Conserving Amazon's Freshwater Ecosystem's Health and Connectivity

Lead Authors
Andrea C. Encalada (Researcher and Provost, Universidad San Francisco de Quito, Ecuador)
Adalberto Val (Researcher, INPA - Brazilian National Institute for Research of the Amazon, Manaus)

Coauthors
Simone Athayde (World Resources Institute, and University of Florida, USA)
Jhan Carlo Espinoza (IRD, Perú)
Marcia Macedo (Woodwell Climate Research Center, USA)
Mirian Marmontel (Instituto Mamirauá, Brazil)
Guido Miranda (Wildlife Conservation Society, Bolivia)
Maria Tereza Piedade (INPA, Brazil)
Tiago da Mota e Silva (Postdoctoral internship, INPA, Brazil)
Julia Arieira (Scientific-Technical Secretariat, Science Panel for the Amazon - SPA)

KEY MESSAGES

I. Acknowledge Essential Biodiversity and Services of Amazonian Freshwater Ecosystems

Amazonian Freshwater Ecosystems deliver invaluable services essential for global ecological balance, including water purification, provision, transportation, energy, and food production, along with carbon sequestration and diverse habitats. 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 km^3 of water each year. This basin also discharges an average of 1,122 megatons (Mt) of suspended sediments annually, crucial for soil fertility and ocean health. Additionally, the region's freshwater ecosystems boast remarkable biodiversity, with approximately 2,500 fish species, nearly half of which are endemic. These ecosystems are vital for the livelihoods of Amazonian communities, exemplified by the Low Solimões where the daily fish consumption per capita reaches 550 grams.

II. Maintain Multidimensional Connectivity in Amazonian Freshwater Ecosystems

Preserving the complex 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 bioeconomic dimensions. Notably, 223 Amazonian fish species are documented as migratory, depending heavily on these longitudinal and lateral connections. Despite this, numerous hydroelectric projects—both existing and planned—pose significant threats by disrupting these vital connections. This situation underscores the urgent need for comprehensive management and proactive policy measures to protect the Amazon’s freshwater ecosystems.

III. Rapid degradation of Amazonian Freshwater Ecosystems

Amazonian Freshwater Ecosystems are undergoing rapid degradation due to water pollution, oil spills, mining, dam construction, deforestation, and climate change. Compounding this issue, there are no sewage treatment plants in any Amazon Basin cities, and mining and oil projects frequently operate with substandard environmental practices, leading to significant environmental liabilities. These factors not only fragment rivers but also sharply reduce their biodiversity, functionality, and the provision of ecosystem services. The repercussions of this degradation are severe, including loss of biodiversity, increased frequency and intensity of fires, disruptions to biogeochemical cycles, and significant deterioration in water quality and availability. These changes have detrimental impacts on fish populations, energy production, and the well-being of Indigenous Peoples and local communities (IPLCs).

IV. Conservation, Remediation and Restoration as Imperatives

Conservation, remediation, and restoration must be prioritized across the entire Amazon Basin. This includes developing specialized conservation frameworks for freshwater ecosystems and enhancing sewage treatment in Amazonian cities. There is a critical need for major projects that actively restore riparian vegetation, buffer floodplain areas, and reconnect rivers, streams, and wetlands. These efforts should aim to improve water quality, protect headwater regions, and establish connectivity corridors. Moreover, applying innovative technologies to develop more effective water treatment solutions is essential for maintaining ecological flows and restoring the health of freshwater ecosystems. Collaborative interdisciplinary efforts involving citizens, stakeholders, NGOs, academia, and governments are vital for these initiatives to succeed.

V. Inclusivity and Community Management

The Amazon Basin is home to 47 million people, including an indigenous population of 2.2 million. Recognizing Indigenous Peoples and Local Communities (IPLCs) as essential stewards of Amazon Freshwater Ecosystems is crucial. Integrating their traditional knowledge with scientific approaches enhances conservation, remediation, and restoration efforts. There is compelling evidence that inclusive governance and co-management not only sustain ecosystem health but also boost local economies. Emphasizing the recovery of ancestral knowledge and cultural beliefs about water—including its reverence as a deity and its role in healing social ties with nature—further enriches these efforts.

VI. Transnational Coordination, Collaboration and Financial Support

Each Amazonian country must develop and implement national public policies for freshwater ecosystems, recognizing rivers, streams, and wetlands not merely as water sources but as unique ecosystems providing essential services. It is imperative to establish transnational agreements for the management and recovery of these systems, acknowledging that eight countries and one territory are interconnected by the Amazon Waters. Enhanced collaboration among these nations is crucial to tackle transboundary environmental challenges effectively and to promote the adoption of sustainable alternative energy sources. This approach will ensure comprehensive, cohesive management across the Amazon Basin.

RECOMMENDATIONS

I. **Cease Dam Construction and Promote Decentralized Sustainable Energy**: Halt dam construction in the Amazon and invest in decentralized sustainable energy projects that bolster the local community economies.

II. **Enhance Water Treatment and Pollution Control**: Urgently invest in water treatment infrastructure, enforce pollution control policies, and strengthen monitoring efforts. Promote the restoration of riparian vegetation, especially in areas degraded by illegal mining.

III. **Integrate Deforestation Reduction with Climate Policy**: Reduce deforestation and degradation in Amazonian forests and freshwater ecosystems by incorporating climate change policies and forest protection strategies into regional development planning.

IV. **Invest in Science and Cross-Disciplinary Research**: Urgently invest in science, technology, and innovation to improve monitoring and support cross-disciplinary research aimed at understanding and addressing stressors on Amazonian Freshwater Ecosystems.

V. **Empower IPLCs in Freshwater Management**: Support the leadership of Indigenous Peoples and Local Communities (IPLCs) in freshwater management and conservation, respect cultural diversity, and integrate Indigenous knowledge into governance structures and scientific innovation.

VI. **Debate New Conservation Frameworks**: New conservation frameworks should be discussed and proposed, such as the creation of Fluvial Community Reserves.

VII. **Establish Transnational Governance for River Protection**: Transnational governance agreements are crucial for the protection of longitudinal river ecosystems.

VIII. **Secure International Financial Support**: Call for international and intergovernmental financial support to enable local, regional, and global initiatives aimed at conserving and restoring Amazon Freshwater Ecosystems.

GRAPHICAL ABSTRACT (UNDER CONSTRUCTION)

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

Amazon freshwater characteristics, functions and biodiversity

The formation of the Amazon River dates from 10 to 4,5 million before present time, when western and eastern Amazon became connected, driven by the uplift of the Andes and long-term erosion processes. Through millions of years, the historical changes in the courses of major lowland rivers and floodplains had a profound effect on the richness and resilience of the Amazon biodiversity (Cracraft et al. 2020; Laranjeiras et al. 2021; Val et al. 2021). Nowadays, the Amazon basin spans 7.3 million km^2, of which around 40% is in the Andes. At the mouth of the river, it boasts a discharge of approximately 220,000m^3 per second (Costa et al. 2021), constituting 16-22% of the Earth's freshwater river discharge (Costa et al 2021). The intricate Amazonian hydrological network comprises approx. 15,000 catchments (300-1000 km2) (Venticinque et al., 2016) and a diverse array of other freshwater ecosystems, such as tectonic lakes, swamps, wet meadows, Andean freshwater marshes, mangroves, meander lagoons, riparian wetlands, and expansive floodplains (Junk et al. 2014, Moraes et al. 2021).

Roughly 30% of the Amazon region can be described as wetlands, encompassing various types of ecosystems at the interface between land and water, distinguished by factors such as flood frequency, depth, duration, water chemistry, vegetation, and associated wildlife (summarized in Junk et al. 2011). Carving through the landscape, these waters sculpt a mosaic of aquatic (e.g., rivers and lakes), semi-aquatic (i.e., systems with periodically flowing waters), and semi-terrestrial (i.e. systems flooded during periods of different length) freshwater habitats (Milton and Finlayson 2017). Also, the distinctive geomorphological, and physical-chemical water attributes (e.g. temperature, pH, dissolved oxygen, and organic and inorganic carbon) of these environments foster unparalleled adaptive strategies among its organisms (Guayasamin et al. 2021; Val & Almeida-Val, 1995; Gonzalez et. al. 2002, 2024; Johansson et al. 2017).

Variability through time is a major aspect of the definition of these wetlands. That is because fluctuations in rainfall and river discharge drive pronounced seasonal changes in the water level of large Amazon rivers, causing them to overflow their banks into adjacent floodplains. Because it extends into both hemispheres, the Amazon is characterized by several rainfall regimes due to the alternating warming of each hemisphere. The Amazonian rainy season occurs in austral winter in the north and austral summer in the south. The northwest equatorial region experiences low rainfall seasonality, with wet conditions throughout the year (e.g., Figueroa and Nobre, 1990; Espinoza et al. 2009, 2015). The northern portion of the Amazon basin, in the Roraima region, as well as the southern part, by the Cerrado, present smaller wetland areas, as precipitation is much lower. Because of this, as environmental degradation advances in both of those areas, the native forest there is replaced by grasslands, or savannas, losing critical ecological services.

