NATURE-BASED RESILIENCE

Confronting the triple planetary crisis of climate change, environmental pollution, and biodiversity loss using freshwater nature-based solutions (NbS)

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Table of Contents

Description 4

Background on Global Agendas for Climate Change and Biodiversity 5

Recent Developments 5

The Need for — and Limits to — Systems Governance and Management 6

From Systemic Risks to Systemic Resilience 7

Water Resilience: An Organizing Principle for Climate Change, Biodiversity, and Pollution Reduction 9

Rivers, Streams, and Estuaries 12

Lakes 15

Aquifers 18

Wetlands 20

Challenges and Opportunities for Freshwater NbS in Supporting Climate Change and Biodiversity Agendas 25

Recommendations for Maximizing Synergies between National Climate and Biodiversity Agendas to Tackle the Triple Planetary Crisis 29

Description

The latest IPCC reports (AR6) highlight the urgency of taking decisive and immediate action to address the interlinked challenges of climate change, biodiversity loss, and environmental pollution. Furthermore, AR6 Working Group II on adaptation specifically calls out the important role of nature-based solutions (NbS) for "water-based adaptation." At the same time, freshwater biodiversity — a key indicator of ecosystem health — is being lost at an alarming rate. According to the World Wildlife Fund's 2022 Living Planet report, global freshwater species populations have declined by an average of over 80% in the past 50 years.[1] One of the many negative impacts of this catastrophic loss is that it undercuts our ability to effectively adapt to climate change. Adding to this crisis, traditional conservation measures which attempt to preserve existing habitat or restore degraded ecosystems are being undermined by an uncertain climate future in which replicating or maintaining past environmental conditions may no longer be possible. We argue that a new paradigm for biodiversity conservation, one that emphasizes ecosystem resilience rather than restoration, may be in order.

"Nature-based Resilience" demonstrates the important contribution freshwater NbS can make in achieving climate and biodiversity targets, while also reducing water-based pollution. However, we also argue that in order to realize the multiple benefits of freshwater NbS, we must transform the ways in which we manage freshwater ecosystems, moving from an exclusive emphasis on efficiency and preservation towards managing for resilience. This report builds on IUCN's foundational work on NbS, as well as the 2020 publication "Locking Carbon in Wetlands" from AGWA and Wetlands International, which demonstrated the value of wetlands as key contributors to mitigation action and argued for the inclusion of freshwater wetlands in national climate plans, the UN Decade on Ecosystem Restoration 2021-2030, as well as SDG 6.[2] This new report will expand on that call to action regarding the role of freshwater ecosystems for resilience to include benefits for biodiversity and pollution reduction.

Guidance around NbS for nature-based resilience is particularly salient in 2022 following COP26, which created new momentum for adaptation and ecosystem restoration. Over 80% of Parties have included NbS in their updated 2020/2021 Nationally Determined Contributions (NDCs)[3] under the Paris Agreement and are now seeking guidance and funding for implementation. At the same time, the upcoming COP 15.2 to the Convention on Biological Diversity (CBD) will review the achievement and delivery of the CBD's Strategic Plan for Biodiversity 2011-2020 and take a final decision on the post-2020 Global Biodiversity Framework with implications for ecosystem restoration and the potential upscaling of NbS for biodiversity. Freshwater NbS is a particular area of confluence between the two global agendas, and this paper seeks to demonstrate solutions that address these interlinked crises in a coordinated and coherent manner.

We caution that freshwater NbS should not be viewed as a panacea for these complex global challenges. In each case, local environmental and socioeconomic factors mediate the healthy function of a given watershed, meaning that the NbS case studies presented in this paper will be more effective and practical to implement in some areas than others. However, given the important role that freshwater ecosystems play in regulating and provisioning life on earth, we strongly believe that freshwater NbS are a critical component of national climate change, biodiversity, and sustainable development planning.

1 WWF. 2022. *Living Planet Report 2022 - Building a nature positive society.* Almond, R.E.A., Grooten, M., Juffe Bignoli, D. & Petersen, T. (Eds). World Wildlife Fund: Gland, Switzerland.

2 Anisha, N.F., Mauroner, A., Lovett, G., Neher, A., Servos, M., Minayeva, T., Schutten, H. & Minelli, L. 2020. *Locking Carbon in Wetlands: Enhancing Climate Action by Including Wetlands in NDCs.* Alliance for Global Water Adaptation and Wetlands International: Corvallis, OR, USA and Wageningen, The Netherlands.

3 Nature-Based Solutions Initiative. 2022. *Revised climate pledges show enhanced ambition for nature-based solutions.* Retrieved from: https://www.naturebasedsolutionsinitiative.org/news/nbs-policy-platform-ndc-submissions

Background on Global Agendas for Climate Change and Biodiversity

For many years, the international scientific community has continued to sound the alarm, warning that without immediate, accelerated action to limit global warming and biodiversity loss, we risk far-reaching and devastating consequences for people and ecosystems worldwide.[4] These impacts include increasing vulnerability to food and water insecurity, health risks, disrupted livelihoods, forced displacement, and accelerated species extinction.[5] Efforts to heed these warnings are ongoing under global policy agendas for biodiversity loss and climate change, set by the Convention on Biological Diversity (CBD) and the UN Framework Convention on Climate Change (UNFCCC), respectively, each of which has its own suite of mechanisms and timelines for implementation. While some progress has been made — particularly at local and regional scales — both Conventions have thus far failed to spur significant progress to halt or reverse these global crises.

Recent Developments

During the tenth meeting of the Conference of the Parties (COP) to the CBD, held in October 2010, the Parties adopted a revised and updated Strategic Plan for Biodiversity, including what came to be known as the Aichi Biodiversity Targets. This Plan provided an overarching framework on biodiversity for the 2011-2020 period targeting the entire UN system, as well as all other partners engaged in biodiversity management and policy development. Under this Plan, Parties are asked to submit, implement, and revise National Biodiversity Strategies and Action Plans (NBSAPs) which outline how each country will integrate the consideration of the "conservation and sustainable use of biological resources"[6] into their national decision making across all sectors and scales of governance.

A complete assessment of progress towards the Aichi Targets, as well as a new global framework for the post-2020 period is ongoing, having been delayed by two years due to the global COVID-19 pandemic. It is anticipated that the post-2020 Global Biodiversity Framework (GBF) will be finalized at the fifteenth CBD COP meeting, now postponed to December 2022. This new framework is considered a step towards achieving the CBD 2050 vision of "living in harmony with nature." However, recent reports from IPBES,[7] UNEP-IUCN,[8] and others[9,10,11] have cautioned that the world is dangerously off target to meet the goals set forth in 2010. Consequently, there is increasing pressure to significantly restructure

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4 IPCC. 2022. *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama, eds.. Cambridge University Press: Cambridge, UK and New York, NY, USA.

5 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. 2019. *Global Assessment Report on Biodiversity and Ecosystem Services.* Díaz S, Settele J, Brondízio ES, Ngo HT, Guèze M, Agard J, Arneth A, Balvanera P, Brauman KA, Butchart SHM, Chan KMA, Garibaldi LA, Ichii K, Liu J, Subramanian SM, Midgle GF, Miloslavich P, Molnár Z, Obura D, Pfaff A, Polasky S, Purvis A, Razzaque J, Reyers B, Roy Chowdhury R, Shin YJ, Visseren-Hamakers IJ, Willis KJ, and Zayas C N, eds. IPBES: Bonn, Germany.

6 CBD. 2018. *Key Elements of the Strategic Plan 2011-2020, including Aichi Biodiversity Targets.* Retrieved from: https://www.cbd.int/sp/elements

7 Secretariat of the Convention on Biological Diversity. 2020. *Global Biodiversity Outlook 5*. CBD: Montreal, Canada.

8 UNEP-WCMC and IUCN. 2021. *Protected Planet Report 2020.* UNEP-WCMC and IUCN: Cambridge, UK and Gland, Switzerland.

9 Xu, H., Cao, Y., Yu, D., Cao, M., He, Y., Gill, M., & Pereira, H. M. 2021. Ensuring effective implementation of the post-2020 global biodiversity targets. *Nature Ecology & Evolution, 5*(4), 411-418.

10 Nature. 2020. New biodiversity targets cannot afford to fail. *Nature, 578*, 337-338.

11 Arneth, A., Shin, Y. J., Leadley, P., Rondinini, C., Bukvareva, E., Kolb, M., ... & Saito, O. 2020. Post-2020 biodiversity targets need to embrace climate change. *Proceedings of the National Academy of Sciences, 117*(49), 30882-30891.

the new GBF targets as well as the NBSAPs,[12] in part so that they are more explicitly aligned with other global agendas such as the Sustainable Development Goals (SDGs) and the Paris Agreement.

Progress on climate action under the UNFCCC has been similarly uneven. Under the 2015 Paris Agreement, Parties agreed on restricting the increase in the global average temperatures to “well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels” and to “enhance adaptive capacity, strengthen resilience, and reduce vulnerability” to climate change.[13] Each Party to the Convention is responsible for setting and communicating national targets for reducing greenhouse gas (GHG) emissions and supporting adaptation in a document known as a Nationally Determined Contribution (NDC), which is reviewed and revised every five years.

Although the human activities that most directly contribute to global warming and biodiversity loss — as well as the interventions needed to reverse these trends — often overlap, there is currently limited coherence between the NDCs and NBSAPs.[14] This lack of coordination is potentially problematic as uncoordinated efforts to address one set of issues have the potential to undermine efforts to address the other. For example, initiatives aimed at protecting freshwater biodiversity by limiting access to certain water supplies or fisheries could increase human vulnerability to climate change, while reforestation projects for climate mitigation and adaptation benefits may adversely impact biodiversity if the trees planted are not matched to the local environment.

