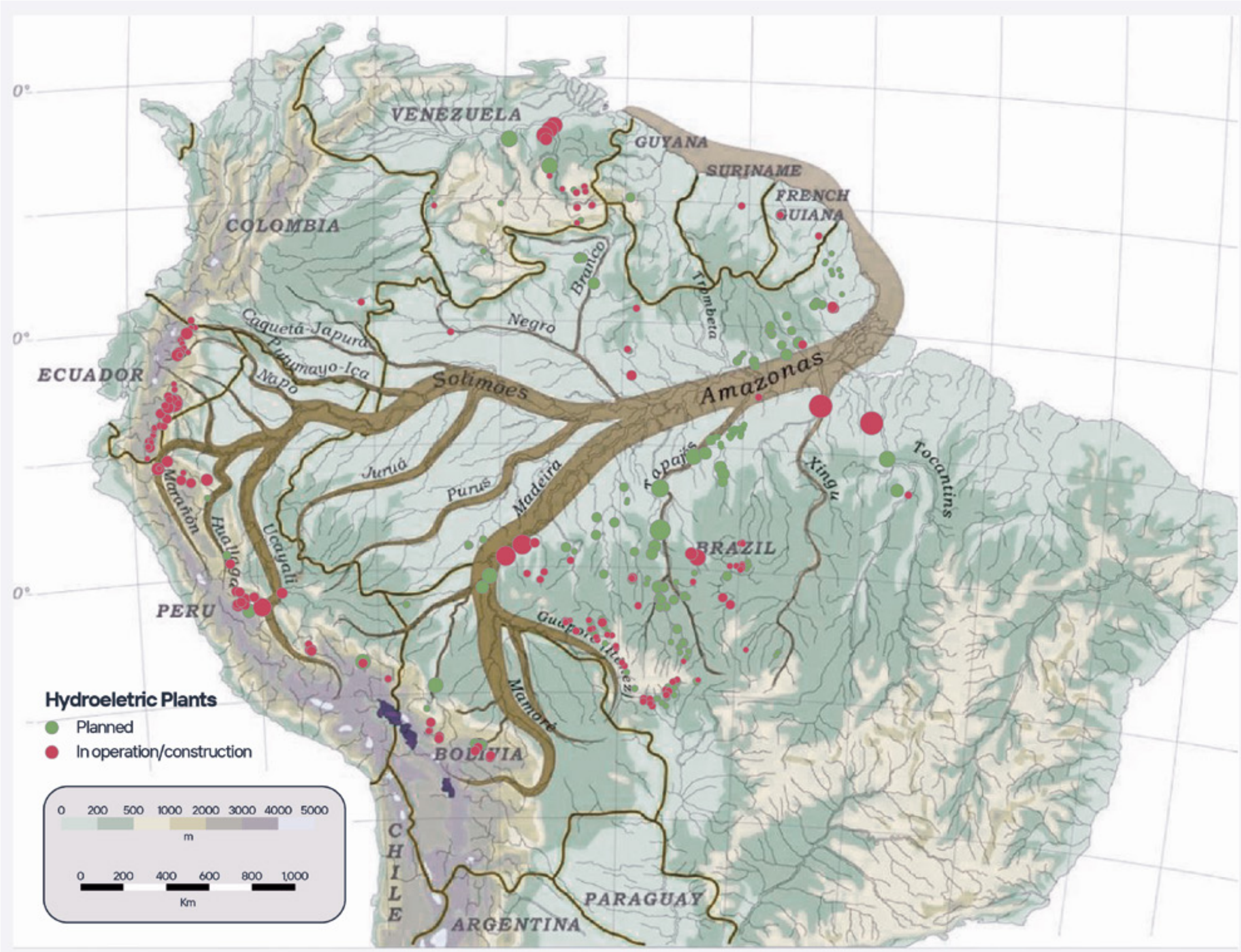

FIGURE 3. Existing and planned hydroelectric plants in the Amazon pose significant threats to freshwater ecosystems by disrupting their vital connections. Adapted from [103, 106].

including water diversion dams captured for **agricultural activities and livestock.** Land-cover change related to cattle ranching and crop production has affected about 15% (1985-2020) of the Amazon basin, particularly into the south and southwestern region, where native forest has been replaced by grassland and savannas [58, 59].

Mining impacts freshwater ecosystems directly by altering stream and river morphology due to excavations, increased sediment loads, and necessitating large-scale deforestation [61]. In Brazil, for instance, mining was responsible for the loss of 11,670 km^2 of Amazonian forests between 2000 and 2015 [62].