Depending on the type of flooding, wetlands can be subject to stable water-levels or oscillating water-levels. The wetlands with predictable monomodal pulses are of two classes, interfluvial wetlands subject to low-amplitude pulses, and floodplains of large rivers subject to high-amplitude pulses. In particular, the seasonal flood pulse of the major rivers strongly influences the structure and function of floodplains (Junk et al. 1989; Melack and Coe 2021). Floodplains of large rivers cover approximately 750,000 km2 (aprox. 11%) of the area of the Amazon basin (Wittmann and Junk, 2016). The associated rivers may be of Andean sedimentary origin, constituting the *várzeas* of fertile white waters (e.g. Amazon River), or the igapós, when draining the ancient Guianas or Central Brazil geologically old shields, which are acidic and carry low amounts of sediments. These seasonally flooded forests are of vital importance and constitute the most species-rich floodplain forests on the Planet. Lastly, periodic flooding and high (sometimes variable) salinity create specific conditions in coastal wetlands, such as mangroves that occur mostly along the coasts of Amapá, Pará, and Maranhão, which are centers of biodiversity and play an important role as link between inland water and the marine environment (Junk et al. 2011).

All this rich tapestry of life experiences seasonal fluctuations in river levels and the receding and rising of seasonal floods are crucial for sustaining the nutrient and biological cycles of the region as a whole. Connectivity between river systems and their associated lakes is vital for the vegetation and fauna of these environments, in terms of the maintenance of viable habitat, seed dispersal and feeding. Ultimately, the essence of the Amazon hinges upon the interconnectedness of its waterways, facilitating the exchange of water, nutrients, sediments, and biodiversity (Junk, 2013).

The multidimensional connections of the Amazon

We can identify distinct dimensions of water connectivity within the basin. In all of them, time takes a significant role, as there is intense variability and change in freshwater habitats through the seasons. For the purposes of this policy brief, we consider five dimensions of connectivity through the basin taking into consideration both ecological and socio-economic aspects: the **longitudinal dimension**, linking the Andes with the rest of Amazon and with the Atlantic Ocean; the **lateral dimension**, connecting rivers, forests, and wetlands to provide conditions for numerous species to strive; the **vertical dimension**, encompassing interactions between wetlands, aerial rivers, and groundwater; the **biocultural dimension**, incorporating the relationship of human population's cultural traditions and beliefs with rivers, wetlands and their aquatic biodiversity; and the **bio-economical dimension**, acknowledging the provision of food, transportation, drinking water, and economic activities by aquatic ecosystems. We advocate for conservation initiatives that ensure open connectivity within the basin, considering all these dimensions, while ensuring equity and inclusion in conversation planning, policies and practices.

Longitudinal Dimension: The Amazon-Andes-Atlantic transition is a crucial zone of hydrological connection (Encalada et al. 2019). The region experiences high rainfall rates (between 6000 and 7000 mm/year) due to interactions between regional atmospheric circulation and temperature and moisture contrasts (Giovannettone and Barros, 2009; Poveda et al., 2014; Espinoza et al., 2015; Chavez and Takahashi, 2017). These rainfall rates result in significant 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/year of sediment load to the Atlantic Ocean (Wittmann et al 2011), with 90% of total originating in the Andes (Meade et al. 1985). In regard to the transport of nutrients, the primary contributions from the longitudinal connectivity of the river channel consist of water and inorganic material, whereas the lateral connection between the river and floodplain plays a more significant role in the production of organic material (Junk et al. 2011). 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 (Baigún and Valbo-Jørgensen, 2023).

Lateral Dimension: The varied aquatic and semi-aquatic habitats of the lowland Amazon are subject to seasonal fluctuations (Figure 1, **Box 1**), creating interconnected corridors during high-water periods that facilitate species migration and seed dispersal between rivers and lakes with the floodplain, and as refuge during low-water periods (Junk 2001). The adaptive capabilities and genetic diversity of Amazonian aquatic biota is highly dependent on habitat exchange, allowing organisms such as fish and aquatic mammals to seek optimal conditions for survival (Martin and da Silva 2004; Caldas et al. 2022; Junk 1984). Moreover, floodplains store and transport water, sediments and nutrients during high water periods influencing high primary and secondary production, thus sustaining fishery resources (Junk 2001). 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 (Correa et al. 2015; Araújo-Lima & Goulding 1998).

Vertical Dimension: Approximately 25–50% of the total annual rainfall observed in the tropical Andes originates from Amazon tree transpiration (Staal et al. 2018). Part of the produced moisture is transported westward by winds flowing in low altitudes (~1km), known as "aerial rivers" reaching as far south as northern Argentina and supplying water to other major river basins on the continent (Costa et al. 2021; Chung et al. 2022). These aerial rivers carry an amount of water vapor equivalent to the average flow of water at the mouth of the Amazon River (10-23 billion liters per day) (Arraut et al. 2012). Moreover, the large amount of rainfall infiltrates the ground and contribute to the formation of large aquifers like the Alter do Chão-Içá aquifer system, with a recharge amount estimated to be at least 236,400 and 350,000 m3/year (Val et al. 2021, Azevedo & Campos, 2021).

Biocultural Dimension: IPLCs hold worldviews (**Box 2**), linguistic conceptualizations, spiritual connections and experiential knowledge of Amazonian Freshwater Ecosystems gained over many years (Clement et al. 2015; Neves et al. 2021; Athayde et al. 2024 in progress). Archaeological sites found in both large rivers and small tributaries indicate that pre-Columbian Indigenous populations have modified significant portions of Amazonian forests and freshwater ecosystems such as floodplains and wetlands over different time periods (McMichael et al.

2012; Thomas et al. 2015). Recently, indigenous and local knowledge (ILK) systems have been combined with scientific knowledge and technology to protect and restore freshwaters and headwaters through co-management experiences and fisheries agreements (**Box 3**), including cases in which IPLCs have been meaningfully involved in decision-making processes (Campos-Silva et al. 2019; Correa et al. 2020).

Bioeconomic dimensions: Fish are important providers of protein, micronutrients, and income for both rural and urban households across the Amazon Basin (Barletta et al. 2010). The estimated total extraction of fish in the Amazon basin is between 422,000 and 473,000 tons per year, almost 75% of which is represented by the Brazilian part of the basin (Sirén and Valbo-Jørgensen, 2022). 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 IPLCs (Clement et al. 2010; Athayde et al. 2021). Finally, fluvial transport plays a crucial role in accessing remote areas, enabling services such as public health to meet the demands of rural areas (Rocha et al. 2023).

B. MAIN DRIVERS OF DEGRADATION OF FRESHWATER ECOSYSTEMS

The ecosystems of the Amazon have been facing significant challenges due to human actions that promote degradation of aquatic habitats and compromise the crucial connectivity of the water network. In this topic, those drivers of degradation that cause greater concerns are detailed.

River Fragmentation

The primary threat to freshwater connectivity is river fragmentation, particularly due to hydropower development (Grill et al. 2019), which currently impacts rivers ranging from the Andes to large basins like the Marañon, Madeira, Napo, Tapajós, Tocantins, and Ucayali (Winemiller et al. 2016; Latrubesse 2017; Anderson et al. 2018; Caldas et al. 2022) (Figure 2).

Dams alter riverine habitats by changing hydrological patterns, sediment flows (Timpe & Kaplan 2017; Anderson et al. 2019; Caldas et al. 2022; Chaudhari and Pokhrel 2022), temperature, and nutrient balance (Pavanato et al. 2016), affecting various freshwater organisms and causing declines in migratory species (Caldas et al. 2022). Additionally, studies show that some lowland dams in the Amazon may exceed in greenhouse gas emissions per unit of electricity generated when compared to fossil fuel power plants (Almeida et al. 2019).

Fragmentation of Amazon's Freshwater Ecosystems cause significant socio-economic and socio-cultural impacts on IPLCs, including livelihood impoverishment, loss of food security, as well as psychological and spiritual effects (Athayde et al. 2019). Research has shown that changes in diets and fisheries can affect food security and consumption patterns among Amazonian populations (Torres-Vitolas et al. 2019; Begossi et al. 2018; Blundo-Canto et al. 2020), exacerbating malnutrition in riverine and urban communities (Heilpern et al. 2021).

