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Scoping review: what is the state of knowledge on the role of biodiversity in the design, delivery and benefits of Nature-Based Solutions?

The James Hutton Institute

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What is Biodiversa+

Biodiversa+ is the new European co-funded biodiversity partnership supporting excellent research on biodiversity with an impact for policy and society. It was jointly developed by BiodivERsA and the European Commission (DG Research & Innovation and DG Environment) and was officially launched on 1 October 2021.

Biodiversa+ is part of the European Biodiversity Strategy for 2030 that aims to put Europe's biodiversity on a path to recovery by 2030.

The Partnership aims to connect science, policy and practise for transformative change. It currently gathers 80 research programmers and funders and environmental policy actors from 40 European and associated countries to work on 5 main objectives:

1. Plan and support research and innovation on biodiversity through a shared strategy, annual joint calls for research projects and capacity building activities
2. Set up a network of harmonised schemes to improve monitoring of biodiversity and ecosystem services across Europe
3. Contribute to high-end knowledge for deploying Nature-Based Solutions and valuation of biodiversity in the private sector
4. Ensure efficient science-based support for policy-making and implementation in Europe
5. Strengthen the relevance and impact of pan-European research on biodiversity in a global context

More information at: https://www.biodiversa.eu/

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Table of acronyms

BEF	Biodiversity-Ecosystem Function
CBD	Convention on Biological Diversity
COP	Conference of the Parties
EbA	Ecosystem-based Adaptation
EC	European Commission
EU	European Union
EcoDRR	Ecosystem-based Disaster Risk Reduction
EBVs	Essential Biodiversity Variables
GI	Green Infrastructure
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
MEA	Millennium Ecosystem Assessment
NBS	Nature-Based Solutions
NCP	Nature's contributions to people
NWRM	Natural Water Retention Measures
PICO	Population-Intervention-Comparator-Outcome framework
QSR	Quick Scoping Review
TEEB	The Economics of Ecosystems and Biodiversity
UK NEA	United-Kingdom National Ecosystem Assessment
UNEA	UN Environmental Assembly
UNDP	UN Development Programme
WOSCC	Web of Science Core Collection

Executive summary

Key messages

- A Quick Scoping Review of the peer-reviewed literature on the role of biodiversity in nature-based solutions (NBS) revealed a broad and relatively recent evidence base of 45 articles and 48 NBS cases, covering a wide range of journal types, geographic locations, NBS types, type of ecosystems, taxonomic species, biodiversity metrics, issues addressed and NBS outcomes, but with important evidence gaps.
- Biodiversity may play multiple roles in NBS by delivering: supporting ecosystem services (ES) and ecosystem or biological processes that underpin the delivery of regulating, provisioning and cultural services (supporting role of biodiversity); regulating ecosystem services (regulating role of biodiversity); direct material or non-material contributions to people through provisioning and cultural services, respectively (Living nature's material and non-material contributions to people).
- Four types of NBS and their combinations were reported in the evidence base: NBS1-Protection and conservation (8 cases); NBS2-Sustainable management (21 cases); NBS3-Restoration (9 cases); NBS4-Habitat Creation (5 cases); and NBS5-Combinations of management and protection, restoration of habitat creation actions (5 cases) This suggested that 43.75% of the evidence base comprised cases exploring the role of biodiversity in NBS2-Sustainable management.
- Topics and terms that frequently co-occurred with the terms biodiversity and NBS across the evidence base, suggesting strong relatedness, included: crop diversification, pollination service, ecological intensification, agroecological practice, soil fertility, sustainability, and pest control.
- The interventions that were considered as NBS by their authors took place across a wide range of geographic and climatic regions except polar regions and Oceania. Most studies were implemented in terrestrial ecosystems (33 out of 45), of which 18 referred to farming and agroforestry systems and 12 to forests, and the remainder to grasslands, riparian areas, and drylands. Ten studies were implemented in coastal/marine ecosystems.
- The taxa investigated for their role on NBS outcomes in the selected studies belonged to five kingdoms (Animalia, Plantae, Fungi, Protista, and Eubacteria). Trees, insects, and marine benthic invertebrates were the most common types of taxa reported. Trees, including shrubs, were used in NBS2 (forestry, agroforestry, ecosystem-based disaster risk reduction (EcoDRR)), NBS3 (forest restoration for multiple benefits, including water quantity regulation) and NBS4 (studies reporting evidence on created urban parks). Insects were commonly used in NBS2. Marine invertebrates were reported in all types of NBS (NBS1-4). The role of taxa in NBS was determined by the intended outcomes and the biodiversity metric used.
- The biodiversity metrics used to assess the effectiveness of biodiversity on delivering a measurable NBS outcome across the evidence base were divided into seven broad categories: Biomass, Diversity, Ecosystem composition, Ecosystem functioning and Population dynamics,

Landscape structure, Conservation status, and Perception/Experiential knowledge. The most common category of broad metric used across the evidence base was Diversity (21 studies) and the least common were metrics linking biodiversity directly to the role of NBS in addressing societal challenges, i.e., Conservation status (2 studies). Ten out of 45 studies relied on a single biodiversity metric, such as species abundance, species richness, taxa presence, functional diversity, density, and degree of connectivity and fragmentation within the landscape.

- Five types of NBS outcomes were reported in the evidence base on the role of biodiversity in NBS: climate change mitigation, well-being and health, adaptation and resilience to disasters, food provision and food security, and biodiversity and habitat maintenance.
- The effect of biodiversity (positive, negative, mixed or “no effect”) on NBS outcomes was assessed in 38 cases using different metrics. A positive effect for at least one metric was reported in 28 cases, which included: 13 cases for NBS2-Sustainable management, six cases for NBS3-Restoration, five cases for NBS1-Protection, four cases for NBS4-Habitat creation and two cases for NBS5-Combination of management and restoration or habitat creation actions. A negative effect for at least one metric was reported in five cases and a mixed effect (i.e., when both negative and positive effects of biodiversity metric were reported) in eight cases.
- Overall, the role of biodiversity depended on the biodiversity metric used and intended outcomes. Indeed the role: supporting, regulating, or as material or non-material contributions to people varied among studies for the same type of ecosystem, taxa, metric, and type of NBS. Thus, the role of biodiversity is not intrinsic to the taxa or the metric but is context-specific. The context is determined by the issues that need to be addressed by NBS and the intended outcomes. This finding is consistent with the spirit of the IPBES framework of nature’s contributions to people (NCP), which recognises that there are multiple ways of understanding and categorising relationships between people and nature and avoids leaving these perspectives out of the picture or forcing them into a specific pre-determined category.

Evidence gaps

The Quick Scoping Review identified important evidence gaps across the evidence base.

- Limited use of biodiversity metrics linking biodiversity directly to the role of NBS in addressing societal challenges, such as Conservation status and Perception/Experiential knowledge, and metrics relevant to nature’s contributions to people that could inform decision-making on NBS design and type and the assessment of NBS outcomes.
- Limited use of metrics such as Conservation status, Landscape structure and Public perception of biodiversity (e.g., related to cultural, educational, spiritual or aesthetic values of species and landscapes) compared to other broad categories of metrics.
- Limited evidence on the role of biodiversity in interventions not involving agricultural and agroforestry systems, particularly on how protecting biodiversity addresses societal and

economic challenges and on the role of biodiversity in restoration and creation of artificial habitats and the sustainability of these projects.

- Absence of evidence on:
  - the role of biodiversity in NBS implemented in freshwater ecosystems, such as inland wetlands.
  - the role of terrestrial, freshwater and marine vertebrates in NBS outcomes.
  - material and non-material contributions of biodiversity to people such as energy provision, feed provision, medicinal and biochemical resources, learning and supporting identities.

Recommendations

To address the evidence gaps:

- Identify and develop metrics to directly examine and monitor the effect of multiple dimensions and perceptions of biodiversity on NBS.
- Review existing evidence on conservation status, geospatial imaging and public perceptions of living nature and biodiversity and identify how this evidence could be repurposed to inform their use for NBS or to help design biodiversity metrics for addressing societal challenges with NBS.
- Design the role and metric of biodiversity in NBS from the outset of NBS projects to enable a process of learning by doing (adaptive management) and improvements in their design and implementation.
- Align NBS implementation with existing environmental policies and conservation efforts across the EU, such as EU's Natura 2000 Network of protected areas designated under the Birds and Habitats Directives, as well as upcoming legislation, such as the proposed Nature Restoration Law under the EU Biodiversity Strategy.
- Map policy needs that can be addressed by improving understanding and practices related to the role of biodiversity in NBS.
- Explore how perceptions of biodiversity and contributions, both positive and negative, of living nature (i.e. all organisms, ecosystems, and their associated ecological and evolutionary processes) to people determine stakeholder engagement to support and upscale NBS projects.
- Review the literature on the biodiversity metrics used to quantify the roles of vertebrates in conservation, rewilding, sustainable management, and restoration to put vertebrates in the context of NBS and repurpose existing evidence on vertebrate research for harnessing their role in NBS.

Introduction

This report focuses on the contribution that biodiversity makes to addressing social, economic, and environmental challenges using actions that involve working with nature and are widely known under the umbrella term nature-based solutions (NBS). The report explores the link between biodiversity, ecosystem services and the outcomes (i.e., the benefits) provided to humans by different types of NBS. In doing so, the report looks at the link between biodiversity metric (i.e., how biodiversity is measured), metrics used for assessing NBS outcomes and the role biodiversity plays in delivering these outcomes.

This study aims to provide Biodiversa+, the European Biodiversity Partnership, with a state of knowledge on the various roles biodiversity can play in the design, delivery and benefits of NBS while also summarising the effects of environmental context, time, and geographical scales on NBS performance. The aim is to guide decisions on future calls for research, particularly under the Biodiversa+ flagship programme, "better knowledge to develop, deploy and assess Nature-Based Solutions". The scope, objectives and approach of the study were agreed in consultation with the French Foundation for Research on Biodiversity (FRB) and Biodiversa+ Partners such as the Finnish Ministry of Environment (MoE_FI), the Irish Environmental Protection Agency (EPA), the Slovak Academy of Sciences (SAS), the Swedish Environmental Protection Agency (SEPA), the Italian Ministry of Universities and Research (MUR), and the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas).

Objectives

- Identify existing evidence on how knowledge on the different components of biodiversity (genes, species, ecosystems) and their role in ecosystem services are applied to guide the design, development, and delivery of NBS outcomes, such as climate mitigation, adaptation and resilience to the impacts of climate change, disaster risk management and human well-being.
- Elucidate the role of biodiversity in synergies and/or trade-offs between ecosystem services supported, enhanced, or supplied by NBS and how this influences NBS outcomes.
- Highlight knowledge-gaps, best practices, and barriers to stimulate further research, especially on the extent to which geographical regions, ecosystems, NBS types, and policy are underrepresented in the literature.
- If possible, outline recommendations for actions/steps that can help to integrate biodiversity (all levels) into the design of different NBS strategies and interventions and further systematic reviews or research on emerging trends or concerns.

The report is structured as follows:

- Section 1 contextualises the existing terminologies and perspectives on biodiversity, ecosystem services, nature-based solutions and biodiversity metrics which formed the background to co-developing and co-designing the current evidence review strategy on the roles of biodiversity in NBS.

- Section 2 describes the resources used and key steps of the Quick Scoping Review methodology applied to map the evidence, further detailed in Annex I and a comprehensive spreadsheet presenting the evidence sources and content (i.e., coding of the evidence).
- Section 3 describes empirical, meta-analyses and review studies that provided evidence on the interlinkages between biodiversity, ecosystem services and NBS outcomes, and discusses how biodiversity metrics and contextual information, including NBS type, challenge addressed, ecosystem type, and country/climatic region influence the roles played by biodiversity.
- Section 4 provides the synthesis of available evidence.

1. Brief review of terminology

1.1. Definitions of Nature-Based Solutions

Nature-Based Solutions (NBS) is an umbrella term used to describe a range of established approaches that involve working with nature to cost-effectively address societal and environmental challenges. In addition to being prioritised in the EU policy agenda, there is also substantial policy momentum for NBS in different geographical and policy contexts, including at global level. The terminology depends on context, usually ecosystem type, ecosystem service, or challenge addressed. Depending on the specific context, the NBS umbrella term covers concepts such as Ecosystem-based Adaptation (EbA), Green Infrastructure (GI), Ecosystem-based Disaster Risk Reduction (EcoDRR), and Natural Water Retention Measures (NWRM) (European Commission 2021).

A summary of widely used terms and definitions are given here to help understand the various perspectives on the roles of biodiversity in NBS design (i.e., what challenges are addressed, what types of ecosystems and ecosystem services are targeted, and degree of human intervention) and outcomes (i.e., what types of benefits to humans are to be delivered as solutions, policy context).

1.1.1. Nature-based or ecosystem-based adaptation

The Intergovernmental Panel on Climate Change (IPCC) Glossary defines ecosystem-based adaptation (EbA) as "the use of ecosystem management activities to increase the resilience and reduce the vulnerability of people and ecosystems to climate change" (Campbell et al. 2009 cited in IPCC 2019). In this regard, EbA approaches rely on biodiversity and ecosystem services but also maintain or counteract threats to biodiversity as a co-benefit. For example, the report on Changing Ocean, Marine Ecosystems, and Dependent Communities of IPCC endorses the use of "nature-based or ecosystem-based adaptation" that "uses biodiversity and ecosystem services as part of an overall strategy to help people to adapt to the adverse effects of climate change" (Bindoff et al. 2019). In a similar vein, the UN Development Programme (UNDP) has provided a framework for governments to identify potential NBS for inclusion as mitigation and/or adaptation action in their nationally determined contributions (NDCs) under the Paris Agreement in a cost-effective manner and with multiple co-benefits, including for biodiversity (UNDP 2019). Ecosystems that can act as carbon sinks, support disaster risk reduction (e.g., from extreme weather) or provide alternative sources of food or income, such as forests, mangroves, and saltmarshes, are increasingly considered for their potential as EbA approaches. In the NDCs, biodiversity is delivered as a co-benefit of EbA approaches but EbA effectiveness, i.e., the delivery of multiple ecosystem services, relies on healthy ecosystems.

For example, more biodiverse ecosystems enable greater supply of ecosystem services, such as when niche complementarity (i.e., coexisting species use different forms of a resource) leads to increased biomass production and carbon storage (Qiu and Cardinale, 2020).

1.1.2. Benefits from biodiversity and ecosystem services

The document on the Aichi Biodiversity Targets of the Strategic Plan for Biodiversity 2011–2020 (Decision X/2) by the Convention on Biological Diversity (CBD) envisages a world of "living in harmony with nature", a term considered to refer to NBS (CBD COP, 2010). According to this vision, biodiversity is valued, conserved, restored, and wisely used, maintaining ecosystem services, sustaining a healthy planet, and delivering benefits essential for all people. Strategic Goal D (i.e., "Enhance the benefits to all from biodiversity and ecosystem services") describes a list of benefits, such as eradicating poverty and inequalities, mitigating climate change and adapting to climate change impacts on society and the environment.

From a similar perspective, the Kunming Declaration by the CBD supports the application of ecosystem-based approaches, referred to as being synonymous to NBS, to boost resilience and ensure benefits across economic, social, and environmental dimensions of sustainable development (CBD 2021). The Declaration emphasises that biodiversity, and the ecosystem functions and services it provides, support all forms of life on Earth and underpin our human and planetary health and well-being, economic growth, and sustainable development. The CBD promotes NBS as actions to address biodiversity loss, mitigate and adapt to climate change, restore, and maintain life-supporting ecosystem processes, support sustainable food production, and eliminate contaminants and pathogens before they pose a risk to wildlife and humans. The implication of these two definitions (i.e., "living in harmony with nature" and the "ecosystem-based approach") is that NBS are reliant on biodiversity and its linkages to ecosystem services and ecosystem health.

Boosting ecosystem resilience and ecological resistance are at the heart of the ecosystem approach. Resilience is the ability of a system to absorb or recover from disturbance and change, while maintaining its functions and services, and ecological resistance is the ability of an ecosystem to withstand disturbance without undergoing a phase shift or losing neither structure nor function" (IUCN, 2021). Greater biodiversity tends to enhance resilience because biodiversity plays an "insurance role" (Yachi and Loreau 1999). For example, more species in a biological community buffer ecosystems against change and therefore, maintain key ecosystem processes and services and allow for adaptation (Hooper et al. 2005; Oliver et al. 2015). A meta-analysis by Biggs et al. (2020) showed that there was a correlation between functional redundancy (species loss compensated for by other species contributing similarly to functioning) and ecosystem stability and resilience. Further, there are synergies between biodiversity and ecosystem services, i.e., more species have the potential to supply more ecosystem services (Maes et al. 2012; Chausson et al. 2020).

1.1.3. Nature-Based Solutions

International Union for the Conservation of Nature (IUCN). The definition of NBS by IUCN (2016) states that "Nature-based solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits". In the wake of its rapid uptake across policy and practice, IUCN released a global standard to operationalise the definition and guide the implementation and evaluation of NBS (IUCN, 2020). The IUCN Global Standard for NBS focuses on the role of NBS to increase ecosystem integrity. The goal is "to address major societal challenges" which are explicitly confined to (1) Climate change mitigation and adaptation; (2) Disaster risk reduction; (3) Economic and social development; (4) Human health; (5) Food security; (6) Water security; and (7) Environmental degradation and biodiversity loss. Furthermore, IUCN emphasises in its supporting principles and criteria in the Global Standard that NBS must be understood and applied at the scale of landscapes. It also requires that actions directly respond to evidence-based assessments of the current ecosystem state and pressures; social, economic, and environmental baseline conditions are understood before initiation of interventions; biodiversity conservation and human wellbeing contribution outcomes are identified, benchmarked, and periodically assessed; and trade-offs and risks are addressed beyond the intervention site.

European Commission (EC). The definition of NBS by the European Commission (2021) refers to "solutions that are inspired by and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits, and help build resilience". The definition further emphasises that "such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions". It is additionally a requirement that NBS must "benefit biodiversity and support the delivery of a range of ecosystem services". While the EC's definition does not have an official set of principles which should be followed, the EC presents in recent policy communications a set of basic guiding questions which underline that NBS should support environmental, social, and economic benefits.

United Nations (UN). At the United Nations Environment Assembly 5.2 in 2022 countries adopted a definition of NBS as being "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, resilience and biodiversity benefits" (UNEA 2022). This definition has been inspired by the ones by IUCN and by the EC. Both the IUCN and UNEA definitions pose certain criteria for what types of actions, challenges, and benefits can be defined as NBS. An additional component is the delivery of resilience as a requirement. The UNEA resolution 5/5 also provides a framing of the concept. It states that NBS respect social and environmental safeguards.

Communities around the world have always relied on nature to benefit their well-being and livelihoods and overcome challenges such as water shortages, soil fertility and loss, waste removal, flooding and food insecurity. What is new about the actions that fall under the umbrella of Nature-Based Solutions is the way they are framed. NBS aim to deliver outcomes over and above the ecosystem services provided by ecosystems as a result of natural processes, and address multiple societal, environmental and economic challenges while at the same time benefitting biodiversity.

NBS typology. Eggermont et al. (2015) do not explicitly define NBS but suggested that the approach involves managing “the (socio-)ecological systems in a comprehensive approach in order to sustain and potentially increase the delivery of the ecosystem services (ES) to humans”. They also proposed a typology that has become foundational in its definition of NBS. The authors define three types of NBS:

- ”Type 1 consists of no or minimal intervention in ecosystems, with the objectives of maintaining or improving the delivery of a range of ecosystem services both inside and outside of these preserved ecosystems. Examples include the protection of mangroves in coastal areas to limit risks associated with extreme weather conditions and to provide benefits and opportunities to local populations and the establishment of marine protected areas to conserve biodiversity within these areas while exporting biomass into fishing grounds”.
- ”Type 2 corresponds to the definition and implementation of management approaches that develop sustainable and multi-functional ecosystems and landscapes (extensively or intensively managed), which improves the delivery of selected ecosystem services compared to what would be obtained with a more conventional intervention. Examples include innovative planning of agricultural landscapes to increase their multifunctionality and approaches for enhancing tree species and genetic diversity to increase forest resilience to extreme events”.
- ”Type 3 consists of managing ecosystems in very intrusive ways or even creating new ecosystems (e.g., artificial ecosystems with new assemblages of organisms for green roofs and walls to mitigate city warming and clean polluted air). Type 3 is linked to concepts like green and blue infrastructures or objectives like the restoration of heavily degraded or polluted areas”.

The three types can be thought of as Protect, Manage and Restore/Create. However, the authors admit that particular solutions may be hard to fit within only one type. Further, Type 3 could be split into restoring and creating ecosystems, if habitat creation refers to urban and artificial ecosystems (i.e., man-made ecosystems that rely on human supply of species).

1.1.4. Limitations of NBS definitions and typologies

Although Eggermont et al. (2015) added clarity on the definitions of NBS with their proposed typology, they did not provide a definitive set of criteria and aspects to operationalise the concept. One of the aspects that need to be further clarified is related to biodiversity and its role in the design of each type of NBS, delivery of outcomes, and the scale of NBS implementation.

That said, the IUCN Global Standard (IUCN, 2020) proposed monitoring for identifying baseline conditions and impacts of NBS on biodiversity. It also requires that (at least two of) the outcomes of NBS are "net biodiversity gain" and improvement in ecological integrity compared to a baseline, and these outcomes are measurable at a landscape/seascape scale. Further exploring how this requirement can be applied is outside the scope of this study and therefore it is not further discussed. However, the issue of measuring biodiversity and selecting a metric that is fit for the purpose of NBS is discussed in Section 1.2.

