frontiers | Frontiers in Environmental Science

TYPE Editorial
PUBLISHED 13 December 2022
DOI 10.3389/fenvs.2022.1101919

Editorial: Nature-based solutions for natural hazards and climate change

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OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Interdisciplinary Climate Studies, a section of the journal Frontiers in Environmental Science

RECEIVED 18 November 2022
ACCEPTED 24 November 2022
PUBLISHED 13 December 2022

CITATION
Reguero BG, Renaud FG, Van Zanten B, Cohen-Shacham E, Beck MW, Di Sabatino S and Jongman B (2022), Editorial: Nature-based solutions for natural hazards and climate change. *Front. Environ. Sci.* 10:1101919. doi: 10.3389/fenvs.2022.1101919

KEYWORDS

nature-based solutions, climate change, natural hazards, disaster risk, risk management, nature-based adaptation, ecosystem-based adaptation

Editorial on the Research Topic
Nature-based solutions for natural hazards and climate change

Manuscript contribution to the field *

The interactions between the coupled systems of climate, ecosystems and human society increasingly represent the basis of emerging risks. Nature-based Solutions (NbS) are increasingly seen in this context as a fundamental approach to address natural hazards and climate risks. Despite the global momentum for NbS in climate and environmental agendas, their implementation and uptake face policy, institutional, technical and financial challenges. This multidisciplinary collection demonstrates the increasing scientific evidence on the effectiveness of NbS for natural hazards and climate risks, which is essential to increase acceptance and uptake. The examples, case studies and experiences presented across watersheds, agricultural lands, and coastlines, urban and rural settings, offer new knowledge to address key challenges and demonstrate the potential of NbS to align climate, environmental and sustainable development goals. The collection aims to help advance the use of NbS in multiple contexts, but especially in regions at the forefront of climate change and natural hazard risks.

Why a focus on nature-based solutions for natural hazards and climate change?

Climate change, environmental degradation, and disasters from natural hazards are some of the most pressing global threats society faces today. The interactions between the coupled systems of climate, ecosystems (including biodiversity) and human society increasingly represent the basis of emerging risks (IPCC 2022) (Figure 1). This collection on "Nature-based Solutions for natural hazards and climate change" exemplifies such needed integration of knowledge across the natural, ecological, social and economic sciences.

From 2000 to 2019, 7,348 major recorded disasters claimed 1.23 million lives and affected 4.2 billion people resulting in approximately US$2.97 rillion in global economic losses (UNDRR 2020). This represents a sharp increase over the previous two decades, which is explained by a rise in climate-related disasters, including extreme weather events. The economic cost from climate-related events, caused by atmospheric-driven phenomena, totaled $329 billion in 2021 and marked the third-highest loss on record after adjusting for inflation, only behind the years 2017 and 2005 (AON 2021). Human-induced climate change is also affecting extreme events and causing widespread impacts to people and nature, beyond natural climate variability (IPCC 2022). In developing countries and areas most exposed to climate change, climate impacts exacerbate existing vulnerability and injustices, undermining sustainable development efforts (IPCC 2022).

Nature-based Solutions (NbS) are increasingly seen as a fundamental approach to address these challenges and an essential component to achieve the goals of the Paris Agreement on Climate Change (UNFCCC 2015) and of the Sendai Framework for Disaster Risk Reduction (UNISDR 2015). There are multiple definitions of NbS. However, the Fifth session of the United Nations Environment Assembly of the United Nations Environment Programme adopted a multilaterally agreed definition as (UNEP 2022): "*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*". Therefore, NbS can be considered central to Climate Resilient Development, as conceptual and operational framework to deal with climate risks, adaptation, and mitigation efforts, while also benefiting the environment and human well-being. NbS also underpin the Sustainable Development Goals, by enhancing the provision of vital ecosystem services and job creation (e.g., Edwards et al., 2013).