Freshwater Degradation

The loss of freshwater and its biodiversity in Amazonian ecosystems is strongly related to environmental degradation, resulting from manifold activities (Piedade et al. 2024), including such as water capture for agricultural activities and livestock. Agricultural and livestock uses are the prime drivers of wetland loss. Land-cover change related to cattle ranching and crop production has affected about 20% of the Amazon basin, particularly to the south and southwestern region, where native forest has been replaced by grassland and savannas (Castello & Macedo, 2016). Thus, this land use is usually associated with removal of vegetation, loss in biodiversity and the occurrence of hydrological droughts, which are exacerbated during severe hydrometeorological events.

Different sources of pollution are also a major concern. Domestic and industrial sewage discharged into water bodies represent dangerous sources of contamination. Also, inadequate disposal of solid waste results in leaching of liquids generated by their decomposition, which are 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 (Lopes et al. 2009) or intoxication in fish (Brauner et al. 1999; Val & Almeida-Val, 1999). Exposure to oil spills on humans may lead to negative impacts such as effects on mental health, physical and physiological effects, toxic effects in the immunological and endocrine systems, damages in the genetic material (summarized by Laffon et al. 2016).

Mining impacts freshwater ecosystems directly by altering stream and river morphology due to excavations, by increase in sediment loads, by the large-scale deforestation related to it, and by introducing pollutants such as mercury (Wittman & Junk, 2016). 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 mercury (Basta et al. 2023). In humans, long term exposure to either inorganic or organic mercury can permanently damage the brain, the kidneys, and also bring harm to the developing fetus (summarized by Chan et al. 2010).

Climate Change

Ongoing climate change poses significant threats to the Amazon, impacting the entire ecosystem and its interconnections. Climate change alters rainfall, temperature, and moisture patterns across the Amazon Basin, impacting freshwater and wetlands ecosystems. Climate models predict a decline in annual precipitation for the future, particularly in the southern basin, heightening the region's vulnerability (Agudelo et al. 2023). 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 (Datry et al. 2023). Such changes lead to adaptations in aquatic fauna and flora, but can also result in higher mortality rates among fish (Barletta et al. 2010) and aquatic mammals (Marmontel et al. 2024).

Deforestation and Forest Fragmentation

High deforestation rates impact Amazon Freshwater Ecosystems in different ways, including important changes in the regional hydrological cycle. Deforestation reduces evapotranspiration and increases temperatures, thereby decreasing the amount of water vapor in the atmosphere (Wongchuig et al. 2023). This can reduce the recycling of precipitation, the surface runoff and sediments exported from the Andes to the low-lying Amazon, increasing the risk of droughts, tree mortality and fires (Nobre et al. 2016; Sierra et al. 2021.).

C. SOLUTIONS TO MAINTAIN AND RESTORE AMAZON FRESHWATER ECOSYSTEMS

Concrete actions and the formulation of public policies (Figure 3) 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. We highlight the need for coordination, cooperation, and collaboration among the Amazonian countries around policies, practices, and incentives to protect and restore freshwater ecosystems. The following recommendations are put forth:

I. Reduction of River Fragmentation: Promoting Longitudinal Connectivity in Amazon Freshwater Networks

1. **Cease Construction of Dams**: We advocate for a moratorium on dam construction within the Amazon basin. Instead, we propose investment in innovative, decentralized, and sustainable alternative energy projects, which engage society and communities as stake and right holders. These initiatives not only provide income for local populations but also safeguard biocultural and bioeconomy connections and activities, as well as critical ecosystem functions such as migratory routes and sediment transportation.
2. **Dam Removal for Connectivity Restoration**: Obsolete and inefficient dams that significantly disrupt local economies and impede fish migration and fisheries production should be considered for removal. Other existing dams can be integrated with alternative energy systems, such as solar, in order to be more efficient.
3. **Establishment of Fluvial Community Reserves**: We recommend the creation of local and/or regional fluvial community reserves spanning international borders. These reserves would uphold diverse levels of freshwater connectivity, supporting IPLCs to sustainably manage resources while preserving invaluable ecosystems by recognizing the interconnectedness of freshwater ecosystems with socio-economic well-being.
4. **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 identify and implement sustainable energy and infrastructure projects with minimized impacts and identifying solutions for energy and infrastructure projects.

II. Addressing Water Pollution and Restoring Riparian Vegetation to Preserve Lateral Connectivity in the Amazon Freshwater Network

5. **Investment in Water Treatment Infrastructure**: It is imperative to invest in water treatment plants to effectively treat domestic and industrial effluents originating from

Amazonian cities and rural communities. This investment aims to restore the freshwater quality of Amazon waterways, safeguarding the health of aquatic ecosystems and human populations.

6. **Formulation of Pollution Control Policies**: Public policies must be formulated and enforced to regulate pollution from diverse sources, including agricultural runoff and industrial discharges. These policies are essential for maintaining optimal water quality across Amazonian water bodies and mitigating the adverse impacts of pollution on both ecological and human health.
7. **Strengthening Monitoring and Enforcement**: Implementing stringent monitoring mechanisms and imposing penalties for both illegal and legal activities, such as mining, that contribute to freshwater degradation and pollution is crucial. This approach ensures accountability and deters harmful practices that compromise the integrity of Amazonian Freshwater Ecosystems.
8. **Restoration of Riparian Buffer Zones**: To uphold lateral and vertical connectivity, efforts should be directed towards restoring and maintaining riparian buffer zones with native plant species along river corridors. Also, these riparian buffers retain sediments, favor successional processes, and serve as natural filtration systems, mitigating influx of pollutants into freshwater ecosystems while promoting biodiversity and ecological resilience.

III. Addressing Climate Change Impacts to Preserve Vertical Connectivity in the Amazon Freshwater Network

9. **Deforestation and Degradation Reduction**: Urgent action is required to significantly reduce deforestation and degradation of forests and freshwater ecosystems (Figure 4). These activities are vital for maintaining crucial processes such as carbon sequestration and water evaporation and evapotranspiration. Also, this will promote the reduction of emissions, which is a key step to mitigate global climate change.
10. **Integrating Climate Change Strategies**: It is imperative to integrate climate change mitigation and adaptation strategies into regional and local planning efforts. This holistic approach fosters sustained ecosystem resilience, enabling Amazonian freshwater ecosystems to withstand and adapt to the challenges posed by climate change, such as changes in precipitation, while maintaining their vital connectivity.

IV. Promoting Investment in Science, Technology, and Innovation to Foster Scientists, Indigenous Communities and Civil Society Connectivity within the Amazon Freshwater Network

9. **Enhanced Monitoring of Freshwater Ecosystems**: It is imperative to monitor Amazonian freshwater ecosystem dynamics across various scales and their responses to drivers of environmental degradation. Also monitor hydrology, chemistry diversity, life-history of organisms, food web dynamics, critical ecosystem process and fisheries, the relationship between water-use by agro-industry and water table, among others. This necessitates investment in research focused on understanding the impacts of compounding disturbances and fostering freshwater resilience, providing vital information to bolster local governance efforts.

15. **Invest in Research and Innovation.** We advocate for substantial investment in transdisciplinary research aimed at developing innovative and technological solutions (**Box 4**) tailored for the unique bioeconomic challenges concerning fisheries, floodplain production, and conservation across various scales. Investment in programs dedicated to Amazon Freshwater Research and Technologies Initiatives within higher education institutions across Amazonian countries is also crucial.

16. **Facilitating Scholar, Researcher and Practitioner Exchange**: Developing public policies to facilitate the exchange of scholars, researchers and practitioners within the Amazon region is essential. By promoting collaboration and knowledge sharing, these policies catalyze the advancement of science, technology, and innovation initiatives, fostering a more holistic approach to addressing the complex challenges facing Amazonian freshwater ecosystems.

IV. Enhancing Collaboration and Conservation Strategies for Biocultural and Bioeconomic Connectivity in the Amazon Freshwater Network

17. **Community Empowerment for Conservation**: Local communities must be protagonists of the conservation of Amazon Freshwater Ecosystems, particularly through the designation of protected areas and the establishment of *Fluvial Community*

Reserves. By empowering communities in conservation efforts and recognizing them as stake and right holders, we can ensure the sustainable management of these invaluable resources.

18. **Restoration Initiatives**: Investment in science-based and nature-based restoration programs tailored to the unique characteristics of each ecosystem is essential. Empowering local communities to develop restoration projects fosters a sense of ownership and responsibility, potentially leading to effective conservation outcomes.
19. **Management of Fisheries:** Implement local and regional public policies for the sustainable management of fisheries. Encourage 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.
20. **Recognition of Indigenous and Local Knowledge:** The traditional knowledge of local and indigenous communities regarding the management and use of freshwater ecosystems must be recognized and respected. Integrating this knowledge into conservation strategies enhances their effectiveness and promotes cultural preservation.