As the Parties to the CBD gather this December to set the global biodiversity agenda for the next ten-year period, the international community has a window of opportunity to align these global agendas more closely and to push for managing terrestrial and aquatic ecosystems in a more resilient, systemic way. The post-2020 GBF, at a minimum, must account for climate change and acknowledge that ecosystems are already rapidly changing and will continue to do so for the foreseeable future, even if we reach our global net-zero GHG emissions target by 2050. What we must collectively grapple with is how to make these changes more manageable for people and nature. Doing so will require an all-hands-on-deck approach: from local communities to national policymakers, resource managers, engineers, businesses, farmers, fishers, and pastoralists. This entails a fundamental rethinking of how we govern and manage our natural resources, and a new humility about the limits of our own knowledge of how best to adapt to these uncertain changes.

The Need for — and Limits to — Systems Governance and Management

Much has already been written about the need for transformative policies and governance systems to address complex, interlinked global challenges including biodiversity loss, pollution, and climate change. Systemic challenges require systemic solutions, as the thinking goes, and our current governance and management systems are often deeply siloed, entrenched, and ill equipped to manage dynamic challenges that cross spatial, organizational, and/or temporal boundaries.[15] Worse, these systems often reinforce or inadvertently transmit risks across those same boundaries.[16] For example, efforts to reduce

12 See, for example: https://www.campaignfornature.org/open-letter
13 https://unfccc.int/sites/default/files/english_paris_agreement.pdf
14 OECD. 2020. *Towards Sustainable Land Use: Aligning Biodiversity, Climate and Food Policies.* OECD Publishing: Paris, France. https://doi.org/10.1787/3809b6a1-en
15 Hynes, W., M. Lees and J. Müller, Eds. 2020. *Systemic Thinking for Policy Making: The Potential of Systems Analysis for Addressing Global Policy Challenges in the 21st Century.* New Approaches to Economic Challenges, OECD Publishing: Paris, France. https://doi.org/10.1787/879c4f7a-en
16 Schweizer, P.-J. 2021. Systemic risks – concepts and challenges for risk governance. *Journal of Risk Research, 24*, 78-93. doi:10.1080/13669877.2019.1687574.

dependence on fossil fuels by investing in biofuels can negatively impact biodiversity through the use of monocrop feedstocks, increased pesticide pollution, and reduced local water security.

Encouragingly, efforts to work across boundaries are growing. One relevant example of systems thinking is the Water-Energy-Food (WEF) nexus approach,[17,18] which acknowledges the inherent connections between water, energy, and food systems and works to coordinate planning, reduce costs, balance trade-offs, maximize benefits, and minimize risks across all three. Another example is Germany's One Health initiative,[19] which considers interdependencies and interactions between human, animal, and environmental health and seeks to identify and reduce systemic risks through improved cooperation within and across government ministries.

This type of systemic risk management (also known as multi-hazard risk management) is a growing area of practice that has been embraced by the global disaster risk reduction (DRR) and climate communities.[20] However, it has been increasingly argued that systemic risk management itself is not sufficient if the underlying methodologies used are based on traditional risk models, which emphasize command-and-control systems optimization and use historical baselines to predict and deliver specific outcomes.[21,22] This argument posits that uncertainty regarding future climate conditions mortally undermines any approach founded on stationary historical conditions. Furthermore, even if we had a perfect understanding of future climate conditions, the impacts of those conditions will likely manifest in very different and unpredictable ways across geographies and socioeconomic boundaries. Simultaneously, unknown or unforeseen disruptions — so-called "emergent" risks — are becoming more likely and must be factored into planning and decision-making.

This is particularly true when it comes to predicting future changes to the water cycle, where climate change intensifies ongoing impacts to water-dependent ecosystems including land use change, pollution, and overextraction. According to the IPCC AR6 Working Group II Report, "Climate change impacts via water availability changes are projected to increase with every degree of global warming (high confidence), but there are high regional uncertainties."[23] Thankfully, uncertainty does not mean that we cannot confidently plan for the future; indeed, uncertainty arguably makes sound planning more necessary than ever before. Effective planning for uncertainty does require a different approach, however.

From Systemic Risks to Systemic Resilience

In managing complex social, ecological, and technological systems, instead of planning for a specific outcome or end state, researchers such as Carl Folke and Johan Rockström have advocated for the adoption of process-based methodologies such as "resilience thinking" which, in this context, are focused on improving adaptive capacity in the face of multifaceted, non-linear shocks and stressors

17 World Economic Forum Water Initiative. 2012. *Water security: the water-food-energy-climate nexus.* Island Press.

18 Simpson, G. B., & Jewitt, G. P. 2019. The development of the water-energy-food nexus as a framework for achieving resource security: a review. *Frontiers in Environmental Science, 7*, 8.

19 GIZ. 2021. *One Health: Preventing and combating pandemics worldwide.* Project Description. Retrieved from: https://www.giz.de/en/worldwide/95590.html

20 Sillmann, J., Christensen, I., Hochrainer-Stigler, S., Huang-Lachmann, J., Juhola, S., Kornhuber, K., Mahecha, M., Mechler, R., Reichstein, M., Ruane, A.C., Schweizer, P.- J. & Williams, S. 2022. *ISC-UNDRR-RISK KAN Briefing note on systemic risk.* International Science Council: Paris, France.

21 Smith, D., & Fischbacher, M. 2009. The changing nature of risk and risk management: The challenge of borders, uncertainty and resilience. *Risk management, 11*(1), 1-12.

22 Sikula, N. R., Mancillas, J. W., Linkov, I., & McDonagh, J. A. 2015. Risk management is not enough: a conceptual model for resilience and adaptation-based vulnerability assessments. *Environment Systems and Decisions, 35*(2), 219-228.

23 Caretta, M.A., Mukherji, A., Arfanuzzaman, M., Betts, R.A., Gelfan, A., Hirabayashi, Y., Lissner, T.K. Liu, J. … & Supratid, S. 2022. Water. In: *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, … &, Rama, B. (eds.)]. Cambridge University Press: Cambridge, UK and New York, NY, USA, pp. 551-712.

and incorporate three essential strategies: persistence, adaptation, and transformation.[24] Instead of engineering a solution to a current problem with a predetermined outcome, the resilience model is designed to cope with uncertainties and dynamically manage trade-offs as new risks emerge.

We argue that this emerging practice of "planning for resilience"[25] is essential to meaningfully address the triple planetary crisis, where important decisions about how to adapt and which species and habitats to prioritize must be made today without knowing precisely what environmental systems will look like five, ten, or fifty years from now.[26] Planning for resilience is distinct from traditional models of biodiversity conservation, which focus on protecting and restoring ecosystems to specific historic conditions — conditions which may no longer be attainable or even desirable in a landscape transformed by rapid climate and land use change.

This is not to say that ecosystem protection or restoration should be entirely abandoned; rather, the emphasis of conservation should focus on the underlying structure and function of the target ecosystem, and work to maintain functionality even if the composition changes. Our managed adaptations (and, in some cases, transformations) should ideally aim to preserve as much of the natural freshwater ecosystem identity and function as possible, to sustain their many valuable contributions to human well-being, and to preserve their natural resilience capabilities; however, tough decisions will have to be made about which contributions to prioritize, and how to manage those trade-offs as our ecosystems change. Encouragingly, leading freshwater ecologists have also begun to embrace this model,[27] and there is a growing body of evidence to support resilience-based approaches.[28]

A key element of managing for uncertainty involves choosing policies and management options that are both effective in the near term while also avoiding maladaptive path dependencies, policy traps, or catastrophic failure in the future as conditions change.[29,30] These so-called low- or no-regret solutions are prioritized because they combine robustness with flexibility to allow for persistence, adaptation, and/or transformation over time.

The remainder of this paper delves into a specific category of tools known as Nature-based Solutions, or NbS. The UN Environment Assembly defines[31] NbS as: "actions to protect, conserve, restore, sustainably use, and manage natural or modified terrestrial, freshwater, coastal, and marine ecosystems, which address social, economic, and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, and resilience and biodiversity benefits." NbS exemplify low-regret options as they are typically more responsive to changing conditions than engineered infrastructure alone while delivering multiple co-benefits.[32]

NbS are particularly attractive for resilience-based approaches to climate adaptation in at least three ways: 1) they can complement gray infrastructure to create solutions that incorporate multiple resilience strategies over different temporal and spatial scales, 2) they are multi-functional and well suited to

24 Folke C, Carpenter SR, Walker B, Scheffer M, Chapin T, Rockstrom J. 2010. Resilience thinking: integrating resilience, adaptability and transformability. *Ecol Soc 15*(4): 20. http://www.ecologyandsociety.org/vol15/iss4/art20/

25 Global Resilience Partnership. 2019. *Resilience Insights: Lessons from the Global Resilience Partnership*. GRP: Stockholm, Sweden.

26 Anderies JM, Folke C, Ostrom E, Walker B. 2012. *Aligning key concepts for global change policy: robustness, resilience, and sustainability.* Center for the Study of Institutional Diversity, CSID Working Paper Series. #CSID-2012-002

27 Poff, N. L. 2018. Beyond the natural flow regime? Broadening the hydro-ecological foundation to meet environmental flows challenges in a non-stationary world. *Freshwater Biology, 63*(8), 1011-1021.

28 Miralles-Wilhelm, F., et al. 2022. Emerging Themes and Future Directions in Watershed Resilience Research. [In press].

29 Kwadijk, J. C., Haasnoot, M., Mulder, J. P., Hoogvliet, M. M., Jeuken, A. B., van der Krogt, R. A., ... & de Wit, M. J. 2010. Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Wiley interdisciplinary reviews: climate change, 1*(5), 729-740.

30 Nair, S., & Howlett, M. 2016. From robustness to resilience: avoiding policy traps in the long term. *Sustainability science, 11*(6), 909-917.

