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SPECIAL ISSUE ARTICLE

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Science for conserving Amazon freshwater ecosystems

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Abstract

1. The Amazon Basin is being degraded at unprecedented rates, yet conservation efforts have implemented protected areas to curb deforestation, leaving freshwater ecosystems vulnerable to degradation. Amazon freshwater ecosystems are largely unprotected because a terrestrial bias has limited the ability of science to affect policy.
2. Overcoming this bias requires increasing exchange of information among stakeholders across the basin to raise awareness of threats to Amazon freshwater ecosystems and promote discussions and access to conservation solutions. To help address this need, this Special Issue collates 15 synthetic articles that advance knowledge and identify conservation solutions.
3. Three articles highlight the importance of considering the hydrological and limnological processes that control the integrity of these freshwater ecosystems and offer new insights on how to extrapolate them across the basin.
4. Three articles on crocodilians, aquatic mammals, and migratory fishes document threats and knowledge gaps, and identify the missing role of governments as an impediment to conservation of their populations.
5. Three articles evaluate the multi-faceted effects of hydropower dams on fish, birds, and floodplain trees. They reinforce perceptions that dams are key environmental threats and offer guidance for improving protocols for dam site selection and impact assessment.
6. Three articles assessing the effectiveness of protected areas to safeguard fish and aquatic invertebrates show there is an urgent need to redesign the Amazon protected area network to adequately protect freshwater biota.
7. Three forward-looking articles show that: (i) conservation initiatives by local communities are ‘bright spots’ for freshwater conservation; (ii) microchemistry analyses of the ear bones of fishes could boost the knowledge base needed to conserve them; and (iii) strengthening the Amazon conservation framework requires a reversal of Brazil's current governmental priorities, remobilization of stakeholders, investments in capacity building, and expanding protections to terrestrial and freshwater ecosystems.

KEYWORDS

bias, conservation, hydrological connectivity, integrated terrestrial-freshwater planning, policy, protected areas, science communication

1 | INTRODUCTION

People have tended to settle near streams, rivers, and lakes of the Amazon Basin for millennia, using freshwater ecosystem resources for a range of purposes (Roosevelt, 1999). Today, most of the approximately 30 million Amazonians continue to live on river margins, although mostly in cities, as they exert a range of pressures on these ecosystems. Mining (Asner, Llactayp, Tupayachi, & Luna, 2013), over-harvesting (Albernaz & Ayres, 1999; Castello, McGrath, & Beck, 2011), land cover change (Coe, Costa, & Soares-Filho, 2009), and construction of hydropower dams (Winemiller et al., 2016), among other pressures (e.g. climate change; Costa & Foley, 1999) are degrading Amazon freshwater ecosystems at unprecedented rates (Castello & Macedo, 2016).

Mainstream scientific and managerial efforts have responded to this situation by working to curb deforestation in terrestrial ecosystems (Laurance et al., 2001; Soares-Filho et al., 2006). Led by a range of stakeholder partnerships, those efforts have produced a network of 'terrestrial' protected areas that leaves Amazonian rivers, lakes, and wetlands largely vulnerable to human impacts (Castello et al., 2013). Unlike terrestrial ecosystems, which can be split into somewhat self-sustaining subunits (e.g. protected areas), freshwater ecosystems are directly connected to, and integral components of, the water cycle, requiring a basin-wide conservation framework.

The vulnerability and conservation of Amazon freshwater ecosystems are increasingly understood. Recent studies have assessed the impacts of invasive species (Pelicice, Vitule, Lima Junior, Orsi, & Agostinho, 2014), gold mining (Asner et al., 2013), energy development (Anderson et al., 2019; Azevedo-Santos et al., 2016), climate change (Herrera-R et al., 2020; Sorribas et al., 2016), and hydropower development (Anderson et al., 2018; Latrubesse et al., 2017; Timpe & Kaplan, 2017), among other threats. Recent research has also identified requirements and possible approaches to conserve Amazon freshwater ecosystems (Castello & Macedo, 2016). As the knowledge needed to conserve Amazon freshwater ecosystems grows, the ability of science to affect policy needs scrutiny.