24. **Collaborative Governance Structures:** Establishing collaborative governance structures is vital to ensure culturally sensitive and sustainable management of freshwater resources. These structures should include local communities in decision-making processes, fostering a sense of shared responsibility and ownership.
25. **Regional Collaboration:** Encouraging collaborative efforts among Amazon basin countries is essential to address shared challenges and formulate joint conservation and restoration strategies.
26. **Global Support for Sustainable Practices:** Seeking global cooperation and financial support is crucial to aid in the implementation of sustainable policies and practices in the Amazon freshwater network.

REFERENCES

Agudelo, J., Espinoza, J.C., Junquas, C., Arias, P. A., Sierra, J. P., Olmo, M. E. 2023. Future projections of low-level atmospheric circulation patterns over South Tropical South America: Impacts on precipitation and Amazon dry season length. Journal of Geophysical Research: Atmospheres. https://doi.org/10.1029/2023JD038658

Almeira, O. Fisheries management in the Brazilian Amazon. 2004. PhD thesis. Faculty of Science of the University of London.

Anderson, E. P., Jenkins, C. N., Heilpern, S., Maldonado-Ocampo, J. A., Carvajal-Vallejos, F. M., Encalada, A. C., Rivadeneira, J. F., Hidalgo, M., Cañas, C. M., Ortega, H., Salcedo, N., Maldonado, M., & Tedesco, P. A. 2018. Fragmentation of Andes-to-Amazon connectivity by hydropower dams. *Science Advances, 4*, aa1642

Araújo-Lima, C.A.R.M. and Goulding, M. (1998) So fruitful a fish. Ecology, Conservation, and Aquaculture of the Amazon's tambaqui, Columbia University Press, New York.

Arraut, J.M; Nobre, C.; Barbosa, H.M.J; Obregon, G.; Marengo, J. 2012. Aerial Rivers and Lakes: Looking at Large-Scale Moisture Transport and Its Relation to Amazonia and to Subtropical Rainfall in South America. J. Climate, 25, 543–556.

Athayde, S.; Utsunomiya, R.; Victoria-Lacy, L.; Beveridge, C.; Jenkins, C.; Laufer, J.; Heilpern, S.; Olivas, P.; Anderson, E.. 2024. Interdependencies between Indigenous peoples, local communities and freshwater systems in a changing Amazon. Submitted to Conservation Biology, under review.

Azevedo, J.H; Campos, J.E.G. 2021. Flow patterns and aquifer recharge controls under Amazon rainforest influence: The case of the Alter do Chão aquifer system. Journal of South American Earth Sciences. V. 112.,

Baigún, C. R. M.; Valbo-Jørgensen, J. (dirs.) 2023. La situación y tendencia de las pesquerías continentales artesanales de América Latina y el Caribe. FAO Documento Técnico de Pesca y Acuicultura N.º 677. Roma, FAO. https://doi.org/10.4060/cc3839es

Barletta, M *et al.* 2010. Fish and aquatic habitat conservation in South America: a continental overview with emphasis on neotropical systems. Journal of Fish Biology, Vol. 76, issue 9: 2118-2176.

Basta, P.C.; de Vasconcellos, A.C.S.; Hallwass, G.; Yokota, D.; Pinto, D.d.O.d.R.; de Aguiar, D.S.; de Souza, C.C.; Oliveira-da-Costa, M. 2023. Risk Assessment of Mercury-Contaminated Fish Consumption in the Brazilian Amazon: An Ecological Study. Toxics, 11, 800. https://doi.org/10.3390/toxics11090800

Basta, P. C., Viana, P. V. D. S., Vasconcellos, A. C. S. D., Périssé, A. R. S., Hofer, C. B., Paiva, N. S., … & Hacon, S. D. S. 2021. Mercury exposure in Munduruku indigenous communities from Brazilian Amazon: Methodological background and an overview of the principal results. International journal of environmental research and public health, 18(17), 9222.

Begossi, A. et ak. 2018. Fish consumption on the Amazon> a review of biodiversity, hydropower and food security. Braz. J. Biol. 79 (2).

Blundo-Canto, G., Cruz-Garcia, G.S., Talsma, E.F. *et al.* Changes in food access by mestizo communities associated with deforestation and agrobiodiversity loss in Ucayali, Peruvian Amazon. *Food Sec.* **12**, 637–658 (2020). https://doi.org/10.1007/s12571-020-01022-1

Caldas, B.; Thieme, M. L. Shahbol, N.; Coelho, M. E.; Grill, G.; Van Damme, P. A.; Aranha, R.; Cañas, C.; Fagundes, C. K.; Franco-Leon, N.; Herrera-Collazos, E. E.; Jézéquel, C. E.; Montoya, M.; Mosquera-Guerra, F.; Oliveira-da-Costa, M.; Paschoalini, M.; Petry, P.; Oberdorff. T.; Trujillo, F.; Tedesco, P. A.; Ribeiro, M. C. L. B. 2022. Identifying the current and future status of freshwater connectivity corridors in the Amazon Basin. *Conservation Science and Practice, 5*(1), e12853. https://doi.org/10.1111/csp2.12853

Campos-Silva, J.V., Hawes, J.E., Andrade, P.C.M. et al. 2018. Unintended multispecies co-benefits of an Amazonian community-based conservation programme. Nat Sustain 1, 650–656. https://doi.org/10.1038/s41893-018-0170-5.

Chug, D.; Dominguez, F; Yang, Z. The Amazon and La Plata River Basin as moisture sources of South America: Climatology and Intraseasonal. 2022. Journal of Geophysical Research. 127:12.

Clement CR, De Cristo-Araújo M, Coppens D'Eeckenbrugge G, Alves Pereira A, Picanço-Rodrigues D. 2010. Origin and Domestication of Native Amazonian Crops. *Diversity*, 2(1):72-106. https://doi.org/10.3390/d2010072.

Clement, C. R., Denevan, W. M., Heckenberger, M. J., Junqueira, A. B., Neves, E. G., Teixeira, W. G., & Woods, W. I. (2015). The domestication of Amazonia before European conquest. *Proceedings of the Royal Society B: Biological Sciences, 282*(1812), 20150813. https://doi.org/10.1098/rspb.2015.0813

Correa, A., Ochoa-Tocachi, B. F., Birkel, C., Ochoa-Sánchez, A., Zogheib, C., Tovar, C., & Buytaert, W. 2020. A concerted research effort to advance the hydrological understanding of tropical páramos. Hydrological Processes, 34(24), 4609-4627. https://doi.org/10.1002/hyp.13904

Costa MH, Borma LS, Espinoza JC, Macedo M, Marenjá JA, Marra DM, Ometto JP, Gatti LV. 2021. Chapter 5: The physical hydroclimate system of the Amazon. In: Nobre C, Encalada A, Anderson E, Roca Alcazar FH, Bustamante M, Mena C, Peña-Claros M, Poveda G, Rodriguez JP, Saleska S, Trumbore S, Val AL, Villa Nova L, Abramovay R, Alencar A, Rodríguez Alzza C, Armenteras D, Artaxo P, Athayde S, Barretto Filho HT, Barlow J, Berenguer E, Bortolotto F, Costa FA, Costa MH, Cuvi N, Fearnside PM, Ferreira J, Flores BM, Frieri S, Gatti LV, Guayasamin JM, Hecht S, Hirota M, Hoorn C, Josse C, Lapola DM, Larrea C, Larrea-Alcazar DM, Lehm Ardaya Z, Malhi Y, Marjágo JA, Melack J, Moraes R M, Moutinho P, Murmis MR, Neves EG, Paez B, Painter L, Ramos A, Rosero-Peña MC, Schmink M, Sist P, ter Steege H, Val P, van der Voort H, Varese M, Zapata-Ríos G (Eds). Amazon Assessment Report 2021. United Nations Sustainable Development Solutions Network, New York, USA. Available from https://www.theamazonwewant.org/spa-reports/

Cracraft, J. *et al.* 2020. The Origin and Evolution of Amazonian Species Diversity. In: Rull, V., Carnaval, A. (eds) Neotropical Diversification: Patterns and Processes. Fascinating Life Sciences. Springer, Cham. https://doi.org/10.1007/978-3-030-31167-4_10.

Cuvi N, Guiteras Mombiola A, Lehm Ardaya Z. 2021. Chapter 9: Peoples of the Amazon and European Colonizat^{io}n–(16th - 18th Centuries). In: Nobre C, Encalada A, Anderson E, Roca Alcazar FH, Bustamante M, Mena C, Peña-Claros M, Poveda G, Rodriguez JP, Saleska S, Trumbore S, Val AL, Villa Nova L, Abramovay R, Alencar A, Rodríguez Alzza C, Armenteras D, Artaxo P, Athayde S, Barretto Filho HT, Barlow J, Berenguer E, Bortolotto F, Costa FA, Costa MH, Cuvi N, Fearnside PM, Ferreira J, Flores BM, Frieri S, Gatti LV, Guayasamin JM, Hecht S, Hirota M, Hoorn C, Josse C, Lapola DM, Larrea C, Larrea-Alcazar DM, Lehm Ardaya Z, Malhi Y, Mjáengo JA, Melack J, Moraes R M, Moutinho P, Murmis MR, Neves EG, Paez B, Painter L, Ramos A, Rosero-Peña MC, Schmink M, Sist P, ter Steege H, Val P, van der Voort H, Varese M, Zapata-Ríos G (Eds). Amazon Assessment Report 2021. United Nations Sustainable Development Solutions Network, New York, USA. Available from https://www.theamazonwewant.org/spa-reports/.