31 UNEA. 2021. *5th Meeting of the UN Environment Assembly: Nature-based Solutions for supporting sustainable development.* Draft EU+MS resolution proposal. Retrieved from: https://wedocs.unep.org/bitstream/handle/20.500.11822/37720/EU%20resolution%20proposal%20on%20NBS_16Dec.pdf?sequence=1&isAllowed=y

32 Nesshöver, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., ... & Wittmer, H. 2017. The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of the total environment, 579*, 1215-1227.

integrated solutions, and 3) they can reduce maladaptive aspects or negative impacts of traditionally engineered approaches.[33]

Over the past decade, the application of NbS at all scales has risen,[34] and most Parties have now incorporated NbS into their NDCs, National Adaptation Plans (NAPs), and NBSAPs. In its capacity as President of the 26th meeting of the Conference of the Parties (COP26) in Glasgow, the UK Government took a leading role in elevating the role of NbS, stating that, "As there is no pathway to net zero without protecting and restoring nature, we are encouraging countries to include nature-based solutions in their climate plans."[35] While there are many different types and categories of NbS,[36] this paper specifically focuses on the role of freshwater-based NbS for climate and biodiversity resilience due to water's essential role[37] in the success (or failure) of both agendas.

Water Resilience: An Organizing Principle for Climate Change, Biodiversity, and Pollution Reduction

The IPCC recently noted that adaptation to water-related risks and impacts makes up the majority of all documented adaptation efforts.[38] But, water does not just pose a risk. It is also one of Earth's most essential resources. Well-functioning freshwater ecosystems, including rivers and streams, lakes, wetlands, aquifers, and estuaries, provide important biodiversity and ecosystem services such as water storage, water flow, natural water purification, and flood protection. Most NbS for climate adaptation — such as reforestation, re-wetting marshes, or coastal habitat protection — are dependent on freshwater resources; without adequate availability and quality of freshwater, trees will not survive, wetlands will dry out, and coastal areas will become too saline.

Freshwater biodiversity underpins healthy aquatic and terrestrial ecosystems;[39] as freshwater biodiversity declines, aquatic ecosystems degrade and the services they can provide also suffer. WWF's 2022 *Living Planet* report noted that over 80% of global freshwater species populations were lost between 1970 and 2016,[40] and freshwater ecosystems continue to decline at a faster rate than any other natural system. Anthropogenic pollution is further threatening freshwater ecosystems and biodiversity. Over 80% of the world's wastewater — and over 95% in some least developed countries — is released to the environment without treatment. This results in increased levels of nutrients such as nitrogen and phosphorus, causing eutrophication and harmful effects on aquatic lifeforms. Pollution of freshwater ecosystems leads to physical (e.g., temperature), chemical (e.g., oxygen uptake), and biological changes

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33 Cassin, J., Davis, K., & Matthews, J.H. 2021. *Nature for Climate Action in the Nationally Determined Contributions.* Forest Trends and Alliance for Global Water Adaptation: Seattle, WA, USA and Corvallis, OR, USA.

34 Seddon, N., Chausson, A., Berry, P., Girardin, C. A., Smith, A., & Turner, B. 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B*, *375*(1794), 20190120.

35 UK COP26 Presidency. 2021. *Nature: Protecting and restoring nature for the benefit of people and planet.* Retrieved from: https://ukcop26.org/nature

36 IUCN. 2020. *IUCN Global Standard for Nature-based Solutions: a user-friendly framework for the verification, design and scaling up of NbS: first edition.* IUCN: Gland, Switzerland.

37 Timboe, I., Pharr, K. & Matthews, J.H. 2020. *Watering the NDCs: National Climate Planning for 2020—How water-aware climate policies can strengthen climate change mitigation & adaptation goals.* Alliance for Global Water Adaptation: Corvallis, OR, USA.

38 Caretta, M.A., Mukherji, A., Arfanuzzaman, M., Betts, R.A., Gelfan, A., Hirabayashi, Y., Lissner, T.K. Liu, J. … & Supratid, S. 2022. Water. In: *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, … &, Rama, B. (eds.)]. Cambridge University Press: Cambridge, UK and New York, NY, USA, pp. 551-712.

39 Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.-I., Knowler, D.J., Lévêque, C. et al. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews*, *81*, 163–182.

40 WWF. 2022. *Living Planet Report 2022 - Building a nature positive society.* Almond, R.E.A., Grooten, M., Juffe Bignoli, D. & Petersen, T. (Eds). World Wildlife Fund: Gland, Switzerland.

(e.g., distribution of aquatic macroinvertebrates). Eventually these changes result in a less productive environment, a less prosperous economy, and a diminished quality of life.

Given water's centrality to adaptation, addressing the freshwater biodiversity and pollution crises are a critical but often overlooked adaptation strategy, and — in some cases — popular adaptation efforts such as tree planting or crop varietal replacement can inadvertently undermine biodiversity goals if the chosen trees or crops are not suitable for the local ecosystem. Investing in water resilience using freshwater NbS seeks to balance these trade-offs and increase benefits for both people and nature.

The International Union for the Conservation of Nature (IUCN) defines freshwater NbS as adaptation responses that rely on natural processes to enhance water availability, water quality, and mitigate risks associated with water-related disasters.[41] For the purposes of this paper, we divide freshwater NbS into four main categories: 1) rivers, streams, and estuaries; 2) lakes; 3) aquifers; and 4) wetlands. Table 1 outlines each of these categories and provides relevant examples of the benefits they provide, which are further detailed in the case studies included throughout this paper.

Table 1. Types of freshwater ecosystems and NbS interventions

Freshwater ecosystem types	Examples of climate adaptation / mitigation, biodiversity, and water quality benefits	Examples of specific NbS	Case studies
1. Rivers, streams, and estuaries	• Habitat for freshwater and marine species • Nutrient cycling • Fisheries / food production • Drinking water supply • Cultural and spiritual support • Transportation	• Upstream watershed protection • Floodplain reconnection • Reducing urban stormwater, agricultural, and forestry runoff (non-point source pollution) • Check dams for flood control • Riparian buffer construction / habitat protection • Beach grass and dune restoration	"Restoring Zambia's Rivers through Integrated Watershed Management and Catchment Protection in the Lower Kafue Sub-Catchment" (Zambia) "Building Nature-based Resilience through Public Employment Programs in India" (India)

41 IUCN. 2020. *IUCN Global Standard for Nature-based Solutions: a user-friendly framework for the verification, design and scaling up of NbS: first edition.* IUCN: Gland, Switzerland

2. Lakes[42]	• Fisheries / food production • Habitat for fish and wildlife • Drinking water supply • Climate regulation • Recreation • Nutrient cycling • Cultural and spiritual support • Transportation	• On-farm soil water management to reduce harmful algal blooms (HABs) • Reducing urban stormwater runoff • Invasive species control • Nutrient removal • Sediment control	"The Mar Menor Coastal Lagoon: A Unique but Endangered Ecosystem" (Spain)
3. Aquifers[43,44]	• Drinking water supply • Water for irrigation • Water storage and filtration • Nutrient cycling • Flood control and stormwater management	• Managed aquifer recharge (MAR) for storage and filtration • Sand filters / dams • Soil remediation • Integrated forest-water management	"Greening of Hillocks through an Integrated Watershed Management Approach" (India)
4. Wetlands[45]	• Improved water quality • Habitat for fish and wildlife • Flood control and stormwater management • Maintaining eco-hydrological functioning • Carbon storage and sequestration • Cultural and spiritual support	• Safeguarding existing wetlands • Restoration / regeneration of mangroves and other coastal forests • Constructed wetlands for water treatment and storage • Urban bioretention ponds / wetlands for stormwater, flood and drought protection	"Wetland Conservation and the Challenge to Enhance Water Security in the Bolivian Chiquitania Region" (Bolivia) "Integrative Management Plan for Peatland Restoration in Kalimantan" (Indonesia)

42 Sterner, R. W., Keeler, B., Polasky, S., Poudel, R., Rhude, K., & Rogers, M. 2020. Ecosystem services of Earth's largest freshwater lakes. *Ecosystem Services*, *41*, 101046.
43 Griebler, C., & Avramov, M. 2015. Groundwater ecosystem services: a review. *Freshwater Science*, *34*(1), 355-367.
44 GRIPP. 2022. *Overview on Groundwater-Based Natural Infrastructure.* Retrieved from: https://gripp.iwmi.org/natural-infrastructure/overview-on-groundwater-based-natural-infrastructure
45 Anisha, N.F., Mauroner, A., Lovett, G., Neher, A., Servos, M., Minayeva, T., Schutten, H. & Minelli, L. 2020. *Locking Carbon in Wetlands for Enhanced Climate Action in NDCs.* Alliance for Global Water Adaptation and Wetlands International: Corvallis, OR, USA and Wageningen, The Netherlands.

Rivers, Streams, and Estuaries

Worldwide, streams and rivers are the primary source of renewable water supply for humans, livestock, and (freshwater) ecosystems.[46] These complex and dynamic ecosystems are home to water, sediment, aquatic organisms, and riparian vegetation moving from a source (i.e., headwaters) to an outlet (i.e., a larger body of water such as an ocean or an inland lake) and provide multiple services for people and nature both upstream and downstream. Rivers and streams also exchange water, materials, biota, energy, and nutrients with the surrounding environment, feeding groundwater reserves and providing soil and mineral deposits for cultivated agriculture and terrestrial biodiversity in floodplain regions.[47] They support fisheries, provide drinking water, and are used in electricity production and industrial cooling. In addition, rivers provide flood and drought protection, channeling and absorbing stormwater during high flow events while also storing water and providing refugia for aquatic species during periods of low precipitation. In many regions, rivers are also important sources of renewable energy generated by hydropower.

Healthy estuaries are particularly important ecosystems where habitats such as tidal marshes, dunes, and mangroves provide food, shelter, nutrient filtration, and temperature regulation. Estuaries and their associated wetlands are also important buffer zones, stabilizing shorelines and beaches, protecting coastal infrastructure, inland habitats, and coastal settlements from floods, storm surges, and sea level rise.