2 | BIASED CONSERVATION

The ability of freshwater ecosystem science to shape policy in the Amazon can be assessed with respect to the Amazon's main conservation advance. The concept of integrated river basin management, which has existed since at least the 1930s, establishes river catchment areas as operational landscape units for planning and execution of environmental management (Barrow, 1998). This concept was prominently called for by the 1992 Dublin Conference on Water and the Environment and the 1992 UN Conference on Environment and Development. However, in the years after 1992, hundreds of protected areas (*sensu* Soares-Filho et al., 2010) were implemented in the Amazon, creating the world's largest network of protected areas for a tropical forest. These protected areas were designed largely based on the biogeography of terrestrial taxa (Peres & Terborgh, 1995), limiting their ability to protect freshwater ecosystems. In another example, Junk, Ohly, Piedade, and Soares (2000) comprehensively assessed and identified management options for Amazon floodplain resources, with few of their management recommendations having affected policy at the local or basin level. Such lack of uptake of science by policy processes is difficult to comprehend, but it can be explained by a terrestrial bias in conservation that has been observed worldwide. Terrestrial biases have led to marginalization of several freshwater ecosystem issues, including fisheries (Welcomme et al., 2010), biodiversity (Reid et al., 2019), protected area design (Abell, Allan, & Lehner, 2007), conservation priorities (Brooks et al., 2006), and systematic conservation assessments (Nel et al., 2007), among others.

Conventional explanations for this lack of uptake of freshwater science have been articulated mostly in terms of poor communication of scientific information to the public (Cooke et al., 2013) and ineffective mechanisms for science to inform decision-making (Azevedo-Santos et al., 2017). While science communication to the public and decision-making processes are important, other issues are probably at play in the Amazon. One is that conservation of terrestrial environments is more attractive because it can be done by locating protected areas away from 'hot' problem areas in freshwater ecosystems that tend to have higher human populations densities. Evidence of freshwater ecosystem impacts is also likely to be ignored because addressing them requires long-term, basin-wide approaches, which can scare off soft-money conservation initiatives that typically have to produce results in the short term. There is also the possibility that policy makers and conservationists lean towards addressing problems that people can see rather than problems under water that are mostly invisible to the (untrained) human eye (Richter, Braun, Mendelson, & Master, 1997). This last form of bias can be important, as some of the most successful conservation campaigns such as 'Save the Whales' (Worldwide Fund for Nature, 2021) have relied on emotional appeals, often of charismatic megafauna.

The marginalization of Amazon freshwater ecosystems from mainstream conservation has produced a disconnect between threats to Amazon terrestrial and freshwater ecosystems and efforts to conserve them despite available evidence. This implies that new knowledge on Amazon freshwater ecosystems will not suffice to foster their conservation.

3 | TOWARDS SCIENCE-BASED CONSERVATION

Following recent research on human impacts on Amazon freshwater ecosystems, there has been ample reporting in the news media (e.g. Mongabay) of the effects of three large dams that were recently built in the Brazilian Amazon: the Belo Monte, Jirau, and Santo Antonio dams. Those studies and news reports should contribute to calling attention to the need to advance conservation of Amazon freshwater ecosystems. However, there are still no plans to develop a basin-wide conservation framework.

Scientific research and news articles could play a major role in raising awareness to the urgent need for integrated conservation. To disseminate more scientific information on Amazon freshwater ecosystems, it is important to recognize that the basin comprises a very diverse range of stakeholders, from the general public (e.g. farmers, Indigenous peoples, urban and riverine populations), to the private sector (e.g. hydropower companies, non-governmental organizations), and government agencies (at local, state, federal, and international levels). Effective communication with this diverse audience requires an understanding of its many concerns and interests (Nguyen, Young, & Cooke, 2017) to develop and implement multi-pronged communication plans.

It is also important to move away from dialogue focused on either terrestrial or freshwater ecosystem conservation to a view that acknowledges the interdependence of both and the obvious need for integrated conservation. In this vein, a recent study showed that protection of Amazonian freshwater species can be vastly improved without undermining terrestrial conservation through relatively minor changes to protected area design to account for hydrological connectivity (Leal et al., 2020). Given the relevance of this finding, it should be amply disseminated across the basin to guide the redesign of protected areas, not to accommodate economic interests as is often done (Bernard, Penna, & Araujo, 2014), but to strengthen protection for freshwater ecosystems.