Datry, T. Boulton, A. J.; Fritz, K.; Stubbington, R.; Cid, N. Crabot, J; Tockner, K. Non-perennial segments in river networks. 2023. Nature Reviews Earth & Environment, Volume 4: 815–830.

Encalada, A. C., A. S. Flecker, N. L. Poff, E. Suárez, G. A. Herrera-R, B. Ríos-Touma, S. Jumani, E. I. Larson, and E. P. Anderson. 2019. A global perspective on tropical montane rivers. Science 365:1124.

Espinoza JC, Chavez S, Ronchail J, et al. 2015. Rainfall hotspots over the southern tropical Andes: Spatial distribution, rainfall intensity, and relations with large-scale atmospheric circulation. Water Resour Res 51: 3459–75.

Espinoza JC, Guyot JL, Ronchail J, et al. 2009. Contrasting regional discharge evolutions in the Amazon basin (19742004). J Hydrol 375: 297–311.

Figueroa SN and Nobre CA. 1990. Precipitation distribution over central and western tropical South America. Climanálise 5: 36–45.

Grill, G., Lehner, B., Thieme, M., Geenen, B., Tickner, D., Antonelli, F., Babu, S., Borrelli, P., Cheng, L., Crochetiere, H., Ehalt Macedo, H., Filgueiras, R., Goichot, M., Higgins, J., Hogan, Z., Lip, B., McClain, M. E., Meng, J., Mulligan, M., & Zarfl, C. 2019. Mapping the world’s free-flowing rivers. *Nature*, *569*(7755), 215–221. https://doi.org/10.1038/s41586-019-1111-9

Gonzalez, R.J., Wilson, R.W., Wood, C.M., Patrick, M.L., Val, A.L., 2002. Diverse strategies for ion regulation in fish collected from the ion-poor, acidic Rio Negro. Physiological and Biochemical Zoology 75, 37-47.

Gonzalez, R.J., Patrick, M.L. & Val, A.L. (2024) Ion Uptake in Naturally Acidic Water. Journal of Comparative Physiology, in press.

Guayasamin JM, Ribas CC, Carnaval AC, Carrillo JD,Hoorn C, Lohmann LG, Riff D, Ulloa Ulloa C, Albert JS. 2021. Chapter 2: Evolution of Amazonian Biodiversity. In: Nobre C, Encalada A, Anderson E, Roca Alcazar FH, Bustamante M, Mena C, Peña-Claros M, Poveda G, Rodriguez JP, Saleska S, Trumbore S, Val AL, Villa Nova L, Abramovay R, Alencar A, Rodríguez Alzza C, Armenteras D, Artaxo P, Athayde S, Barretto Filho HT, Barlow J, Berenguer E, Bortolotto F, Costa FA, Costa MH, Cuvi N, Fearnside PM, Ferreira J, Flores BM, Frieri S, Gatti LV, Guayasamin JM, Hecht S, Hirota M, Hoorn C, Josse C, Lapola DM, Larrea C, Larrea-Alcazar DM, Lehm Ardaya Z, Malhi Y, Marengo JA, Melack J, Moraes R M, Moutinho P, Murmis MR, Neves EG, Paez B, Painter L, Ramos A, Rosero-Peña MC, Schmink M, Sist P, ter Steege H, Val P, van der Voort H, Varese M, Zapata-Ríos G (Eds). Amazon Assessment Report 2021. United Nations Sustainable Development Solutions Network, New York, USA. Available from https://www.theamazonwewant.org/spa-reports/. DOI: 10.55161/CZWN467

Gurdak, D. J.; Arantes, C. C.; Castello, L.; Stewart, D. J.; Watson, L. C. 2019. Evidence of recoveries from tropical floodplain fisheries: Three examples of management gains for South American giant arapaima. In Krueger, C.C.,Taylor, W.W., & Youn, S.J., From catastrophe to recovery: Stories of fish management success. American Fisheries Society, Bethesda, MD, pp. 267-295.

Heilpern, S.A. *et al.* 2021. Declining diversity of wild-caught species puts dietary nutrient supplies at risk.*Sci. Adv.*7, eabf9967.DOI:10.1126/sciadv.abf9967

Johannsson, O.E., Scott Smith, D., Sadauskas-Henrique, H., Cimprich, G., Wood, C.M., Val, A.L. 2017. Photo-oxidation processes, properties of DOC, reactive oxygen species (ROS), and their potential impacts on native biota and carbon cycling in the Rio Negro (Amazonia, Brazil). Hydrobiologia 789, 7-29. DOI 10.1007/s10750-016-2687-9

Junk WJ, Piedade MTF, Lourival R, Wittmann F, Kandus P., Lacerda LD, Bozelli RL, Esteves FFA, Nunes da Cunha C, Maltchik L, Schongart J, Schaeffer-Novelli Y, Agostinha AA. 2014. Brazilian wetlands: their definition, delineation, and classification for research, sustainable management, and protection. Aquatic Conservation: marine and freshwater ecosystems. 24: 5-22.

Junk, W. J. ; Piedade, M.T.F ; Schongart, J. ; Cohn-Haft, M.; Adeney, M; Wittmann, F. 2011. A classification of major naturally occurring Amazonian lowland wetlands. Wetlands (Wilmington, N.C.), v. 31, p. 623-640.

Junk, W.F. 2001. The flood pulse concept of large rivers: learning from the tropics, Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen, 27:7, 3950-3953, DOI: 10.1080/03680770.1998.11901733.

Junk, W.J. 1980. Áreas inundáveis - Um desafio para Limnologia. Acta Amaz. 10 (4).

Latrubesse, E. M., Arima, E. Y., Dunne, T., Park, E., Baker, V. R., D'Horta, F. M., Wight, C., Wittmann, F., Zuanon, J., Baker, P. A., Ribas, C. C., Norgaard, R. B., Filizola, N., Ansar, A., Flyvbjerg, B., & Stevaux, J. C. (2017). Damming the rivers of the Amazon basin. *Nature*, *546*, 363–369

Lopes, A.; Rosa-Osman, S. M.; Piedade, M. T. F.2009. Effects of crude oil on survival, morphology, and anatomy of two aquatic macrophytes from the Amazon floodplains. Hydrobiology; 636(1):295-305.

Martin, A. R.; V. M. F. da Silva. 2004. River dolphins and flooded forest: seasonal habitat use and sexual segregation of botos (*Inia geoffrensis*) in an extreme cetacean environment. *Journal of Zoology, 263,* 295–305. https://doi.org/10.1017/S095283690400528X

McMichael, C. H., Bush, M. B., Piperno, D. R., Silman, M. R., Zimmerman, A. R., & Anderson, C. (2012). Spatial and temporal scales of pre-Columbian disturbance associated with western Amazonian lakes. The Holocene, 22(2), 131–141. https://doi.org/10.1177/0959683611414932

Meade, R.H., Dunne, T., Richey, J.E., Santos, U., and Salati, E., 1985, Storage and remobilization of suspended sedi ment in the lower Amazon River of Brazil: Science, v. 228, p. 488–490, doi: 10.1126/science.228.4698.488

Moraes R M, Correa SB, Doria CRC, Duponchelle F, Miranda G, Montoya M, Phillips OL, Salinas N, Silman M, Ulloa Ulloa C, Zapata-Ríos G, Arieira J, ter Steege H. 2021. Chapter 4: Biodiversity and Ecological Functioning in the Amazon. In: Nobre C, Encalada A, Anderson E, Roca Alcazar FH, Bustamante M, Mena C, Peña-Claros M, Poveda G, Rodriguez JP, Saleska S, Trumbore S, Val AL, Villa Nova L, Abramovay R, Alencar A, Rodríguez Alzza C, Armenteras D, Artaxo P, Athayde S, Barretto Filho HT, Barlow J, Berenguer E, Bortolotto F, Costa FA, Costa MH, Cuvi N, Fearnside PM, Ferreira J, Flores BM, Frieri S, Gatti LV, Guayasamin JM, Hecht S, Hirota M, Hoorn C, Josse C, Lapola DM, Larrea C, LarreaAlcazar DM, Lehm Ardaya Z, Malhi Y, Marengo JA, Melack J, Moraes R M, Moutinho P, Murmis MR, Neves EG, Paez B, Painter L, Ramos A, Rosero-Peña MC, Schmink M, Sist P, ter Steege H, Val P, van der Voort H, Varese M, Zapata-Ríos G (Eds). Amazon Assessment Report 2021. United Nations Sustainable Development Solutions Network, New York, USA. Available from https://www.theamazonwewant.org/spa-reports/. DOI: 10.55161/IKRT9380