An additional aspect of concern is that the concept of 'ecosystem services' is integrated into both the EC, IUCN and the UN Environmental Assembly: UNEA definitions as a key term which implies the need for measurement and valuation of ecosystem services. Both the NBS definitions and the definitions of EbA and the ecosystem approach imply that there is a need to understand trade-offs between different ecosystem services to inform site selection of NBS and decide what design is fit-for-purpose. There are also questions about the linkages between biodiversity and ecosystem services and whether these should be considered separately, or not, in the design of NBS. This matter is discussed in Section 1.2.

1.2. Biodiversity and ecosystem services: context and definitions

1.2.1. Context

The role of biodiversity in addressing a wide range of challenges is widely acknowledged. For example, Decision XII/31 of the Conference of the Parties (COP) to the CBD (2016), highlights the crucial role of biodiversity in the reduction of poverty due to the basic goods and ecosystem services it provides. Decision XII/31 specifically puts biodiversity at the centre of many economic activities (mainstreaming), highlighting the monetary benefits of biodiversity. The decision focuses on biodiversity benefits related to crop and livestock agriculture, forestry, and fisheries and acknowledges that nearly half of the human population is directly dependent on natural resources for its livelihood, and many of the most vulnerable people depend directly on biodiversity to fulfil their daily subsistence needs.

Further, the assessment of the diverse values and valuation of nature, biodiversity and ecosystem functions and services (referred to as the "Values Assessment"), which was approved by the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES 2022), proposes the use of multiple approaches to value living nature in decision-making. Nature is understood by IPBES and by the Values Assessment in an inclusive way, encompassing multiple perspectives and understandings of the natural world, such as biodiversity, ecosystems, concepts like Mother Earth and other related concepts and perspectives used by indigenous peoples and local communities.

The Values Assessment recognises that the different worldviews of nature's values and knowledge systems (i.e., bodies of knowledge, practices and beliefs, pertaining to the relationships of living beings, including people, with one another and with nature) lead to different, but not mutually exclusive, interpretations of nature. For example, academic (or techno-scientific) knowledge, referring mainly to academic research data supporting expert-, evidence- and data-driven policies, is a commonly reported knowledge system. Indigenous, traditional, and local knowledge, which is place-based and experiential, comprises a different knowledge system using different types of knowledge (e.g., written and oral tradition, visual, implicit, practical). The Values Assessment calls for embracing the synergies and intersections across knowledge systems (e.g., academic, indigenous, and local) that can help to build dialogue between different stakeholders and minimise conflicts in decision making.

This is of particular relevance to the present study due to the potential of knowledge systems to influence problem definition (e.g., "what is biodiversity", "what are the benefits of biodiversity to humans") and the knowledge production process (e.g., "how is biodiversity used or assessed to address societal problems or climate change?").

1.2.2. Definitions

1.2.2.1 Biodiversity

The Convention on Biological Diversity (CBD)[1] defines Biological Diversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems". Common usage has constricted Biological Diversity to Biodiversity.

The CBD definition has been adjusted slightly by the IPBES[2] as "the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part. This includes variation in genetic, phenotypic, phylogenetic, and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities and ecosystems".

Both biodiversity definitions complement each other and are widely accepted. It is worth noting that these definitions include people in the living earth system. A consequence of this is that biodiversity can be measured at many scales and in many ways, from genetic to functional to behavioural or cultural diversity (O'Conor et al. 2021).

[1] https://www.cbd.int/doc/legal/cbd-en.pdf
[2] https://ipbes.net/glossary/biodiversity

1.2.2.2 Ecosystem services

Different ways of defining ecosystem services have been developed. For example, the Millennium Ecosystem Assessment (MEA) identified ecosystem services in fairly simple terms, as 'the benefits ecosystems provide' (MEA, 2005, p.1). Examples of benefits include climate change mitigation, prevention of coastal erosion, sea defence from flooding, food (wild and farmed), pollutant burial and removal, fertiliser and biofuels, medicines and biotechnology, tourism and nature watching, well-being, and mental health. For The Economics of Ecosystems and Biodiversity (TEEB) ecosystem services are the direct and indirect contributions of ecosystems to human well-being (TEEB, 2010). A more informative definition was provided by the UK National Ecosystem Assessment (UK NEA) as ecological processes and functions and interactions between living and non-living nature that generate benefits, monetary or non-monetary, valued by individuals or society at large (Turner et al. 2014). IPBES (see footnote 2) slightly modified this definition as "*the benefits people obtain from ecosystems.*" This definition, however, is superseded in IPBES assessments by the term "Nature's contributions to people" (Diaz et al. 2018), a framework that marks a paradigm shift from the concept of ecosystem services as it emphasises the role culture and diverse sources of knowledge and views play in assessing benefits to humans. Nature's contributions to people (NCP) include both positive (benefits) and negative (detriments) contributions of living nature (diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to human well-being. Many NCP may be perceived as benefits or detriments depending on the cultural, socioeconomic, temporal or spatial context, and thus the NCP concept is considered as having a higher potential for involving stakeholders and policy makers than the ecosystem services concept (Diaz et al. 2018).

A variety of ecosystem services typologies has also been proposed. The MEA framework is in wide use and underpins subsequent typologies. However, new typologies also recognise that many services fit into more than one of the four broad MEA categories. A few examples of typologies are briefly described below to help understand the interlinkages between biodiversity and benefits to humans and inform the methodology of the Quick Scoping Review.

The MEA framework. This laid down four broad ecosystem services categories: (1) supporting services (e.g., nutrient recycling, primary production and soil formation); (2) provisioning (e.g., food, water, raw materials and energy); (3) regulating (e.g., carbon sequestration, water purification, sediment accumulation and stabilisation and wave dissipation); (4) cultural services (e.g., sense of place, landscape and seascape provision, heritage value of nature, ecotourism and scientific discovery).

The TEEB typology. TEEB proposed a similar typology but omitted supporting services, which was considered as a subset of ecological processes and not as ecosystem services. Instead, TEEB introduced the category of habitat services (e.g., gene pool and habitat maintenance and fish nurseries).

The UK NEA typology. The ecosystem services typology proposed by UK NEA builds on the MEA framework and the TEEB typology using the three broad categories of provisioning, regulating and cultural services. It introduces the role of human intervention and management in the delivery of ecosystem services and distinguishes between final and intermediate ecosystem services and/or ecosystem processes to avoid double counting when valuing the benefits derived from ecosystems. Final ecosystem services are provisioning, regulating and cultural services directly contributing to the benefits that are valued by people, and therefore people tend to intervene or manage ecosystems to influence the delivery of these ecosystem services. Intermediate ecosystem services and/or ecosystem processes form one group and their role is to underpin the final ecosystem services, but are not directly linked to benefits and are less often the focus for management. In this context, examples of processes include decomposition, pollination, disease and pest regulation, ecological interactions, evolutionary processes, and wildlife diversity. It should be noted that provisioning and cultural services are always classed as final ecosystem services; regulating services may be either final services or intermediate services/processes; and supporting services are always intermediate ecosystem services services/processes. Further, there is considerable overlap between ecosystem services categories. For example, pollination is an ecosystem process underpinning provisioning ecosystem services such as crop production but it is also essential for the development of fruits, vegetables and seeds as a regulating ecosystem services. Wild species diversity underpins many regulating and provisioning services but is also valued for other reasons such as appreciation of wildlife and of scenic places, therefore it is also a cultural ecosystem service.

The IPBES framework. This framework introduces the concept of NCP, therefore there is re-organisation of services and processes into 18 NCPs divided into three new categories: regulating NCP, non-material NCP, and material NCP. For example, regulating ecosystem services have been replaced by regulating NCP which include habitat creation and maintenance, pollination, larva/seed dispersal, and regulating services as in the MEA, TEEB and UK NEA typologies. Non-material NCP include cultural services as in the MEA, TEEB and UK NEA typologies but may also include regulating services. Material NCP mainly include the provisioning services recognised in the MEA, TEEB and UK NEA typologies but, depending on perceptions and local cultural context, may also include cultural services. Supporting ecosystem services or intermediate ecosystem services and/or processes are no longer used by the IPBES framework. However, the framework recognises that NCP are provided, depending on the case, by particular organisms, by ecosystems, or by particular mixtures of organisms, assembled naturally (e.g., the assemblage of pollinators in a landscape) or artificially (e.g., a planted grove, or a plant mixture on a green roof). Further, the eighteenth NCP ("maintenance of options") spans all NCP categories and refers to the role of biodiversity (genotypes, species, habitats, and ecosystems) in keeping options open to support a good quality of life.

1.2.2.3 Ecosystems and ecosystem health

Ecosystems are complexes where biotic and abiotic components interact (Currie 2011). Those interactions, including all the biodiversity components, determine the quantity, quality, and reliability of ecosystem services. As the physical, chemical, and biological features and components of ecosystems change, so will the processes and, consequently, the services. The complexity in these interactions is poorly understood even in simple ecosystems and, even worse, it is not yet possible to predict how these processes and interactions will change under complex and global stressors, such as climate change.

Key et al. (2022) argued that NBS are reliant not only on biodiversity but also on the broader health of ecosystems. This is defined as “the state or condition of an ecosystem in which its dynamic attributes are expressed within the normal ranges of activity relative to its ecological state of development” (Society for Ecological Restoration International Science & Policy Working Group 2004). These attributes comprise both biotic and abiotic features of ecosystems, including biodiversity. According to IPBES ecosystem health[3] is a metaphor used to describe the condition of an ecosystem, by analogy with human health. However, there is no universally accepted benchmark for a healthy ecosystem as there is for human health. Rather, the apparent health status of an ecosystem can vary depending upon which metrics are employed in judging it, and which societal aspirations are driving the assessment. This has led authors such as Cochran et al. (2019) cited in Key et al. (2022) to propose that to be healthy and sustainable an ecosystem should maintain its metabolic activity level and its internal structure and organisation and resist external stresses. Hence the ecosystem health paradigm is akin to the concept of ecosystem resilience. Note that the term “ecosystem health” is distinct from “ecosystem integrity and intactness” (Society for Ecological Restoration International Science & Policy Working Group 2004).

1.2.2.4. Limitations of definitions on biodiversity and ecosystems

Nature-based actions/interventions tap into a wide range of ecological, biogeochemical, hydrological, and other physical processes controlling the fluxes of carbon, water, energy, genes, nutrients, and pathogens through the environment. These are examples of the processes underpinning the ecosystem services that generate the benefits people obtain from ecosystems. A discussion on the linkage between biodiversity and ecosystem function and services is outside the scope of this report. However, it is important to note that this linkage is still debated and the subject of ongoing research. In fact, few studies have been able to trace the complete “production chain” from biodiversity to ecological structure to human well-being (Haines-Young and Potschin 2010).

A key problem is that of definitions, and particularly distinguishing biodiversity from ecosystem services and the benefits they generate for humans. As Mace et al. (2012) explain, in some cases the two terms (biodiversity and ecosystem services) are used almost synonymously, implying that they are effectively the same thing and that if ecosystem services are managed well, biodiversity will be retained and vice versa.

1.3. Measuring the role of biodiversity

The IPBES definition of biodiversity recognises variability as a key, intrinsic feature of biodiversity. Level and degree of variability defines the metric to be used to measure and assess biodiversity (Mace et al. 2012). For example,

- Within Species Variability is measured with genetic and population-level metrics;

[3] https://www.ipbes.net/glossary/ecosystem-health

- Between Species Variability is measured with species abundance metrics;
- Within Ecosystems Variability measurements rely on measures at landscape or regional levels, such as major vegetation types or biomes;
- variability that arises from species being part of ecological complexes, recognising that ecological interactions are both causes and consequences of biodiversity.

It must also be borne in mind that some variability might be attributable simply to composition, such as the presence of certain key species or the correlation between species diversity and functional trait diversity (Hooper et al. 2005). The extent to which species diversity is important compared to biomass or structural habitat heterogeneity and trait diversity is an area of active research. For example, van der Plas et al. (2020) showed that there are limits to the extent to which traits per se can predict the long-term functional consequences of biodiversity change, so that data on additional drivers, such as interacting abiotic factors, may be required to improve predictions of ecosystem property levels.

A wide range of metrics are used to quantify biodiversity and there can be confusion between their precise meaning due to the use of the term “diversity” in different ways. The following sub-sections summarise the sources of evidence this report relied upon to understand the linkage between the metric of biodiversity and assessment of biodiversity roles in NBS.

1.3.1 Species diversity as biodiversity

The IPBES definition identifies a range of ways of capturing species richness or diversity. Species richness means the number of different entities present within the limits of the area. So, an area with 20 species has a higher richness than one with 10. Diversity index – a range of measures have been proposed to capture information about relative abundance of species within an area. So, if two areas have 10 species, one has a highly dominant species making up 90 % of the individuals or biomass and the other has an even distribution of species abundance, then the latter area is seen as more diverse. Typical measures used are Shannon’s and Simpson’s indices.

This is reflected in different metrics to capture different axes of variation in biodiversity:

- Species richness/diversity – the most commonly used metrics deal with the number or diversity of species within an area.
- Taxonomic richness/diversity – effectively capturing similar information to species metrics but at a different level to species, e.g., generic or family richness.
- Phylogenetic richness/diversity – the assumption behind these metrics is that communities made up of species that are closely evolutionary related are less diverse than those made up of species that are distantly related.
- Functional richness/diversity – these measures were developed to assess how different species were in their contribution to ecosystem function. The measures use species traits as proxies for

these contributions and a community is seen as more functionally rich or diverse if there is a wide spread of trait values.

1.3.2 Essential Biodiversity Variables

The Values Assessment uses the 'Essential Biodiversity Variables' (EBV)[4], a global system of harmonised observations proposed for the study, reporting, and management of biodiversity change (Pereira et al. 2013). The EBVs are defined as measurements required for study, reporting, and management of biodiversity change. To select a suite of essential variables, Pereira et al. (2013) screened dozens of biodiversity variables to identify those that fulfil criteria on scalability (i.e., applied at a range of scales and contexts), temporal sensitivity, feasibility, and relevance. They also accounted for the relevance of each variable to CBD targets and indicators.

The EBV variables can be organised into six classes on the basis of commonalities, general enough for use across taxa and terrestrial, freshwater, and marine realms, as follows:

- Genetic (allelic) composition, e.g., genotypes of selected species
- Species populations, e.g., abundance and distributions
- Species traits, e.g., the timing of life events, such as flowering, germination, and leaf-out (Phenology)
- Community composition, e.g., Taxonomic diversity
- Ecosystem structure, e.g., habitat structure, vegetation cover or height
- Ecosystem function, e.g., nutrient retention.

1.3.3 Living natural capital attributes

Smith et al. (2017) identified five pathways by which "living natural capital attributes" influence the delivery of different bundles of ecosystem services. These include:

- Amount of vegetation: the air, soil and water regulating services — air quality, atmospheric regulation, water flow, mass flow and water quality — are governed mainly by a group of biotic attributes related to the physical amount of vegetation within an ecosystem. Attributes such as community/habitat type and area, structure, stand age, successional stage, stem density and above- and below-ground biomass control the provision of these services. For the service of water supply, these attributes all tend to have a negative impact.
  - Provision of supporting habitat: for services that rely on particular animal species — pollination, pest regulation and freshwater fishing — the existence of suitable habitats to support those species is found to be important: Community type, area and structure are therefore often

[4] https:// portal.geobon.org

correlated with these services. It is likely that supporting habitat is equally important for the service of species-based recreation, but this does not emerge strongly in the literature reviewed. As a sub-division of this category, habitat type is also important for providing aesthetic value to humans.

- Presence of a particular species, functional group, or trait: the presence of particular species is found to be important for most services, especially species-based recreation and the provision of fish, timber and food. Specific functional groups are cited as being important for some services: these include groups of pollinators and pest predators such as bees and wasps, and, for air quality and mass flow regulation, functional groups of plants such as large-leaved vs small-leaved trees or deep vs shallow-rooted shrubs.
- Biological and physical diversity: Biological diversity, reflected in the attributes of species and functional richness, functional diversity and (for food crops) intra-species population diversity, is often positively correlated with timber, food, and fish production due to resource-use complementarity and oriented-species facilitation such as nitrogen fixation from the atmosphere by leguminous plants.
- Abiotic factors: interaction of species with abiotic factors such as nutrient availability, temperature, precipitation etc.

This typology enables attributes to be linked to the services that depend on them. Smith et al. (2017) proposed that many of these attributes could be used as indicators of ecosystem condition.

1.3.4 Ecosystem health metrics

Key et al. (2022) drew on the typology of Smith et al (2017) to formulate a three-tiered hierarchy to describe the ecosystem health outcomes of NBS types (Eggermont et al. 2015). At the lowest level of the hierarchy are the individual ecosystem health metrics (e.g., Shannon's diversity index). These are grouped into metric types (e.g., species diversity). The metric types were grouped into broad metric categories (e.g., diversity). They assigned each ecosystem health metric to just one broad category, to avoid double-counting in data analysis, although some metrics may be relevant to other categories.

1.4. Role of biodiversity

The hypothesis central to this report is that there is a link between biodiversity and the ecosystem processes and services that generate benefits to humans and this linkage is amenable to actions such as those described under the umbrella term nature-based solutions. Linking biodiversity and ecosystem resilience through its relationship to ecosystem processes and services is an active area of research with a wide range of open questions to address (Martin et al. 2020).

Biodiversity and ecosystem function. The starting point for the development of these ideas was the notion that species loss could affect the functioning of ecosystems (Schulze and Mooney 1993, Vitousek & Hooper 1993), an idea that represented a paradigm shift. Prior to this species were seen as reacting to the environment, but since the acceptance of these ideas they are also seen as driving ecosystem function (van den Plas 2019). The initial focus of research into Biodiversity-Ecosystem Function (BEF) relationships were theoretical, but they were quickly followed by experimental testing. This provided evidence of positive relationships between diversity of species and ecosystem functions such as productivity (e.g., Hector et al. 1999, Tilman et al. 1996). In a major meta-analysis, van den Plas (2019) showed that in many cases, biodiversity promotes average biomass production and its temporal stability, and pollination success but there were also trade-offs between herbivore diversity and plant biomass.

Scale of the BEF relationship. An additional problem is that studies on the BEF relationship have focused on the effects of biodiversity on ecosystem processes at relatively small spatial scales rather than on the impact of larger-scale biodiversity on ecosystem services (Srivastava and Vellend 2005; Isbell et al. 2017). This lack of a mechanistic understanding on how biodiversity at larger spatial scales affects the delivery of multiple ecosystem services precludes the upscaling of biodiversity–ecosystem service relationships to the large spatial scales relevant to policy and management (Isbell et al. 2017), and the implementation of NBS. It should be borne in mind that the IUCN Gold Standard (2020) requires that NBS are implemented at landscape scale to enable delivery of benefits to humans.

Biodiversity and ecosystem services. Several authors have noted that there is a lack of understanding on how biodiversity and abiotic attributes of ecosystems at landscape scale influence the capacity of ecosystems to be multifunctional and supply multiple different services (Mace et al. 2012; Isbel et al. 2017; Maseyk et al. 2017; Smith et al. 2017; Metzger et al. 2021). Further, various studies have demonstrated a certain degree of spatial congruence between areas that have high biodiversity and those that have high potential to deliver ecosystem services (e.g., Egoh et al. 2009; Maes et al. 2012) or shown that land use scenarios that favour biodiversity conservation can also benefit ecosystem service provision (e.g., Nelson et al. 2009). However, there is growing concern that focussing on the provision of benefits for humans may conflict with conservation priorities (Schröter et al. 2014) and that minimising trade-offs between humans and wildlife are hard to achieve in practice (McShane et al. 2011). As noted by Ingram et al. (2012) a focus on single ecosystem services may result in additional (over-)exploitation of ecosystems, for example through prioritising provision of food or timber, or by assigning a low (economic or societal) value to rare or endemic species that are of high conservation interest.

As noted by Mace et al. (2012) biodiversity combines with the concept of ecosystem services at all levels: it provides the support to key processes, it affects the delivery of regulating ecosystem services, and it may itself be the benefit that is valued. The components (e.g., genes, species or traits) and attributes (e.g., amount, variability or composition) of biodiversity that are necessary or desirable to retain any specific ecosystem service will vary according to the service or benefit being considered, and the processes on which it depends.

The question on the role of biodiversity in NBS can in fact translate into a question about the roles of biodiversity in the ecosystem services protected, managed, restored or created by NBS to deliver benefits valued by humans.

1.5. How does this background information influence the methodology of this project?

The paradigm followed in the development of the literature review methodology is that there is a relationship between biodiversity and ecosystem function as well as for ecosystem services and the benefits they generate for humans, individuals and the society. Consequently, there should be a role or roles in the inclusion of any of the types of biodiversity attributes and metrics (described in Section 1.3) as well as values (in the context of the Values Assessment) in the design of actions under the umbrella term of NBS to make them more efficient in addressing challenges and delivering multiple benefits. This means that only studies on how biodiversity underpinned ecosystem function or enabled the delivery of ecosystem services and benefits harnessed by NBS to deliver outcomes provided useful evidence for this report. Assessing the suitability of a biodiversity metric (albeit biophysical, based on perception or anecdotal, traditional knowledge) was outside the scope of this study. Further, this report reflects the descriptions of interventions under the umbrella term NBS as they were captured by a wide range of search terms rather than selecting approaches that qualify as NBS according to pre-selected criteria.