Finally, there is a need to foster communication and engagement among stakeholders. The ability of science to produce societal impact is determined in part by personal interactions among researchers, stakeholders, and managers (Catalano, Lyons-White, Mills, & Knight, 2019; Noble & Fulton, 2020), but such interactions are limited in the Amazon by its large size. Current initiatives to connect stakeholders include the Amazon Cooperation Treaty Organization (2021), which binds all Amazonian countries in a framework for basin-wide collaboration on socio-environmental issues. The goal of this initiative was recently reinforced through the signing of the Leticia Pact, which emphasizes international coordination among Amazonian countries for the exchange of research, monitoring data, and experiences in conservation. These initiatives are valuable starting points to foster communication and engagement among stakeholders, but their capacity would have to be expanded substantially to meet the challenge at hand. One way to help achieve this could be through the development of digital platforms that now allow exchange of knowledge with unparalleled scale and scope (Faraj, Jarvenpaa, & Majchrzak, 2011). Online communities for 'Amazon Conservation' could allow researchers, the public, and other key stakeholders to exchange information and experiences, and to discuss key issues. The multitude of stakeholders could be organized in multiple, hierarchical levels of community groups following the Basin's catchment areas. Such online communities would not replace personal or other forms of interaction, but communication and engagement among stakeholders is indispensable for building the community that should be responsible ultimately for the fate of the Amazon.

4 | THE CONTRIBUTION OF THIS SPECIAL ISSUE

This Special Issue makes a small contribution to correct some of the misleading perceptions of environmental problems in the Amazon and develop an integrated, basin-wide conservation framework. It collates 15 studies that advance knowledge on key issues, draw attention to a developing crisis, and identify conservation solutions. In the text that follows, author citations are given without dates as the 15 articles form the contents of this Special Issue, published in 2021.

4.1 | Hydrology and limnology

Three articles identify characteristics of the hydrology and limnology of Amazon freshwater ecosystems that deserve consideration in attempts to understand human impacts. This is key as too often characterizations of water flows and biogeochemical processes in these systems have been oversimplified. Siddiqui et al. show that even though Amazon river flows exhibit huge variability across rivers, they can be grouped in a few classes that provide insights into riverine functions and facilitate prediction of human impacts. Melack and Coe demonstrate that floodplain hydrology depends not only on seasonal flood pulses but also on local catchment inputs, with both being modulated by climatic conditions at different spatial and temporal scales. They describe modelling and remote sensing tools that can inform conservation research and policy making. Melack, Kasper, Amaral, Barbosa, and Forsberg describe the physical aspects, hydrological inputs, and processes regulating limnological processes in floodplain lakes, emphasizing that the complexity and variability of these systems have yet to be adequately considered in conservation efforts. These three articles make the case for increasing consideration of the underlying processes that control the integrity of freshwater ecosystems in any location in the basin, and offer insights to extrapolate them across the basin.

4.2 | Conservation of animals

Three articles assess threats to and conservation of crocodilians (Marioni et al.), aquatic mammals (Brum et al.), and migratory fishes (Duponchelle et al.). These articles show that many species in these groups perform bottom-up and top-down control of ecosystem processes, but that these animal groups are threatened by over-harvesting, loss of habitat connectivity, and habitat degradation. Aquatic mammals appear to be the most threatened group, followed by crocodilians and migratory fishes. These articles also show that although the biology and ecology of these species are generally understood, assumptions about them often do not survive scrutiny in attempts to predict their responses to human impacts. This limited knowledge limits detection of ecosystem effects induced by their population declines, which in some cases (e.g. manatees, *Arapaima* spp.) have been substantial. Although protected areas and community-based initiatives are key forms of protection for some of them, these articles identify the missing role of government agencies as a major impediment to their conservation. Exacerbating data deficits, shortages in governmental human and financial resources too often leave these animals wholly unprotected, even when simple measures would suffice.

4.3 | Hydropower dams

Three articles assess the ecological effects of hydropower dams. Vasconcelos, Alves, da Câmara, and Hahn show that the density of fish eggs and larvae in a dammed river is about half of that in a free-flowing river with almost identical limnological characteristics. Schöngart et al. show that attenuation of river flood pulses induced by a dam caused large-scale tree mortality at the higher and lower elevations of downstream floodplains. This in turn made those forests vulnerable to wildfires and susceptible to colonization by tree species from the adjacent uplands. Latrubesse et al. show that if currently planned dams are built without adequate consideration of the balance of energy production and environmental conservation, they will severely affect Amazonian riverine biodiversity, habitats, and hydromorphology, particularly in Andean rivers. By showing the multi-faced and far-reaching effects of dams, these articles reinforce growing perceptions that dams are serious threats to the Amazon. They also provide new information to improve current protocols used to select sites for dam construction and assess their impacts.