Neves, E.G., Furquim, L.P., Levis, C., Rocha, B.C., Watling, J.G., Almeida, F.O., Betancourt, C.J., Junqueira, A.B., Moraes, C.P., MorcoteRios, G., Shock, M.P., EK, T., 2021. Chapter 8: Peoples of the Amazon before European colonization, in: Nobre, C.A., Encalada, A., Anderson, E., Roca Alcazar, F.H., Bustamante, M., Mena, C., Peña-Claros, M., Poveda, G., Rodriguez, J.P., Saleska, S.R., Trumbore, S.E., Val, A.L., Villa Nova, L., Abramovay, R., Alencar, A., Rodríguez Alzza, C., Armenteras, D., Artaxo, P., Athayde, S., Barretto Filho, H.T., Barlow, J., Berenguer, E., Bortolotto, F., Costa, F.A., Costa, M.H., Cuvi, N., Fearnside, P.M., Ferreira, J., Flores, B.M., Frieri, S., Gatti, L.C., Guayasamin, J.M., Hecht, S.B., Hirota, M., Hoorn, C., Josse, C., Lapola, D.M., Larrea, C., Larrea-Alcazar, D.M., Lehm Ardaya, Z., Malhi, Y., Marengo, J.M., Melack, J., Moraes, M., Moutinho, P., Murmis, M.R., Neves, E.G., Paez, B., Painter, L., Ramos, A., Rosero-Peña, M.C., Schmink, M., Sist, P., ter Steege, H., Val, P., van der Voort, H., Varese, M., Zapata-Ríos, G. (Eds.), Amazon Assessment Report 2021. United Nations Sustainable Development Solutions Network, New York.

Pavanato, H. J., Melo-Santos, G., Lima, D. S., Portocarrero-Aya, M., Paschoalini, M., Mosquera, F., Trujillo, F., Meneses, R., Marmontel, M., & Maretti, C. 2016. Risks of dam construction for South American river dolphins: a case study of the Tapajós River. *Endangered Species Research, 31*, 47-60. https://doi.org./10.3354/esr00751

Prideaux, B.; Lohmann, G. 2009. The Amazon: a River Tourism Frontier. In: Preudeaux, B. Cooper, M (editors). River Tourism. MPG Book Group, London.

Randy Milton, G; Max Finlayson, C. 2017 'Diversity of Freshwater Ecosystems and Global Distributions', 1in Jocelyne Hughes (ed.), *Freshwater Ecology and Conservation: Approaches and Techniques*, Techniques in Ecology & Conservation.

Rocha, T.A.H., Silva, L.L., Wen, F.H. *et al.* 2023. River dataset as a potential fluvial transportation network for healthcare access in the Amazon region. *Sci Data* 10, 188. https://doi.org/10.1038/s41597-023-02085-3

Sierra, J. P., Junquas, C., Espinoza, J. C., Segura, H., Condom, T., Andrade, M., et al. 2021. Deforestation impacts on Amazon-Andes hydroclimatic connectivity. Climate Dynamics, 58(9), 2609–2636. https://doi.org/10.1007/s00382-021-06025-y

Sirén,A; Valbo-Jørgensen, J. 2022.Quantifying fish catches and fish consumption in the Amazon Basin. *Aquatic Ecosystem Health & Management*; 25 (1): 59–71. doi: https://doi.org/10.14321/aehm.025.01.59

Staal, A.; Tuinenburg OA; Bosmans JHC; et al. 2018. Forest- rainfall cascades buffer against drought across the Amazon. Nat Clim Chang 8: 539–43.

Thomas, E., Caicedo, C. A., McMichael, C. H., Corvera, R., & Loo, J. (2015). Uncovering spatial patterns in the natural and human history of Brazil nut (Bertholletia excelsa) across the Amazon Basin. Journal of Biogeography, 42(8), 1367–1382.

Timpe, K.; Kaplan, D. 2017. The changing hydrology of a dammed Amazon. *Science Advances*, *3*, e1700611.

Torres-Vitolas, C.A., Harvey, C.A., Cruz-Garcia, G.S. *et al.* The Socio-Ecological Dynamics of Food Insecurity among Subsistence-Oriented Indigenous Communities in Amazonia: a Qualitative Examination of Coping Strategies among Riverine Communities along the Caquetá River, Colombia. *Hum Ecol* **47**, 355–368 (2019). https://doi.org/10.1007/s10745-019-0074-7.

Val, A. & Almeida-Val, V. M. F. (1995) Biology of tropical fishes. Editora INPA: Manaus.

Val P, Figueiredo J, Melo G, Flantua SGA, Quesada CA, Fan Y, Albert JS, Guayasamin JM., Hoorn C 2021. Chapter 1: Geological History and Geodiversity of the Amazon. In: Nobre C, Encalada A, Anderson E, Roca Alcazar FH, Bustamante M, Mena C, Peña-Claros M, Poveda G, Rodriguez JP, Saleska S, Trumbore S, Val AL, Villa Nova L, Abramovay R, Alencar A, Rodríguez Alzza C, Armenteras D, Artaxo P, Athayde S, Barretto Filho HT, Barlow J, Berenguer E, Bortolotto F, Costa FA, Costa MH, Cuvi N, Fearnside PM, Ferreira J, Flores BM, Frieri S, Gatti LV, Guayasamin JM, Hecht S, Hirota M, Hoorn C, Josse C, Lapola DM, Larrea C, Larrea-Alcazar DM, Lehm Ardaya Z, Malhi Y, Marengo JA, Melack J, Moraes R M, Moutinho P, Murmis MR, Neves EG, Paez B, Painter

L, Ramos A, Rosero-Peña MC, Schmink M, Sist P, ter Steege H, Val P, van der Voort H, Varese M, Zapata-Ríos G (Eds). Amazon Assessment Report 2021. United Nations Sustainable Development Solutions Network, New York, USA. Available from https://www.theamazonwewant.org/spa-reports/

Venticinque, E., Forsberg, B., Barthem, R., Petry, P., Hess, L., Mercado, A., Cañas, C., Montoya, M., Durigan, C., and Goulding, M.: An explicit GIS-based river basin framework for aquatic ecosystem conservation in the Amazon, Earth Syst. Sci. Data, 8, 651–661, https://doi.org/10.5194/essd-8-651-2016, 2016.

Winemiller, K. O., McIntyre, P. B., Castello, L., Fluet Chouinard, E., Giarrizzo, T., Nam, S., Baird, I. G., Darwall, W., Lujan, N. K., Harrison, I., Stiassny, M. L. J., Silvano, R. A. M., Fitzgerald, D. B., Pelicice, F. M., Agostinho, A. A., Gomes, L. C., Albert, J. S., Baran, E., Petrere, M., … Saenz, L. 2016. Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. *Science*, *351*, 128–129.

Wittmann H.; von Blanckenburg, F; Maurice L; Guyot, J.; Filizola, N.; Kubik, P.W. 2011. Sediment production and delivery in the Amazon River basin quantified by in situ–produced cosmogenic nuclides and recent river loads. *GSA Bulletin*; 123 (5-6): 934–950.

Wittmann, F., & Junk, W. J. 2016. The Amazon River basin. The Wetland book II: Distribution, description and conservation, 1-16.

Wongchuig S, Espinoza JC, Condom T, Junquas C, Sierra JP, Fita L, Sörensson A, Polcher J. 2023. Changes in the surface and atmospheric water budget due to projected Amazon deforestation: Lessons from a fully coupled model simulation, Journal of Hydrology, Volume 625, 130082. doi:10.1016/j.jhydrol.2023.130082.