Deforestation associated with these infrastructure projects and economical activities impact Amazonian Freshwater Ecosystems in different ways. Deforestation causes loss of vegetation evapotranspiration (20-41%) and increases temperatures (28-45%) [63], thereby decreasing the amount of water vapor in the atmosphere [64], harming vertical connectivity, and increasing the risk of droughts and fires [65]. With less rainfall, there is also less surface runoff and less sediment exported from the Andes to the Amazon, increasing tree mortality [66, 67].

Ongoing **climate change** also impacts connectivity within the basin. Climate models predict a future precipitation decline, particularly in the southern basin, heightening the region's vulnerability [68, 70]. This can lead to many streams and rivers ceasing to flow for several months in certain areas, which can result in local extinctions of species [70]. Additionally, as the region gets warmer, even small increases in water temperature are sufficient to push many fish species beyond their thermal tolerance limits [71, 72, 73]. Such changes lead to adaptations in aquatic fauna and flora, but can also result in higher mortality rates among fish [71] and aquatic mammals [74], just as was observed during the severe drought of 2023 (See more in Droughts in the Amazon Policy Brief)..

Fragmentation of Amazonian Freshwater Ecosystems holds a dangerous synergy with **overfishing** [75]. Even though there aren't robust fish stock assessment models yet, intensive fishing pressure throughout the basin appears to be among the primary drivers for declining fish stocks [76, 77] and biodiversity depletion [78]. For instance, dams and overfishing combined are responsible for a sharp depletion of the stock of goliath catfishes (Brachyplatystoma rousseauxii), a migratory species [75, 79].

All these forms of fragmentation are followed by significant socio-economic and socio-cultural impacts, which affect riverine and urban communities as well as Indigenous people. Research has shown that changes in diets and fisheries can affect food security and consumption patterns among all Amazonian populations [80, 81, 82], exacerbating malnutrition [83] and causing psychological and spiritual effects in Indigenous populations [84].

Chemical Barriers

Chemical pollution is a major cause of water degradation and decreased water quality in the Amazon. Notably, many Amazonian cities lack water treatment plants, leading to the **discharge of domestic and industrial sewage directly into water bodies,** posing significant contamination risks [85, 86]. This issue underlines the critical need for comprehensive strategies to manage and treat wastewater effectively in the region. Also, **inadequate disposal of solid waste** results in the leaching of liquids generated by their decomposition, which reach water bodies and may be highly toxic to the environment and to human health.

Oil spills affect organisms in many ways, leading to negative effects such as impaired development in aquatic plants [87] or intoxication in fish [88, 89]. Exposure to oil spills for humans may lead to negative impacts such as effects on mental health, physical and physiological effects, toxic effects in the immunological and endocrine systems, and damages in genetic material [90].

Besides altering river morphology, mining introduces pollutants such as **mercury** [61], which easily accumulates in the soil, litterfall, and leaves, or enters and magnifies in the food chain, potentially causing devastating impacts on wildlife [91]. Currently, all Amazonian countries have reported environmental and human exposure to mercury [92]. The latest study shows that more than a fifth of the fish sold in 17 cities in six states of the Amazon region of Brazil contains dangerous levels of it [93]. In humans, long term exposure to either inorganic or organic mercury can permanently damage the brain and kidneys, as well as bring harm to developing fetuses [94].

C. SOLUTIONS TO MAINTAIN AND RESTORE THE AMAZON'S FRESHWATER ECOSYSTEMS

Concrete actions and the formulation of public policies are proposed here to address the pressing need for preserving and enhancing freshwater connectivity in the Amazon, encompassing longitudinal, lateral, vertical, temporal, biocultural, and bioeconomic linkages.

The following actions needed are put forth:

1. Halt Dam Construction and Implement Other Sources of Renewable Energy

1a. Cease Construction of Dams

Dams small or large should not be built in the Amazon. We advocate for a moratorium on dam construction within the basin.