2. Materials and Methods

2.1. Quick Scoping Review and systematic evidence mapping

We carried out a Quick Scoping Review to address the project's objectives. Indeed, a Quick Scoping Review is a type of evidence synthesis that aims to map existing literature in a systematic manner to provide balanced conclusions in relation to one or more policy questions (Grant & Booth, 2009, Collins et al. 2014; Tricco et al. 2016). It can involve a structured, step-wise methodology, preferably following an a priori protocol, to collate and describe existing research evidence (traditional academic and grey literature) on a broad topic area in a short period of time (Collins et al. 2014; Dicks et al. 2017). We followed the systematic mapping methodology described by James et al. (2016) in order to produce a map of evidence, an essential output of the process (Collins *et al.* 2014).

Indeed, a Quick Scoping Review may answer broad or topic-focused questions, potentially requiring a fast response. It is also preliminary in that it aims to assess the scope and extent of existing evidence on a given topic potentially prior to carrying out a thorough systematic map or review (Munn et al. 2018). With regards to any evidence synthesis, developing the search strategy via 'trial runs' to identify the questions, search terms and inclusion criteria is vital. Trialling can help the reviewers find evidence that is relevant to policy needs and feasible to review, given the available resources (James *et al.* 2016). An a priori protocol is recommended to track the evidence-finding strategy. The number of results found is recorded. Synthesised evidence usually comes from a range of sources and disciplines and is repackaged into accessible knowledge that improves understanding of a topic and is presented typically in tabular form with some narrative synthesis.

Evidence synthesis methods such as the Quick Scoping Review can follow rigorous and transparent processes that, unlike traditional literature reviews, aim to reduce bias in the selection of the evidence, and enable policy makers to view how research evidence was chosen and how conclusions were reached (The Royal Society 2018). The Quick Scoping Review is suggested when there is a need to clarify key concepts and definitions of a given topic, and to identify and analyse knowledge gaps (Munn *et al.* 2018). By contrast, Systematic Reviews require long-term timeframes and are mainly suggested when there is a need to identify new practices, investigate conflicting results and guide policy-making (Collins *et al.* 2014, Munn *et al.* 2018).

It must be noted that there is a range of approaches in terms of techniques, protocols and terminologies being adopted across different scientific disciplines under the umbrella term Evidence synthesis. Quick Scoping Reviews are considered condensed versions of Systematic Reviews and Systematic Maps (Dicks et al. 2017). Indeed, the systematic mapping methodology applied in Quick Scoping Reviews may be simplified - even certain steps omitted - to produce results in a shorter time frame. The exact set of methods used, or the components of Systematic Maps left out, are flexible (Dicks et al. 2017).

Again, Quick Scoping Reviews can be conducted as precursors to Systematic Reviews allowing to identify the nature of a broad field of evidence so that ensuing subsequent Reviews can be assured of locating adequate numbers of relevant studies for inclusion (Munn et al 2018). Thus, this report applied the systematic mapping methodology by James et al. (2016) without overly simplifying or omitting components of the process but uses the term Quick Scoping Review to show that a considerable effort was dedicated to refining the scope and coverage of the literature on the role of biodiversity in NBS.

Further, evidence synthesis approaches developed in one discipline such as health research can be transferred to other disciplines such as social and environmental. This is the case of the so-called PICO framework which was initially developed to support systematic reviews in health care and health policy[5] to help define the question of interest and design the search strategy for the evidence synthesis. The PICO framework gathers information in a structured way to define the health problem (P) and the intervention under investigation (I), the type of appropriate study design to test treatments using a comparator or control (C), and how outcomes (O) such as benefits and harms will be measured.

Translating the PICO protocol into environmental contexts is common (e.g., James et al. 2016; Chausson et al. 2020). For example, Chausson et al. (2020) designed a PICO protocol to identify the state of evidence on the effectiveness of NBS for addressing the adverse impacts of climate change and hydro-meteorological hazards. In their PICO protocol, population (P) refers to human individuals, groups, communities and economic sectors; intervention (I) refers to the actions described as NBS by IUCN; comparator (C) refers to pre-intervention baselines and experimental controls (among other things); and outcomes (O) refers to measured or modelled outcomes affecting impacts of climate change and hydrometeorological hazards. As noted by Haddaway et al. (2016), population (P) may also refer to specific systems investigated and the presence of a comparator (C) is not always required in a Quick Scoping Review.

Hence, the project team developed a PICO approach tailored to the objectives of this project to refine the scope of the study (Section 2.2), formulate questions (Section 2.3) and develop the search terms for the evidence mapping (Section 2.4).

2.2. Refining the scope of the study

We engaged Biodiversa+ in fortnightly discussions to help refine the scope of the project with regards to geographic range, ecosystem types, type of biodiversity metric, NBS types and types of outcomes. These discussions recognised that biodiversity and NBS are complex concepts and led to the selection of specific and broad biodiversity and NBS terms that encompassed all the nuances of these concepts (see review of terms and definitions in Section 1). It was also agreed that the different roles of biodiversity are examined in the context of the NBS typology recommended by Eggermont et al. (2015).

Combinations of broad terms (keywords) were trialled to help predict the number of relevant sources of information and plan the review strategy. Preliminary searches in Google Scholar included the keywords “biodiversity”, “ecosystem function”, “ecosystem services” and “nature-based solutions”. More than 26,000 search results were retrieved, including peer-reviewed research and review

[5] Cochrane Reviews: https://www.cochranelibrary.com/

articles as well as grey literature sources. These search terms were mentioned frequently together in the context of societal challenges such as climate change addressed by NBS. The review articles that were retrieved (approximately 2,000) focused on biodiversity as an outcome (primary benefit or co-benefit) of NBS, which as a topic was out of the scope of this study. Random sampling of the documents retrieved by this preliminary search showed that very few studies focused on exploring the role of biodiversity, particularly the link between:

Biodiversity = process ➔ ecosystem services ➔ nature-based solutions ➔ contributions valued by humans, or,

Biodiversity = ecosystem service ➔ nature-based solutions ➔ contributions valued by humans, or,

Biodiversity = contributions valued by humans ➔ nature-based solutions.

Building on these preliminary results and the background evidence described in section 1, the search string (combinations of search terms) and selection criteria were designed to match a wide range of terms and concepts referring to biodiversity and its metric and interventions, goals (i.e., challenges to address) and outcomes within the NBS umbrella concept. As there was an interest in identifying examples from Europe but also evidence that is transferable to the European context, this Quick Scoping Review aimed to capture studies on all types of ecosystems and geographic locations.

A PICO protocol (section 2.1) was developed to help create a standardised search string with terms specific to each component of the PICO protocol (Annex 1; section 2.4). Evidence mapping normally aims to incorporate both peer-reviewed and grey literature but due to time constraints, it was decided to focus on peer-reviewed articles written in English. The search string was used to search two peer-reviewed publication databases – Web of Science (CORE collection citation index) and Google Scholar.

The search terms and strategy are detailed in section 2.4.

2.3. Formulating questions

A conceptual model on the roles of biodiversity was built (Figure 1). The model was based on the background evidence described in section 1.4. The conceptual model connected the roles of biodiversity with ecosystem processes, ecosystem services and contributions to humans drawing on ecosystem services typologies by MEA (2005), TEEB (2010) and the UK NEA (Turner et al. 2014) as well as on the IPBES framework on NCP (Diaz *et al.* 2018). The roles of biodiversity were set out according to Mace *et al.* (2012).

- Biodiversity may play multiple roles in NBS by delivering:
  - Supporting ecosystem services and ecosystem or biological processes that underpin the delivery of regulating, provisioning and cultural services (Supporting role of biodiversity).
  - Regulating ecosystem services (Regulating role of biodiversity).

- Direct material or non-material contributions to people through the delivery of provisioning and cultural services, respectively (Living nature's contributions to people).

The three roles of biodiversity considered determined the search terms used in the literature searches.

Linking the roles of biodiversity to NBS involved the development of three additional conceptual models, one for each type of NBS (Eggermont *et al.* 2015). The premise of these three models was that each type of NBS uses ecosystems and ecosystem services differently (section 1.1.3 – NBS typology). Each of these models connected the types of challenges (P in the PICO protocol) that could be addressed by embedding biodiversity in the design of a specific type of NBS (I in the PICO protocol) to NBS outcomes (O in the PICO protocol) (Figures 2a, b, c). This enabled the formulation of specific questions and communication of complex ideas and ecosystem processes with Biodiversa+ partners seeking specific and sensitive search terms in terms of the objectives and revised scope of the project.

The conceptual models underpinned the Population-Intervention-Comparator-Outcome (PICO) framework for the formulation of primary and secondary questions and informed literature search terms (see Annex 1).

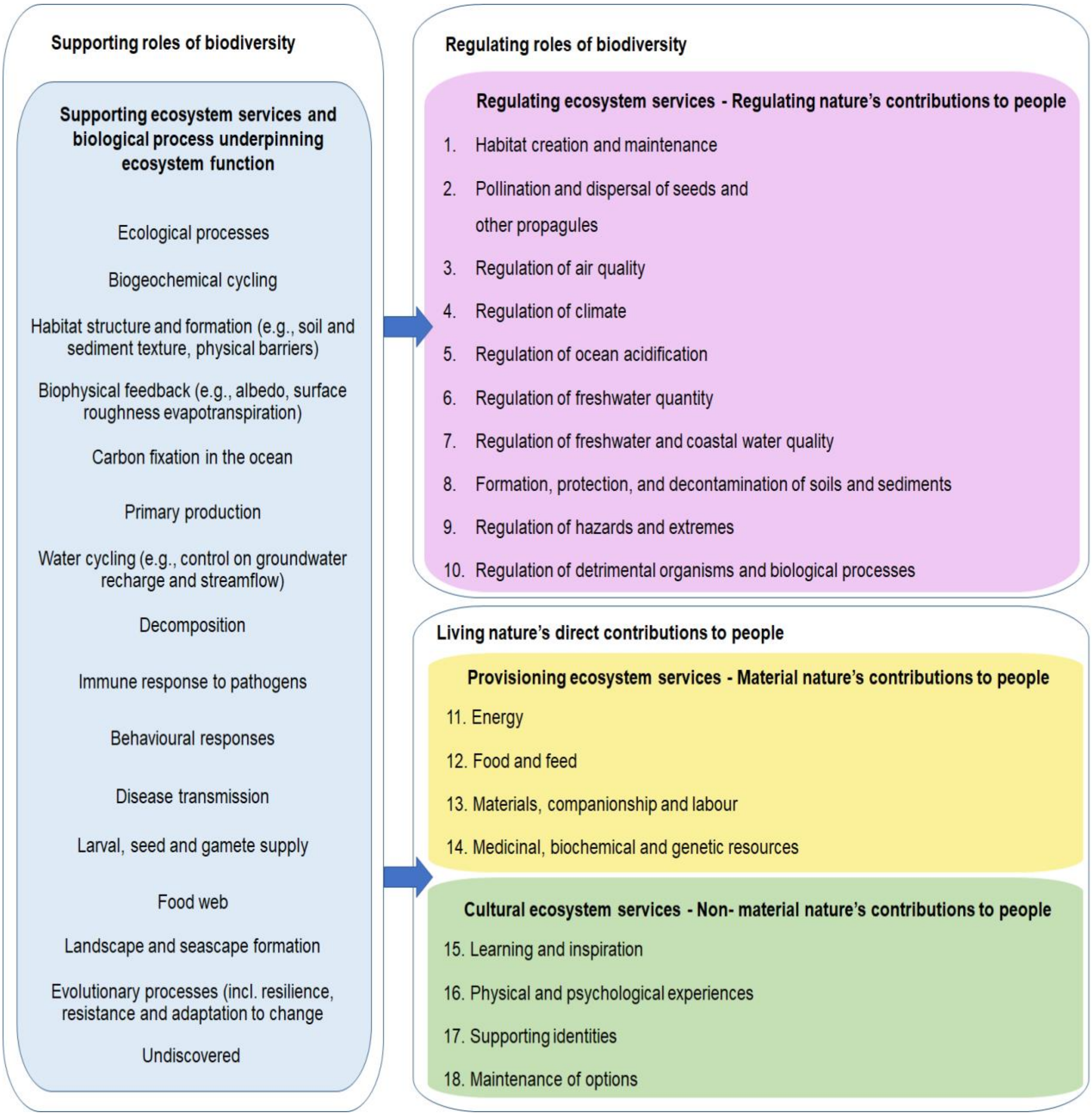

Figure 1. A framework linking the roles of biodiversity with ecosystem processes and ecosystem services and benefits to humans overlaid on the IPBES reporting categories of Nature's Contributions to People (NCP) as in Table S1 in Diaz et al. 2018. This figure provides information for Figure 2.

Problem to be addressed (P)	Intervention (I)			NBS outcomes (O)
Problem (P) ⇨ Societal challenges : • Biodiversity loss leading to loss of ecosystem services due to urban sprawling, agriculture, pollution, unsustainable fishing etc.	**Ecosystem type:** • Coral reefs • MPAs • *Natura* sites • Any designated areas e.g. Ramsar • Rewilding	**Intervention:** Type 1 (Eggermont *et al* 2015): Minimal Intervention **Intervention (I) includes PA types (IUCN, Dudley 2008)** • Strict nature reserve • Wilderness • National Park • Natural Monument • Habitat/species management area • Protected landscape/ seascape • Sustainable use	**Role of biodiversity in NBS:** • Depends on PA, ecosystem type and geography. • **Role of biodiversity:** - Supporting - Regulating - As a benefit • **Scale of role:** - Local within PAs - Regional in the case of ecological networks among PAs and between PAs and non protected areas - Global (e.g., global biodiversity maintenance).	• Depends on PA and context • Supporting livelihoods (€) • Drinking Water purification (€) • Infrastructure protection from coastal/river flooding (€) • Well-being industry (€) • Tourism (€) • Net-Zero Carbon (€) • Any non-monetary values (health, sense of place, coherence etc.)

Aim of **Type 1** NBS : Protect / Maintain / Improve all or most Ecosystem Services

Figure 2A. Conceptual framework of the role of biodiversity in Type 1 NBS. NBS typology was based on Eggermont et al. 2015. The framework applies the PICO approach (see text). Problem (P) refers to a problem (challenge) addressed by NBS. Intervention (I) refers to NBS type. NBS Outcomes (O) refers to the range of outcomes potentially intended with the implementation of NBS. See also Figure 1.

Problem to be addressed (P)	Intervention (I)			NBS outcomes (O)
Problem (P) ⇨ Societal challenges : • Loss of specific ecosystem functions and ecosystem services due to unsustainable use of resources.	**Ecosystem type:** • Agricultural land • Coastal zone with multiple anthropogenic activities.	**Intervention:** Type 2 (Eggermont et al 2015): Sustainable Ecosystem management **Intervention (I) includes:** • Agri-environment schemes • Marine spatial planning • Integrated coastal zone management (ICZM) • Land-to-sea approaches (e.g., Ridge-to-reef, Mountain-to-mangrove and Source-to-sea).	**Role of biodiversity in NBS:** • Depends on management and intended outcomes, i.e., ecosystem service selected to be improved or supplied. • **Role of biodiversity:** - Supporting - Regulating - As a benefit • **Scale of role:** - Local within area of application (e.g. farm-plot) - Regional (e.g., river basin management, fisheries management, ICZM).	• Drinking Water purification (€) • Infrastructure protection from coastal/river flooding (€) • Well-being industry (€) • Tourism (€) • Any non-monetary values (biodiversity, health, sense of place, democracy etc.)

Aim of **Type 2** NBS: Sustainably manage ecosystems to maximise synergies between selected ecosystem services and minimise conflicts between different uses of ecosystems

Figure 2B. Conceptual framework of the role of biodiversity in Type 2 NBS. NBS typology was based on Eggermont et al. 2015: The framework applies the PICO approach (see text). Problem (P) refers to problem (challenge) addressed by NBS. Intervention (I) refers to NBS type. NBS Outcomes (O) refers to the range of outcomes potentially intended with the implementation of NBS. See also Figure 1.

Problem to be addressed (P)	Intervention (I)			NBS outcomes (O)
Problem (P) ⇨Societal challenges : • Loss of key ecosystem functions and ecosystem services due to unsustainable use of resources in the past	**Ecosystem type:** • Artificial environments, incl. Infrastructure • Restored habitats • Urban greening • Degraded/ polluted environments amenable to improvement	**Intervention:** Type 3 (Eggermont et al 2015): • Habitat restoration • Intrusive management of degraded ecosystems • Ecosystem creation **Intervention (I) includes:** • Sustainable drainage • Constructed wetlands • Green roofs • Green/blue spaces • Planning to integrate living organisms in the design of infrastructure and urban / spaces. • Providing the needs included in the 'Hutchinsonian niche'* ⇨Design depends on the species *environmental conditions and resources that permit a species population to exist indefinitely (Hutchinson 1957).	**Role of biodiversity in NBS:** • Depends on habitat created, challenge addressed and pool of species in the surrounding environment • **Role of biodiversity:** - Supporting - Regulating - As a benefit • **Scale of Role:** - Local within area of application (e.g. farm-plot) - Regional (e.g., river basin management, fisheries management, ICZM)	• Depends on PA and context • Supporting livelihoods (€) • Drinking Water purification (€) • Infrastructure protection from coastal/river flooding (€) • Well-being industry (€) • Tourism (€) • Net-Zero Carbon (€) • Any non-monetary values (biodiversity, health, sense of place, coherence etc.)

Aim of **Type 3** NbS: Restore or create new ecosystem services

Figure 2C. Conceptual framework of the role of biodiversity in Type 3 NBS. NBS typology was based on Eggermont et al. (2015): The framework applies the PICO approach (see text). Problem (P) refers to problem (challenge) addressed by NBS. Intervention (I) refers to NBS type. NBS Outcomes (O) refers to the range of outcomes potentially intended with the implementation of NBS. See also Figure 1.

2.3.1. Primary questions

Initially, the study aimed to address the following overarching question:

What is the state of knowledge on the role of biodiversity in NBS?

The conceptual models presented in Figures 1 and 2 helped to recognise that the role played by biodiversity in the delivery of ecosystem services varies, as also discussed in Section 1. Figure 1 illustrates how biodiversity operates at the various levels of the ecosystem services framework. We can see that the role of biodiversity at the level of community and ecosystem species composition is directly controlling processes such as microbial decomposition and food web dynamics and enabling delivery of ecosystem services such as supporting (e.g., nutrient cycling and primary production) and regulating (e.g., carbon sequestration and natural hazard protection by rooted vegetation) services. Figure 1 also shows that biodiversity at the level of gene and species contributes directly to provisioning (such as food and wild crop genetic diversity) i.e., biodiversity is the ecosystem service. Finally, Figure 1 shows the role of biodiversity as a cultural value (e.g., nature watching) to humans and, in its own right, as in conservation.

With this in mind, and in the context of the three types of NBS and the definitions of NBS discussed in Section 1, the initial question is modified as follows:

What is the evidence on the roles of biodiversity as regulator of ecosystem function, as an ecosystem service and as a value to humans in the design and delivery of nature-based solutions (defined as actions that protect, conserve, restore, sustainably use, and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems) to address climate change, disaster risk, water crisis, food crisis, environmental issues, social issues while delivering human well-being, ecosystem services, resilience and biodiversity benefits?

2.3.2. Secondary questions

To help extract further detail and help identify evidence gaps, we broke down the primary question to secondary questions:

- Environmental context:
  - What is the geographic distribution, ecosystem types, NBS type, and geographical scales of studies providing evidence on biodiversity's roles in the delivery of ecosystem services and NBS outcomes?
- Metric:
  - What metric is used to assess the roles of biodiversity in NBS?
- Types of challenges:
  - What is the linkage between the type of challenges addressed and the roles of biodiversity assessed?
- Types of outcomes:
  - What is the linkage between biodiversity and NBS outcomes and how are NBS outcomes assessed?

2.4. Search strategy

The search strategy was designed to identify scholarly, peer-reviewed literature and deliver an unbiased sample of the evidence base. A string of search terms for each component of the PICO protocol (Annex 1) was used to search two peer-reviewed publication databases - Web of Science Core collection citation indexes (WOSCC) and Google Scholar. An initial scoping search was performed to test for specificity and sensitivity of the search terms using the online database WOSCC and a list of 10 experts researching biodiversity and NBS (their studies hereafter referred to as benchmark studies). Benchmark studies included review and perspective articles on NBS proposing further research on the role of biodiversity in NBS, such as: Eggermont et al. (2015); Connop et al.

(2016); Cohen-Shachma et al. (2019); Scheffers and Pecl (2019); Chausson et al. (2020); Marselle et al. (2021); Martin et al. (2020); Mori (2020); Seddon et al. (2020); Seddon et al. (2021); Donatti et al. (2022); Kabisch et al. (2022); and Seddon 2022.

The scoping searches were based on the terms identified using the PICO approach. The results of the scoping search were used to inform the final search strategy (Annex 1). For example, terms for Problems (Table A1) were combined with terms for Intervention (Table A2) and terms for outcomes (Table A3) using the Boolean operator "AND". The results of this search were further refined using the agreed selection criteria (Table A4).