Despite the increasing momentum for NbS across global climate and biodiversity agendas, implementation remains rather limited (IPCC 2022). While investments in NbS for natural hazards and climate change are increasing, both in emerging and advanced economies, much more is needed for NbS to effectively complement gray infrastructure for climate adaptation (UNEP 2021; UNFCCC 2022; World Bank 2022). Barriers to bringing NbS investment to scale include policy, institutional, technical and financial challenges. This Research Topic provides a collection of evidence, new findings and insights that contribute to address some of these challenges to advance NbS for climate resilience across NbS types and environments, including coastlines, forests, watersheds, agriculture and small islands. The different contributions are summarized below.

Summary of contributions

The articles in this collection provide multidisciplinary insights and scientific evidence on the effectiveness of NbS for reducing impacts from natural hazards and climate risks; recommendations for the planning and design of NbS; and case studies on their benefits.

As editors, we highlight six particularly compelling conclusions from the contributions that are essential to increase acceptance and uptake of NbS are:

1) It is possible to identify the conditions under which NbS can effectively deliver critical risk reduction benefits;
2) The knowledge base on the effectiveness of NbS is rapidly increasing;
3) Addressing stakeholder acceptance and perceptions are critical to increase the uptake and scale of NbS projects, and collaborative co-design and participatory approaches can help;
4) Large-scale experiences with NbS in watersheds for flood mitigation have been proved to deliver environmental benefits.
5) Lack of economic information on benefits and costs remains a key barrier to broader uptake of NbS.

The specific contributions are summarized below:

1. It is possible to identify the conditions under which NbS can effectively deliver critical risk reduction benefits;

Roelvink et al. uses physics-based simulations to investigate where coral reef restoration projects could be most effectively implemented for reducing coastal flooding. The study compares different types of reefs morphology and offers important guidance for reef-based coastal protection demonstrating that the flood reduction effectiveness of a project can vary significantly depending on the reef profile types, location and dimensions. As a result, coastlines fronted by three-slope profiles are relatively unprotected from wave action in unrestored conditions, but could benefit the most from reef restoration projects.

Van Bijsterveldt et al. provides insight for optimizing mangrove restoration, one of the most widely used NbS globally, by combining planting with ecological restoration, which relies on natural mangrove regeneration by facilitating trapping seeds in target ponds. However, seaward mangrove expansion through planting alone, without additional measures to restore mangrove habitat, are likely to be unsuccessful and represent poor practices (or similarly, planting non-pioneer species at newly colonized sites).

In many cases, NbS will be combined with engineered or "grey" measures in hybrid approaches. One good example is the use of vegetation to add safety to engineered structures. Schoutens et al. provide the first direct experimental proof of the stability of marshes during breaching scenarios and high flow velocities showing that they could mitigate water flow during discharges after a dike is breached. Historic analysis from flood disasters in North Europe have shown that saltmarshes reduce the chance and size of the breaching of engineered defenses by reducing water flow (Zhu et al., 2020). The article by Schoutens et al. provides new important insight for using marshes in multi-layer defense systems and dike strengthening strategies, with potential application in many countries.

2. The knowledge base on the effectiveness of NbS is rapidly increasing.

Moraes et al. provides a review of implemented cases and projects in coastal and estuarine areas of Europe, to capitalize on lessons learnt and support future implementation. The results show an increasing number of experiences between 2005 and 2015, but dominated by hybrid designs and restoration projects, mostly for wetlands, while the creation of new habitat represents