4.4 | Protected areas

Three articles assess the effectiveness of protected areas to safeguard aquatic biota. Brasil et al. show that only about 30% of Odonata species in the Brazilian Amazon have distribution ranges that fall within the boundaries of existing protected areas, which leaves most Odonata species vulnerable to growing impacts. Frederico et al. estimate that about 34% of fish species in the Amazon could be adversely affected by climate change. Whereas protected areas cover the minimum required range for the persistence of about 60% of the species, over 25% of those are in the central and lower Basin regions where there are strong human pressures and few protected areas. Dagosta, de Pinna, Peres, and Tagliacollo identify 10 bioregions of freshwater fish distribution in the Basin. Those fish distribution patterns do not match those of terrestrial organisms or those of protected areas. Regions with high endemism of fish species tend to have many hydropower dams. These articles show an urgent need to redesign the Amazon protected area network.

4.5 | Solutions to advancing freshwater conservation

Three articles identify overlooked issues that can change perceptions of how conservation could be advanced in these ecosystems. Lopes et al. show that participatory initiatives led by local communities promote many conservation objectives while improving social justice through gender equality, sharing of economic benefits, and prevention of power grabbing in decision-making and resource access. Similar to the role played by local people in establishing protected areas, these riverine initiatives lay the foundations on which future conservation efforts can be built.

Hermann et al. assess the use of microchemistry analyses of fish otoliths (i.e. ear bones) to boost understanding of the life cycles of Amazonian fishes. The authors show that otolith microchemistry is much more cost-effective than conventional methods to study fish ecology, but its potential to foster conservation requires overcoming bottlenecks in key data, information, and funding.

In closing the Special Issue, Pelicice and Castello discuss the continuing dismantling of the Amazon conservation framework. Although it is widely considered that Bolsonaro's Brazilian government has inflicted major damage to Amazon conservation, the authors show that the extent to which it has undermined decades of institutional and policy development has been immense. The status quo in Amazon conservation is not entirely due to Bolsonaro's government, but rather the result of a trend of deteriorating environmental policy that began in the 2000s. They conclude that strengthening the Amazon conservation framework requires a reversal of Brazil's current governmental priorities, remobilization of stakeholders, investments in capacity building, and expanding protections to terrestrial and freshwater ecosystems.

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CONFLICT OF INTEREST

The author has no conflict of interest to disclose.

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REFERENCES

Abell, R., Allan, J. D., & Lehner, B. (2007). Unlocking the potential of protected areas for freshwaters. *Biological Conservation*, *134*, 48–63. https://doi.org/10.1016/j.biocon.2006.08.017

Albernaz, A. L. K., & Ayres, J. M. (1999). Selective logging along the middle Solimoes River. *Advances in Economic Botany*, *13*, 135–151.

Amazon Cooperation Treaty Organization. (2021). Retrieved from http://www.otca-oficial.info/

Anderson, E. P., Jenkins, C. N., Heilpern, S., Maldonado-Ocampo, J. A., Carvajal-Vallejos, F. M., Encalada, A. C., … Ortega, H. (2018). Fragmentation of Andes-to-Amazon connectivity by hydropower dams. *Science Advances*, *4*, eaao1642. https://doi.org/10.1126/sciadv.aao1642

Anderson, E. P., Osborne, T., Maldonado-Ocampo, J. A., Mills-Novoa, M., Castello, L., Montoya, M., … Jenkins, C. N. (2019). Energy development reveals blind spots for ecosystem conservation in the Amazon Basin. *Frontiers in Ecology and the Environment*, *17*, 521–529. https://doi.org/10.1002/fee.2114

Asner, G. P., Llactayp, W., Tupayachi, R., & Luna, E. R. (2013). Elevated rates of gold mining in the Amazon revealed through high-resolution monitoring. *Proceedings of the National Academy of Sciences*, *110*, 18454–18459. https://doi.org/10.1073/pnas.1318271110