Many of the world's largest cities are located around estuaries and roughly 70% of the world's coastal population is located within 50 km of one.[48] Because estuaries are located at the terminus of rivers, they are highly vulnerable to degradation as rivers collect, transport, and discharge nutrients and other pollutants downstream. Simultaneously, global warming is adversely affecting rivers, streams, and estuaries by raising water temperatures, reducing water quality, and negatively impacting species richness and abundance.

Common river-based NbS include efforts to improve water quality such as stabilizing riverbanks and riparian zones, reconnecting floodplains, and transplanting native vegetation. Riverine green infrastructure such as check dams and natural flood management (NFM) have been shown to provide flood risk benefits, although the evidence base for these interventions alone at larger scales remains limited.[49] Estuary management projects such as tidal marsh rehabilitation or mangrove seeding can provide additional habitat for coastal and freshwater species, while providing storm surge and flood protection to coastal cities and settlements.

Hybrid green-gray approaches are also available and, in some cases, may be more effective than NbS alone.[50] Combining green infrastructure such as constructed marshes or floodplain reconnection with gray infrastructure such as masonry revetments or reservoirs can offer additional robustness and flexibility to downstream and coastal adaptation efforts.

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46 World Water Assessment Programme. 2009. *Water in a Changing World. The Third World Water Development Report*. UNESCO: Paris, France.

47 Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., ... & Van Den Belt, M. 1997. The value of the world's ecosystem services and natural capital. *Nature, 387*(6630), 253-260.

48 Janetos, A. C., Kasperson, R., Agardy, T., Alder, J., Ash, N., DeFries, R., & Nelson, G. 2005. Synthesis: condition and trends in systems and services, trade-offs for human well-being, and implications for the future. *Millennium Ecosystem Assessment. Ecosystems and human well-being: current state and trends.* Island Press: Washington, DC, USA.

49 Wingfield, T., Macdonald, N., Peters, K., Spees, J., & Potter, K. 2019. Natural flood management: Beyond the evidence debate. *Area, 51*(4), 743-751.

50 Al, S. 2018. *Adapting cities to sea level rise: Green and gray strategies.* Island Press: Washington, DC, USA.

Restoring Zambia's Rivers through Integrated Watershed Management and Catchment Protection in the Lower Kafue Sub-Catchment

Soil bunds for harvesting water

Zambia's water resources are under pressure due to an increase in demand caused by population and economic growth. Climate change, droughts, and shifting rainfall patterns heavily impact the availability and supply of water for domestic, industrial, and agricultural use nationwide. Smallholder farmers in the Lower Kafue Sub-Catchment (LKSC) in the Southern and Central parts of Zambia are particularly affected by climate variability. On top of this, catchment degradation aggravates the situation. Factors like deforestation lead to higher erosion, eventually causing siltation of rivers and reservoirs, reduced groundwater recharge, and loss of fertile soils. In line with Zambia's Water Resources Management Act No. 21 of 2011, the European Union (EU) and Germany's Federal Ministry for Economic Cooperation and Development (BMZ) funded the AWARE project that implemented 16 Catchment Protection Measures through Integrated Watershed Management in the LKSC.

Building on indigenous knowledge, using locally available materials, and connecting the communities with local funding opportunities have offered diverse solutions. AWARE worked closely with local communities and Water User Associations (WUAs) and implemented several activities to restore degraded lands and enhance water availability for the local communities at six project sites. These included the planting of over 70,000 trees, the digging of over 72 km of soil bunds and trenches, and the construction of eight check dams, creating rainwater harvesting potential of 25 million liters benefitting approximately 6,000 people around the project sites.

Challenges Faced & Outcomes: The main challenges resulted from the fact that these types of measures are relatively new in Zambia. There have been similar structures and interventions historically that mainly focused on reducing erosion, whereas the component of water harvesting is relatively new. Therefore, stakeholder and community engagement were key to raise awareness and gain more support for implementation. Additionally, catchment protection measures usually take longer to yield positive effects; therefore, AWARE combined measures which produce short-term results with long-term-oriented measures.

Through AWARE's community-led approach and spearheaded by four WUAs, catchment degradation has been countered. Groundwater has been recharged while important headwaters and rivers have been restored and protected due to a combination of NbS interventions. This has improved year-round water availability for water users, especially Zambia's rainfall dependent smallholder farmers. The combination of these measures has increased the vegetation cover and reduced erosion and flash floods, thus creating a steadier water flow into the local river systems.

For more information, please visit: https://www.youtube.com/watch?v=43Wt1Jm8KIo

Building Nature-based Resilience through Public Employment Programs in India

The Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) is one of the largest Public Employment Schemes in the world that aims to guarantee the right to work and enhance livelihood security in rural areas. This allows at least 100 days of wage employment in a financial year to at least one member of every household whose adult members volunteer to do unskilled manual work. Activities cover a wide range of NbS interventions for freshwater ecosystems, including greening of hillocks, drainage line treatment, river rejuvenation, soil conservation, rainwater harvesting, groundwater restoration, afforestation, horticulture, and pasture development.

Water security is a prime concern in India, especially as climate change exacerbates existing challenges. According to India's Composite Water Management Index (2018), 600 million people in the country are suffering from an acute shortage of water. A shrinking and sometimes contaminated water supply, heavy reliance on rainfall, and a lack of alternative irrigation systems are major problems in rural areas, where some 70% of the Indian population live.

The project Water Security and Climate Adaptation in Rural India (WASCA), commissioned by Germany's Federal Ministry for Economic Cooperation and Development (BMZ), supports the Ministry of Rural Development (MoRD) and the Ministry of Jal Shakti/Water (MoJS) to contribute to water security and climate resilience. The goal is to produce consistent and evidence-based development options for water resources management (including NbS plans) at a massive scale while accounting for contextual meteorological data, climate vulnerability, soil, geology, land use, topography, water resources, and socioeconomic data in order to improve water security, climate resilience, and natural resources management.

Challenges Faced & Outcomes: So far, 5,345 villages and local administrative areas (Gram Panchayats) covering an area of 7.4 million hectares and a population of 22 million have prepared Composite Water Resource Management (CWRM) plans that have identified 700,000 water-related, predominantly nature-based interventions, most of which have already received budgetary approvals by the national and state governments and are under implementation.

For more information, please visit: https://drive.google.com/file/d/1_WjMGiKGawqwcJcBsmjJ9FeY1puaGNXn/view

Lakes

Over 80% of all liquid surface freshwater is found in lakes and reservoirs.[51] And although the total area of the Earth's surface covered by lakes is relatively small (roughly 4.5 million km2 or >3%),[52] these unique ecosystems harbor high levels of biodiversity and contribute many important services including water for drinking, industrial, and agricultural use, aquatic habitats, food and shelter for migratory species, flood and drought protection, recreation, transportation, nutrient cycling, and climate regulation, among other benefits.[53]

The physical, chemical, and biological properties of lakes are highly sensitive to air temperature changes, and they have often been referred to as "sentinels" of climate change.[54] While climate change is certainly an emerging threat, the greatest anthropogenic risk to lakes and reservoirs continues to be over-extraction and mismanagement — see for example the dramatic and devastating declines of Lake Aral (Central Asia), Lake Chad (Central Africa), Lake Poopó (Bolivia), and the Great Salt Lake (United States). In all four cases, climate change is combining with existing stressors to accelerate desiccation.

As climate change continues to combine with other anthropogenic stressors to impact the structure and function of these important ecosystems, ecological thresholds are likely to be crossed, potentially tipping these systems into new states and triggering a cascade of serious socio-ecological impacts.[55] It has been

51 Shiklomanov, I. A., & Rodda, J. C. (Eds.). 2004. *World water resources at the beginning of the twenty-first century.* Cambridge University Press: Cambridge, UK.
52 Downing, J. A., Prairie, Y. T., Cole, J. J., Duarte, C. M., Tranvik, L. J., Striegl, R. G., ... & Middelburg, J. J. 2006. The global abundance and size distribution of lakes, ponds, and impoundments. *Limnology and Oceanography, 51*(5), 2388-2397.
53 Schallenberg, M., de Winton, M. D., Verburg, P., Kelly, D. J., Hamill, K. D., & Hamilton, D. P. 2013. Ecosystem services of lakes. In *Ecosystem services in New Zealand: conditions and trends.* Manaaki Whenua Press: Lincoln, New Zealand.
54 See for example the 2008 AGU Chapman Conference on "Lakes and Reservoirs as Sentinels, Integrators, and Regulators of Climate Change": https://www.agu.org/-/media/Files/Meetings/AGU-Chapman-Conference-Special-Issue-of-Limnology-and-Oceanography.pdf
55 Scheffer, M., & Carpenter, S. R. 2003. Catastrophic regime shifts in ecosystems: linking theory to observation. *Trends in ecology & evolution, 18*(12), 648-656.

argued that this cascade is already happening in the Lake Urmia (Iran)[56] and Great Salt Lake[57] basins. Fostering the capacity of the ecosystem to absorb small-scale variability and change can reduce the likelihood of large-scale changes.[58] Thus, identifying hotspots of rapid change and working to improve the resilience of these systems are critical first steps in addressing the worst impacts of climate change.

Given their hydrological connectivity to rivers and streams, lakes can often benefit from some of the same NbS interventions mentioned above. Efforts to reduce water temperatures and improve water quality in lakes by limiting pollution inflows can support biodiversity and livelihoods (e.g., through sustainable fisheries). Recycling excess sediment to create new habitat for species and improve ecological productivity is another NbS option that has been successfully implemented in the Netherlands[59] and elsewhere.

In urban settings, non-water based NbS such as green roofs and retention ponds can also support lake health by reducing polluted stormwater runoff and flooding. Larger-scale biofiltration systems or stormwater treatment plants can also help protect lakes and other receiving waters (e.g., estuaries, oceans) from harmful stormwater pollutants.