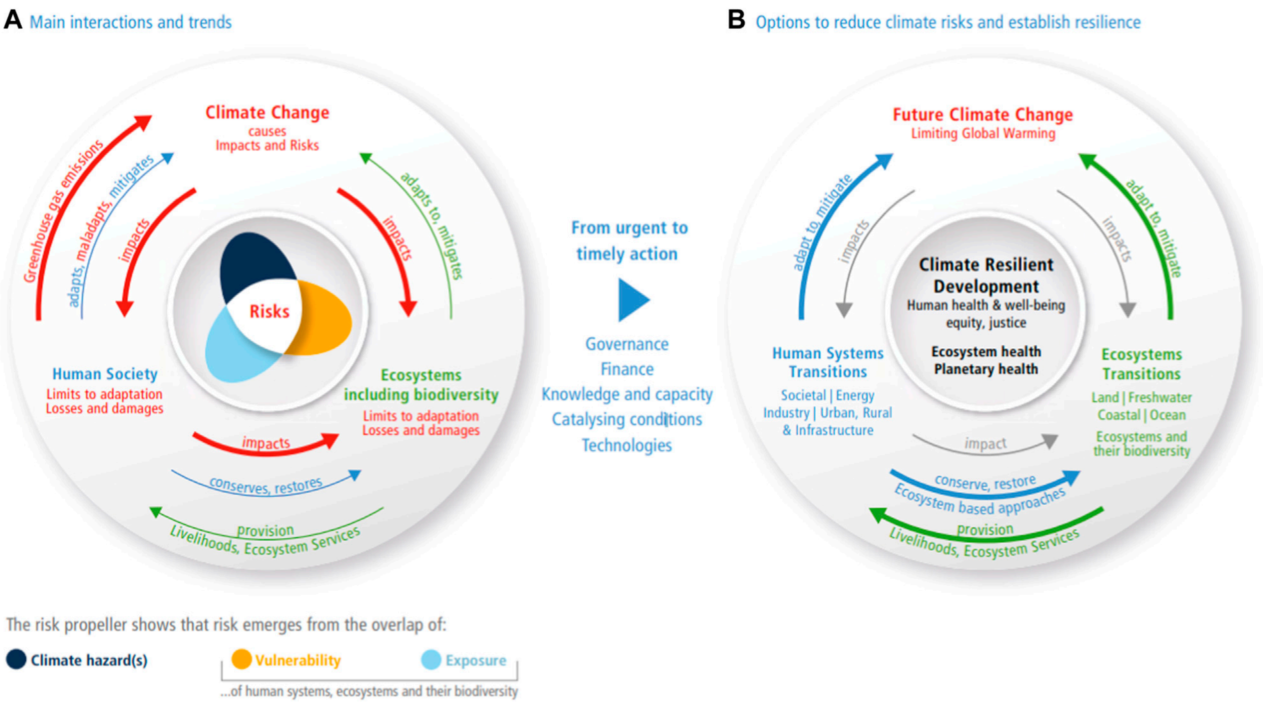

FIGURE 1
From climate risk to climate resilient development: climate, ecosystems (including biodiversity) and human society as coupled systems. Interactions among the coupled systems climate, ecosystems (including their biodiversity) and human society are the basis of emerging risks from climate change, ecosystem degradation and biodiversity loss and, at the same time, offer opportunities for the future. **(A)** Human society causes climate change. Climate change, through hazards, exposure and vulnerability generates impacts and risks that can surpass limits to adaptation and result in losses and damages. Human society can adapt to, maladapt and mitigate climate change, ecosystems can adapt and mitigate within limits. Ecosystems and their biodiversity provision livelihoods and ecosystem services. Human society impacts ecosystems and can restore and conserve them. **(B)** Meeting the objectives of climate resilient development thereby supporting human, ecosystem and planetary health, as well as human well-being, requires society and ecosystems to move over (transition) to a more resilient state. The recognition of climate risks can strengthen adaptation and mitigation actions and transitions that reduce risks. Taking action is enabled by governance, finance, knowledge and capacity building, technology and catalysing conditions. Transformation entails system transitions strengthening the resilience of ecosystems and society (Section E in IPCC, 2022). In **(A)** arrow colours represent principle human society interactions (blue), ecosystem (including biodiversity) interactions (green) and the impacts of climate change and human activities, including losses and damages, under continued climate change (red). In **(B)** arrow colours represent human system interactions (blue), ecosystem (including biodiversity) interactions (green) and reduced impacts from climate change and human activities (grey). Taken from: IPCC, 2022, Figure TS.2, page 42, and chapter 1.2, Figure 1.2.

only 20% of the projects. Most of the projects were supported by more than one funding source, which highlights the importance of co-financing, although they overwhelmingly relied on public funding sources. The analysis also reveals a lack of reporting of monitoring and co-benefits, which are often used to promote the project but that remain, in most cases, largely unquantified. The review may be timely, given that 37% of the European Recovery and Resilience Facility (about 267 billion euros) could support climate investments and reforms that may include coastal NbS for adaptation and mitigation benefits (European Commission 2021).