Azevedo-Santos, V. M., Fearnside, P. M., Oliveira, C. S., Padial, A. A., Pelicice, F. M., Lima, D. P., … Vitule, J. R. S. (2017). Removing the abyss between conservation science and policy decisions in Brazil. *Biodiversity and Conservation*, *26*, 1745–1752. https://doi.org/10.1007/s10531-017-1316-x

Azevedo-Santos, V. M., Garcia-Ayala, J. R., Fearnside, P. M., Esteves, F. A., Pelicice, F. M., Laurance, W. F., & Benine, R. C. (2016). Amazon aquatic biodiversity imperiled by oil spills. *Biodiversity and Conservation*, *25*, 2831–2834. https://doi.org/10.1007/s10531-016-1192-9

Barrow, C. J. (1998). River basin development planning and management: A critical review. *World Development*, *26*, 171–186. https://doi.org/10.1016/S0305-750X(97)10017-1

Bernard, E., Penna, L. A., & Araujo, E. (2014). Downgrading, downsizing, degazettement, and reclassification of protected areas in Brazil. *Conservation Biology*, *28*, 939–950. https://doi.org/10.1111/cobi.12298

Brasil, L., Andrade, A., Ribeiro, B., Spigoloni, Z., Juen, L., & De Marco, P. (2021). A niche-based gap analysis for conservation of Odonata species in the Brazilian Amazon. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1150–1157. https://doi.org/10.1002/aqc.3599

Brooks, T. M., Mittermeier, R. A., Fonseca, G. A., Gerlach, J., Hoffmann, M., Lamoreux, J. F., … Rodrigues, A. S. L. (2006). Global biodiversity conservation priorities. *Science*, *313*, 58–61. https://doi.org/10.1126/science.1127609

Brum, S., Rosas-Ribeiro, P., Amaral, R. D. S., de Souza, D. A., Castello, L., & da Silva, V. M. F. (2021). Conservation of Amazonian aquatic mammals. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1068–1086. https://doi.org/10.1002/aqc.3590

Castello, L., & Macedo, M. N. (2016). Large-scale degradation of Amazonian freshwater ecosystems. *Global Change Biology*, *22*, 990–1007. https://doi.org/10.1111/gcb.13173

Castello, L., McGrath, D. G., & Beck, P. S. A. (2011). Resource sustainability in small-scale fisheries in the Lower Amazon floodplains. *Fisheries Research*, *110*, 356–364. https://doi.org/10.1016/j.fishres.2011.05.002

Castello, L., McGrath, D. G., Hess, L. L., Coe, M. T., Lefebvre, P. A., Petry, P., … Arantes, C. C. (2013). The vulnerability of Amazon freshwater ecosystems. *Conservation Letters*, *6*, 217–229. https://doi.org/10.1111/conl.12008

Catalano, A. S., Lyons-White, J., Mills, M. M., & Knight, A. T. (2019). Learning from published project failures in conservation. *Biological Conservation*, *238*, 108223. https://doi.org/10.1016/j.biocon.2019.108223

Coe, M. T., Costa, M. H., & Soares-Filho, B. S. (2009). The influence of historical and potential future deforestation on the stream flow of the Amazon river–land surface processes and atmospheric feedbacks. *Journal of Hydrology*, *369*, 165–174. https://doi.org/10.1016/j.jhydrol.2009.02.043

Cooke, S. J., Lapointe, N. W. R., Martins, E. G., Thiem, J. D., Raby, G. D., Taylor, M. K., … Cowx, I. G. (2013). Failure to engage the public in issues related to inland fishes and fisheries: Strategies for building public and political will to promote meaningful conservation. *Journal of Fish Biology*, *83*, 997–1018. https://doi.org/10.1111/jfb.12222

Costa, M. H., & Foley, J. A. (1999). Trends in the hydrologic cycle of the Amazon basin. *Journal of Geophysical Research-Atmospheres*, *104*, 14189–14198. https://doi.org/10.1029/1998JD200126

Dagosta, F. C. P., de Pinna, M., Peres, C. A., & Tagliacollo, V. A. (2021). Existing protected areas provide a poor safety-net for threatened Amazonian fish species. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1167–1189. https://doi.org/10.1002/aqc.3461