The scoping search delivered 25,520 unique articles: 3,546 articles on interventions related to protection and conservation; 14,336 articles on management; 6,609 articles on habitat restoration; and 1,029 articles on created habitats. These searches captured the benchmark studies, suggesting high sensitivity, as well as review articles on the topic of biodiversity or NBS with a large number of citations, but these were not relevant to the primary and secondary questions of the project. As the screening of this number of articles was deemed infeasible to complete within the timescale of the project, additional search terms were sought to help capture specific studies and enhance sensitivity of searches to the scope of the project.

The strategy was therefore re-visited before agreeing the final search strategy. Search string per PICO component, selection criteria and coding framework were evaluated by the Biodiversa+ partners in a series of meetings held from August to October to ensure search results relevant for Biodiversa+ strategy. Revision relied on expertise and feedback from Biodiversa+ to identify benchmarks and involved scanning titles and abstracts for a random subset of studies retrieved by the scoping search. Terms defined in the studies screened were added to the search string. The added search terms were combined with the existing search string to produce a more manageable and specific number of hits. The search string was refined iteratively to ensure it was sensitive enough to capture the benchmark studies and reduce the number of irrelevant or broad studies. In addition to tweaking search terms, there were also modifications of the search string structure using Boolean operators such as proximity (e.g., NEAR in Web of Science) to increase specificity. The revised search string captured studies by the authors of benchmark studies, however most of these studies were mostly review or perspective/opinion papers and some of them did not match the selection criteria.

The final search strategy involved combining the intervention terms (Table A2) with a string of search terms reflecting the reliance of NBS on biodiversity by design ("biodiversity-based search string") in the WOSCC as well as in Google Scholar. Additional, related records were also identified by searching the free online app Research Rabbit, which identified articles related in terms of topic with the articles retrieved using WOSCC and Google Scholar, and by "snowball searches". Finally, there were searches within the results of the scoping search looking at specific terms such as "biodiversity-based" and "resilien*". Table A5 denotes search engines used and way of retrieval for each article selected after full text screening.

The "biodiversity-based search string" included the terms:

"ecosystem approach" OR "biodiversity based" OR "biodiversity and resilience" OR "biodiversity driven" OR "working with biodiversity" OR "living nature" OR "biodiversity dependence" OR "biodiversity reliant" OR "nature based solution*". The search strategy is summarised in Figure 3.

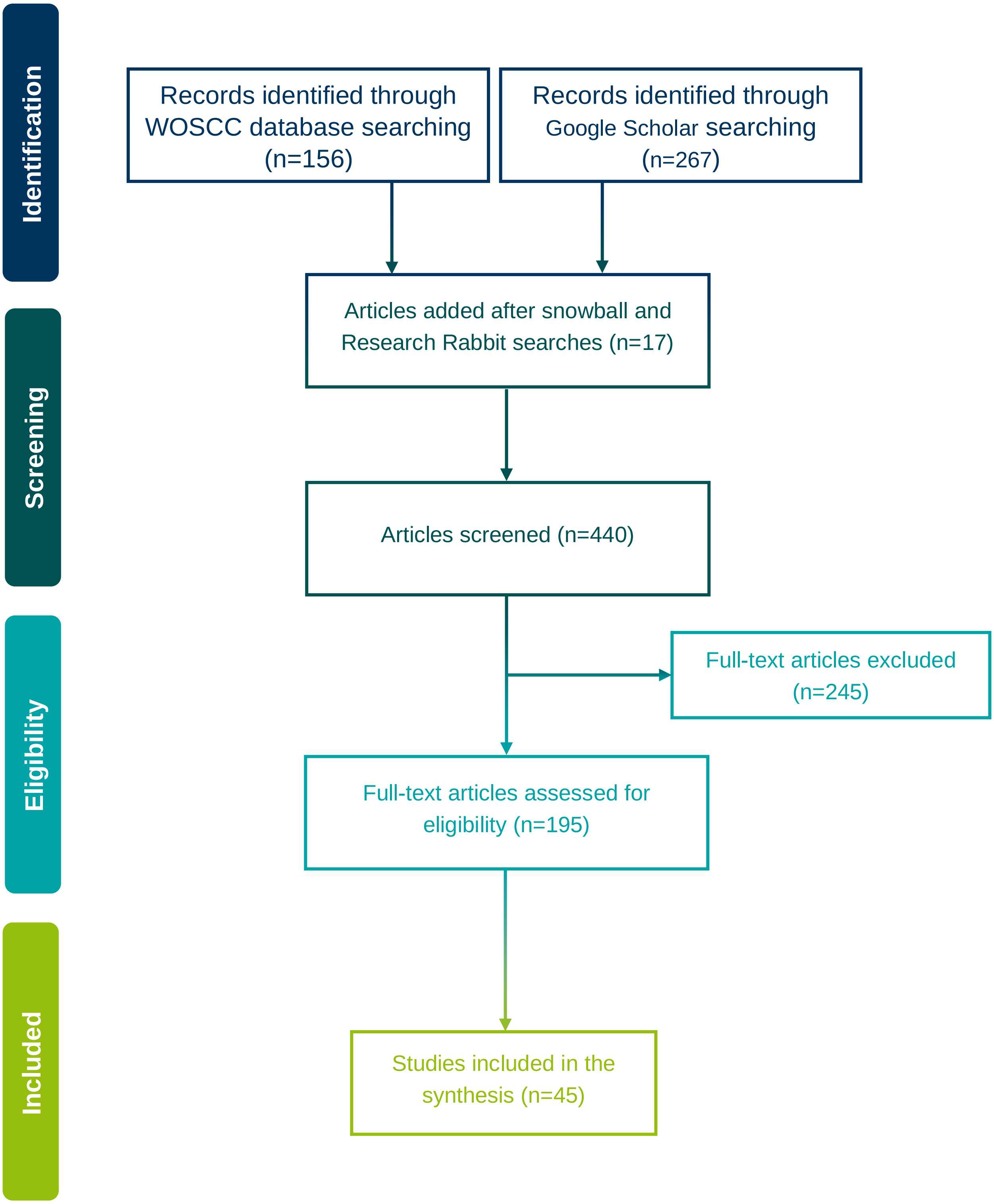

Figure 3. Flow diagram of the process followed to identify studies that met inclusion criteria for the present Quick Scoping Review.

2.5. Screening strategy

Publications were manually screened by the project team using a stepwise application of inclusion and exclusion criteria at the title, abstract, and full text levels. Inclusion and exclusion criteria of the output are detailed in Annex A1.2. Prior to screening, we progressively refined the criteria to ensure they were clear to all reviewers and interpreted consistently. Selection criteria were also refined after abstract screening to produce a manageable number of studies. Decisions on studies for which inclusion eligibility was unclear were assessed at the next screening stage. Additionally, at the title screening stage, all those labelled as relevant were also assessed at the abstract stage. Subsequently, all abstracts then labelled as relevant or potentially relevant were assessed at the full text level. Selection and exclusion criteria for full text screening are described in Table A4 (Appendix A1.2). The final list of included articles was reviewed for relevance by an additional reviewer to avoid inclusion errors. There were also consistency checks, i.e., checking selection decisions by two different reviewers. Inconsistencies (i.e., disagreement in whether a paper should be included) occurred in the case of review papers. These review papers were removed. Emerging inconsistencies helped revise and refine eligibility criteria, as for example for biodiversity metrics.

Screening was conducted by two authors. Ioanna Akoumianaki (IA) undertook scoping searches and trial searches, which helped identify selection criteria; screened WOSCC and Google Scholar search results; conducted “snowball searches”; explored related articles in Research Rabbit; and checked consistency of the process. Robin Pakeman (RP) screened WOSCC search results.

Citation outputs from WOSCC and Google Scholar were exported to EndNote (v 8.2). Duplicate records were manually removed. Titles and Abstracts were reviewed to screen papers based on relevance, full papers (i.e., research, review, perspective, and meta-analyses) were retrieved and stored for screening and reporting purposes. Grey literature (i.e., documents by IPBES, IPCC, EC, UN, UNEP, UNDP, IUCN, and Biodiversa+ and more) were included if they reported approaches or data on harnessing the roles of biodiversity in addressing environmental, societal and economic challenges to deliver well-being, resilience and ecosystem services according to the conceptualisations presented in Figures 1 and 2. Proceedings, theses, editorials, opinions and commentaries were excluded. Further, articles were excluded that did not have a scientific or technical focus to support the understanding of the roles of biodiversity, or did not address a challenge, or did not report NBS outcomes. All the studies included contain empirical, qualitative or quantitative, biophysical or otherwise, evidence. As illustrated in Figure 3, a total of 45 relevant studies were identified for inclusion in this review. The list of excluded papers is also available.

It must be noted that this study focused on interventions that were considered by their authors as “nature-based solutions” or were described using one of the terms falling under the umbrella term “NBS, as specified in Table A2 (Annex 1). It is beyond the scope of this Quick Scoping Review to assess whether these interventions met the criteria of NBS identified by the definitions given in Section 1.

All literature searches were completed by December 2022.

2.6. Coding

This Quick Scoping Review builds on the coding developed in three earlier evidence syntheses: a global systematic map assessing the outcomes of nature-based interventions in any ecosystems, except urban and agricultural, to address climate change or related hydrometeorological impacts (Chausson et al. 2020); a systematic review of biodiversity outcomes of NBS for climate change adaptation (Key et al. 2022); and a systematic review of NBS nomenclature and the unique characteristics, common applications and multiple co-benefits of NBS (Anderson and Gough, 2022).

The selected papers were coded across 50 categories, including NBS type (as per Eggermont et al. 2015), biodiversity metric used, and the roles of biodiversity in delivering NBS outcomes (positive, negative, mixed, no effect, unclear, not mentioned). The coding framework is described in Annex 1.3. A list of coding categories is presented in Table A5 in Annex 1.3.

Coding was conducted by two authors. IA undertook the coding of results from WOSCC, Google Scholar, snowball and Research Rabbit searches. RP coded a part of the results from WOSCC searches.

2.7. Critical appraisal

This Quick Scoping Review did not apply a critical appraisal of the quality of included studies. This is not normally conducted for scoping reviews, the focus of which is to catalogue the evidence-base and make it accessible. However, the evidence used is based on peer-reviewed publications, which is an indirect assurance of their quality. Further, the coding framework included information on study design and evidence type.

2.8. Evidence mapping

The evidence-base i.e., the selected studies, was characterised through descriptive statistics including ‘mapping’ the quantity of articles per journal and type of article, taxonomic category, and type of NBS. This helped to highlight knowledge gaps and guide the identification of clusters of evidence amenable to Systematic Reviews. Mapping the geographic range of studies relied on EviAtlas, an Open Source tool for creating and hosting visualisations from databases of studies created within systematic maps and systematic reviews (https://estech.shinyapps.io/eviatlas/).

The relevance and sensitivity of the search terms used was also assessed using VOSViewer, a software tool for constructing and visualising bibliometric networks (https://www.vosviewer.com/). Of particular relevance to the objectives of this Quick Scoping Review was VOSviewer’s text mining functionality. This can be used to construct and visualise co-occurrence networks of important terms extracted from text data, i.e., title and abstracts of scientific literature.

Using VOSViewer to identify knowledge gaps and knowledge clusters in the evidence-base related to biodiversity and NBS included the broad steps described in the VOSviewer Manual (van Eck and Waltman, 2018) and summarised below.

1 Transforming publication information into a file type that is available to VOSviewer: the scientific publications retrieved from WOSCC, Google Scholar and Research Rabbit using the search strategy before and after screening were extracted to a RIS file, a the file types supported by VOSviewer. The RIS file contained bibliographic information on each paper, including title, abstract, authors, citations, year of publication and journal. Co-occurrence links between terms use “text data”, which are extracted by the title and abstract of each publication in the RIS file.

2 Creating a term co-occurrence map in VOSviewer based on the text data: VOSviewer used text data to construct a network of co-occurrence links between terms identified in the text data using natural language processing algorithms. VOSviewer uses the part-of-speech tagging algorithm provided by the Apache OpenNLP library.

3 Selecting terms: VOSviewer yields a set of noun phrases (terms) terms based on the text data. Occurrences of terms indicate the total number of occurrences in all publications in the RIS file. The selection of terms is made by excluding terms with a small number of occurrences (e.g., by default, terms with fewer than 10 occurrences are excluded), by excluding terms with a low relevance score, and possibly also by manually excluding certain terms. VOSviewer calculates for each term a relevance score. Terms with a high relevance score tend to represent specific topics covered by the text data, while terms with a low relevance score tend to be of a general nature and tend not to be representative of any specific topic. The selected terms are included in the map that is created.

The present study applied the cut-off threshold of 10 term occurrences for the text data before screening. This yielded 97 terms for mapping evidence from 440 publications (before screening). A cut-off threshold of three occurrences was applied to the text data after screening. This yielded 145 terms for mapping evidence from 45 publications (after screening).

3. Results

3.1. Studies identified

The search of the scientific literature on the roles of biodiversity in NBS identified a total of 440 papers, of which 45 met our selection criteria (Table A4). The VOSviewer density visualisation of the list of papers before screening (440) showed the presence of three key clusters of topics (in yellow): : biodiversity, ecosystem-based approach, and nature-based solutions (Figure 3a). This shows that the search strategy successfully captured the key topics of this project. However, the lack of linkages in the literature between biodiversity and ecosystem approach/NBS reflects the difficulty observed during trials and the scoping literature searches in identifying studies exploring the role of biodiversity in NBS outcomes.

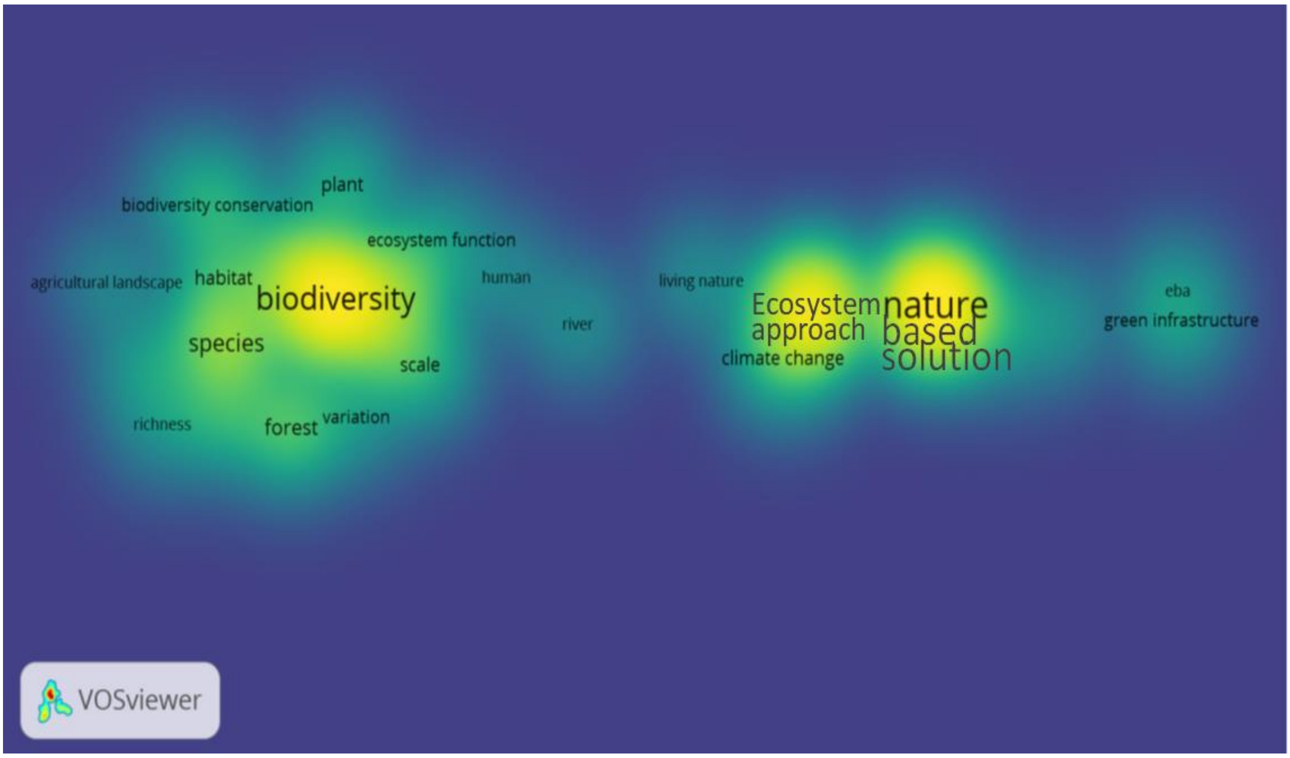

Figure 3a. Density mapping of keyword co-occurrences analysis in the list of studies retrieved applying the search strategy before screening. A keyword's colour indicates the degree of citations from yellow (highest number of co-occurrences) to blue-green (lowest number of co-occurrences). eba: ecosystem-based adaptation.

The VOSviewer visualisation of the studies selected after screening (45 papers) identified common topics in studies linking biodiversity and NBS, which in this visualisation were closely arranged (Figure 3b). These included interventions such as crop diversification, pollination service ecological intensification, agroecological practice, sustainable use, and conservation. It also included ecosystem-related terms such as ecosystem function and associated ecosystem service. Common topics included issues and challenges addressed with NBS such as pathogen, erosion, and environmental impact. Topic related to types of habitat referred to forest and soil. Lastly, biodiversity metrics were represented by common topics such as species, characteristic, functional diversity, and experiential knowledge.

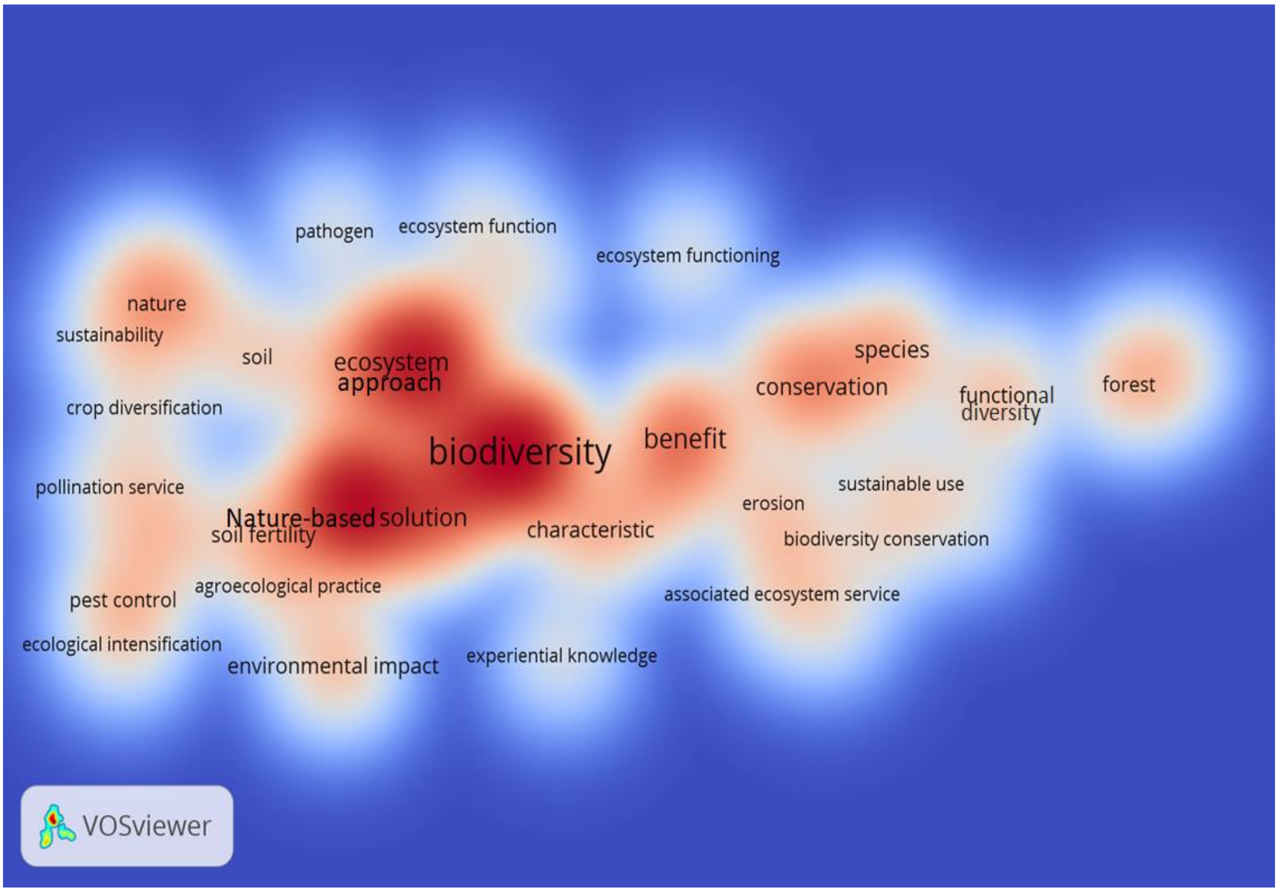

Figure 3b. Density mapping of keyword co-occurrences analysis in the list of studies retrieved applying the search strategy after screening. A keyword's colour indicates the degree of citations from red (highest number of co-occurrences) to pink (lowest number of co-occurrences).