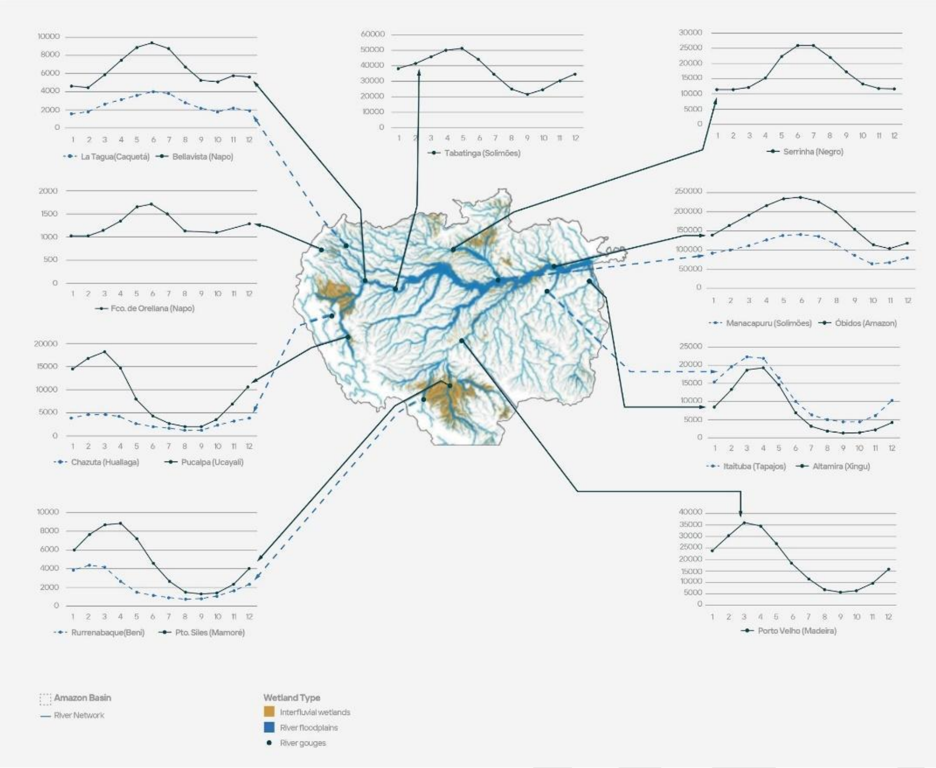

Figure 1. Seasonal cycles of river discharges ($m^3 s^{-1}$). Fluctuations in river discharge drive pronounced seasonal changes in the water level of large Amazon rivers, causing them to overflow their banks into adjacent floodplains.

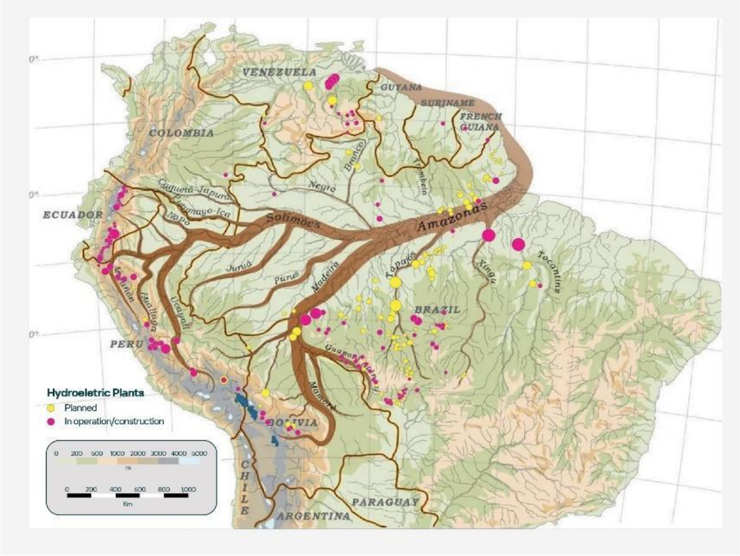

Figure 2. Existing and planned Hydroelectric Plants in the Amazon pose significant threats to freshwater ecosystems by disrupting their vital connections.

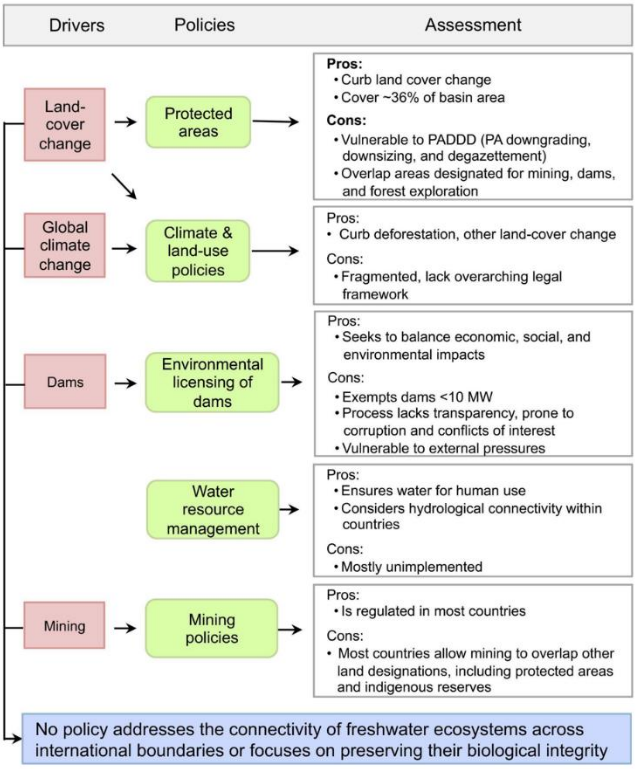

Figure 3. Drivers of freshwater ecosystem degradation and public policies proposed to address the pressing need for preserving and enhancing freshwater connectivity in the Amazon.

Figure 4. Actions needed to avoid degradation of freshwater ecosystems.

Box 1: Seasonal rainfall cycles

Seasonal rainfall cycles in the upper part of the Andean-Amazon Basins of Colombia and Ecuador follow an unimodal regime with a wet season during the austral winter (Laraque et al. 2007; Arias et al. 2021). In the lowland part of the Amazon-Andes of Ecuador predominates a bimodal annual cycle of precipitation, with peak discharge observed around March-April and October-November (Campozano et al. 2018). Seasonal rainfall cycles in the upper part of the Andean-Amazon Basins of Colombia and Ecuador follow an unimodal regime with a wet season during the austral winter (Laraque et al. 2007; Arias et al. 2021). In the lowland part of the Amazon-Andes of Ecuador predominates a bimodal annual cycle of precipitation, with peak discharge observed around March-April and October-November (Campozano et al. 2018). Fluctuations in rainfall and river discharge drive pronounced seasonal changes in the water level of large Amazon rivers, causing them to overflow their banks into adjacent floodplains

Box 2: Water, myths and traditional knowledge

Regarding the conservation of freshwater ecosystems, these traditional knowledges offer healthy guidance regarding the management of these habitats and respect to the services it provides. That is because the worldview of many Indigenous Peoples understands natural resources not as owned by humans, since spirits or masters inhabit plants, animals, minerals or rocks (Athayde et al. 2014). For the Munduruku people, for example, to relate to the forest and to the rivers also implies relating to the spirits that inhabit them. Therefore, they must negotiate conviviality and respectful exchanges with all beings, being able to articulate multiple existing worlds. Traditional knowledge also forms the basis for understanding complex ecological processes that would not be described without communities passing them down from generation to generation. Another example of this is the description of a spawning area in the Beni basin based on fishermen's accounts indicating the fishing of pairs of dorados near the Altamirani community. Characterizing this area allowed extrapolation of its characteristics to other basins, identifying at least 22 other potential dorado spawning zones (Miranda & Venticinque, 2022), a key basis for management decision-making in these areas and enhancing another role of overlapping protected areas.

Box 3: The quest for community management and inclusive governance

By integrating the local population’s territoriality and traditional ways of living with new techniques to enhance current practices, community management of natural resources contributes to conservation efforts and to the political and social strengthening of areas where it is implemented. The community-based approach (Figure 5) aims to develop decentralized and locally based systems that both provide benefits to local inhabitants and protect ecological systems (Peralta et al., 2019; Lavandera, 2023).

Essentially, co-management involves participatory decision-making processes where the regulation of natural resource use is shared among users, with joint responsibility among national or subnational governments, NGOs, and local cooperatives. In Brazil, for instance, the Mamiraua Institute has demonstrated the success of this approach, particularly in pirarucu management (Castello et al., 2009), community-based timber extraction (Waldhoff et al., 2013), ecotourism (Peralta et al., 2018), and in monitoring of caiman and dolphin hunting- (Pimenta et al., 2018).

