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Supplementary Information

The Evolution and Future of Research on Nature-based Solutions to Address Societal Challenges

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The supplementary information presented below comprises the following:

- **Supplementary Fig. 1** with accompanying text on the keyword analysis.
- **Supplementary Discussion** to provide additional background information on the four understudied societal challenges and the applications of NbS within these fields.

Keyword Analysis

To complement the evaluation of the global distribution of research production in **Fig. 2**, an analysis of 'Author Keywords' was conducted to understand the five most prevalent terms across the NbS research landscape for the 20 countries with the highest proportion of research production (see countries list in **Supplementary Fig. 1**). This analysis demonstrates that among these 20 countries, 'Nature-based Solutions' is only in the top five keywords for European countries. The top keyword for each of the 20 countries is one of the diverse ecosystem-based/related approaches within the 'NbS' umbrella: 'ecological restoration', or 'green infrastructure'. Other common terms include 'ecosystem services', 'biodiversity' and 'climate change'.

1. USA	2. China	3. United Kingdom	4. Australia	5. Germany
ecological restoration	ecological restoration	green infrastructure	ecological restoration	green infrastructure
green infrastructure	green infrastructure	nature-based solutions	green infrastructure	ecosystem services
ecosystem services	climate change	ecosystem services	climate change	nature-based solutions
restoration	ecosystem services	ecological restoration	ecosystem services	ecological restoration
climate change	ecological engineering	climate change	restoration	biodiversity

6. Canada	7. Italy	8. Spain	9. France	10. Netherlands
ecological restoration	green infrastructure	ecological restoration	ecological restoration	nature-based solutions
green infrastructure	nature-based solutions	green infrastructure	ecological engineering	green infrastructure
climate change	ecosystem services	ecosystem services	ecosystem services	ecological restoration
ecosystem restoration	green infrastructures	nature-based solutions	restoration	ecosystem services
ecosystem services	climate change	climate change	nature-based solutions	climate change

11. Brazil	12. Sweden	13. India	14. New Zealand	15. Poland
ecological restoration	green infrastructure	ecological restoration	ecological restoration	green infrastructure
ecosystem services	nature-based solutions	green infrastructure	green infrastructure	nature-based solutions
green infrastructure	ecosystem services	climate change	ecosystem services	ecosystem services
natural regeneration	ecological restoration	ecological engineering	restoration	ecological restoration
forest restoration	biodiversity	restoration	biodiversity	urban greening

16. South Africa	17. Portugal	18. Japan	19. Switzerland	20. Mexico
ecological restoration	nature-based solutions	green infrastructure	ecological restoration	ecological restoration
ecosystem services	green infrastructure	ecological restoration	green infrastructure	green infrastructure
green infrastructure	ecosystem services	ecosystem services	biodiversity	biodiversity
biodiversity	ecological restoration	climate change	ecosystem services	ecosystem services
resilience	biodiversity	biodiversity	nature-based solutions	conservation

Supplementary Fig. 1: *Summary of the top 5 'Author Keywords' found in NbS research for the 20 countries with the highest proportion of NbS research production. The colour gradient of the headings corresponds to the proportion of research production for each country as per the colour gradient in Fig. 2a.*

Supplementary Discussion

Economic and social development

Economically, NbS can generate revenue streams through various sectors such as eco-tourism, and sustainable agriculture. For example, protecting and restoring wetlands can improve water quality, mitigate flood risks, and provide recreational opportunities, thereby benefiting local economies. Socially, NbS can contribute to improved public health and well-being, enhance community resilience to climate change, and promote social cohesion. Green spaces, urban parks, and green infrastructure can have positive social impacts as gathering places where people can come together, socialise, and engage in recreational activities. Urban parks often host community events, festivals, and cultural activities that foster a sense of belonging, strengthen social ties, and promote community cohesion. Addressing social and economic challenges through NbS is critical to the reduction of poverty (SDG 1)[1], and contributions can have long-lasting impacts.