Finally, lakes and reservoirs themselves can serve as natural infrastructure to support resilience. They can store water in times of drought and absorb floodwater during storms, provide refugia for species facing habitat threats, reduce nearby air temperatures, and provide a place for people to recreate and cool down.[60] Prioritizing lakes as hubs of resilience can improve overall adaptation efforts and support both local and migratory populations.

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56 Zhongming, Z., Linong, L., Xiaona, Y., Wangqiang, Z., & Wei, L. 2021. After revival, Iran's great salt lake faces new peril. *Science*. Retrieved from: https://www.science.org/content/article/after-revival-iran-s-great-salt-lake-faces-new-peril

57 Weber State University. 2022. *WSU professor, students research Great Salt Lake's threatened ecosystem.* Retrieved from: https://www.weber.edu/WSUToday/080122_GreatSaltLakeResearch.html

58 Landcare Research. 2017. Planning for tipping points and enhancing resilience in production landscapes. Policy Brief. Retrieved from: https://bioheritage.nz/wp-content/uploads/2019/04/2017-Tipping-Points-Policy-Brief.pdf

59 Natuurmonumenten. 2022. *Marker Wadden, An Artificial Archipelago.* Retrieved from: https://www.natuurmonumenten.nl/projecten/marker-wadden/english-version

60 United Nations Environment Programme. 2021. *Beating the Heat: A Sustainable Cooling Handbook for Cities.* UNEP: Nairobi, Kenya.

The Mar Menor Coastal Lagoon: A Unique but Endangered Ecosystem

Plans for renaturalization of wetlands surrounding Mar Menor coastal lagoon as part of a "green belt"

Mar Menor is a very fragile lagoon ecosystem that has suffered significant anthropic pressures. The largest saltwater lagoon in Spain, and one of the largest in Europe, it is currently highly eutrophied as a result of the excess concentration of nutrients in the aquatic environment. To address this eutrophication and its harmful effects on native wildlife, the Spanish Government is undertaking a multi-pronged approach to ecosystem management that includes a combination of gray and green interventions as well as several management and governance changes.

To help protect and restore the Mar Menor Lagoon, a "green belt" is being established around the perimeter through the restoration of wetlands and other valuable ecosystems. Not only will this help reduce the direct inputs of agricultural runoff by creating a buffer zone, but the wetlands are meant to act as a natural filter to prevent fertilizer and pesticides from entering the lagoon. Other actions are also underway to further restore protected surrounding areas, and for the restoration of dune areas and restrictions of urban, industrial, and port activities nearby.

The Campo de Cartagena Basin in which the lagoon sits has an existing network of Ramblas (ephemeral rivers) to serve as a natural drainage system. Part of the project managed by the government is aimed at restoring any degraded Ramblas through efforts such as removal of nonfunctional artificial barriers and obstacles to help them function better for flood risk management and groundwater infiltration filters.

These NbS actions complement gray interventions aimed at flood and stormwater management as well as wastewater treatment.

Challenges Faced & Outcomes: Some challenges involved the large amount of agricultural activity taking place around the lagoon. Interventions included controlling and closure of approximately 8,500 hectares of irrigated land with no water licenses. Agricultural practices were also addressed in order to reduce the overall influx of fertilizers and pesticides into the system. National authorities in charge of the Common Agricultural Practices work with the local farming communities to implement improvements in the mandatory non-productive areas of the farms. A strong scientific program with the support of public research organizations, a communication strategy as well as local cooperation and public participation strategies, and an independent monitoring and surveillance system on the state of the lagoon and the plan of action itself are being established to support the implementation of these measures.

For more information, please visit: https://www.miteco.gob.es/es/ministerio/planes-estrategias/mar-menor/

Aquifers

Groundwater systems, or aquifers, are the largest single source of irrigation water worldwide, supporting billions of lives and livelihoods that depend on pumped agriculture for food production.[61] In addition, groundwater is the primary source of drinking water for over 2.5 billion people, provides industrial water supply, water for livestock, and supports many ecosystems, including wetlands, rivers, lakes, estuaries, lagoons, springs, and terrestrial systems like forests and grasslands.[62]

Groundwater-based NbS primarily include water storage and filtration. Efforts to increase water infiltration through different irrigation techniques and cropping strategies are one way to improve aquifer resilience. Elsewhere, green-gray solutions such as managed aquifer recharge (MAR) are being implemented in places like the Central Valley of California and Mongolia to adapt to increasing precipitation variability, replenish depleted groundwater supplies, and provide supplemental water storage that is less sensitive to changes in air temperature.[63] One of the primary challenges to sustaining groundwater resilience is that aquifers are often "invisible" and not well mapped or defined. Because of this, in most regions we also lack strong regulatory frameworks for groundwater management. Policies to measure, monitor, and protect groundwater resources are urgently needed as aquifers often have an extremely slow recharge rate and may collapse entirely if drawn down too far.

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61 WWAP (United Nations World Water Assessment Programme)/UN-Water. 2018. *The United Nations World Water Development Report 2018: Nature-Based Solutions for Water.* UNESCO: Paris, France.

62 CGIAR Research Program on Water, Land and Ecosystems (WLE). 2015. *Groundwater and ecosystem services: a framework for managing smallholder groundwater dependent agrarian socio-ecologies - applying an ecosystem services and resilience approach*. International Water Management Institute (IWMI): Colombo, Sri Lanka.

63 Casanova, J., Devau, N., & Pettenati, M. 2016. Managed aquifer recharge: an overview of issues and options. *Integrated groundwater management*, 413-434.

For example, megacities such as Mexico City, Chennai, Lahore, and São Paulo depend heavily on groundwater for drinking supply and are rapidly depleting the surrounding aquifers faster than they can naturally recharge, causing several associated challenges including salination and land subsidence. When not used as a primary source of water, aquifers also form an important "back up" supply, which are becoming increasingly important as the climate changes.[64] Increasingly severe and variable drought and floods are already impacting groundwater supplies in some regions. As drought kills off vegetation and reduces soil moisture, the soil compacts. When the rains arrive, compacted soils cannot properly absorb the precipitation, leading to more surface water runoff and less aquifer recharge.[65]

Greening of Hillocks through an Integrated Watershed Management Approach

A range of NbS interventions were used to help restore the functionality of degraded hillocks and address numerous water-related challenges.

Making up around 30% of India's total geographical area, wastelands support approximately 40% of India's population, mostly representing marginalized communities. As climate change impacts are being felt in these regions, new site-specific and locally-led adaptation and mitigation measures are being developed.

The Tiruvannamalai District in India's state of Tamil Nadu has a series of isolated hillocks in degraded conditions, causing severe losses in crucial ecosystem services and in turn impacting the livelihoods of farmers. Vegetation loss from hillside degradation has increased the rate of soil erosion and led to a cascading set of impacts. Soil is exposed to intense heat, and a drying up of the perennial water sources has resulted in alteration of catchment areas, surface runoff, and drainage.

To address these challenges through locally-led adaptation, the Indo-German project Water Security and Climate Adaptation in Rural India (WASCA) was implemented by GIZ with support of M S Swaminathan Research Foundation. GIS and remote sensing tools were used to map and plan for afforestation and land management measures in the district. At the community level, the local government and village panchayats were trained in identifying key water challenges and potential water actions using a "ridge to valley" approach.

Challenges Faced & Outcomes: NbS interventions were used to address the priority challenges, such as planting of native tree species for hillside stabilization, digging of dugout ponds for water storage and runoff control, and creation of water recharge structures for groundwater improvement. These interventions support ten village communities in the area and promote agriculture in a 2,500 hectare area that includes 2,000 farmers and numerous communities.

For more information, visit: https://www.giz.de/de/downloads/giz2019-en-wasca-india.pdf

Wetlands

Globally, wetlands of all types make up only 5-8% of the total landscape but store approximately 30% of the earth's carbon.[66] According to one recent analysis, the ecosystem services provided by natural wetlands make up 43.5% of the monetary value of all natural systems.[67] Wetlands are a prime example of multi-functional ecosystems, supplying critical habitat for vegetation, birds, and aquatic species as well as supporting tourism, recreation, and cultural activities.[68] Their adaptation benefits are numerous, including flood mitigation and the prevention of soil loss through erosion or runoff, salinity control, and temperature regulation.

Wetlands are currently being lost at a rate three times faster than forests and are the single most rapidly declining ecosystem type in the world.[69] On aggregate, wetlands are most impacted by land use change — in particular, land conversion for agriculture, livestock grazing, and urbanization. Climate change has begun to further threaten these diverse ecosystems, particularly in alpine environments throughout northern Alaska, Canada, Russia, and parts of northern Europe, where peatlands (a subtype of wetland) buried under melting permafrost have begun to thaw. As the peat thaws, it releases massive amounts of carbon into the atmosphere and interacts with surrounding organic matter to produce methane, which will rapidly accelerate global warming over the coming decades.[70] Tropical peatlands, such as the ones found in Indonesia, also store massive amounts of carbon and are being rapidly lost to land use conversion. Like lakes, the loss of these peatlands could trigger ecological tipping points, leading to a cascade of far-reaching and unpredictable impacts.

66 Mitsch, W. J., & Gosselink, J. G. 2015. *Wetlands*. John Wiley & Sons: Hoboken, NJ, USA.
67 Davidson, N. C., Van Dam, A. A., Finlayson, C. M., & McInnes, R. J. 2019. Worth of wetlands: revised global monetary values of coastal and inland wetland ecosystem services. *Marine and Freshwater Research*, *70*(8), 1189-1194.
68 Lavorel, S., Colloff, M. J., Mcintyre, S., Doherty, M. D., Murphy, H. T., Metcalfe, D. J., ... & Williams, K. J. 2015. Ecological mechanisms underpinning climate adaptation services. *Global change biology*, *21*(1), 12-31.
69 UNESCO & UN-Water. 2020. *United Nations World Water Development Report 2020: Water and Climate Change*. UNESCO: Paris, France.
70 Fewster, R., & Morris, P. 2022. Permafrost peat carbon approaching a climatic tipping point. *Nature Climate Change*.