Hereafter, NBS are reported the way they were coded (see Annex 1.3). The studies were published across 34 academic journals from 2009 to 2022 (Figure 4). Of these studies, there were 30 primary research articles and two quantitative meta-analyses (i.e., synthesis of results from primary studies investigating relations among common variables), reporting evidence on NBS1-Protection (5 studies), NBS2-Sustainable management (15 studies), NBS3-Restoration (5 studies) and NBS4-Habitat creation (5 studies). There were 10 review articles, reporting evidence on NBS2 (5 articles), NBS3 (2 articles), NBS4 (1 article) and two for NBS5.3-Restoration and management. There were also 3 perspective articles that provided an overview on the role of biodiversity in different types of NBS. The rate of publication increased rapidly after 2020 (Figure 5).

Journal	NBS 1	NBS 2	NBS 3	NBS 4	NBS 5.1	NBS 5.3	NBS 5.4	NBS 1, NBS 3	NBS 1, NBS 2, NBS3
Aerobiologia				1					
Agricultural Systems		1							
Agriculture, Ecosystems & Environment		1							
Agroecology and Sustainable Food Systems		1							
Agronomy for Sustainable Development		3							
Agronomy-Basel		1							
Aquatic Conservation: Marine Freshwater Ecosystems			1						
Biology Letters	1								
Current Opinion in Environmental Sustainability		1							
Ecological engineering		1	1						
Ecosystem services		1					1		
Ecosystems						1			
Environmental Science & Policy						1			
Forest Ecology and Management		1	1						
Frontiers in Environmental Science				1					
Frontiers in Marine Science	1								
Global Biogeochemical cycles	1								
Global food Security		1							
Journal of Applied Ecology		2							
Journal of Environmental Management		1							
Journal of Resources and Ecology					1				
Journal of Soil and Water Conservation		1							
Land Use Policy				1					
Natural Hazards						1			
Nature Communications	1								
Nature Geoscience			1						
People and Nature		1		1					
Philosophical Transactions B									1
PLOS One	1		1	1				1	
PNAS	1	1							
Science			1						
Scientific reports		1							
Soil Biology and Biochemistry			1						
Sustainability		1							

Research
Review
Perspective
Meta-Analysis
Mixed: research, review

Figure 5. Type of journal per type of article and NBS type explored for the role of biodiversity in its outcomes.

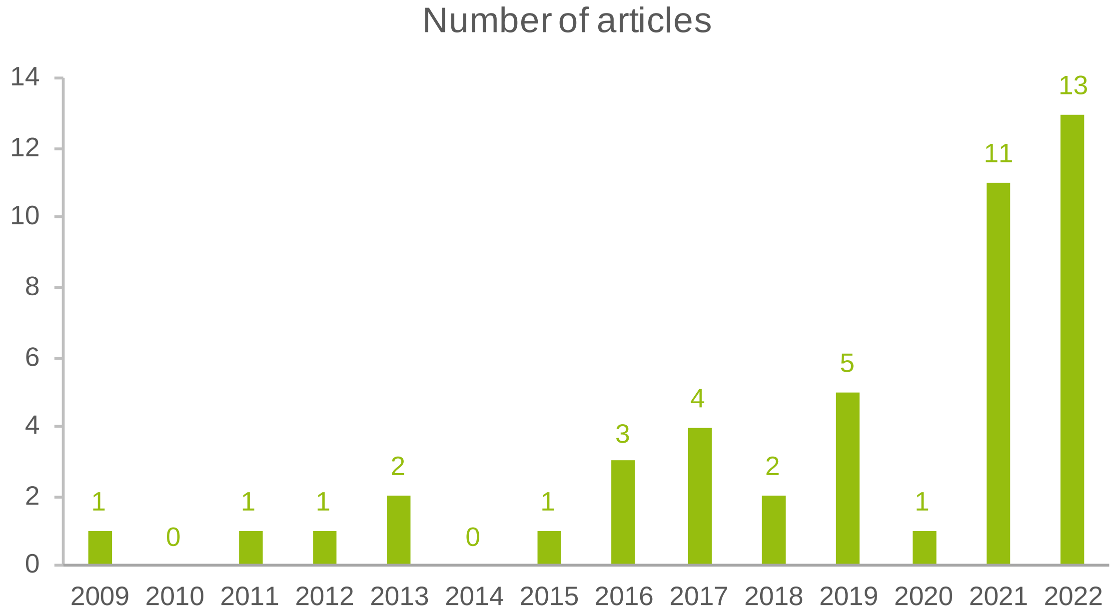

Figure 6. Number of articles per year of publication.

Study designs varied but 34 articles reported experimental or quasi-experimental study designs in the field or through qualitative assessments (e.g., interviews) that used a control or other type of comparator to assess the effectiveness or role of a specific biodiversity metric in achieving intended NBS outcomes. The remainder of studies were review or perspective articles reporting on results of experimental studies.

The role (effectiveness) of biodiversity on NBS outcomes was assessed in a variety of ways. Biophysical evidence was used in 34 studies, including biodiversity metrics and less frequently indices (e.g., allergenicity index), genomics and proteomics. Social, economic, and anecdotal (experiential) evidence was used in four studies and involved capturing non-biophysical definitions of biodiversity such as perceptions and economic value.

3.2. Distribution of the evidence

3.2.1. What are the geographic distribution, ecosystem types, taxonomic categories, NBS types, and geographical scales of studies providing evidence on biodiversity's roles in the delivery of ecosystem services and NBS outcomes?

The applied process enabled the identification of 45 papers providing evidence on the roles of biodiversity in NBS. The interventions that were considered as NBS by their authors took place across a wide range of geographic and climatic regions except polar regions and Oceania (Figure 7). Studies were conducted in both high- and low-income countries (income was not coded in studies retrieved from WOSCC).

The majority of studies were implemented in terrestrial ecosystems (33 out of 45). The most studied terrestrial ecosystems were farming and agroforestry systems (18 out of 45), of which two explored sustainable management combined with restoration of ecosystem functionality (Benayas et al. 2012; Bianchi et al. 2013). Forests (boreal, tropical, alpine) were also frequently studied (12 out of 45 studies). Of these, three studies explored the role of biodiversity in restoration (tropical forest restoration: Poorter et al. 2021; riparian forest restoration: Hasselquist et al. 2021; and alpine forest restoration combined with EcoDRR: Bigot et al. 2009) and three studies reported evidence on sustainable forest management for risk reduction (Dupire et al. 2016; Moos et al. 2019) and recreation (Austen et al. 2021).

Ten studies were implemented in coastal and marine habitats, the most commonly studied NBS type for this habitat being protection (4 studies) to maintain supporting and regulating services of benthic invertebrates and plant biodiversity such as carbon sequestration (Rahman et al. 2021; Kennedy et al. 2022) and wave attenuation (Narayan et al. 2016) and ensure delivery non-material contributions of biodiversity to people such as recreation (Tribot et al. 2019). Coastal restoration was represented by three studies exploring the role of oyster genetic diversity in disease spread control (Sas et al. 2020), the role of oyster reef diversity as natural breakwaters and fish nurseries (Scyphers et al. 2011) and the role of saltmarsh plant species in eco-restoring to reduce nitrous oxide emissions (Zhang et al. 2013).

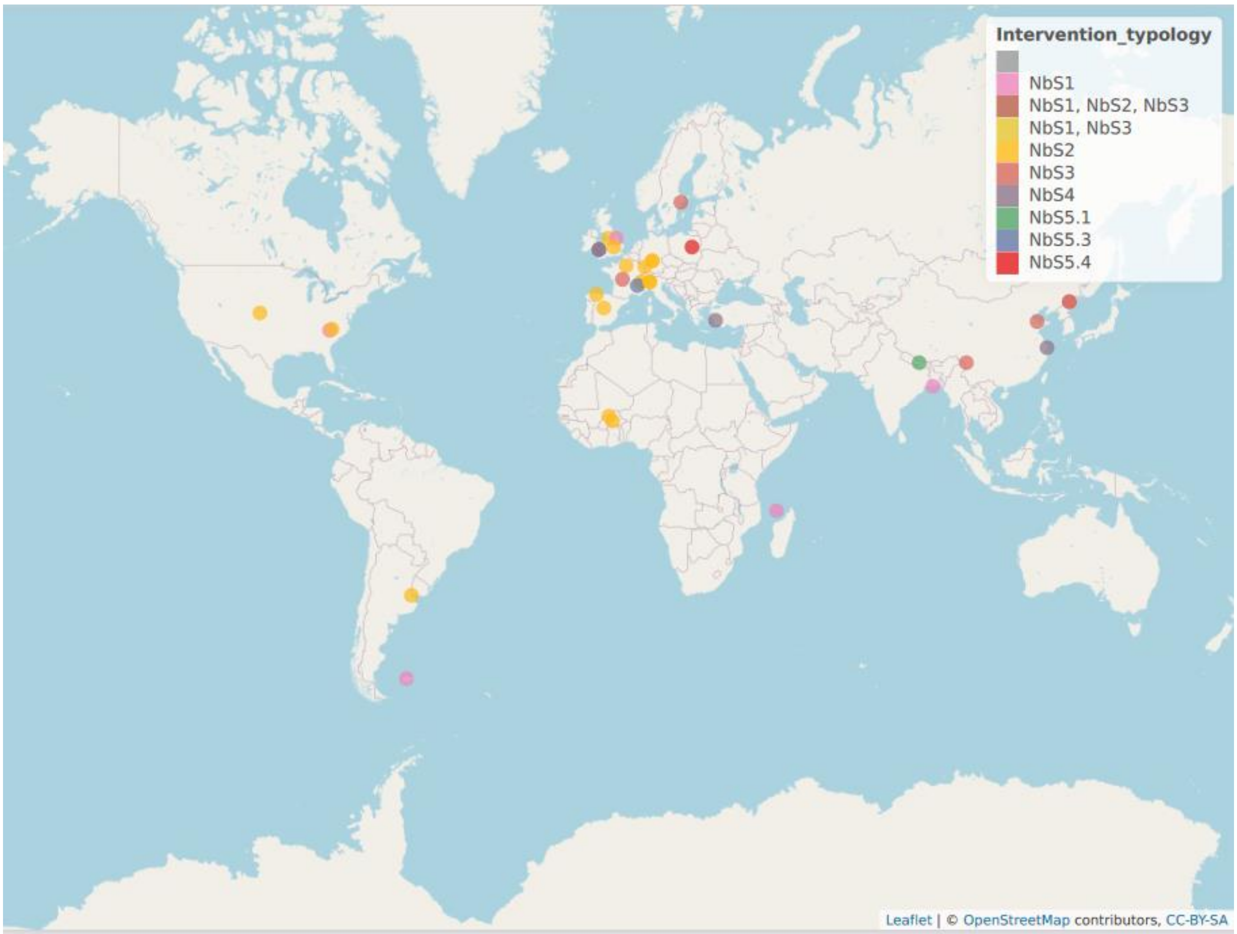

Figure 7. Geographic distribution of studies examining the role of biodiversity in NBS.

NBS1-Protection and Conservation (8 studies) were implemented in both marine and terrestrial realms. Marine studies focused on protected areas including coastal wetlands (mangroves and saltmarsh), seagrass and coral reefs as well as large marine protected areas, including the open sea. The marine studies reported multiple taxonomic categories as part of the NBS design, including plants, benthic invertebrates, coral reef communities, fish assemblages, and squid fisheries. Terrestrial studies focused on temperate forests and woodland-related plant and bird taxa. Terms used by the authors to describe NBS1 comprised: evaluation of the human-nature relationship, conservation (forest, seagrass, mangrove), woodland expansion and farmland abandonment, biodiversity-based, cultural, and aesthetic values of biodiversity, passive rewilding, and RED++. NBS1 were implemented at the landscape scale, and studies reported on evidence from experimental plots within protected areas.

NBS2-Sustainable management (21 studies) were implemented in the terrestrial realm in agroecosystems; in montane environments, involving sustainable forest management, and in the marine environment, involving coastal zone management. Terms used by the authors to describe the NBS2 comprised (*inter alia*): “management to increase structural heterogeneity”, “management that accounts for the effects of alien species”, Eco-DRR (Ecosystem-based disaster risk reduction), "integration of trees or shrubs with crop and animal production", "engage people with nature", coastal zone management, agri-environment schemes, ecological intensification, "biodiversity-based farming techniques", "use of ecosystem services by the farmer, "replace high levels of input with ecosystem services provided by biodiversity". The scale of the intervention was usually small, i.e., farm plot, however some interventions were implemented at larger scales, including landscape, gulf-scale, and regional scale.

NBS3 (Restoration) included interventions such as "regrowing secondary forests", riparian tree planting, reforestation, saltmarsh revegetation and oyster restoration. Restoration was implemented at landscape scale and the studies reported results on a plot and regional scale. Terrestrial restoration was implemented in forests: two in tropical forests (neotropics and West Africa, and China); one in a temperate forest in China; one in boreal forests in Sweden; a global study on the role of global tree restoration. Marine restoration was implemented: a global study on restoration of coastal vegetated habitats such as saltmarshes, mangrove forests and seagrass meadows; a review of the role of different benthic taxa in marine ecological restoration; and one on oyster reef restoration in European waters (UK, Ireland, Belgium and the Netherlands).

NBS4 (Created habitats) were implemented in urban (terrestrial and coastal) environments. They included interventions that used trees in terrestrial contexts and seaweeds and invertebrate hard-substrate species in coastal contexts. Terrestrial-based interventions were described as nature-based cooling strategies, urban green zones, and urban green spaces and were implemented at the neighbourhood, or urban park scale. Coast-based interventions were described as artificial coastal structures, coastal defence structures and artificial coastal habitats and were implemented at the local community scale.

The taxa investigated for their role on NBS outcomes in the selected studies belonged to five kingdoms (Animalia, Plantae, Fungi, Protista and Eubacteria) (Figure 8). The role of taxa was determined by the intended outcomes and the metric used. Here, their role is summarised in relation to intended outcomes[6].

- Marine invertebrates and plants were used in all types of NBS (NBS1-4). Soft-substrate marine invertebrates were assessed for their supporting role in processes such as sediment biogeochemical cycling (Solan et al. 2019), biodiversity maintenance and the food web in the open sea (Bax et al. 2022) and in supporting genetic diversity to resist disease (Sas et al. 2020). Hard-substrate marine invertebrates were assessed for their regulating role in wave attenuation and mitigation of shoreline retreat as a component of living shorelines (Narayan et al. 2016; Scyphers et al. 2011) but also for their role in providing non-material contributions depending on aesthetic perception (Fairchild et al. 2022 ; Tribot et al. 2019).
- Marine plants were assessed for their supporting role in structuring marine food web (Bax et al. 2022) and coastal habitats (Harik et al. 2017) as well as in carbon storage (Rahman et al. 2021; Kennedy et al. 2022) and mitigation of nitrous oxide emissions (Zhang et al. 2013) as well as their regulating role in wave attenuation (Narayan et al. 2016).

[6] There was a wide range of intended outcomes. Trials showed that a graphical visualisation of the role played by the different taxa by outcome would add rather than reduce complexity.

- Insects were commonly used in NBS2. As a group, insects were assessed for their supporting role in biodiversity and habitat maintenance (Sikorski et al. 2021; Fabian et al. 2021) and their role as a non-material aesthetic service to forest visitors (Austen et al. 2021). Several studies assessed the supporting role of pollinator insects (Staton et al. 2022) and the regulatory role of insects in pest control and pollination (Adhikari et al. 2019; Bianchi et al. 2013; Bommarco et al. 2018; Duru et al. 2015; Molina et al. 2022; Palomo-Campesino et al. 2022; Redlich et al. 2021).
- Terrestrial birds such as farmland birds and songbirds were assessed for their supporting role in pest control and pollination (Fabian et al. 2021; Garcia et al. 2021) and as part of ecological interactions (Sikorski et al. 2021; Broughton et al. 2022).
- Terrestrial vertebrates were assessed for their role in providing non-material aesthetic services to forest visitors (Austen et al. 2021).
- Trees, including shrubs, were used in NBS2 (forestry, agroforestry, EcoDRR), NBS3 (forest restoration for multiple benefits, including water quantity regulation) and NBS4 (e.g., studies reporting evidence on created urban parks).
  - Supporting role of trees: this was illustrated in studies reporting evidence on the role of trees in increasing soil carbon in farming systems (Felix et al. 2018); carbon sequestration during tropical forest restoration (Lu et al. 2017); seedling provision in the surrounding area (Broughton et al. 2022 ; Poorter et al. 2021) ; and rockfall risk reduction (Dupire et al. 2016 ; Moos et al. 2019).
  - Regulating role of trees: examples of this can be found in studies reporting evidence on the role of forest restoration in evapotranspiration and water availability at small and large river-basin scales (Hoek van Dijke et al. 2022); tree density in groundwater recharge (Ilstedt et al. 2016) ; urban park trees in cooling (Almenar et al. 2021 ; Wu et al. 2021) ; and allergenicity (Kara et al. 2022).
  - Role of trees as a direct contribution to people: this was assessed more commonly through studies reporting perception of ecosystem services, particularly experiential perceptions of the role of trees as biodiversity refugia (e.g., Sikorksi et al. 2016).
- Cover crops: their supporting role was explored in a study reporting evidence on enhancing biological activity, carbon turnover and total soil carbon (Franzluebbers et al. (2021).
- Crops were reported as part of biodiversity-based systems in studies on the supporting role of biodiversity in habitat provision for insects and birds (Dardonville et al. 2022) and their role in increasing crop yield (Bommarco et al. 2018).

Taxa	NBS 1	NBS 2	NBS 3	NBS 4	NBS 5.1	NBS 5.3	NBS 5.4	NBS 1, NBS 3	NBS 1, NBS 2, NBS3
Animals (Bees)		1							
Animals (Benthic bioturbating shrimps)									1
Animals (Benthic bivalves)									1
Animals (Benthic invertebrates)	1			1					1
Animals (Benthic tube-dwelling polychaetes)									1
Animals (Birds)		2					1		
Animals (Bumblebees)							1		
Animals (Carabid beetles)		1					1		
Animals (Coral reef fish)	1								
Animals (Coral reefs)								1	
Animals (Eastern oysters)				1					
Animals (European native oysters)			1						
Animals (Fisheries)	1								
Animals (Hoverflies)		1							
Animals (Insect pollinators)		1				1			
Animals (Insects)		6							
Animals (Lepidopterans)		1							
Animals (Orthopterans)		1							
Animals (Songbirds)		1							
Animals (Staphylinid beetles)		1							
Animals (Terrestrial invertebrates)		1							
Animals (Vertebrates)		1							
Animals (Wasps)		1							
Eubacteria			1	1					
Fungi (Mushrooms)		1			1				
Fungi (Mycorrhizal and saprotrophic)			1						
Plants (Agroforestry trees)		2				1			
Plants (Alps conifer and mixed forests)		2				1			
Plants (Apple trees)		2							
Plants (Arable weeds)		1							
Plants (Boreal forest trees)			1						
Plants (Coastal vegetation)		1							
Plants (Cover crops)		1							
Plants (Crops)		6				1			
Plants (Flowers)		1							
Plants (Forest Trees)	1	2	1						
Plants (Forest wildflowers)	1								
Plants (Grassland)		2							
Plants (Halophyte vegetation)			1						
Plants (Invasive-Tree of heaven)		1							
Plants (Kelp)	1							1	
Plants (Mangrove)	1							1	
Plants (Open farmland grasses)	1								
Plants (Saltmarsh vegetation)								1	
Plants (Seagrass)	2							1	
Plants (Seaweed)				1					
Plants (Arable weeds)		1							
Plants (Semi-urban Trees)							1		
Plants (Subtropical forest Trees)			1						
Plants (Tropical forest Trees)			1						
Plants (Understorey plants)		1							
Plants (Urban grasses and meadows)				2					
Plants (Urban Shrubs)				1					
Plants (Urban Trees)				3					
Plants (Woodland shrubs)	1								
Plants (Woody perennials)		1							
Protista				1					

Figure 8. Taxa reported in the studies exploring the role of biodiversity in NBS.

- Fungi: few studies assessed the role of fungi. Fungi's role was assessed in connection with their culinary use and as decomposers in forest soils. For example, the role of mushrooms was assessed in studies reporting evidence on their use as food and as a source of income for rural communities (Devkota 2022) and their non-material, aesthetic services to forest visitors (Austen et al. 2021). Evidence on the supporting role of mycorrhizal and saprotrophic fungi in carbon sequestration after reforestation was also captured (Shao et al. 2019).

- Eubacteria: few studies assessed the role of microbial communities. A study used microbial lipid biomarkers to assess their supporting role in carbon accumulation following reforestation (Shao et al. 2019).

3.2.2. What metric is used to assess the roles of biodiversity in NBS?

10 out of 45 studies relied on a single biodiversity metric, such as species abundance, species richness, taxa presence, functional diversity, tree density, and degree of connectivity and fragmentation within the landscape (see also Table A6 for a full list of metrics). Eight studies (comprising 7 review and one research article) reporting evidence on agroecosystems, and particularly on soil fertility, pest control, pollination and productivity did not use any specific biodiversity metric (Fabian et al. 2021; Bommarco 2018; Casagrande et al. 2017; Dardonville et al. 2022; Duru et al. 2015; Palomo-Campesino et al. 2022; Wyckhuys et al. 2022). The remainder of the studies used different combinations of multiple metrics that encompassed all broad categories of metrics. However, the majority of studies (36 out of 45) used a single category of broad biodiversity metric (Annex 2, Table A7). Number of studies using each broad category of biodiversity metric is presented in Figure 9.