Duponchelle, F., Isaac, V., Doria, C., Van Damme, P. A., Herrera-R, G. A., Anderson, E. P., … Castello, L. (2021). Conservation of migratory fishes in the Amazon basin. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1087–1105. https://doi.org/10.1002/aqc.3550

Faraj, S., Jarvenpaa, S. L., & Majchrzak, A. (2011). Knowledge collaboration in online communities. *Organization Science*, *22*, 1224–1239. https://doi.org/10.1287/orsc.1100.0614

Frederico, R. G., Dias, M. S., Jézéquel, C., Tedesco, P. A., Hugueny, B., Zuanon, J., … Oberdorff, T. (2021). The representativeness of protected areas for Amazonian fish diversity under climate change. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1158–1166. https://doi.org/10.1002/aqc.3528

Hermann, T., Duponchelle, F., Castello, L., Limburg, K., Pereira, L., & Hauser, M. (2021). Catalyzing the potential for otolith microchemistry to foster conservation of Amazonian fishes. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1206–1220. https://doi.org/10.1002/aqc.3567

Herrera-R, G. A., Oberdorff, T., Anderson, E. P., Brosse, S., Carvajal-Vallejos, F. M., Frederico, R. G., … Tedesco, P. A. (2020). The combined effects of climate change and river fragmentation on the distribution of Andean Amazon fishes. *Global Change Biology*, *26*, 5509–5523. https://doi.org/10.1111/gcb.15285

Junk, W. J., Ohly, J. J., Piedade, M. T. F., & Soares, M. G. M. (2000). *The Central Amazon floodplain: Actual use and options for a sustainable management*. Leiden: Backhuys Publishers.

Latrubesse, E. M., Arima, E. Y., Dunne, T., Park, E., Baker, V. R., d'Horta, F. M., … Baker, P. A. (2017). Damming the rivers of the Amazon basin. *Nature*, *546*, 363–369. https://doi.org/10.1038/nature22333

Latrubesse, E. M., d'Horta, F. M., Ribas, C. C., Wittmann, F., Zuanon, J., Park, E., … Baker, P. A. (2021). Vulnerability of the biota in riverine and seasonally flooded habitats to damming of Amazonian rivers. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1136–1149. https://doi.org/10.1002/aqc.3424

Laurance, W. F., Cochrane, M. A., Bergen, S., Fearnside, P., Delamonica, P., Barber, C., … Fernandes, T. (2001). The future of the Brazilian Amazon. *Science*, *291*, 438–439. https://doi.org/10.1126/science.291.5503.438

Leal, C. G., Lennox, G. D., Ferraz, S. F. B., Ferreira, J., Gardner, T. A., Thomson, J. R., … Barlow, J. (2020). Integrated terrestrial-freshwater planning doubles conservation of tropical aquatic species. *Science*, *370*, 117–121. https://doi.org/10.1126/science.aba7580

Lopes, P., Campos-Silva, J., Freitas, C., Hallwass, G., Silvano, R., & Begossi, A. (2021). Amazonia as a fertile ground for conservation transformation: The pursuit of Just Aquatic Governance. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1190–1205. https://doi.org/10.1002/aqc.3586

Marioni, B., Barão-Nóbrega, J. A. L., Botero-Arias, R., Muniz, F., Campos, Z., Da Silveira, R., … Villamarín, F. (2021). Science and conservation of Amazonian crocodilians: A historical review. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1056–1067. https://doi.org/10.1002/aqc.3541

Melack, J. M., Kasper, D., Amaral, J., Barbosa, P., & Forsberg, B. (2021). Limnological perspectives on conservation of aquatic ecosystems in the Amazon basin. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1041–1055. https://doi.org/10.1002/aqc.3556

Melack, J. M., & Coe, M. T. (2021). Amazon floodplain hydrology and implications for aquatic conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1029–1040. https://doi.org/10.1002/aqc.3558

Nel, J. L., Roux, D. J., Maree, G., Kleynhans, C. J., Moolman, J., Reyers, B., … Cowling, R. M. (2007). Rivers in peril inside and outside protected areas: A systematic approach to conservation assessment of river ecosystems. *Diversity and Distributions*, *13*, 341–352. https://doi.org/10.1111/j.1472-4642.2007.00308.x

Nguyen, V. M., Young, N., & Cooke, S. J. (2017). A roadmap for knowledge exchange and mobilization research in conservation and natural resource management. *Conservation Biology*, *31*, 789–798. https://doi.org/10.1111/cobi.12857