There are several different types of NbS involving wetlands; the first and foremost type is protecting existing wetland habitat from further degradation or conversion. Encouragingly, several countries have included wetland protection and management in their NDCs and NAPs,[71] but much more could be done at the national level to enact protective policies and support wetland management. In some areas, restoring degraded wetlands is another option, as is the creation of man-made or constructed wetlands for flood risk reduction, habitat establishment, and water storage. However, it should be stressed that the best option for maximizing the benefits of wetlands is preserving habitat that already exists.

In coastal areas, integrating wetlands, such as mangroves, alone or in combination with engineered approaches can provide critical infrastructure to buffer coasts from storms, sea level rise, and floods, while supporting fisheries and habitats for aquatic and terrestrial species. These interventions can create real economic benefits. According to a 2020 report by the Global Commission on Adaptation, mangrove forests provide more than USD $80 billion per year in avoided losses from coastal flooding and protect 18 million people.[72] Investing in these important transitional ecosystems may also provide additional biodiversity benefits to the broader nearshore marine environment, as well as terrestrial and freshwater ecosystems, by regulating flows of water, sediment, and aquatic organisms. However, there may be trade-offs for biodiversity if the primary management objective is flood risk, and vice versa. Understanding, communicating, and managing these trade-offs should be done in consultation with all relevant stakeholders.

In recent years, mangrove planting has become an attractive coastal adaptation strategy, given the multiple benefits listed above. However, experience also shows that simply planting mangroves in degraded habitat, without proper consideration of species or site suitability, is unlikely to be successful; restoration efforts should first focus on creating the right biophysical and socioeconomic conditions that will allow mangroves to take hold and regenerate naturally.[73] As the climate changes, this may mean that some areas once suitable for certain types of mangrove forests can no longer support them[74] and an alternative mix of species or locations will need to be found.

Another type of wetland NbS that has been successfully implemented in many regions are constructed wetlands. Constructed wetlands are a type of green-gray infrastructure engineered to achieve one or more of the functions of natural wetlands. Constructed wetlands include surface flow wetlands, which mimic natural inundated wetlands, or subsurface flow wetlands where the flow passes through a vegetated substrate. Engineered wetlands can provide a number of benefits for adaptation and biodiversity, but they can be challenging — and costly — to maintain over time.[75]

Another challenge is finding sufficient space to construct a wetland. Many constructed wetlands are currently built to treat wastewater; treating large amounts of wastewater requires a large amount of land, which is often especially hard to find in urban settings. Despite these limitations, constructed wetlands have become an increasingly attractive option for ecosystem managers, in particular because they are highly adjustable to changing conditions and needs.

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71 Anisha, N.F., Mauroner, A., Lovett, G., Neher, A., Servos, M., Minayeva, T., Schutten, H. & Minelli, L. 2020. *Locking Carbon in Wetlands for Enhanced Climate Action in NDCs.* Alliance for Global Water Adaptation and Wetlands International: Corvallis, OR, USA and Wageningen, The Netherlands.

72 Beck, M.W., Lange, G.M., & Narayan, S. 2018. *The Miracle of Mangroves for Coastal Protection in Numbers.* World Bank Blog. Retrieved from: https://blogs.worldbank.org/voices/miracle-mangroves-coastal-protection-numbers

73 Wetlands International. 2016. *Mangrove restoration: to plant or not to plant.* Retrieved from: https://www.wetlands.org/publications/mangrove-restoration-to-plant-or-not-to-plant

74 Friess, D. A., Rogers, K., Lovelock, C. E., Krauss, K. W., Hamilton, S. E., Lee, S. Y., ... & Shi, S. 2019. The state of the world's mangrove forests: past, present, and future. *Annu. Rev. Environ. Resour, 44*(1), 89-115.

75 Metcalfe, C. D., Nagabhatla, N., & Fitzgerald, S. K. 2018. Multifunctional wetlands: pollution abatement by natural and constructed wetlands. In *Multifunctional Wetlands* (pp. 1-14). Springer: Cham, Switzerland.

Wetland Conservation and the Challenge to Enhance Water Security in the Bolivian Chiquitania Region

Wildlife is abundant in the wetlands around Bolivia's Paraguá River.

The zone of the upper Paraguá River in Bolivia is an area rich in wetlands, temporary flood zones, and biodiversity. It is very important for water regulation, and very vulnerable not only to the effects of climate change but also to anthropic actions linked to forest fires, deforestation, and unsustainable agricultural production practices. The Resilient Landscapes in the Chiquitania, Santa Cruz (2020-2024) project is co-financed by the European Union and the German Development Cooperation, implemented by GIZ within its project PROCUENCA. This contains the pilot project Wetland conservation through sustainable production practices, resilient communities, and participative water flow monitoring. The goal is to promote transformative alternatives towards sustainable productive systems that reduce the pressures being exerted on wetlands.

The main measures regarding NbS are: implementing diversified systems, maintaining traditional crops, installing fish farming systems of native species in flood zones, establishing a communal native species seedling nursery, promoting the use of non-timber species, and technical assistance for the water-flow monitoring system. These are practiced by the Autonomous Municipal Government of San Ignacio de Velasco, five indigenous communities, Integral Faculty Chiquitana (FAICHI), and the Centre for Research and Promotion of the Peasantry (CIPCA).

Challenges Faced & Outcomes: The main challenges to guarantee the sustainability of the freshwater NbS are to incorporate them into public policies, integrate into the private sector, link sustainable production to local and/or regional value chains, and to implement robust monitoring and evaluation systems. The upper Paraguá territorial management committee is supporting the process and has managed to incorporate the Paraguá wetland into the national program for the integrated management of RAMSAR sites and wetlands, which depends on the Ministry of Environment and Water.

The expected results of the freshwater NbS are to manage approximately 30 hectares of diversified productive systems (direct impact) and to conserve approximately 2,000 hectares of forest areas, of which 1,500 hectares are wetlands (indirect impact). The above mentioned NbS aim to increase soil fertility, carbon sequestration and infiltration, reduce agricultural practices of clearing and slash-and-burn agriculture, diversify agriculture areas, revalue native species, decrease deforestation, conserve wetlands, natural areas, and biodiversity, preserve hydrological cycles, and regulate climate. All the while, the use of NbS can strengthen family economies, assuring sources of income throughout the year, and help to reestablish traditional productive practices such as fish farming.

This case study shows that investing in water resilience using freshwater NbS can increase water security and benefit both people and nature.

For additional information, please visit: https://www.paisajesresilientes.org

Integrative Management Plan for Peatland Restoration in Kalimantan

An aerial view of Indonesia's Middle Mahakam peatlands

The peat ecosystem is known for its fundamental function in absorbing, holding, and regulating water. This unique ecosystem is threatened by unsustainable management and a lack of knowledge at the local level in dealing with agriculture in the peatlands, the potential results of which include loss of soil productivity, flooding, and land fires.

The Government of Indonesia committed to improving peatland ecosystems by implementing corrective action in 2015. Germany's Federal Ministry for Economic Cooperation and Development (BMZ) funded the Peatland Rehabilitation and Management Project in the North and East Kalimantan provinces of Indonesia. The project aimed to provide policy advice and capacity building around best management practices for integrated peatland management to a range of relevant stakeholders. Local communities were encouraged to lead regulation of peat forest management, while farmers were directed towards the use of paludiculture and relevant technical management approaches.

Challenges Faced & Outcomes: Having a shared understanding and commitment from different stakeholders on sustainable peatland management through a landscape approach is quite challenging due to conflicting interests. Moreover, unpredictable flooding is a complicating factor in rehabilitating the peat ecosystem with the community and respective authorities. However, this condition enables local stakeholders and project managers to test the innovative floating nursery and agriculture approach.

The project supported the capacity of management boards in managing peatland through social forestry schemes for developing long-term planning, annual plans, and organizational procedures in both provinces, benefitting 132 villages in an area of approximately 30,000 hectares. In East Kalimantan province, there are future plans to rehabilitate an area of 25 hectares with 10,000 seedlings in two villages together with the local youth groups. These activities have increased awareness of the importance of peatland ecosystems in micro and macro development plans, and as important components in local livelihoods and economies.

For more information, please visit: https://www.giz.de/en/worldwide/113885.html

Challenges and Opportunities for Freshwater NbS in Supporting Climate Change and Biodiversity Agendas

If freshwater NbS are such a win-win-win for biodiversity, climate adaptation, and the reduction of environmental pollution, then why haven't they been more widely adopted? There are several challenges and opportunities for freshwater NbS in supporting climate change and biodiversity, which have been highlighted in literature and pointed out in the case studies mentioned throughout this paper. Some of the barriers are identified below.

Lack of standardization when it comes to what does and does not qualify as a freshwater NbS, as well as capacity to support their implementation

As NbS are still considered to be rather a new concept, their conceptualization remains fluid. While the UN Environment Assembly (UNEA 5.2) has recently adopted a definition of NbS, thus far, scant guidance has been provided on how to enable effective operationalization of NbS, leading to risks in NbS implementation and sustainability or even negative side-effects of interventions due to a lack of clarity in definitions.[76]

IUCN has been working on a standard that provides a robust framework for planning and verifying NbS; however, further work will be required to mainstream the standard and create a key conservation and development tool. The IUCN standard is made up of eight different criteria including societal challenges, design at scale, biodiversity net-gain, economic feasibility, inclusive governance, balancing trade-offs, adaptive management, and mainstreaming and sustainability.[77] This approach provides a practical instrument for engaging in implementation actions and designing measures based on internationally recognized standards.