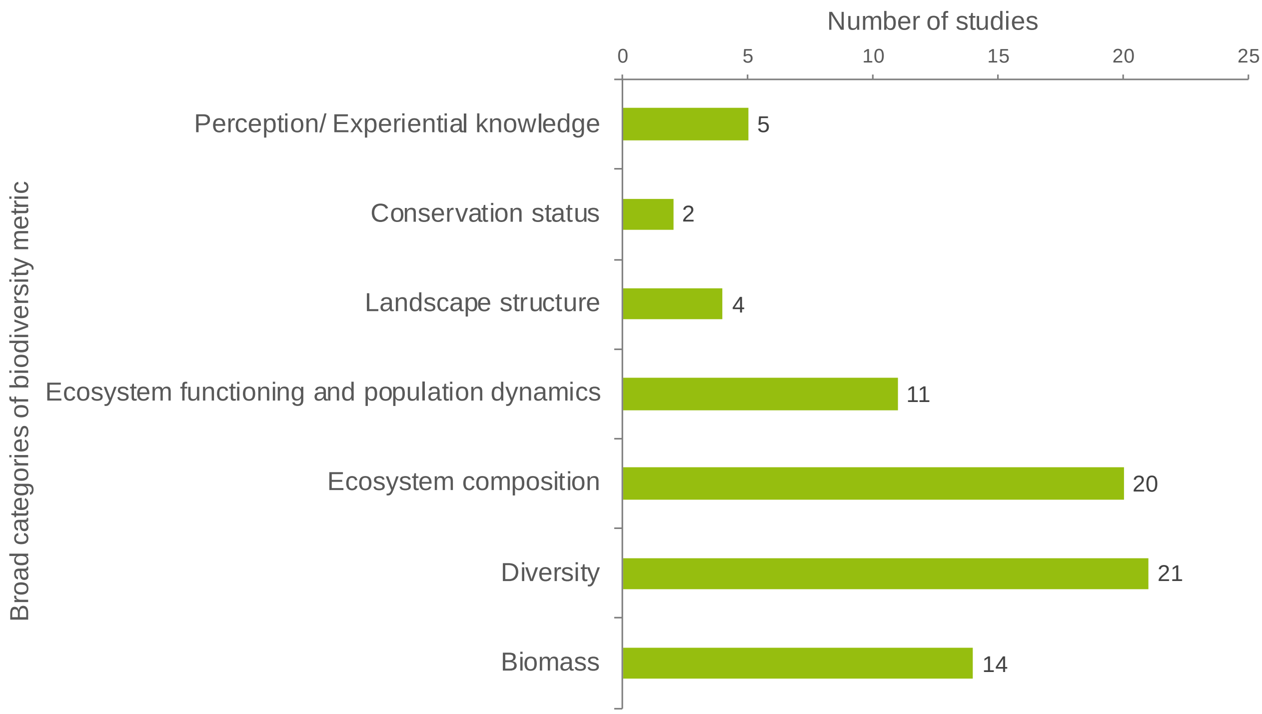

Figure 9. Broad categories of biodiversity metrics used in the studies selected for evidence mapping.

It is interesting to note that the same metrics can be used to assess the roles of biodiversity in different contexts such as ecosystem type and NBS type. Further, there were metrics that could provide information for different broad metric categories. For example, lipid biomarkers were used to assess soil microbial diversity, microbial biomass, soil ecosystem composition and soil ecosystem functioning and population dynamics (Shao et al. 2019).

The use of biodiversity metric assessed by NBS type and in relation to the role of biodiversity is summarised below (see also Table A7).

- In NBS1, diversity and ecosystem composition were the most commonly assessed broad metric categories. Studies that used these metrics reported on supporting and regulating roles of biodiversity in NBS (Bax et al. 2022; Broughton et al. 2019; Rahman et al. 2021; Tribot et al. 2019). Diversity metrics included measurements such as species richness and species diversity and the ecosystem composition metric included measurements such as community composition, organism density and taxa presence. Two studies used aesthetic perception (how biodiversity is valued by humans) metrics to report evidence on non-material contributions of biodiversity to people (Graves et al. 2017; Tribot et al. 2019).

Example on the supporting role of biodiversity. Rahman et al. (2021) investigated the co-benefits of protecting mangroves for biodiversity conservation and carbon storage. Species richness and functional distinctiveness (i.e., the uncommonness of trait combination of a species compared to trait combinations of other species within the community) of wood density, maximum canopy height, and leaf litter nitrogen were positively associated with blue carbon storage. Functional distinctiveness had the strongest association with blue carbon storage. The results indicate that protecting and restoring mangroves using species with specific traits and other species of contrasting functional traits would have the benefit of maximising their capacity for climate change mitigation through increased carbon storage.

- In NBS2, diversity and ecosystem composition were the most commonly assessed broad metric categories. These two metrics were used to assess regulating roles of biodiversity (see section 3.2.1: regulating role of terrestrial plants). The role of biodiversity as a direct material contribution to people could be assessed without the use of a specific biodiversity metric (Palomo-Campesino et al. 2022).

Example on the regulating role of biodiversity. Using a survey of 24 farms, Palomo-Campesino, et al. (2022) tested the hypothesis that agroecological practices enhance the supply of ecosystem services. On farms using agroecological practices there were higher populations of beneficial insects suggesting the potential for replacing chemical control by management to boost the populations of natural enemies.

Example of biodiversity as a direct contribution to people. A review by Benayas & Bullock (2012) advocated combining land sparing and land sharing approaches to reap the benefits of ecological restoration in extensive agricultural landscapes. This approach allows reconciliation of farmland production, conservation of values linked to cultural landscapes, enhancement of biodiversity, and provision of a range of ecosystem services. Biodiversity-based approaches to agricultural land management could boost farm productivity (biodiversity as a direct material contribution to people) and enhance biodiversity and improve other ecosystem services (supporting role of biodiversity).

- In NBS3 (Restoration), diversity, biomass, ecosystem composition and ecosystem functioning & population dynamics were the broad metric categories assessed. The ecosystem function & population dynamics metric referred to measurements of, for example, functional identity (e.g., community of nitrogen fixers in the soil). The studies included in this category reported evidence on supporting and regulating roles of biodiversity.
- In NBS4 (Habitat creation), biomass, diversity, ecosystem composition, ecosystem functioning and population dynamics, landscape structure and perception/ experiential knowledge were the broad metric categories assessed. Biodiversity, for example, was valued in terms of the colourfulness of created habitats (Fairchild et al. 2022).

Example of the regulating role of biodiversity. Using a comparison of different urban green areas Wu et al. (2021) showed that increasing functional group diversity had a positive effect on cooling and thus increased the liveability of cities at the local scale. The urban green areas dominated by tree-shrub-grass showed the highest cooling efficiency compared to simpler vegetation.

Example of the regulating role of biodiversity as a disservice. A study by Kara and Asik (2022) showed that allergenicity of tree flora in urban parks (i.e., the capacity of tree pollen to cause allergy to visitors and residents in adjacent areas) was not correlated with species diversity and tree density. It was, however, determined that allergenicity was increased with the presence of tree species that emit pollen during the flowering period. Therefore, urban park tree community composition and allergenic taxa presence play an important role in causing allergies to the human population. The authors argued that this disservice could be avoided by choosing tree species with low allergenicity when designing and planning urban parks.

3.2.3. What is the link between the type of issues (challenges) addressed and the roles of biodiversity?

All except one study referred to single-issue interventions. There was a wide range of issues addressed from biodiversity loss and ecosystem resilience (8 papers) and climate change (3 papers) to disaster risk such as rockfall risk (3 papers) and coastal flooding and erosion (2 papers), biosecurity (1 paper) and access to amenity space (4 papers). A considerable number of papers (17) reported food production, yield, and pest control in agro-ecosystems as the issue to be addressed. Assessing the effectiveness of the roles of biodiversity in addressing the issue and designing NBS that are fit-for-purpose was not possible because none of the studies selected for inclusion in this review compared the biodiversity-based NBS to an alternative approach predominantly relying on non-living nature or engineered interventions. However, there were studies that used experimental control treatments with no living organisms as part of experimental design at plot scale.

3.2.4. What is the link between biodiversity and NBS outcomes and how are NBS outcomes assessed?

The outcomes of NBS in the studies reviewed here were measured with a wide range of metric categories, which depended on the type of outcomes (see Annex 1, Table A3). The biodiversity metrics used to assess the effectiveness of biodiversity on delivering a measurable NBS outcome across the evidence base were divided into seven broad categories: Biomass, Diversity, Ecosystem composition, Ecosystem functioning and population dynamics, Landscape structure, Conservation structure, and Perception/Experiential knowledge. Biophysical data, observed or modelled, informed the majority of papers (28). Perception of outcomes (social metric) and monetary valuation (economic metric) were also used to assess the effect of biodiversity on outcomes.

Here, the effect of biodiversity on outcomes is reported for a given study design, metric and taxa, bearing in mind that there are studies that evaluate the role of biodiversity using multiple experimental treatments, metrics and compared the effects of different taxa on outcomes. Most studies reported a positive effect of a biodiversity metric or specific taxa on intended outcomes with a given study design (28 studies). Five studies reported a negative effect of biodiversity. No effect was reported in seven studies. Five studies reported unclear or inconclusive effects of biodiversity on outcomes. Given the limited number of studies reporting on the role of biodiversity in similar types of NBS implemented in similar ecosystem types, these results on the effectiveness of biodiversity should be interpreted with caution. Therefore, it may be better to assess the effectiveness of biodiversity per type of outcomes.

The effect of biodiversity on outcomes, as assessed by the authors of these papers based on study design and results, is summarised below by type of outcome.

- **Climate change mitigation.** Six studies referred to the role of biodiversity in climate change mitigation outcomes via carbon sequestration, carbon storage and reduction of nitrous oxide emissions from revegetated soils; co-benefits were not quantified but were mentioned. One study showed that this outcome was enhanced by mangrove species diversity and taxonomic distinctiveness (as in Rahman et al. 2021; see also Section 3. 2 example) and therefore it showed the positive supporting role of biodiversity in mitigation. Another study by Kennedy et al. (2022) showed that biomass metrics, and metrics such as seagrass community composition and taxa presence are directly associated with the provision of climate regulation services by seagrass (carbon sequestration), therefore highlighting the positive supporting of biodiversity at the scale and its regulating role at the regional and global scales. Further, Zhang et al. (2011) showed that the degree of reduction in nitrous oxide emissions following saltmarsh revegetation is determined by plant species. The positive effect of forest soil microbial communities in the role of reforestation as a climate mitigation approach was demonstrated by Saho et al. (2019). Mixed outcomes of the role of forest restoration were reported by Hoek van Diijke et al. (2022), who demonstrated trade-offs between climate change mitigation benefits delivered by forest restoration and reduction in water availability at local and regional scales.

- **Well-being and health (non-material contributions of biodiversity to people).** Ten studies referred to the delivery of NBS outcomes for individual and urban or rural community well-being. Well-being was measured with four different types of metric: biophysical, social based on perception, economic, and anecdotal. Biophysical metrics were used when assessing supporting or regulating roles of biodiversity, such as the impact of green zone biodiversity (regulating role) on temperature reduction by urban parks, assuming that this reduces the impact of the "heat island effect" on human health and well-being (Wu et al. 2021). One study assessed the role of fungi in the well-being and adaptation (e.g., as a source of income) of local upland or remote communities reviewing social perceptions, economic indicators and anecdotal evidence on how communities value fungi diversity, therefore advocating their sustainable management (Devkota et al. 2022). 4 studies used individual and community perception to assess well-being outcomes as non-material contributions of biodiversity to people (see example below). Additionally, these studies provided evidence for the positive role of specific biodiversity metrics such as species richness and evenness and generic richness in the delivery of well-being outcomes in the form of cultural services (non-material NCP). However, functional diversity and arguably scholarly biodiversity metrics were found to have no effect on perceptions of the effect of biodiversity on well-being (Fairchild et al. 2021; Tribot et al. 2019).

Example of species diversity as an aesthetic value (non-material contribution) to humans. A study by Fairchild et al. (2021) investigated how several facets of biodiversity influence how people perceive urban coastal structures at both landscape and close-up scales using image-based questionnaires. They found that species richness and species evenness strongly enhanced people's ratings of images for aesthetic appeal, interest and calming potential at both scales. By contrast, functional diversity was associated with a decline in aesthetic appeal and interest at the close-up scale, indicating that people can disfavour scenes dominated by species with contrasting traits. These findings suggest that managing urban intertidal habitats for biodiversity may simultaneously deliver aesthetic, educational and well-being benefits.

- **Adaptation and resilience to disasters**. 9 studies presented outcomes on enhancing adaptation and resilience to disasters (rockfall risk reduction: Bigot et al. 2009; Dupire et al. 2016; Moos et al. 2019); anthropogenic threats (water purification: Amenar et al. 2021; Hasselquist et al. 2021; Solan et al. 2019) and the impacts of extreme weather and climate change (coastal flooding:

Narayan et al. 2016; water shortages: Ilstedt et al. 2016). These outcomes were assessed using biophysical metrics (observed data and modelled projections). Assessments of the effect of biodiversity varied from positive to negative and depended on complex, poorly understood interactions between physical and climatic conditions, biota, and type of management.

Example of the supporting and regulating role of forest structure and species composition. By comparing forest stands of different composition, Dupire et al. (2016) demonstrated that rockfall hazard was determined by both the structure and composition of forests. Stem density was a key determinant of the protective effect of a forest, as was a high proportion of broad-leaved trees. However, there was an additional effect of diversity, with a richer diversity offering protection through increased structural heterogeneity.

Example of the supporting role of species traits and community compositions as a disservice. Moos et al. (2019) investigated how an invasive species, *Ailanthus altissima*, affected the capacity of native forests to prevent rockfall. The increase in abundance of this alien species reduced the average wood density across the forest and this reduction in strength has the potential to affect a forest's capacity to prevent landslides if the long-term consequence was the replacement of larger trees by the narrow-stemmed *A. altissima*.

- **Zero hunger – Food provision – Food security (material contributions of biodiversity to people).** This type of outcome was reported in 14 studies and was assessed using biophysical metrics and evaluation of material contributions of biodiversity to people for which no specific metric was mentioned. The effect of biodiversity was mainly positive. 2 studies, however, reported trade-offs between farm productivity and biodiversity-based management (Bianchi et al. 2013; Felix et al. 2018).

Example of the regulating role of increased insect species richness directly linking NBS design with NBS outcomes. Adhikari et al. (2019) showed in a comparison of farming systems that if the NBS was Integrated Pest Management then switching from conventional to organic farming with increased insect species richness delivered better crop pest control and better crop yields as well as increasing the number of pollinators (as a co-benefit).

Example of functional diversity in supporting ecosystem function indirectly linked to NBS outcomes. In a meta-analysis Felix et al. (2018) assessed the impact of woody species presence on agricultural soil carbon and crop yields. The presence of woody species reduced soil degradation, increased soil carbon, and generally had beneficial effects on crop productivity.

- **Biodiversity and habitat maintenance**. 8 studies presented outcomes related to biodiversity and ecosystem health through protection, sustainable management or restoration (Almenar et al.

2022; Broughton et al. 2022, Fabian et al. 2021; Garcia et al. 2021; Lu et al. 2017; Palomo campesino et al. 2022; Poorter et al. 2021; Solan et al. 2019). Co-benefits mentioned included climate change mitigation, adaptation and resilience, food security, pollination services, recreation and livelihoods. Outcomes were assessed using biophysical metrics. The role of biodiversity was generally positive.

Example of species richness supporting ecosystem processes and mediating the supply of ecosystem services targeted by NBS. Adding nest boxes to orchards increased local populations of insectivorous birds, reduced the abundance of pests and, also, reduced disease incidences (Garcia et al. 2021). The different prey items taken back to the nest suggest complementarity might be at play and that increasing the diversity of the birds, by providing different types of nest boxes, could have an extra benefit.

4. Synthesis and discussion

4.1. Strengths and weaknesses of the current Quick Scoping Review

We consider the overall search string of this study to be comprehensive in terms of capturing all relevant peer reviewed literature on the role of biodiversity in NBS published by December 2022. However, we applied an adaptive approach. This involved conducting scoping searches to check the ability of the search string to capture benchmark studies (i.e., checking sensitivity; see Section 2.4); address the project question (i.e., checking specificity); and enable a timely completion of the project (i.e., checking feasibility and manageability). Then, the shortcomings were addressed to refine the terms and inform the final strategy and search string.

The scoping searches (see terms in Annex 1: Table A1, Table A2 and Table A3) included a wide range of terms for each component of the PICO protocol (Annex 1; section 2.4) describing multiple aspects of the concepts and practices associated with biodiversity and NBS challenges and outcomes, across multiple types of ecosystems. While this was desirable for a broad and open-ended overarching question (Section 2.3.1), it resulted in a search output of >25,000 articles. This represented an unmanageable workload within the agreed project timeline and budget.

Adding the "biodiversity-based search string" (Section 2.4) to narrow the scope of NBS interventions to those that were 'biodiversity-based' helped to extract articles relevant to the project objectives, while ensuring a manageable number of articles. It is recognised that the use of "biodiversity-based search string" reduced the chances of capturing studies using novel terms or approaches for NBS and novel biodiversity metrics, if any.

Additionally, we only used search terms in English. This further reduced the chances of capturing important biodiversity terms that are relevant to non-English speaking countries. Although, it is noted that only a small proportion of the peer-reviewed articles included in the final search outputs were in other languages, such as French, Spanish, Portuguese, Chinese and Japanese. However, this is a common drawback of all evidence syntheses of peer-reviewed literature.

We also recognise that an important body of practical knowledge on the role of biodiversity in NBS is described in grey literature. However, time constraints precluded a thorough search of grey literature. Time constraints and team capacity also precluded conducting a more thorough exploration of studies within review articles and a more thorough snowballing to identify studies not captured by WOSCC, Google Scholar and Research Rabbit.

Using a different search platform, such as Scopus, may have also increased scientific research coverage. That said, Web of Science and Scopus provide equally good access to academic journals and research literature in English. For example, a recent comparison between Scopus and Web of Science in terms of journal coverage showed that about 99.11% of the journals indexed in Web of Science are also indexed in Scopus (Singh et al. 2021). Further, Google Scholar was found to be the best choice among Web of Science, Scopus and other platforms such as Dimension and Microsoft Academic, for citation counts (without complete list of citing sources) (Martin-Martin et al. 2021). This suggests that capturing the trends and patterns in the current evidence base should not have been strongly affected by our choice of Web of Science, Google Scholar, and Research Rabbit.

Scopus in addition to Web of Science and Google Scholar may have improved identification of literature. Although, combining searches from the three different search platforms, i.e., Web of Science, Google Scholar and Research Rabbit, with an additional snowballing approach likely maximised citation coverage in the time available.

Team capacity issues precluded having at least two reviewers screening each citation through the screening process (i.e., cross-checking), as is recommended for systematic maps to minimise the risk of human error. But, one reviewer (IA) checked all articles screened by the two reviewers (IA and RP) for consistency. Finally, time constraints precluded contacting authors on the topics explored to detect additional sources of evidence, which could be useful for developing case studies and recommendations.

In conclusion, the search strategy retrieved a potentially large number of peer-reviewed and grey literature articles, of which a proportion of 45 peer-reviewed articles were selected as being relevant to biodiversity-based NBS. Lastly, the methods employed allow for the repeating and updating of searches for integrating further publications (i.e., after December 2022) as well as different terms relevant to the role of biodiversity in NBS.

4.2. Overview of findings

This Quick Scoping Review revealed a broad evidence base, covering a wide range of journal types, geographic locations, NBS types, ecosystems, taxa, biodiversity metrics and NBS outcomes, but with considerable evidence gaps. Overall, 45 studies met the criteria agreed between the project team and Biodiversa+ partners providing evidence on the supporting and regulating roles of biodiversity in NBS as well as the biodiversity's direct material and non-material (cultural) contributions to people. The evidence base on the role of biodiversity is leaning towards terrestrial ecosystems, with 73% of all studies implemented in a type of terrestrial ecosystem, be it forests, croplands, grasslands, riparian areas, or drylands. Diversity and ecosystem composition metrics were the most reported biodiversity metrics.

The effect of biodiversity on NBS outcomes was assessed for a wide range of types of outcomes such as climate change mitigation, well-being, resilience to change, anthropogenic impacts and disasters, food provision, and biodiversity. The effect ranged from positive to negative, 62% of studies reporting positive effects, of which 12 studies applied NBS2-Sustainable management, six studies NBS3-Restoration, five studies NBS4-Habitat creation and four studies NBS1-Protection. Negative or mixed effects were related to trade-offs between the various types of supporting and regulating roles and contributions of biodiversity to people. Further, the role of biodiversity depended on used biodiversity metric and intended outcomes, therefore the role, supporting, regulating or as material or non-material contribution to people, varied among studies for the same type of ecosystem, taxa, metric or type of NBS. Therefore, the role of biodiversity is not intrinsic in the taxa or the metric but is context-specific, a context that is determined by the issues that need to be addressed by NBS and the intended outcomes. This finding is consistent with the spirit of the IPBES framework of nature's contributions to people (NCP), which recognises that there are multiple ways of understanding and categorising relationships between people and nature and avoids leaving these perspectives out of the picture or forcing them into a specific predetermined category (Diaz et al. 2018).