1b. Adopt Innovative, Integrated, Alternative, and Renewable energy

The region holds significant potential for renewable energy generation, including photovoltaic (PV) systems, small-scale hydropower plants using hydrokinetic turbines, and modern biomass applications. Wind energy can also be harnessed in specific areas and the Atlantic coast offers opportunities for tidal energy and ocean thermal energy conversion (OTEC). (See more in New Infrastructure for the Amazon Policy Brief)

1c. Consider the Removal of Dams for Connectivity Restoration

The removal or retrofitting of obsolete and inefficient dams should be considered for restoring connectivity in river ecosystems. Dams that significantly disrupt local economies, contribute excessive CO_2 and Methane emissions to the atmosphere, and obstruct fish migration should be targeted. Retrofitting may involve replacing river-wide barriers with free-flowing diversion structures that allow for natural river processes. Additionally, to enhance efficiency, existing dams with large reservoirs could be augmented with alternative energy solutions, such as floating photovoltaic systems.

2. Expand Water Treatment and Pollution Control

2a. Urgent Investment in Water Treatment Infrastructure

Investing in water treatment infrastructure is crucial to effectively manage domestic and industrial effluents from Amazonian cities and rural communities. In Manaus, the largest city in the Amazon, only 21.8% of sewage is treated, with the remainder being discharged directly into water bodies. Throughout the basin, numerous cities lack any sewage treatment facilities whatsoever.

2b. Halt Illegal Mining and Strengthen Monitoring and Enforcement

Address mercury contamination from illegal and artisanal gold mining through enhanced governance, rigorous enforcement, and protection of conserved areas and Indigenous lands. This approach should include banning or restricting the use of heavy machinery on mining barges. Additionally, stringent monitoring mechanisms should be established, alongside penalties for activities that contribute to freshwater degradation and pollution. Increased investment is also necessary to regulate the mercury trade across Amazon hubs. Moreover, ensuring transparency and accountability within gold supply chains is crucial to curbing the circulation of illegally sourced gold in international markets.

2c. Promote Natural Regeneration of Riparian Buffer Zones

Efforts should be directed toward restoring and maintaining riparian buffer zones with native plant species along river corridors. These riparian buffers retain sediments, favor successional processes, and serve as natural filtration systems, mitigating influx of pollutants into water bodies while promoting biodiversity and ecological resilience.

3. Invest in Science, Technology, Innovation, and Water Literacy

3a. Enhance Monitoring of Freshwater Ecosystems

It is imperative to monitor and map key aspects that are unique to these ecosystems: hydrology, chemistry diversity, life-history of organisms, food web dynamics, critical ecosystem process, fish stocks, and the relationship between water-use by agro-industry and water table, among others.

3b. Invest in Technologies to Avoid Degradation

We advocate for investment in transdisciplinary research that develops technological solutions tailored to address unique challenges in fisheries, floodplain production, and conservation at various scales (Box 2). There is a crucial need for initiatives aimed at assisting miners in transitioning to mercury-free extraction methods, remediating areas degraded by mercury mining, and exploring energy alternatives to hydropower as well as advanced water treatment solutions.

BOX 2: TECHNOLOGY AND NATURE-BASED SOLUTIONS: PATHWAYS OUT OF DEGRADATION

Investments in research and innovation have brought forward technologies that preserve the social and economic benefits of traditional extractive activities while offering alternatives that minimize environmental degradation. For instance, the use of cyanogenic plants like bitter cassava has shown potential for gold leaching, representing a less impactful mining alternative [99]. Replacing mercury with local plants could mark a substantial move towards sustainable development in the region, particularly if these technologies are tailored to local conditions.

Furthermore, aquaculture holds significant potential for providing protein both locally and internationally, thereby fostering social and economic development. The implementation of biofloc systems in aquaculture can reduce feed costs, decrease water usage through reduced water exchange rates, and replace fish meal and oil in animal feed, thus combating overfishing [100].

Additionally, there are successful cases of alternative energy sources in Amazonia that could reduce the region’s reliance on hydroelectric dams. For example, 12 villages in Ecuador’s eastern provinces, belonging to the Mukucham family, now depend on solar panels for transportation, powering schools, and supporting ecotourism [101].

3c. Facilitate Knowledge Exchange and Promote Water Literacy

Develop public policies to enable the exchange of scholars, researchers, and practitioners within the Amazon region. Additionally, implement educational programs in public schools to teach about water and the unique characteristics of these ecosystems, encouraging collaboration between students and researchers.

4. Align Deforestation and Degradation Reduction Strategies with Climate Policy

4a. Stop Deforestation and Degradation

Urgent action is required to significantly stop deforestation and degradation of riparian and floodplain forests and other freshwater ecosystems. Forest restoration over terra-firme degraded pastures is also important for freshwater ecosystems. There must be a greater distinction between roads that are important for local people and those which open up forest frontiers and encourage land grabbing. Avoiding selective logging and buffering forest edges with regenerating forests can help preserve microclimates, reduce temperatures, and enable ecosystems to retain their resilience.