NbS and related concepts should be understood as complementing and reinforcing each other's objectives to address sustainable development and resilience holistically. Here it becomes essential to consider multifunctionality and inclusive and just approaches that rely on core governance principles.[78]

76 Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (eds.). 2016. *Nature-based Solutions to address global societal challenges.* IUCN: Gland, Switzerland.

77 IUCN. 2020. *IUCN Global Standard for Nature-based Solutions: a user-friendly framework for the verification, design and scaling up of NbS: first edition.* IUCN: Gland, Switzerland.

78 Terton, A. 2022. *Nature-Based Solutions: An Approach for Joint Implementation of Climate and Biodiversity Commitments.* Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), International Institute for Sustainable Development (IISD), Helmholtz Centre for Environmental Research (UFZ).

Standards and frameworks like the one developed by IUCN are helping to address the NbS knowledge and capacity gap. However, NbS cases have been mainly put into practice in developed countries, which might make them seem less relevant to actors in the Global South. Comparisons also become increasingly difficult due to distinct ecosystem types and the context specificity of NbS interventions.[79]

The case study from Zambia pointed out a lack of knowledge and understanding of NbS due to the novelty of the concept. The main challenges resulted from the fact that these types of measures are relatively new in Zambia. While there have been similar structures and interventions over many generations, such interventions mainly focused on reducing erosion control, and the concept of water harvesting is relatively new. Here, the first step to improve capacity and knowledge on NbS was to focus on raising awareness and creating an understanding on NbS and water harvesting techniques by engaging with communities and stakeholders from the start. Furthermore, the case study from India's Tiruvannamalai District made clear that training has been key to enhancing awareness about identifying key water challenges and potential water actions using a "ridge to valley" approach at the community level.

Another limitation worth mentioning is the limited information available on challenges and failures of NbS implementation. Discussing where and how NbS have not worked as planned and reflecting on these failures creates immense opportunities for improving NbS planning and implementation and enhances the use of adaptive approaches for resilience.

Stakeholder (and investor) perceptions of green versus gray infrastructure

The lack of standardization and novelty of the concepts on top of the current barriers to financing and the risks of investments make up many reasons why stakeholders and investors might often perceive NbS as less attractive compared to gray solutions. When comparing green to gray infrastructure, investors often perceive gray investments as the stronger business cases due to less perceived risks and larger returns based on very specific and measurable effects compared to decentralized and dynamic NbS interventions.[80]

Due to their dynamic structure, NbS are sometimes perceived to be less disaster resilient compared to gray infrastructure when it comes to protecting lives and livelihoods from floods, drought, and storms.[81] To support the establishment of a stronger understanding on what can be expected from NbS compared to gray infrastructure and how these approaches might go hand-in-hand, new guides and frameworks have been established in recent years. For example, the Asian Development Bank's practitioner's guide on integrating NbS for climate change adaptation and disaster risk management includes questions to consider when identifying potential NbS in order to verify their value and relevance for the desired objectives, provide a checklist to test their readiness and suitability for partners, and change the discussion from one of green *versus* gray to one considering both approaches.[82] Practical guidance like this supports changing the perception of stakeholders and investors from "either/or" to "and" when it comes to green and gray solutions. Further, this type of guidance provides hands-on advice that can be integrated in daily processes to help create a better understanding of the benefits and challenges to NbS implementation and investment.

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79 Matthews, J., & Ocampo de la Cruz, E. 2022. *Integrating nature-based solutions for climate change adaptation and disaster risk management: A Practitioner's Guide.* Asian Development Bank: Manila, Philippines.

80 O'Donnell E.C., Gosling, S.N., Netusil, N.R., Shun Chan, F.K. & Dolman, N.J. 2021. Perceptions of blue-green and grey infrastructure as climate change adaptation strategies for urban water resilience. *Journal of the British Academy 9*(s9), 143-182.

81 Dorst, H., van der Jagt, A., Toxopeus, H., Tozer, L., Raven, R., & Runhaar, H. 2022. What's behind the barriers? Uncovering structural conditions working against nature-based solutions. *Landscape and Urban Planning, 220*, 104335.

82 Matthews, J., & Ocampo de la Cruz, E. 2022. *Integrating nature-based solutions for climate change adaptation and disaster risk management: A Practitioner's Guide.* Asian Development Bank: Manila, Philippines.

Diversity of stakeholders in finding a resilient landscape approach that offers ecological connectivity across ecosystem cascades

As highlighted before, there can be a number of competing objectives and uses involved in the implementation of NbS. This multitude of uses and users calls for compromises that often go in favor of the economically/politically strongest stakeholder rather than the most reasonable and sustainable choices for communities, the environment, and the public good.[83] This can create risks to enhancing resilience and enabling sustainable development. Different groups and interests include, for example, the private sector groups engaging in extractive activities (e.g., timber and mining) working towards fulfilling companies' objectives by strengthening returns on investments. Private sector companies tend to put less emphasis on ecosystem integrity and the sustainability of resource use, creating a need for policies and frameworks that support nature positive engagements.[84,85]

Conservation activities are hindered by not engaging with a wide enough swath of relevant stakeholders. Decision makers predominantly view the rural populations who are engaged in livelihood activities in the primary sector (farming, forestry, and fisheries) as users of ecosystem services rather than as potential conservers.[86] Changing the conservation paradigm will help to integrate sustainable livelihood activities with restoration efforts in order to make (or reframe) communities and individuals into custodians of their ecosystems.

Risk assessment standards that do not integrate biodiversity when assessing resilience

Ecosystem and species diversity are considered external factors in most economic calculations. Therefore, they are usually not included in risk calculations that analyze public costs of climate change risks. Public perception mainly sees biodiversity loss as an ecological damage without linking it to further socioeconomic risk and consequences. Therefore, the biodiversity benefits or co-benefits of NbS have not been fully acknowledged, understood, or translated in financial terms.

The case study from Spain pointed out the importance (and challenges) of engaging with relevant stakeholder groups, such as local farming communities in the case study area. The large amount of agricultural activity taking place around the lagoon presented a challenging element. Interventions included controlling and closure of approximately 8,500 hectares of irrigated land with no water licenses. Agricultural practices were also addressed in order to reduce the overall influx of fertilizers and pesticides into the system. National authorities in charge of the Common Agricultural Practices worked with the local farming communities to implement confined substrate farming practices and green filters in the mandatory non-productive areas of the farms. Communication, monitoring, and public engagement have been key to address risks to ecosystems and biodiversity loss.

The difficulty of quantifying (co-)benefits from NbS interventions using traditional benefits calculators and metrics

One of the main critiques and challenges to NbS implementation and scaling refers to the difficulty of quantifying their benefits and measuring their effectiveness over time. This is in part because NbS

83 Dasgupta, P. 2021. *The Economics of Biodiversity: The Dasgupta Review.* HM Treasury: London, UK.
84 Cassin, J., Davis, K., & Matthews, J.H. 2021. *Nature for Climate Action in the Nationally Determined Contributions.* Forest Trends and Alliance for Global Water Adaptation: Seattle, WA, USA and Corvallis, OR, USA.
85 Dempsey, J. 2013. Biodiversity loss as material risk: Tracking the changing meanings and materialities of biodiversity conservation. *Geoforum, 45*, 41-51.
86 Keestra, S., Nunes, J., Novara, A., Finger, D., Avelar, D., Kalantari, Z., & Cerdà, A. 2018. The superior effect of nature based solutions in land management for enhancing ecosystem services. *Science of the Total Environment, 610*, 997-1009.

are part of complex socio-ecological systems that are impacted by different variables including social, economic, biophysical, and ecological aspects; isolating specific characteristics or the "added value" of these interventions can be challenging.[87]

For example, the Indonesian case study notes that unpredictable flooding is a complicating factor in rehabilitating peatland ecosystems, one that can reduce support from the community and respective authorities. Working with nature, especially in a restoration context with unclear baselines, can lead to unforeseen reactions. Climate change brings in further uncertainties that require the use of robust and flexible solutions. Flexibility allows decision makers to select a chain of actions and measures that enable a dynamic navigation in tackling this issue by adjusting to and reacting to emerging conditions.[88] NbS create opportunities for flexible approaches to tackling climate change and allow space to test and adjust innovative approaches. In the case of Indonesia, the unforeseen floods also created an opportunity for testing innovative floating nursery and agriculture approaches. In working with ecosystems, their dynamic nature should be embraced by making use of flexible solutions to deal with climate change impacts and strengthen resilience.