There were also important evidence gaps, including a limited number of studies on the role of biodiversity in interventions such as protection, restoration and habitat creation; interventions in freshwater ecosystems, such as inland wetlands; interventions involving terrestrial, freshwater and marine vertebrates; use of non-academic metric of biodiversity; and a wide range of material and non-material contributions of biodiversity to people (see Figure 1) such as energy provision, feed provision, medicinal and biochemical resources, learning and supporting identities. Some of the gaps may reflect the use of search terms, the selection criteria for the present study, and potentially the authors' (including those of the present report) subjectivity in assigning a particular intervention into a certain type of NBS. For example, including grey literature such as technical reports, government documents and success stories published in government websites (e.g., European Commission n.d.) may help reduce these gaps. The next section considers evidence gaps and evidence clusters in the context of priority areas for further research and policy implementation.

4.2. Evidence gaps and clusters

4.2.1 Biodiversity versus "living nature" and NBS

Visualisation of the topics captured by the search terms used in this study before screening revealed two broad but distinct evidence clusters. The first topic cluster is centred around the term biodiversity (biodiversity cluster). The term biodiversity co-occurs with terms and topics such as species, species richness, variation, habitat, ecosystem function, conservation, agricultural landscapes, plants, forest, human, and river (i.e., biodiversity-related topics). The second topic cluster includes terms found under the umbrella concept of NBS (NBS cluster). The term nature-based solution co-occurs with terms such as ecosystem approach and climate change and are related (in terms of co-occurrences in the literature) to terms such as ecosystem-based adaptation, green infrastructure and living nature (NBS-related topics).

The distance between these two broad clusters may highlight the evidence gap on the interaction between biodiversity and the concept of NBS. This gap suggests a bi-directional evidence gap and a need for deeper understanding of the role of biodiversity in NBS and the role of NBS in delivering biodiversity outcomes. This is consistent with the finding of Key et al. (2022) that there is currently limited evidence for the biodiversity and ecosystem health outcomes of NBS, particularly in terms of the metrics and the taxa assessed.

Further, the visualisation indicated a lack of relatedness between biodiversity and the term "living nature", which includes diversity of organisms, ecosystems, and their associated ecological and evolutionary processes and is used in the context of nature's contributions to people's quality of life and how these contributions are perceived by people (Diaz et al. 2018). Additionally, biodiversity, as reflected in the VOSviewer visualisation, is related to biophysical entities (such as species, habitat, ecosystem). As captured by the VOSviewer visualisation (Figure 3a), the term "living nature" co-occurs in the literature with the actionable concept of NBS. For NBS to address societal challenges, they must accommodate the plurality of preferences brought to bear upon them (Austen et al. 2022).

Therefore, future research could further examine biodiversity metrics beyond species traits, species diversity, and ecosystem function and identify metrics in the context of "living nature" and NBS. This could help link living nature's contributions to people (as in Diaz et al. 2018) with specific, local challenges and NBS projects to address them. This is akin to ongoing research on building ecosystem services frameworks, which however have been predominantly based on expert opinions and views and overlooked the effect of variation in perceptions and values of living nature (Maund et al. 2020).

Evidence gap: limited evidence on biodiversity metrics relevant to decision-making on NBS design and type and the assessment of NBS outcomes.

Recommendation: identify and develop metrics to directly examine and monitor the effect of multiple dimensions of biodiversity on NBS.

4.2.2. Biodiversity-NBS cluster versus biodiversity metric

Visualisation of the topics captured by the search terms used in this study after screening (Figure 3b) shows a greater relatedness between the terms biodiversity, NBS, and ecosystem approach (biodiversity-NBS cluster). However, terms that refer to biodiversity attributes and metrics such as species, ecosystem functioning, functional diversity, (associated) ecosystem service, and experiential knowledge are arranged apart from the biodiversity-NBS cluster, suggesting their weak relatedness to the cluster.

Review and perspective articles captured by the search strategy and screening explored the potential for repurposing existing metrics of biodiversity as metrics of the effect of biodiversity on NBS outcomes (e.g., Solan et al. 2019). This approach provides opportunities for identifying what species future NBS projects might target based on species traits and providing the evidence base for a process of co-production of NBS projects by researchers, policy makers and community stakeholders. As noted by Key et al. (2022), metrics to assess NBS outcomes should be chosen through a process of co-production to suit the ecological and social context and views from multiple stakeholders, including local communities. However, repurposing existing evidence on biodiversity has its limits in addressing existing evidence gaps, as discussed in section 4.2.1. NBS projects must be designed from the outset to assess and monitor multiple dimensions and metrics of biodiversity to enable a process of learning by doing (adaptive management) and improvements in their design.

As for the metrics used in the studies selected in this Quick Scoping Review, biomass, diversity, and ecosystem composition were well represented across different types of NBS in the studies selected for evidence mapping. Ecosystem functioning metrics were used more frequently in NBS1 than in other types of NBS. On the other hand, conservation status, landscape structure and perception metrics were less commonly used than other types of metrics. Additionally, NBS2 reporting on biodiversity as a direct contribution to people did not use a specific biodiversity metric but reported the provisional ecosystem services arising from biodiversity-based agricultural practices (e.g., Palomo-Campesino et al. 2022). In the same vein, Almenar et al. (2021) proposed the use of an ecosystem services framework to link NBS outcomes (usually NBS4 in urban contexts) to urban challenges. This suggests further research is needed on the linkages between biodiversity and ecosystem services supply with NBS, including their synergies and trade-offs. The present study combined the concepts of ecosystem services and NCP to help understand the multiple roles of biodiversity in NBS. Potentially, there is a need to assess the linkages between existing ecosystem services frameworks with the IPBES framework on nature's contributions to people (NCP) in the context of NBS.

The reason for the limited use of metrics based on Conservation status, Landscape structure and Public perception of the role of biodiversity is unclear but not related to evidence or geospatial technology gaps. For example, Conservation status has been assessed for many regions across the world. Landscape structure at any part of the world can be analysed using geospatial tools such as remote sensing, geographic information systems (GIS), Global Positioning Systems (GPS), geostatistics, and geo-visualisation (e.g., 3D displays). However, historically, greater emphasis has been placed on biophysical measurements of ecological processes informing conservation and landscape structure assessments than on evaluations based on human perception of landscape aesthetics and the role of biodiversity and species in well-being or mental health (Tribot et al. 2018).

Human perceptions of biodiversity have been recorded in creative literature and other art forms. For example, Langer et al. (2021), supported by the latest advances in automated processing of natural language, searched for a comprehensive list of 240,000 English labels for biological taxa in the largest open collection of fiction books from 1705 to 1969. Their study was the first analysis of biodiversity patterns in fiction in the context of nature's contribution to people's communication of the impacts of industrialisation and nature loss. Further, aesthetic value has potentially a strong influence on people's motivation for biodiversity conservation at both the landscape and species levels (Tribot et al. 2018 and literature therein). Thus, in addition to reviewing evidence on conservation status and landscape structure and repurposing this evidence to develop biodiversity metrics for addressing societal challenges with NBS, it may be worth also reviewing perceptions of living nature and biodiversity, including representations in creative literature and arts to design novel biodiversity metrics for NBS.

Evidence gap: limited use of metrics such as Conservation status, Landscape structure and Perception of biodiversity compared to other broad categories of metrics.

Recommendations:

- Review existing evidence on Conservation status, geospatial imaging and Public perceptions of living nature and biodiversity and identify how this evidence could be repurposed to inform their use for NBS or to help design biodiversity metrics for addressing societal challenges with NBS.
- The role and metric of biodiversity must be designed from the outset NBS projects to enable a process of learning by doing (adaptive management) and improvements in their design.

4.2.3. Predominant type of NBS: bias, evidence gap or policy gap?

There was considerable imbalance in the distribution of primary research and review articles across different types of NBS, with 46.7% comprising studies exploring the role of biodiversity in NBS2. This may have been related to the use of the term 'biodiversity-based', which is used as a term in the context of sustainable agriculture and agro-forestry indicating specific agri-environment practices to enhance biodiversity and yield. However, a closer look at the journals reporting evidence for NBS2 shows that only 9 out of 20 articles were published in journals specialising in the field of agriculture, food production, and forest management.

It is also interesting to note that NBS2 can include a wide range of actions described as sustainable management, which are not related to agriculture and forestry. The remainder of studies captured by the search strategy explored the role of biodiversity in sustainable management and Eco-DRR, which were classified as NBS2, and touched on a variety of not necessarily related issues, such as coastal zone management, rockfall risk and coastal flooding risk. These studies relied on different taxa and were implemented in different ecosystems with varying levels of anthropogenic activity. Therefore, the claim that the search term ''biodiversity-based'' created this imbalance cannot be supported.

Arguably, this imbalance shows that the role of biodiversity in agriculture is more researched than for other types of managed and anthropogenically-influenced ecosystems as well as in other types of interventions and ecosystems. This need has been captured by perspective and review articles. For example, perspective articles advocated the implementation of NBS in open and deep-sea environments for multiple benefits and ecosystem resilience (Bax et al. 2022); mushroom habitats for adaptation (Devkota et al. 2022); and soft-substrate invertebrates in coastal environments (Solan et al. 2019). Further, review articles identified the need to explore trade-offs and synergies between biodiversity and the ecosystem services supply-NBS nexus in urban systems. For example, Almenar et al. (2022) suggested that in urban contexts there is a need to explore interdependencies between biodiversity and bundles of ecosystem services to understand the characteristics of living systems that enable embedding of biodiversity in urban NBS.

It is also important to note that NBS2 in forestry, agriculture and EcoDRR refer to actions that have clear benefits for people. But the benefits may be unclear or conflicting between different stakeholders in projects such as protection and restoration, with restoration known to require high upfront costs with uncertain returns for investors. The search terms used in this Quick Scoping Review attempted to capture this dimension of the role of biodiversity, but there seems to be an evidence gap (see Annex 1). Additionally, the cost of restoration and creation projects, and risk to their sustainability (e.g., biosecurity issues as in oyster restoration, Sas et al. 2018) may have played an important role in creating an imbalance in the distribution of studies across different types of NBS. Further research on the economics and governance aspects of embedding biodiversity in the outset of NBS projects could help better understand this evidence gap.

It is also important to note that implementing NBS projects such as protection, restoration and habitat creation to address societal, environmental and economic challenges and deliver multiple outcomes requires an enabling policy environment. Current advice on embedding NBS projects in policy refers to a wide range of actions. Examples include alignment of NBS objectives with specific environmental policy objectives (see below Policy Alignment); ensuring environmental sustainability of undergoing NBS projects through the inclusion of relevant stakeholders in the decision making for the type, design, site selection and goal setting for a specific NBS project; and piloting NBS projects (e.g., NBS demonstration projects) to provide the evidence required for evidence-based policy (Riisager-Simonsen 2022; Frantzeskaki et al. 2020).

Policy alignment. In Europe, EU environmental legislation has already taken into account the fact that creating protected areas, restoring ecosystems, rewilding and facilitating nature-based solutions can all contribute to delivering multiple benefits for biodiversity, climate change adaptation and mitigation, disaster risk reduction and well-being in the EU. The heart of EU conservation efforts is the EU's Natura 2000 network of protected areas designated under the Birds and Habitats Directives, which require action to ensure that designated habitats and species reach good conservation status. Further, the European Commission has proposed a Nature Restoration Law (https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en) as part of the EU Biodiversity Strategy, with key targets to enable the long-term and sustained recovery of biodiversity and contribute to achieving the EU's climate mitigation and climate adaptation objectives. A positive component of the proposed Nature Restoration Law is that it requires monitoring of the progress of restoration projects. In the context of these regulatory requirements, there is an opportunity of embedding existing biodiversity metrics in the regulatory monitoring or developing linkages between policy needs and research on biodiversity metrics (e.g., demand-driven research).

Evidence gap: limited evidence on how protecting biodiversity addresses societal and economic challenges and on the role of biodiversity in restoration and creation of artificial habitats and the sustainability of these projects.

Recommendations.

- NBS implementation with existing environmental policies and conservation efforts across the EU, such as EU's Natura 200 Network of protected areas designated under the Birds and Habitats Directives, as well as upcoming legislation, such as the proposed Nature Restoration Law under the EU Biodiversity Strategy.
- Map policy needs that can be addressed by improving understanding and practices related to the role of biodiversity in NBS. (iii) Explore how perceptions of biodiversity and living nature's contributions to people determine stakeholder engagement to support and upscale NBS projects.

Taxa. A wide range of taxa and species was included in the studies selected for mapping. All major taxa of invertebrates and plants were reported. Vertebrate species were represented by farmland birds and fish species, including commercial fisheries and coral reef fish. However, terrestrial and marine vertebrates were absent from the studies captured by search terms before and after screening. This is surprising for two key reasons. First, the search terms included topics pertaining to the management and habitats occupied by vertebrates. Second, the roles played by vertebrates in NBS are gaining traction. For example, a review by Riisager-Simonsen et al. (2022) on embedding marine NBS in the EU legislative framework suggested the use of whale populations as an NBS. For example, they suggested the protection of whale stocks (i.e., NBS1; biodiversity metric: whale body size) to provide carbon sequestration benefits, highlighting the supporting role whale biomass plays in global biogeochemical cycling, and material and non-material services, through the economic potential of whale watching tourism. Further, Lynch et al. (2023) reviewed freshwater biodiversity, from fish to frogs and microbes to macrophytes, in the context of services to people and NBS and presented evidence on beavers as habitat engineers implementing NBS themselves. For example, they described a case of beaver introduction in Scotland where beaver increased habitat heterogeneity and plant richness at plot and site scales (Law et al. 2017 cited in Lynch et al. 2023). The metric used was based on plant species diversity in the area occupied by beaver and not on a beaver-focused metric, indirectly assessing the regulating role of beavers. Arguably, the term NBS has only recently encompassed the concepts of conservation or rewilding (see section 1 for NBS definitions), and potentially this is reflected as an evidence gap in the literature despite past and ongoing research on conservation and rewilding involving vertebrates. Therefore, a systematic review of the literature on the biodiversity metrics used to quantify the roles of vertebrates in conservation, rewilding, sustainable management, and restoration could help include vertebrates in the context of NBS.

Recommendation: review the literature on the biodiversity metrics used to quantify the roles of vertebrates in conservation, rewilding, sustainable management, and restoration to put vertebrates in the context of NBS and repurpose existing evidence on vertebrate research for harnessing their role in NBS.

4.2.4 Under-reported roles of biodiversity

This Quick Scoping Review identified topics of research where no studies exist or a relatively small number of studies have been conducted. These topics refer to important social or ecological issues that warrant further investment in terms of research funding and primary research efforts. Based on the roles of biodiversity presented in Figure 1, no evidence was found on the following roles in the context of NBS:

- Supporting roles of Biodiversity
  - Behavioural responses
  - Disease transmission

- Regulating roles of biodiversity
  - Freshwater habitat creation and maintenance
  - Regulation of ocean acidification
  - Regulation of freshwater quantity in terms of flood management

- Living nature’s direct contributions to people
  - Energy (e.g., biofuel crops)

- Animal feed
- Production of materials derived from organisms for construction, printing, and clothing
- Medicinal and biochemical resources from organisms used for, e.g., veterinary purposes
- Learning, e.g., development of skills for well-being
- Supporting identities, e.g., sense of place.

Recommendation: explore how to maximise synergies between NBS and biodiversity to address disease transmission, ocean acidification, river flooding, freshwater ecosystem degradation, demand for energy and raw materials.

Conclusions

There is a large growing body of evidence that protected, sustainably managed, restored, and created habitats are key to addressing societal, environmental, and economic challenges delivering multiple benefits. On this basis, the concept of Nature-Based Solutions is gaining traction among policy circles. For example, the proposed EU Nature Restoration Law has adopted pioneering plans to restore damaged ecosystems across Europe, from agricultural land and seas, to forests and urban environments and prevent the worst impacts of climate change and biodiversity loss. Additionally, the EU member states have taken important steps in recognising the role of biodiversity in Europe through the Natura 2000 network of protected sites and the requirement for good conservation status. A wide range of European and global strategies promote Nature-Based Solutions in land and seas across Europe and the world and recognise the role of biodiversity in tackling societal challenges. However, meeting these ambitions requires a better understanding on how biodiversity can support, inform, sustain, improve, benefit, and potentially negatively impact NBS projects.

This study mapped the evidence on the role of biodiversity in NBS to help understand what we know and what we need to know to design sustainable NBS projects. The map reveals that the evidence base has important gaps. First, the proportion of studies exploring the role of biodiversity in NBS is very small compared to the number of studies on biodiversity or NBS alone. Second, within studies that reported evidence on the role of biodiversity in NBS, there is a substantial imbalance in the distribution of studies across NBS, with most studies focusing on agricultural and agroforestry systems, their sustainable management, trees, and diversity metrics. This suggests a focus on direct material contributions of biodiversity, particularly food provision. Yet, other ecosystem types and taxa also have the potential to address other multiple pressing challenges, including climate change, disaster risk (such as coastal flooding and rockfall risk), water scarcity, and well-being. Additionally, there is a dearth of investigations on the multiple dimensions, and hence metrics, of biodiversity and how these can be used to minimise trade-offs between different ecosystem services. Further research on biodiversity metrics for assessing NBS outcomes could substantially help to scale up NBS for delivering national, regional, and global outcomes as well as addressing local challenges that matter to local communities. There is also a lack of evidence on the role of biodiversity in informing innovative applications of NBS in energy provision, biotechnology and manufacturing. Aligning research on biodiversity's contributions to people with NBS practice and environmental and climate policy goals will be key in harnessing the roles of biodiversity in addressing current challenges effectively and adaptively.

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Annex 1: Methods

A1.1 Population-Intervention-Comparison-Outcome (PICO)

The PICO elements of this Quick Scoping Review are described below and are outlined in Table A1. The PICO framework was used to 1) refine the questions, 2) develop a keyword search string, 3) define study selection criteria applied stepwise to filter the search hits, and 4) design an evidence framework by topic to help delineate what information to extract from the studies, a process also known as coding.

A1.1.1 Problems (P) - Challenges

Based on the conceptual model presented in Figure 2 and the context for the roles of NBS and biodiversity in addressing policy objectives outlined in Section 1, we focused the literature searches on NBS that addressed the following challenges: Climate change, Disaster risk, Water crisis, Food crisis, Environmental issues, Social issues. Following preliminary literature searches, we collected policy and research terminology related to these challenges so they could be used as search terms. The terms relevant to each challenge are presented in Table A1.

Table A1. Terms related to the challenges addressed by NBS

Problem - Challenge	Related terms
Climate change	"extreme weather" OR “climate AND fire” OR megafire OR "sea level rise" OR “global warming’’ OR “climate hazard” OR drought* OR “storm surge*’’ OR "precipitation deficit" OR “climat* variability" OR “temperature rise” OR “heat wave*" OR GhG OR "greenhouse gas" OR CO2 OR "carbon dioxide" OR “climate emergency” OR “climate crisis” OR “climate breakdown” OR “climate change” OR “climate hazard” OR “climate vulnerab*”
Disaster risk	Fire OR disaster* OR flood OR "natural hazard*" drought* OR hurricane* OR storm* OR cyclone OR mudslide* OR landslide "slope failure*" OR "wave storm“
Water crisis	(salt NEAR/1 intrusion*) OR (water NEAR/2 (conservation OR shortage* OR stress OR scarcity OR insecur* OR quality OR quantity)) OR drought
Food crisis	"crop failure*" OR "soil *fertility" OR "soil conservation" OR "soil stabili*" OR "soil loss" OR "soil erosion" OR "soil health" OR "food shortage*" OR “food insecur*" poverty OR salini$ation OR (pollinator Near/1 ("lack of" OR decline OR fewer)

Problem - Challenge	**Related terms**
Environmental issues (threats to living natural capital)	biodiversity NEAR/1 (decline OR loss OR crisis) OR “environmental degradation" OR desertification OR “land degradation” OR salini$ation OR sedimentation OR siltation OR (pollut* NEAR/1 (diffuse OR "point source" OR chemical* OR industr* OR plastic OR micro* OR bacter* OR soil OR water OR air OR sewage)
Social issues	"lack of green spaces" OR “social cohesion” or “human health” or “natur* capital” or unhealthy or “social inequalities” or unemployment or (crisis NEAR/2 ("cost of living" OR migrat* OR refug* OR economic) OR poverty)

A1.1.2 Intervention (I)

In consultation with Biodiversa+ partners it was agreed to focus on the three NBS types described by Eggermont et al. (2015). Preliminary literature searches suggested a few terms strictly relevant to each NBS type as well as a wide range of terms that are used outside the context of the NBS typology. It is understood that not all interventions and terms considered as NBS in the literature meet the requirements of the definitions discussed in Section 1. However, they reflect the perception of their authors rather than agreement with specific NBS typology. Terms describing the types of habitats targeted by NBS were considered as Intervention-associated terms. Lastly, the potential roles of biodiversity in NBS were explored by terms compiled from an earlier report published by Biodiversa+ (Goudeseune et al. 2018), which created a database of keywords used to search for biodiversity projects; terms reflecting the multiple values and knowledge systems referring to biodiversity, reported in the recent Values Assessment (IPBES 2022); terms reflecting the relationship between biodiversity and ecosystem services (Mace et al. 2012); and terms reflecting the relationship between biodiversity, ecosystem health and the concept of NBS (Key et al. 2022). Table A2 shows the intervention (I) terms.