Providing employment opportunities can contribute to the alleviation of poverty and contribute to decent work[2] and economic growth, as outlined in the United Nations' Sustainable Development Goals[1]. Specifically, the implementation of NbS requires skilled workers, and thus can provide jobs in fields such as landscaping, ecological restoration, biodiversity monitoring, and nature-based tourism. Through nature-based tourism, NbS can stimulate economic benefits for local communities by attracting visitors, leading to revenue generation and job creation in sectors like hospitality, guiding services, and local businesses. This fosters economic development while promoting the appreciation and conservation of biodiversity and natural resources.

The conservation of natural resources can contribute to the improvement of social and economic livelihoods through sustainable agricultural practices. These practices contribute to

increased productivity, food security, and resilience to climate change, while also offering market opportunities for sustainably produced agricultural products. With NbS interventions also improving air quality and providing healthier and more liveable cities, these market opportunities can attract new businesses, answering to an increasing demand for sustainable and environmentally friendly products and services. Businesses that specialise in designing, implementing, and maintaining nature-based solutions can seize these opportunities by providing innovative solutions to address urban challenges and meet the needs of both public and private sector clients.

NbS interventions can further promote disaster risk reduction and build community resilience**.** For example, coastal ecosystems, such as mangroves and oyster reefs, act as natural buffers against storm surges and coastal erosion[3]. Protecting and restoring these ecosystems can save lives, reduce property damage, and enhance community resilience to natural disasters, resulting in cost savings and economic stability. This harmonious relationship between human activities and the environment can be established by adopting a nature-positive economy (NPE) pathway.

Human Health

Human health is defined by the World Health Organization (WHO)[4] as a state *"of complete physical, mental and social well-being and not merely the absence of disease or infirmity"*. This definition recognises that humans are not sole entities but depend on mental and social connections to live healthy lives. Later concepts, such as Planetary Health[5], further recognise the intertwined relationship between human health and natural systems and that collaborations across disciplines are required to understand and address the health challenges that are related to environmental degradation, biodiversity loss, and climate change. Within this context, research on NbS that incorporates human health as an important variable, may

provide new evidence that could promote the use of NbS in policies and planning for healthy lives across the life course, and across generations.

According to the Global Burden of Disease (GBD) study[6], the dominating disease burden in the Global North is related to environments and lifestyles, and consists of chronic diseases, such as cardiovascular disorders and stroke. In some parts of the Global South, infectious diseases are still dominating, but as urbanisation increases, non-communicable, chronic diseases are expected to surge[7].

NbS have untapped potential for addressing these conditions, both directly and indirectly. There are many links between healthy, natural environments and various health behaviours and outcomes, and the evidence for numerous pathways is increasing[8]. Urban green spaces provide opportunities for physical activity, social connections, and stress relief and numerous studies demonstrate that these result in significant health benefits, such as reduced prevalence of depression, and improved life satisfaction and academic performance[9]. NbS in cities can also include tree planting and management programmes to reduce ambient air pollution (the world's greatest killer[10]) and heat-related morbidity and mortality, a threat that is increasing with global warming. Biodiversity can be enhanced through NbS activities, and this improves human health by contributing to a richer human microbiome with a positive impact on the immune system, especially in childhood[11]. Finally, it shall be noted that climate change is itself defined as the greatest global health hazard facing the world[12], and NbS that are aimed at mitigating climate change thus have implicit benefits for human health. There are also numerous co-benefits to be gained. For example, forest-based carbon sink strategies can provide or improve areas for recreation and other cultural ecosystem services with positive bearing on population health[13].

Because of the large societal impact of contemporary health challenges, including life-long conditions and direct consequences of climate change and harmful environmental exposures,

bottom-up solutions like NbS tend to be cost-efficient, especially if targeted at vulnerable populations and in areas of the world where the consequences of climate change are disproportionally felt, and the needs are the direst. Using indices for socioeconomic inequalities and environmental vulnerability indicators should provide guidance for where NbS research must be strengthened so that results can be implemented on a local level.