It has been argued that standardized metrics of NbS might not be the ultimate aim. Instead, NbS should rather be considered context-specific, allowing for better incorporation of and accounting for socio-ecological dimensions and the ability to adapt to changing local circumstances. Considering context-specific factors and comparing these metrics over time will help to take into account the specific perspectives of relevant stakeholders and can reduce unintended maladaptation outcomes.[89]

Barriers to valuation, financing, and perceived return on investments

Risk calculations for future investments require sound quantitative data to calculate the impact of expected threats and enable the accounting of benefits in financial terms. As has already been mentioned, working with ecosystems means working in a dynamic environment shaped by different interests and further uncertainties created by climate change. Translating this dynamic setting and uncertain future impacts into a quantitative system becomes extremely challenging. The difficulty in pricing risks and returns on NbS was identified as the number one risk to investing in these projects. This issue is caused, in part, by limited information on impacts as well as a lack of data on market data and returns.[90] It is further argued that NbS projects often take longer to achieve the desired outcome and the results are often very context-specific, which may deter replication.[91]

It was pointed out that most financial institutions still have limited experience and tools for working with ecosystem-based approaches, as well as the structural challenges related to the placement of NbS in existing asset classes and portfolios.[92] Many financing measures for NbS including blended-finance mechanisms, nature-based insurance, fee-based funding, carbon credits, and green and blue bonds are relatively new. Next to raising awareness regarding NbS financing options, pooling, mainstreaming, and de-risking NbS investments will be key to attract greater investment.[93] To avoid unforeseen negative

87 Seddon, N., Chausson, A., Berry, P., Girardin, C. A., Smith, A., & Turner, B. 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B*, *375*(1794), 20190120.
88 GIZ, PIK, & adelphi. 2020. *Stop Floating, Start Swimming: Water and Climate Change – Interlinkages and Prospects for Future Action.* GIZ Sustainable Water Policy: Bonn, Germany.
89 Seddon, N., Chausson, A., Berry, P., Girardin, C. A., Smith, A., & Turner, B. 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B*, *375*(1794), 20190120.
90 WWF, Terranomics, & Climate Solutions Partnership. 2022. *Nature Based Solutions – a review of current financing barriers and how to overcome these.* Terranomics: London, UK.
91 Tuhkanen, H. 2020. *What is holding back the promise of nature-based solutions for climate change adaptation?* SEI Perspectives. Retrieved from: https://www.sei.org/perspectives/what-is-holding-back-the-promise-of-nature-based-solutions-for-climate-change-adaptation
92 WWF, Terranomics, & Climate Solutions Partnership. 2022. *Nature Based Solutions – a review of current financing barriers and how to overcome these.* Terranomics: London, UK.
93 Tuhkanen, H. 2020. *What is holding back the promise of nature-based solutions for climate change adaptation?* SEI Perspectives. Retrieved from: https://www.sei.org/perspectives/what-is-holding-back-the-promise-of-nature-based-solutions-for-climate-change-adaptation

outcomes, including the violation of human rights, and to ensure long-term sustainability of NbS investments, proper monitoring and regulation of NbS investments is critical.[94] Engaging in training, building understanding and capacities on NbS, and exploring innovative financing mechanisms for NbS creates opportunities for enhanced financing of NbS from the public and private sector.

Lack of policy integration

As clarified by the case studies, NbS planning and implementation face the challenge of managing multiple, sometimes competing, objectives. Different stakeholders and users have distinct perspectives on the use of ecosystem services and NbS. It becomes challenging for policies to address all interests involved and create a suitable and just framework for trade-offs between actors and sectors. Due to a variety of factors, NbS are sometimes perceived as less effective and more time-intensive when compared to gray solutions.[95] Political decision makers often prefer short- or medium-term outcomes and less uncertainty, making NbS potentially less attractive.[96] Implementing NbS takes time and requires adaptive approaches. This can be challenging when integrating them to existing plans and political strategies. Nevertheless, the mainstreaming of NbS in NDC- and NBSAP- related processes is inevitable.

The case study from Zambia pointed out that catchment protection measures usually take longer to yield positive effects. The project therefore combined measures which produce short-term results with long-term oriented measures. Combining different measures with varied timescales can create great opportunities for enhanced support by a wider range of stakeholders. Combining activities with outcomes on distinct time scales enables sustained resilience by focusing on positive results in the short-, medium-, and long-term.

The Bolivian case highlighted that one of the main challenges to guarantee the sustainability of the freshwater NbS is the incorporation into public policies. Here the upper Paraguá territorial management committee is supporting the process, and has managed to incorporate the Paraguá wetland into the national program for the integrated management of Ramsar sites and wetlands, which depends on the Ministry of Environment and Water. This policy integration can help attract additional finance as well as support for the continuation of these projects over the medium- to long-term.

Recommendations for Maximizing Synergies between National Climate and Biodiversity Agendas to Tackle the Triple Planetary Crisis

The policy recommendations listed below have been formulated in consultation with the case study authors included in this report and build on a joint event organized by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the International Union for the Conservation of Nature (IUCN), and the Alliance for Global Water Adaptation (AGWA) at the 2022 World Water Week in Stockholm, Sweden. While not every recommendation will be equally applicable in all cases, our hope is that they provide a solid entry point for countries looking to maximize the effectiveness and longevity of their climate change and biodiversity strategies.

94 Chami, R., Cosimano, T., Fullenkamp, C., & Nieburg, D. 2022. Toward a Nature-Based Economy. *Front Clim*, 4.

95 Dominique, K., Matthews, N., Danielson, L., & Matthews, J. H. 2021. Why governments embrace nature-based solutions: The policy rationale. In *Nature-based Solutions and Water Security* (pp. 109-124). Elsevier.

96 Seddon, N., Chausson, A., Berry, P., Girardin, C. A., Smith, A., & Turner, B. 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B*, *375*(1794), 20190120.

Recommendations for climate planners:

1. **Screen existing climate change policies and plans, including NDCs and NAPs, for water- and ecosystem-related risks in order to better understand the potential impacts of climate change mitigation and adaptation activities on water security and biodiversity.** Strategies to reduce carbon emissions from the agriculture, transportation, or energy sectors — such as transitioning to electric vehicles or utilizing biofuels, wind, and hydropower — as well as investments in terrestrial or marine NbS all have the potential to affect freshwater ecosystems, both positively and negatively. Understanding these interactions is important to robust decision making, can help evaluate trade-offs between different management objectives, and, most critically, help avoid maladaptation. Monitoring the effects of these activities on freshwater ecosystems from the start of project implementation over time will also be important to document any unintended consequences and learn more about which interventions work, or don't, in a given context as part of an adaptive management process.

2. **Consider how adding green or hybrid infrastructure such as floodplain reconstruction or managed aquifer recharge might safeguard existing climate investments and improve the reliability of those projects over time.** For example, investments in passive solar housing, green buildings, or alternative cropping strategies may be at risk if they are placed in areas prone to flooding or drought, or if the surrounding ecosystems are degraded. Freshwater-based NbS including those featured in this paper can help mitigate these risks and provide additional robustness and flexibility as conditions change. However, it is also important to note that in some cases, there will be so-called hard limits to the adaptive capacity of NbS to provide their intended benefits. This underscores the urgent need to simultaneously limit average global temperature increases to well below 2°C.

3. **Before developing new national climate strategies, work with local and regional stakeholders — including municipalities and planners, farmers associations, utility operators, businesses, indigenous and civil society organizations — to identify critical freshwater ecosystem services in their region and develop a common understanding and vision for what is needed to protect those services.** Some questions to jointly consider with stakeholders: For each ecosystem service, are there existing protection measures in place? Are those measures themselves vulnerable to a changing climate? Where no such measures exist, work with the community members to co-design adaptive ecosystem management protection strategies. Insufficient community engagement is a key barrier to the widespread adoption of sound NbS strategies, and can lead to the unintended consequences of displacement, further marginalization of vulnerable populations, and maladaptation. Ensuring stakeholder engagement from the start is essential.

4. **Coordinate the development of new climate plans, including NDCs and NAPs, with agencies or individuals responsible for developing NBSAPs and other national natural resource management plans to ensure coherence and compatibility between national strategies.** This will help identify areas where freshwater-based ecosystem services can be utilized as NbS for both strengthening biodiversity and addressing climate change, and where trade-offs between different management objectives may need to be considered and monitored.

5. **Strengthen the capacity of cities and rural areas in climate change adaptation and climate resilience, especially in vulnerable areas, by helping improve sustainable use of land and natural resources, strengthen water security, and enhance green infrastructure and disaster risk management.** Lack of capacity and knowledge are commonly-cited barriers to the wider uptake of NbS. Furthermore, there can also be conflict between resource users, which may undermine the adoption of NbS. This further underscores the need to bring everyone to the table before implementation to work on shared vision planning.

Recommendations for environmental / natural resource managers and planners:

1. **Promote the active conservation of existing freshwater ecosystems using resilience-based management approaches that encompass the entire catchment and its inhabitants.** Prioritize management objectives that reduce external pressures, especially land use changes, on the system and allow it to adapt, thus reducing the likelihood that the system will reach thresholds beyond which it cannot recover. Where transformation is not possible, support efforts to ease the transition to the extent possible, be it by providing refugia for species or focusing on maintaining the underlying structure and function of an ecosystem.

2. **Conduct a comprehensive climate risk assessment of your current portfolio of biodiversity protection policies and projects to help plan for a more uncertain climate future.** Freshwater ecosystems are highly sensitive to changing precipitation patterns. But, the effects are unevenly distributed and are mediated by a wide range of context-specific factors such as soil moisture, vegetation cover, elevation, underlying geology, and land use, among others. Existing management plans need to be adapted to consider a range of different climate futures and how they might affect the ability of the current policies and projects to achieve their desired outcomes.

3. **Coordinate the development, implementation, monitoring, and evaluation of new NBSAPs setting clear restoration goals that take into consideration climate uncertainty as well as all relevant stakeholders.** Identify complementary objectives that could benefit from freshwater NbS interventions, as well as areas of divergence that may need to be managed to ensure that competing objectives do not undermine the overall success of either plan.

4. **Prioritize locally-led freshwater ecosystem management and support capacity building efforts at all levels to increase understanding of the benefits of healthy freshwater ecosystems for human resilience, as well as different nature-based interventions available to reduce climate impacts and support biodiversity.** Given that water is a fundamentally local resource connected to a much larger hydrological system which often crosses political and geographic boundaries, efforts to connect national policies, such as NBSAPs, to local management should be adopted. Similarly, these policies should also be connected to any transboundary water management agreements to ensure that upstream-downstream interactions are not negatively impacted.

5. **Work beyond single ecosystems to restore and protect the connectivity of interdependent terrestrial, freshwater, marine, and coastal ecosystems at a landscape scale.** Fragmentation of habitats and ecosystems is currently one of the most serious threats to biodiversity worldwide; maintaining connectivity is crucial to facilitate species movements between different habitats. Freshwater NbS support the maintenance of terrestrial, coastal, and marine ecosystems and should be considered as a key component of all natural resource management plans and policies. For example, forest conservation measures should include forest hydrology elements, including monitoring, to better understand forest-water interactions and how changes to the forest ecosystem impacts freshwater and vice versa.