4b. Encourage and Support Local Management Efforts to Address Climate Change

Local strategies that promote the maintenance of free-flowing rivers (Figure 4) can enhance the resilience of aquatic ecosystems to climate change and extreme weather events, such as severe droughts and floods.

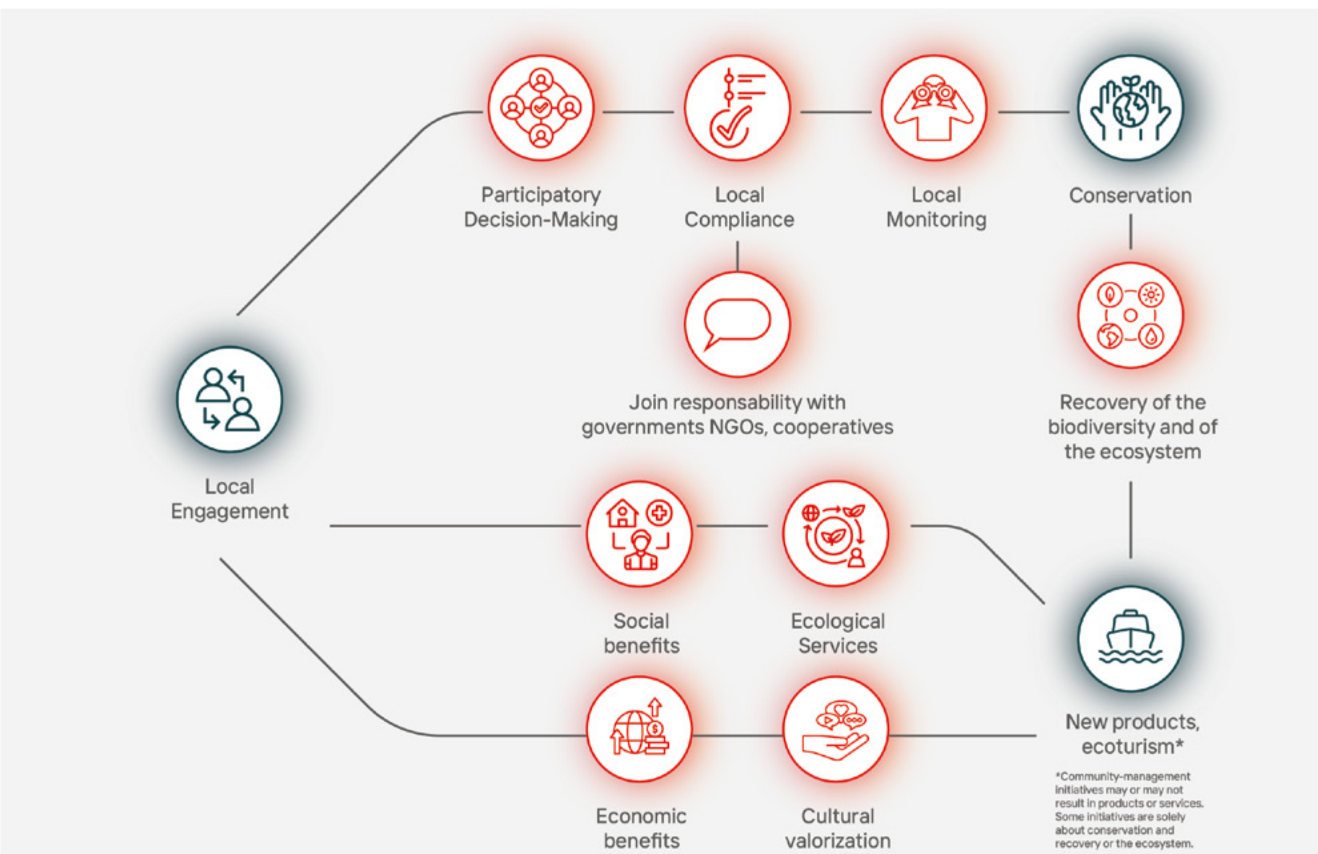

FIGURE 4. Community-Based Management for Conservation and Socio-Political Resilience in Freshwater Ecosystems [107]. How does it work?