Noble, M. M., & Fulton, C. J. (2020). Pathways to impact for aquatic conservation science via multi-modal communication and stakeholder engagement. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *30*, 1791–1797. https://doi.org/10.1002/aqc.3380

Pelicice, F. M., & Castello, L. (2021). A political tsunami hits Amazon conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1221–1229. https://doi.org/10.1002/aqc.3565

Pelicice, F. M., Vitule, J. R. S., Lima Junior, D. P., Orsi, M. L., & Agostinho, A. A. (2014). A serious new threat to Brazilian freshwater ecosystems: The naturalization of nonnative fish by decree. *Conservation Letters*, *7*, 55–60. https://doi.org/10.1111/conl.12029

Peres, C. A., & Terborgh, J. W. (1995). Amazonian nature-reserves—An analysis of the defensibility status of existing conservation units and design criteria for the future. *Conservation Biology*, *9*, 34–46. https://doi.org/10.1046/j.1523-1739.1995.09010034.x

Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T. J., … Cooke, S. J. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, *94*, 849–873. https://doi.org/10.1111/brv.12480

Richter, B. D., Braun, D. P., Mendelson, M. A., & Master, L. L. (1997). Threats to imperiled freshwater fauna. *Conservation Biology*, *11*, 1081–1093. https://doi.org/10.1046/j.1523-1739.1997.96236.x

Roosevelt, A. C. (1999). Twelve thousand years of human-environment interaction in the Amazon floodplain. *Advances in Economic Botany*, *13*, 371–392

Schöngart, J., Wittmann, F., Faria de Resende, A., Assahira, C., de Sousa Lobo, G., Rocha Duarte Neves, J., … Piedade, M. T. F. (2021). The shadow of the Balbina dam: A synthesis of over 35 years of downstream impacts on floodplain forests in Central Amazonia. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1117–1135. https://doi.org/10.1002/aqc.3526

Siddiqui, S., Zapata-Rios, X., Torres-Paguay, S., Encalada, A. C., Anderson, E. P., Allaire, M., … Kaplan, D. (2021). Flow regimes of the Amazon Basin. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1005–1028. https://doi.org/10.1002/aqc.3582

Soares-Filho, B., Moutinho, P., Nepstad, D., Anderson, A., Rodrigues, H., Garcia, R., … Maretti, C. (2010). Role of Brazilian Amazon protected areas in climate change mitigation. *Proceedings of the National Academy of Sciences*, *107*, 10821–10826. https://doi.org/10.1073/pnas.0913048107

Soares-Filho, B. S., Nepstad, D. C., Curran, L. M., Cerqueira, G. C., Garcia, R. A., Ramos, C. A., … Schlesinger, P. (2006). Modelling conservation in the Amazon basin. *Nature*, *440*, 520–523. https://doi.org/10.1038/nature04389

Sorribas, M. V., Paiva, R. C. D., Melack, J. M., Bravo, J. M., Jones, C., Carvalho, L., … Costa, M. H. (2016). Projections of climate change effects on discharge and inundation in the Amazon basin. *Climatic Change*, *136*, 555–570. https://doi.org/10.1007/s10584-016-1640-2

Timpe, K., & Kaplan, D. (2017). The changing hydrology of a dammed Amazon. *Science Advances*, *3*, e1700611. https://doi.org/10.1126/sciadv.1700611

Vasconcelos, L. P., Alves, D. C., da Câmara, L. F., & Hahn, L. (2021). Dams in the Amazon: The importance of maintaining free-flowing tributaries for fish reproduction. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*, 1106–1116. https://doi.org/10.1002/aqc.3465

Welcomme, R. L., Cowx, I. G., Coates, D., Béné, C., Funge-Smith, S., Halls, A., & Lorenzen, K. (2010). Inland capture fisheries. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *365*, 2881–2896. https://doi.org/10.1098/rstb.2010.0168

Winemiller, K. O., McIntyre, P. B., Castello, L., Fluet-Chouinard, E., Giarrizzo, T., Nam, S., … Sáenz, L. (2016). Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. *Science*, *351*, 128–129. https://doi.org/10.1126/science.aac7082

Worldwide Fund for Nature. (2021). Retrieved from https://wwf.panda.org/?199987/Saving-the-whales

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