Kiddle et al. presents examples of nature-based approaches to adapt and mitigate the impacts of climate change and urbanization in Pacific islands, which are on the frontline and amongst the most vulnerable to the impacts of climate change (IPCC, 2022). Based on the analyses of experiences in three Pacific Island Nations, Kiddle et al. highlights the critical role of traditional ecological knowledge in shaping localized, place-based, nature-based adaptation. Solutions like "ridge to reef" approaches, restoration and protection of coastal vegetation and watersheds, or the intensification of home gardens and urban greening, are increasingly available for Small Island Developing States.

Smith et al. further contributes to the effectiveness evidence base by reviewing NbS experiences in Bangladesh for the mitigation of climate impacts and natural hazards and their contribution to sustainable development. Bangladesh is one of the most climate vulnerable countries in the world, where climate risks are compounded by environmental degradation and socio-economic challenges. Smith et al. finds robust evidence that, across landscapes, well-designed NbS can be effective in reducing hazard risks, adapting to climate change and reducing greenhouse gas emissions, while empowering marginalized groups, reducing poverty, supporting local economies and enhancing biodiversity. Furthermore, four enabling factors can maximize benefits: policy support; participatory approaches; strong and transparent governance; and finance and land tenure.

NbS can also be effective against landslides and erosion events, through interventions that reinforce slopes with vegetation. Gonzalez-Ollauri et al. propose a comprehensive set of key performance indicators towards building a more robust evidence base on NbS performance for landslide and erosion prevention. The proposed framework aims to address a gap in demonstrating the multifunctional performance of nature-based landslide prevention and mitigation, by combining indicators and metrics that balance monitoring, engineering performance, and the provision of ecosystem functions and services.

Yet, gaps in knowledge across landscapes remain. Simelton et al. find limited evidence for and underutilization of NbS in agricultural systems, especially in developing countries. The authors propose a framework that establishes four essential functions to add functionality, purpose and scale when designing NbS in agriculture projects, which aims to overcome the divide between production- and conservation-oriented approaches. Key challenges involve economic valuations; social aspects, like farmers' willingness to adopt new practices; and policy dimensions, which should address governance barriers.

3. Addressing stakeholder acceptance and perceptions are critical to increase the uptake and scale of NbS projects, and collaborative co-design and participatory approaches can help.

Lupp et al. discuss the implementation of NbS through participative approaches, and studies stakeholder perceptions of NbS in rural mountain areas, which have been less attended by research compared to urban contexts. Despite the importance of NbS in the political and research agendas, they find limited knowledge at the on-the-ground level. In rural mountain areas, many landowners (in particular farmers) initially perceive NbS as a limitation to economic outcomes of their land, in contrast with urban areas, where public landowners or real estate developers may be more attracted by the creation of multiple co-benefits. Despite these challenges, upscaling and replication of good NbS interventions were perceived to be an attractive opportunity. As a solution, they recommend creating economic and business cases based on real-life examples.

Anderson et al. examine public acceptance of NbS, by exploring interactions between societal attitudes and values towards risk, nature, and place. The authors use surveys from three distinct sites where specific hazards are addressed through NbS: landslides and coastal erosion; eutrophication and algal blooms; and river flooding and water scarcity. Their findings confirm demand for evidence of effectiveness of NbS to counter initial skepticism, hesitant attitudes and cautious positive perceptions. To increase public acceptance, they recommend framing NbS in relation to place-based values, historic characteristics, and evidence of the effectiveness of projects for risk reduction.