5. Empower Indigenous Peoples and Local Communities in Freshwater Management

5a. Encourage, Empower, and Support Community Conservation

Indigenous people and local communities, urban and rural, must be protagonists of the conservation of freshwater ecosystems, particularly through the designation of protected watershed corridors.

5b. Integrate Indigenous and Local Knowledge

The traditional knowledge of local and indigenous communities regarding the management and use of freshwater ecosystems must be integrated into conservation strategies, as it enhances their effectiveness and promotes cultural preservation.

5c. Implement Local and Regional Public Policies for the Sustainable Management of Fisheries

Enable the exchange of successful regional practices and strategies in fisheries management to prevent the depletion of fish stocks respecting the carrying capacity of the ecosystem and the patterns of migratory fish (Box 3). This must be coupled with an enhanced and wide basin effort in monitoring fish stocks.

BOX 3: FLUVIAL COMMUNITY RESERVES: A MODEL FOR TRANSNATIONAL RIVER CONSERVATION

River systems, though critical for biodiversity and ecosystem services, often lack the protection afforded to terrestrial environments. Recognizing rivers as conservation entities is essential for addressing these disparities. The concept of *Fluvial Community Reserves* proposes a novel conservation model that integrates the protection of river ecosystems with the empowerment of local communities who depend on them.

In Southeast Asia, the success of **Community-based Freshwater Fish Reserves** exemplifies this approach [102]. Local involvement in management, which blends traditional practices with modern conservation techniques, has led to significant ecological improvements. For instance, in Thailand, designated no-take zones around critical spawning areas have successfully rejuvenated fish populations, bolstering sustainable fishing and enhancing overall river health.

Applying this model in the Amazon could establish a transnational framework for conserving riverine ecosystems vital to biodiversity and local communities. Implementing *Fluvial Community Reserves* across the Amazon basin, especially in transboundary rivers, could enhance ecological connectivity and resource integrity. This initiative would necessitate collaborative inter-country efforts to synchronize conservation strategies with the socio-economic dynamics of indigenous and local populations, backed by robust legal and financial support. Additionally, fostering institutional agreements and adaptive management practices would be crucial for the sustainability of these reserves.

6. Establish New Conservation Frameworks

6a. Shift the Amazon Conservation Paradigm

It is necessary to expand the conservation focus centered on terra-firme forests to include strategies specifically tailored for the conservation of freshwater ecosystems in the Amazon. This requires a protection model at the basin level, from springs to floodplain areas. Fragmentation of connectivity strongly occurs in the middle Amazon River, the Tapajós River, the Xingu River and other important waterways in the basin. For these rivers, it is essential to maintain or reforest uninterrupted freshwater connectivity corridors (FCC), especially for long-distance migrants such as several species of fish and turtles (migrations > 500 km) [28].

6b. Develop a Catchment-based Conservation Framework for the Whole Basin

This framework must establish protected freshwater connectivity corridors of longitudinal and lateral connectivity, thus conserving a variety of productive aquatic ecosystems and its biodiversity. A whole basin management strategy could use a multiple-use zoning framework [95], integrating various freshwater ecosystems inside and outside protected areas.

6c. Establishment of Fluvial Community Reserves

This new conservation framework must support Indigenous people and local communities to sustainably co-manage resources. Therefore, we advocate for the concept of Fluvial Community Reserves, which integrate conservation efforts with the sustainable management of resources linked to these ecosystems (Box 3).

7. Establish Transnational Governance for River Protection

7a. Transnational Governance Agreements

Developing transnational agreements for regional governance is essential to safeguard free-flowing rivers along national boundaries. Cross-border collaboration efforts are needed to regulate and control mining activities, implement renewable energy alternatives and appropriate infrastructure projects with minimized impacts, and ensure Indigenous peoples' rights to territory

7b. Collaborative Governance Structures

Establishing collaborative governance structures involving science institutions, public management agencies, local communities, and the private sector are vital to ensure sustainable management of freshwater resources. Examples of collaborative partnerships in the Amazon include the BR-163 participatory planning process and the development of river floodplain co-management in the Lower Amazon region [96]. Once again, the OTCA is an appropriate governance body for this purpose.

7c. Ensure Indigenous Rights

Furthermore, such governance structures should include environmental, social, and governance safeguards in line with the highest standards of Indigenous rights, including their right to free and prior informed consent (FPIC) as required by the ILO Convention 169, the UN Declaration on the Rights of Indigenous Peoples, and by the UN Human Rights Council Res. 39/12.

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