Food Security

Food security is achieved when *"all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life"*[14]. The need for healthy food to always be made available and accessible, is linked to the inherent connection between food production, economic livelihoods, healthy ecosystems, and long-term environmental changes. This relationship is impacted by changes to land use[15], economies and trade[16], water security[17], and human health[18], where conventional solutions that seek to address one aspect of food security may no longer be sufficient. NbS present alternatives that can simultaneously support the restoration and conservation of ecosystems, the sustainable management of fisheries and livestock, and the mitigation of disease outbreaks[19]. The capacity for NbS to be self-sustaining amidst long-term environmental change means that NbS offer continued availability and access to food for communities suffering from chronic and seasonal food insecurity[20]. NbS can subsequently offset the continued costs of direct humanitarian aid, which may instead be used to complement NbS during extreme events and periods of fluctuating food production.

The rise of global hunger and deepening food crises have led to a call for more resilient food systems that can achieve food security and nutrition targets[21]. The introduction of agroecological practices in crop management has seen a reduced reliance on industrial methods for food production and chemical fertilisers for crop growth[22]. For example, the genetic diversity of planted species can increase the resilience of the landscape to extreme

events[23], attract pollinating species, combat the introduction of disease, and enrich crop soils to enhance crop yields[24].

Water Security

Defined as having sustainable access to enough good quality water, the societal challenge of water security is crucial to human life, and ecosystem health. However, water insecurity and scarcity are often addressed at the expense of aquatic and water-dependent ecosystems. Grey infrastructure, such as dams, reservoirs, and canals, heavily impacts hydrological characteristics and environmental processes, often leading to streamflow reduction, dampened ecosystem resilience, and biodiversity loss. NbS have the potential to reverse these impacts and directly improve water security, such as by filtering contaminants from waterways, restoring sustainable groundwater recharge rates, mitigating floods, and reconnecting floodplains. Therefore, research prioritising NbS for water security is required to understand how ecosystems can contribute to the sufficient availability, and fair and just accessibility of clean and fresh water.

NbS concerning freshwater processes are often discussed in terms of disaster risk reduction, where the restoration of rivers and wetlands, and the implementation of (near-natural) retention reservoirs, can mitigate impacts related to riverine floods[25, 26]. Impacts related to extreme precipitation and stormwater management can vastly profit from NbS as a retention measure and to minimise erosion. However, NbS or hybrid solutions, especially in urban areas, can increase infiltration and groundwater recharge rates, mitigating widespread groundwater depletion due to excessive groundwater pumping. The concept of 'Sponge Cities' has become increasingly popular in recent years[27, 28]. The goal is to design urban spaces that minimize runoff losses and allow rainwater to be absorbed, purified, and retained locally within cities where it is most needed. To achieve this, hybrid approaches that combine green and grey infrastructure, such as semi-permeable concrete or porous pavement, green roofs, and

bioswales, can be used in urban areas. These solutions, among others, improve groundwater recharge rates, reduce water pollution, and decrease stormwater peak flows. In addition, the construction or restoration of wetlands can aid in wastewater treatment.

Source water protection, such as upstream wetland restoration and reforestation, can help provide clean and fresh water, mitigate contamination, and assist in protecting and restoring downstream riverine systems[29]. Restoring source watersheds has several advantages for both rural and urban communities downstream. These benefits include, for example, reduced water treatment costs due to minimized nutrient and sediment pollution, ensuring reliable and steady flows, and better access to clean water for rural and agricultural communities. There is significant potential for utilising nature-based solutions in agricultural practices and irrigation. A variety of nature-based soil conservation and water management measures can, for example, increase soil water holding capacities, irrigation efficiency, and water quality.

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