Similarly, O'Donnell et al. investigate resident perceptions of the performance of mangroves, beaches and hardened shorelines after Hurricane Irma in the lower Florida Keys. Their study indicates a disconnect between perceptions and performance outcomes: although mangroves cost less to repair (averaging $64.33 USD per meter) than hardened shorelines ($105.14 USD per meter) and were perceived as the most effective for storm protection, the majority of Florida Keys residents own hardened shorelines. Beaches were perceived as the most damaged shoreline type, followed by mangroves, and hardened shorelines. The study provides important timely guidance in the aftermath of hurricane Ian (2022) in the Caribbean and Florida, but it is also useful in long-term strategies given the increasing impacts of tropical cyclones globally.

4. Large-scale experiences with NbS in watersheds for flood mitigation have been proved to deliver environmental benefits.

Gooden and Pritzlaff discuss "Dryland Watershed Restoration with Rock Detention Structures" as NbS to address land degradation, mitigate drought, watershed erosion and flooding, and contribute to revegetation. In the arid southwestern United States and northern Mexico, rock detention structures (RDS) are a technology adapted from traditional indigenous practices that include a variety of types, such as check dams, one rock dams, and gabions. RDS can represent simple, cost effective, hand-built solutions, with proven positive impacts on stream flow, reduction of peak runoff, and increased sedimentation. They also indicate benefits for increased biodiversity and wildlife abundance, increased in vegetative cover; and surface water provisioning over time. However, five barriers to replication and scalability include: limited awareness of degradation and benefits of restoration; lack of legislation, policies, and regulation; technical capacity; finance; and research on costs and carbon sequestration potential.

Norman provides commentary on the potential of RDS for land restoration. Norman describes RDS scalability throughout landscapes, perseverance over time, and contributions to a restoration stewardship economy that supports RDS. In particular, the commentary elaborates on the scalability in space and time of RDS and how they differ from green infrastructure in built environments, which is implemented to passively harvest rainwater. Instead of retaining water, RDS are designed for allowing water to slowly pass through, infiltrate the soils and regenerate landscapes. The commentary also provides more information on their costs and benefits, one of the critical gaps.

Kasada et al. examine the influence on flood hazard and biodiversity of land-use pattern changes in rural Japan. The study demonstrates that land-use change can reduce flood risk while also positively influencing species richness and abundance. The demonstrated benefits in local biodiversity of targeted management of an agricultural landscape (dominated by paddy fields) fill a gap in the lack of quantitative evaluations of the impacts of ecosystem-based disaster risk reduction on biodiversity.

5. Lack of economic information on benefits and costs remains a key barrier to broader uptake of NbS.

To guide investments in NbS, stated preference studies have become a common tool to evaluate the benefits of NbS in developing countries. Hagedoorn et al. provide a comparison of time and money payment methods for evaluating the willingness to pay in Ghana. In "money payments", respondents make trade-offs between changes in ecosystem services and monetary compensation. Time payments, however, serve as an alternative where the willingness to pay is also a function of non-monetary contributions (e.g., time). The authors suggest that a combination of wage-based and non-wage-based conversion approaches is the most adequate approach to convert time to money valuations.

The examples, case studies and experiences presented across watersheds, agricultural lands, and coastlines in both urban and rural settings, add new knowledge to address key challenges of NbS and further demonstrate their potential to align climate, environmental and sustainable development goals. Overall this collection helps advance our understanding of the scalability and uptake of NbS in multiple contexts, but especially in regions at the forefront of climate change and natural hazard risks.

Author contributions

BGR wrote the first version of this editorial. All the editors contributed to the final version of this Editorial.

Acknowledgments

All the editors also thank the reviewers for their service, insight, and comments during the revisions of this Research Topic. BR acknowledges the support from an Early-Career Research Fellowship from the Gulf Research Program of the National Academies of Sciences, Engineering, and Medicine for the support provided during the guest editorial service that enable this Research Topic, although the content is solely responsibility of the authors and does not necessarily represent the official views of the Gulf Research Program of the National Academy.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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