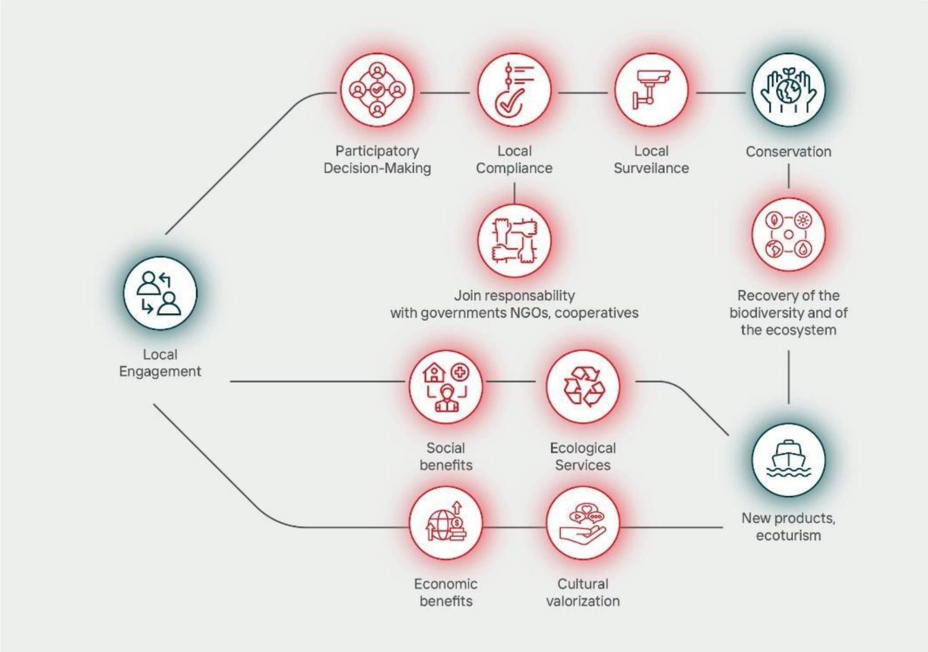

Figure 5. Community-Based Management for Conservation and Socio-Political Resilience in Freshwater Ecosystems.

Box 4: Technology and nature-based solutions: a pathway out of degradation

Investments in research and innovation have led to already existing technologies with the potential to maintain social and economic importance of some extractive activities, while offering alternatives that avoid further degradation. For example, a potential use of cyanogenic plants has been demonstrated for gold leaching, such as the bitter cassava, presenting itself as an alternative for less impactful artisanal and small-scale gold mining (Torkaman, 2023). The replacement of mercury by local plants would be a significant step towards sustainable development for the region, given the technologies are adapted to site-specific conditions. Also, aquaculture has a great potential in providing protein to the region or even abroad, promoting social and economic development. In that regard, the development of biofloc systems in aquaculture reduces feed costs, stimulates lesser water use by reduction of water exchange rates and, finally, and replaces fish meals and fish oils in the feeding of the animals (Khanjani et al. 2023). Lastly, there are already successful cases for alternative energy sources in Amazonia that could help the region phase out of the dependency on hydroelectric dams. For instance, in Ecuador, 12 villages of the Mukucham family, deeply in eastern provinces of the country, already rely on solar panels for transportation, for powering schools and for fueling ecotourism (Alarcon, 2024).

Box 5: Fluvial Community Reserves: Pioneering a Novel Conservation Approach

River systems, unlike their terrestrial counterparts, have historically received less regulatory attention despite their critical ecosystem services. Globally, a significant proportion of rivers lack protection, with many facing severe conservation challenges surpassing those of terrestrial ecosystems. Addressing this disparity in river conservation necessitates acknowledging rivers as conservation entities and instituting effective governance for their preservation.

Simultaneously, any new policy in that matter must not only prioritize conservation objectives but also recognize the rightful communities who directly benefit from river systems. Across the Amazon Basin, rivers provide essential resources such as water, food, tourism, transportation, and imbue significant cultural and spiritual connections. Hence, empowering and involving indigenous and local communities in crafting conservation frameworks becomes imperative. This ensures that issues related to river use are identified and solutions are aligned with their cultural and socioeconomic contexts.

Therefore, the concept of **Fluvial Community Reserves** is presented as a provocative idea aiming to spark discussions on governance models that address the challenges of river conservation while empowering dependent communities. These reserves should be a result of a transdisciplinary approach, one that seeks to protect river flow, riparian vegetation, biodiversity, and ecosystem functions, while equally preserving legitimate and sustainable human interactions with the river.

To effectively establish Fluvial Community Reserves, several key elements must be considered: **active community involvement in decision-making**, backed by political and long-term financial support; **comprehensive assessment** of river and watershed qualities to identify key ecological attributes requiring action; **establishment of appropriate legal frameworks** and rights over natural resources through community engagement and river assessments; fostering **institutional agreements** and **transnational collaboration structures**; and implementing evaluation and adaptive management through **monitoring and periodic assessments.**

An illustrative case is the Curaray River, home to the Curaray-Nushiño River Reserve, situated within the habitat of indigenous Waorani and Kichwa communities. This reserve, protecting the Curaray River's headwaters, serves as a vital corridor linking two Biosphere Reserves: Yasuní and Sumaco-Napo Galeras. Indigenous communities recognize the interconnectedness of river headwaters and lowlands, crucial for the forest's interaction with floodplain areas. Such river systems provide habitats for migratory fish, aquatic mammals, and other species sustaining local livelihoods. From examples of conservation and management like these, we can foster the last opportunity to protect rivers for their natural properties.

References

Alarcon, I. (2024) How solar power is changing life deep in the Amazon. The Washington Post, March 2nd. https://www.washingtonpost.com/climate-solutions/interactive/2024/amazon-solar-panels-ecuador/

Arias Paola A., Garreaud R., Poveda G., Espinoza JC.,, Molina-Carpio j.,, Masiokas M., Viale M., Scaff L., van Oevelen P. J. (2021) Hydroclimate of the Andes Part II: Hydroclimate Variability and Sub-Continental Patterns . Frontiers in Earth Science, 8. https:// doi.org/10.3389/feart.2020.505467

Athayde S. (2014). Indigenous Peoples, Dams and Resistance in Brazilian Amazonia.Tipití: Journal of the Society for the Anthropology of Lowland South America, 12 (2).

Campozano L, Robaina L, Gualco LF, Maisincho L, Villacís M, Condom T, Ballari D, Páez C. (2021). Parsimonious Models of Precipitation Phase Derived from Random Forest Knowledge: Intercomparing Logistic Models, Neural Networks, and Random Forest Models. Water. 2021; 13(21):3022. https://doi.org/10.3390/w13213022.

Castello, L., Viana, J.P., Watkins, G. et al (2009). Lessons from Integrating Fishers of Arapaima in Small-Scale Fisheries Management at the Mamirauá Reserve, Amazon. Environmental Management 43, 197–209. https://doi.org/10.1007/s00267-008-9220-5.

Khanjani, M. H., Mozanzadeh, M. T., Sharifina, M., Emerenciano, M. (2023). Biofloc: A sustainable dietary supplement, nutritional value and functional properties. Aquaculture, Volume 562. https://doi.org/10.1016/j.aquaculture.2022.738757.

Laraque, A., Ronchail, J. , Cochonneau, G. , Pombosa, R. , & Guy1ot, J. L. . (2007). Heterogeneous Distribution of Rainfall and Discharge Regimes in the Ecuadorian Amazon Basin. Journal of Hydrometeorology, 8(6), 1364-1381. https://doi.org/10.1175/2007JHM784.1

Lavandera, A. (2023). Beyond Conservation: Unlocking livelihoods, empowering communities : The case of Mamirauá (Dissertation). Retrieved from https://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-200220

Miranda-Chumacero G., Venticinque E. (2022). Identificación de potenciales zona de desove del dorado (Brachyplatystoma rousseauxii) en la cuenca Madeira. Neotropical Hydrobiology and Aquatic Conservation, 3 (1): 91-103. https://doi.org/10.55565/nhac.tmti7029.

Pimenta N.,, Barnett, A., Botero-Arias R., Marmontel, M. (2018). When predators become prey: Community-based monitoring of caiman and dolphin hunting for the catfish fishery and the broader implications on Amazonian human-natural systems. Biological Conservation,Volume 22. https://doi.org/10.1016/j.biocon.2018.04.003.

Peralta, N. & Ozorio, R. & Nassar, P. & Pinto, G. (2018). Community-Based Tourism in Protected Areas: A move beyond 'paper parks'. Tourism and protected areas in Brazil: Challenges and Perspectives. New York: Nova Science Publishers.

Peralta, N., El Bizri, H. R., P. Paim, F., & Valsecchi, J. (2019). Mamirauá Reserve: Primate-based Flooded Forest Conservation in the Amazon. In K. Nowak, A. Barnett, & I. Matsuda (Eds.), Primates in Flooded Habitats (326-330). Cambridge University Press (CUP). https://doi.org/10.1017/9781316466780.042

Torkaman, P. (2023). Study of unconventional techniques to eliminate mercury use from artisanal gold mining operations (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0431613

Waldhof P., Souza S. E. X. F. Vidal E., Abdala A. (2013). The impact of timber forest management on the livelihoods of local managers: Case study of the Mamirauá Reserve of Sustainable Development. Magro, T. C.; Rodrigues, L. M.; Silva Filho, D. F. ; Polizel, J. L.; Leahy, J.; (Eds.) 2013. Protected Areas and Place Making: How do we provide conservation, landscape management, tourism, human health and regional development. Piracicaba: ESALQ.