Table A2. Intervention (I) terms.

NBS **type**	**Relevant terms**
Type 1*	protect* OR conserv* OR preserv*) NEAR (“ecosystem service*” or “nature’s contributions to people” OR “natural capital”)
Type 2*	Manage* NEAR (agriculture* or farm* OR coast* OR forest*)

NBS type	Relevant terms
Type 3*	Restor* NEAR ecosystem* AND Creat* NEAR ecosystem*)
Terms that fall under the umbrella term "NBS"	ecosystem approach*" OR "ecosystem-based" OR "community-based" OR "disaster risk reduction" OR ((“low regret” OR “no regret” OR “win win”) NEAR/1 (adaptation OR action* OR measure*)) OR (management NEAR/2 (traditional OR adaptive OR protected OR coast* OR river OR wetland* OR flood* OR catchment OR watershed OR forest OR woodland OR landscape OR rangeland OR ecosystem OR water OR sustainable OR environment* OR integrated OR “natural resource”)) OR restoration OR "protected area" OR "nature based solution*" OR NBS OR conservation OR protect* OR “sustainable use” OR (agricultur* NEAR/1 (conserv* OR resilien* OR sustainable OR ecolog* OR "natural systems")) OR "climate-smart" OR "adaptation service*" OR "animal-aided design" OR revegetat* OR afforest* OR "land management" OR reforest* OR rehabilit* OR "agro-pastoral" OR agropastoral OR silvopastoral OR "agri-environment*" OR “evolutionary orientated forestry” OR "constructed wetland*" OR (creat* NEAR/1 (ecosystem* OR habitat* OR ecotone*)) OR ((recovery OR infrastructure) NEAR/1 (blue OR green OR blue-green OR natural OR ecological)) OR (regenerative NEAR/1 (agriculture OR farming)) OR “close to nature" OR (conver* NEAR/2 (land OR use OR intensive)) OR “strict nature reserve” OR Wilderness OR “National Park” OR “Natural Monument” OR “Habitat management area” OR “species management area” OR “Protected landscape” OR “Protected seascape” OR “no take zone” OR “nature positive” OR ((biotechnical OR “bio technical” OR bioengineering) NEAR stabilization) OR biomanipulation OR bioremediation OR (sustainable NEAR/1 (drainage OR catchment OR management OR agricultur* OR aquacultur* OR farmland* OR pastoral*)))
Habitat types targeted by NBS	agro-forest*" OR agroforest* OR riparian OR estuar* OR lake* OR stream* OR aquifer* OR marsh* OR catchment* OR watershed* OR plantation OR floodplain* OR "flood plain*" OR peatland* OR saltmarsh OR "salt marsh*" OR marshland* OR savannah OR tropic* OR shrub* OR intertidal OR pond* OR fjord* OR soil* OR "dry-field*" OR dryfield* OR wildlife OR livestock OR delta* OR brackish OR "blue carbon" OR seagrass OR kelp OR meadow* OR sediment OR "sand dune*" OR dune* OR beach* OR ((biogenic OR coral OR shellfish OR oyster) NEAR reef*))
Biodiversity terms	taxon OR "biological diversity" OR biodiversity OR "habitat connectivity" OR organism OR agrobiodiversity OR ecosystem OR “eco region” OR "ecological

NBS type	Relevant terms
	network" OR (species NEAR/5 (diversity OR richness * OR population OR composition OR level OR distribution OR extinct* OR interaction* OR abundance OR indigenous OR native OR “non native” OR “non indigenous” OR naturali$sed OR invasive OR allien OR threatened)) OR "gene pool" OR genotype OR phenotype OR (habitat NEAR/1 (heterogeneity OR variability OR fragmentation OR degradation)) OR ((diversity OR biodiversity) NEAR/5 (“natural capital” OR habitat OR landscape OR seascape OR spatial OR temporal OR global OR regional OR coastal OR terrestrial OR aquatic OR marine OR function* OR pattern OR biocultural OR agricultural OR genetic OR phylogenetic OR trophic OR “food web”)) OR (composition NEAR/5 (species OR functional OR homogeni$ OR landscape OR seascape)) OR species OR “living nature” OR ”ecosystem services” OR “nature’s contributions to people” OR “genetic resource*” OR biosphere OR biome OR “co evolution” OR refugia OR “biological communit*’’ OR “ecological community” OR “biodiversity hotspot” OR “biodiversity offset” OR biota OR “biological corridor*” OR biotope* OR ecotone* OR “life cycle” OR endemic* OR evenness OR “extinction debt” OR “functional trait” OR competition” OR “indigenous and local knowledge systems” OR “trophic cascade” OR “carrying capacity” OR “key biodiversity area*” OR “landscape configuration” OR “mainstreaming biodiversity” OR “mother Earth” OR (flow* NEAR/5 “ecosystem service*"))

A1.1.3 Comparator (C)

The questions for this Quick Scoping Review are qualitative and seek to report and integrate data from different types of NBS rather than compare data. Therefore, no comparator was used. However, the use and type of comparator in experimental designs per individual study (e.g., control data, or initial conditions in restoration studies) were reported as part of coding (Section A1.3).

A1.1.4 Outcomes (O)

These included terms for the four categories of outcomes (mentioned in the UNEA definition of NBS, i.e., human well-being, ecosystem services, resilience biodiversity, and other outcomes related to policies such as the SDGs and the Paris Agreement (Table A3).

Table A3. Terms referring to outcomes related to the roles played by biodiversity on NBS.

Broad term	Related outcomes (benefits to humans)
Well being (SDG3)	Health OR “well being” OR wellbeing) NEAR/5 (human OR ecosystem OR “cultural ecosystem services” OR environment* OR “spiritual value*” OR ecological OR ecotourism OR “good quality of life” OR “living in harmony with nature”
Resilience	(“disaster risk” OR flood OR erosion) NEAR/5 (adapt* OR cope OR coping OR alleviat* OR mitigat* OR resilien* OR strategy OR protect* OR reduction OR preparedness OR governance OR management or defen*) (mitigat* OR manag* OR Control) NEAR/5 (“climate change impact*” OR “climate extreme*” OR carbon OR CO2 OR “carbon dioxide” OR “greenhouse gas” OR pollution OR nutrient OR erosion OR flood OR "storm surge*" OR “sea level rise” OR emission OR sewage) water NEAR/5 (purification OR treatment OR storage OR filtration OR resilience OR availability OR security OR quality OR quantity OR improv* OR “rainwater harvest*” OR “soil moisture” OR “groundwater recharge”))
Zero hunger (SDG2)	food NEAR/5 (nexus OR security OR provision* OR supply OR resilien* OR sustainab* OR agriculture* OR farm* OR aquaculture OR “land use” OR soil OR fertile* OR “crop system”))
No poverty (SDG1)	“poverty reduction" OR “income diversification” OR “alternative livelihood*” OR (capital NEAR/1 (social OR human)) OR "agricultural development")
Climate change mitigation (Paris Agreement)	(Climate) NEAR/5 (change OR risk OR extreme OR impact OR adapt* OR cope OR coping OR alleviat* OR mitigat* OR resilien* OR strategy OR protect* OR preparedness OR governance)

Broad term	Related outcomes (benefits to humans)
Biodiversity and ecosystem health	Biodiversity and ecosystem health

A1.2. Inclusion and exclusion criteria

Table A4. Selection and exclusion criteria for full text screening

Selection criteria for full text screening	
Articles will be **included** if they meet these criteria	For a study to be included it will have to mention the targeted issue, the intervention used, and the roles of biodiversity in the design, performance and/or delivery of outcomes, and the study tests the assumption that there is a linkage between the roles of biodiversity and the outcomes. The metric of biodiversity and outcomes may vary. Biodiversity in the design of NBS: This means that the intervention is relying on "adding biodiversity" (genetic, species, habitat, ecosystem, landscape and functional variability) to control processes, as ecosystem service and as a value to humans. Types of articles: Research, review and perspective articles, meta-analyses and grey literature (i.e., documents by IPBES, IPCC, EC, UN, UNEP, UNDP, IUCN, and Biodiversa and more) were included if they reported approaches or data on harnessing the roles of biodiversity in addressing environmental, societal and economic challenges to deliver well-being, resilience and ecosystem services Study type: Studies quantitatively, or qualitatively assessing the role of biodiversity in ecosystem function and ecosystem services and the delivery of desired outcomes (benefits valued by humans) of an NBS intervention (proposed or implemented). These included studies reporting primary data (experimental, scenario modelling forecasts, observational, interview data, or multi-criteria expert assessments for empirical evaluations), and reporting data from secondary sources such as review articles on a narrow topic poorly explored or understood. Interventions: Studies reporting results for interventions termed as NBS (see Terms that fall under the umbrella term "NBS" in TableA2). Geographic range: Global. Ecosystem type: All types.

Selection criteria for full text screening	
	Biodiversity metric: Studies reporting the metrics used by Key et al. (2022), which linked biodiversity and ecosystem health; metrics related to the EBV variables (Pereira et al. 2013); and metrics related to the "living natural capital attributes" that influence the delivery of different bundles of ecosystem services proposed by Smith et al. (2017). It must be noted that the review allowed for adding more categories of biodiversity metrics, as it is considered that the linkages between biodiversity and NBS is an area of novel research exploring new ways of measuring and valuing biodiversity. NBS outcomes metric: Studies reporting qualitative and quantitative outcomes linked to the roles of biodiversity.
Articles will be excluded from this report if they meet these criteria	1. Irrelevant interventions or evidence: interventions that did not harness or study the roles of biodiversity. 2. Irrelevant outcomes: studies that did not link NBS outcomes to the roles of biodiversity. 3. Irrelevant study or article types: ● Studies not aiming to assess impact or effectiveness or role of biodiversity in addressing an identified or predicted issue (e.g., studies that characterize choices made by local communities or expert workshops, without aiming to provide an assessment of how biodiversity was linked to effectiveness or outcomes). ● We suggest excluding studies investigating NBS implementation, such as how effectively interventions were implemented or enforced (e.g., uptake of a measure by farmers), but not reporting on the roles of biodiversity in the outcomes or implementation (uptake). ● Theoretical studies, or studies proposing new conceptual frameworks or tools for evaluation, (e.g., effectiveness case studies used to demonstrate new methodologies such as controlled experiments) unless they also provide evidence to help understand the roles of biodiversity. ● Articles not published in English.

A1.3 Coding variables

The coding framework was designed to extract bibliographic information, as well as information as reported by the authors of the selected studies on taxa used, ecosystem type, geographic location or range, type of intervention, biodiversity metric, type of challenge addressed, outcomes of NBS and the role of biodiversity in the design of a study and in delivering NBS outcomes. Information on how the study was captured (for example, via WOSCC, Google Scholar, snowballing or Research Rabbit) was also reported. Intervention (NBS) types were reported as presented in the paper without considering other sources of information, including other studies in our map or our own personal knowledge. However, assigning a study to a particular NBS type was determined by the authors of the present study.

Each study was assigned an ID. The same ID applied for the range of interventions, taxa, ecosystem types/biomes and outcomes reported in a study.

Taxa categories reported included broad (i.e., Kingdom) and detailed description down to species level. Information on species was not always mentioned; for example, insects were often mentioned as pollinators, or forest or urban park species were frequently reported as trees, or shrubs. For evidence mapping, taxa were described by Kingdom and, in parenthesis, the information on taxa that was relevant to the type and outcomes of the intervention. For example, "Plants (urban trees)". Information on whether the taxa used in the intervention were native or imported, or whether this information was provided by the article, was also reported.

The ecosystems in which interventions took place were grouped according to the Mapping and Assessment on Ecosystems and their Services (MAES) typology (European Commission 2013). The countries in which interventions took place were classified with respect to broad geographical regions. Income groups were identified according WorldData online, open-access database.

The selected studies were grouped into eight intervention categories:

(i) NBS1: Protection

(ii) NBS2: Sustainable management (other than protection or restoration)

(iii) NBS3: Restoration

(iv) NBS4: Habitat creation

(v) NBS5.1: Combination of protection and management actions

(vi) NBS5.2: Combination of protection and restoration actions

(vii) NBS5.3: Combination of management and restoration actions

(viii) NBS5.4: Combination of actions in created and natural/semi-natural ecosystems (created/non-created)

The type of biodiversity metric was also reported. Coding was based on a list of biodiversity metrics used in the literature, as described in Section 1. Table A6 presents the list of specific and broad biodiversity metrics used. Detail on the metric was also reported.

Study design was coded to provide information on experimental design (i.e., type of comparator, spatial and temporal details), scale of intervention, and whether the description was detailed or not.

Coding of issues addressed by NBS drew on the categories identified when developing the PICO framework for this project (see Table A1). Coding of outcomes focused on reporting the desired outcome as reported in each study. This coding field was also informed by the outcomes identified when developing the PICO framework for this project (see Table A3). The type of evidence provided to assess the role of biodiversity on outcomes was reported and included categories such as biophysical, social, economic, mixed and anecdotal evidence.

The role of biodiversity on the delivered outcomes was reported based on self-assessment. Direction of the role of biodiversity varied within the same study, depending on metric and taxa used. The key categories used to assess the role of biodiversity on outcomes included:

- Positive role – when the authors were explicit in describing the biodiversity metric used as having benefits for the desired outcome. There was a line for each metric reported in the study.
- Negative role – when the authors were explicit in describing the biodiversity metric as having negative effects on the desired outcomes.
- Mixed role – when both negative and positive effects of biodiversity metric were reported.
- No effect/neutral – when the authors were explicit in describing the biodiversity metric as having no effect on the desired outcomes.
- Unclear – when the authors did not derive an explicit conclusion as to whether the biodiversity metric has either negative, positive, mixed, or neutral effect as per above definitions.

Table A5. Coding categories

Search engine
ID
Search engine (GS: Google Scholar; WoS: Biodiversity-based 195)
Way of retrieval (S:search string; C: Cited in (snowball searches); Related (via Research Rabbit)
Paper title
Authors
Year of publication
Journal
DOI
Type of Article
Taxa categories
NBS Intervention_typology
Interventions-actions as described by authors
NBS spatial scale
ID

Habitat-Ecosystem Categories (Level 1 Ecosystem Type MAES)
Broad_habitat_type (Level 2 MAES)
Location of Ecosystem Component -IA
Country
Latitude
Longitude
Geographical region
Income group
ID
Type of study (Experimental / Quasi-experimental)
Type of data (Qualitative/Quantitative/Mixed)
Evaluation approach (In situ-Field/Ex situ-Lab-Remote Sensing/ Not applicable
Methodology
Control
Modelled scenario
Historical baseline
Threshold
Data collection method
Issue addressed (use a separate row for each issue addressed)
Key or desired Outcomes reported by authors (use a separate row for each outcome)
Role of biodiversity on Key Outcomes Biodiversity metric Broad category of biodiversity metric

Table A6. List of biodiversity metric categories explored in the papers selected for evidence mapping.

Biodiversity metric	Broad metric category	Definition of metric
Genetic diversity	Diversity	Measures of the number or diversity of genetic polymorphisms or genotypes.
Phylogenetic diversity	Diversity	Measures of branch lengths on a phylogenetic tree for a given group of species.
Species richness	Diversity	The number of species represented in an ecological community, landscape or region, a.k.a. alpha diversity. Usually measured by using species density (number of species found per sampled area) as a proxy.
Species evenness	Diversity	The relative abundance of different species in a community, landscape or region, a.k.a. beta diversity.
Species diversity	Diversity	Metrics combining the number of species present in an ecosystem and relative abundance of each of those species, e.g., Shannon-Wiener diversity index and Simpson's diversity index.
Generic richness	Diversity	The number of genera present in a community, landscape or region.
Family and above richness	Diversity	The number of different families (or higher taxonomic group) present in a community, landscape or region.
Functional diversity	Diversity	The diversity of functional traits within a population, community, landscape or region; includes measures of functional redundancy.[1]
Habitat diversity	Diversity	Metrics of the diversity of habitats within a landscape, e.g., applying the Shannon-Wiener diversity index to habitats.[2]
Biomass	Biomass	Quantities per unit area of living or dead biomass of plants, animals or microbes.
Canopy cover	Biomass	Absolute or proportional canopy cover, and vertical canopy structure.
Habitat extent	Biomass	Area covered by habitat, including vegetation, coral and waterbodies, unless measured as canopy cover or litter cover.
Habitat density	Biomass	Proportional cover by a habitat, including vegetation, coral and waterbodies, unless measured as canopy cover or litter cover.
Litter cover	Biomass	Absolute or proportional cover of leaf litter or dung.
Stem density	Biomass	The absolute or proportional number of stems or individual plants.
Age structure	Ecosystem functioning and population dynamics	Change in the age structure of populations, such as age of animals or diameter of trees.[3]
Ecological vulnerability	Ecosystem functioning and population dynamics	Assessing ecological vulnerability by assessing its sub-components: exposure, sensitivity and adaptive capacity (ref).
Elevation rate	Ecosystem functioning and population dynamics	Vertical changes in sediment, reefs or marshes through accretion or growth.

Biodiversity metric	Broad metric category	Definition of metric
Functional identity	Ecosystem functioning and population dynamics	Metrics indicating dominant functional features within communities or species groups, e.g., mean trait values, and relative abundance of competitive, stress-tolerant and ruderal strategists (Schwarz et al. 2017).
Growth rate	Ecosystem functioning and population dynamics	Growth rate of individuals, e.g., change tree height over time.
Phenology	Ecosystem functioning and population dynamics	Changes in phenology or presence of phenological mismatch among taxa or between taxa and seasonal events.
Reproductive rate	Ecosystem functioning and population dynamics	Reproductive rate of species e.g., fledglings per adult male, young-of-the year fish numbers, or related measures e.g., runner length.
Recovery rate	Ecosystem functioning and population dynamics	Measures of the recovery rate (sometimes referred to as 'resilience') after disturbances such as extreme climatic events. This is restricted to empirical measures of resilience, rather than use of proxies such as functional redundancy.
Resistance	Ecosystem functioning and population dynamics	Measures of ecosystem or species ability to withstand disturbances such as extreme climatic events. This is restricted to empirical measures of resistance, rather than use of proxies such as functional redundancy.
Survival rate	Ecosystem functioning and population dynamics	The survival rate within a population, e.g., of trees after planting.
Community composition	Ecosystem composition	Identity and relative abundance of (all) different taxa in a community, which could be grouped by phylogeny, niche or function. E.g., the proportion of native and non-native species, the community-level physiological profiles of soil and microbial communities, and analyses of species composition similarities between communities.
Organism density	Ecosystem composition	Abundance of taxa not defined at the species level, e.g. number of benthic organisms per unit area.
Species abundance	Ecosystem composition	The number of individuals of a given species in a community, landscape or region.
Taxa presence	Ecosystem composition	The presence (not abundance) of a given taxon, e.g. use of thresholds to determine whether a given taxon or group of taxa can survive, or reported presence of a keystone, endangered or invasive species.
Habitat quality	Habitat quality	Metrics of the quality of habitat that do not fit into other metric categories, such as the quality of habitat for supporting specific taxa, the presence of particular landscape features, soil quality, or habitat conservation status.
Connectivity and fragmentation	Landscape structure	Fragmentation is transformation of larger expanses of habitat into a number of patches with a smaller total area, isolated from each other by a matrix of habitats

Biodiversity metric	Broad metric category	Definition of metric
		unlike the original. Connectivity is the degree to which separate patches of habitat are connected, allowing organisms to move between patches.
Conservation status	Conservation status	Change in conservation status or likelihood of extinction, for a taxon.
Perceived overall change	Unspecified	Statements of changes in ecosystem health where it is not made explicit which aspect of ecosystem health or biodiversity was affected.
Ecosystem services	Unspecified	Observations of delivery of ecosystem services as benefits to people, not always quantified

Annex 2. List of papers selected for evidence mapping

Table A7. List of articles selected for evidence mapping linking NBS type with broad biodiversity metric (see Table A6) used in each study. Bio: Biomass; Div: Diversity; EComp: Ecosystem composition; EF & PD: Ecosystem functioning and population dynamics; Lstruc: landscape structure; Cons: Conservation status; P/Expe: Perception/Experiential knowledge.

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Ecomp	EF & PD	Lstruc	Cons	P/Expe
1	ALMENAR, J. B., ELLIOT, T., RUGANI, B., PHILIPPE, B., GUTIERREZ, T. N., SONNEMANN, G. & GENELETTI, D. 2021. Nexus between nature-based solutions, ecosystem services and urban challenges. *Land use policy*, 100, 104898.	NBS4			x				
2	BAX, N., BARNES, D. K., PINEDA-METZ, S. E., PEARMAN, T., DIESING, M., CARTER, S., DOWNEY, R. V., EVANS, C. D., BRICKLE, P. & BAYLIS, A. M. 2022. Towards incorporation of blue carbon in Falkland Islands marine spatial planning: a multi-tiered approach. *Frontiers in Marine Science*, 9.	NBS1	x		x	x	x	x	
3	KARA, B. & AŞıK, Y. 2022. Assessing allergenicity of urban parks: a case study	NBS4		x	x				

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
	from Aydin, Turkey. *Aerobiologia*, 1-16.								
4	DUPIRE, S., BOURRIER, F., MONNET, J.M., BIGOT, S., BORGNIET, L., BERGER, F. & CURT, T., 2016. The protective effect of forests against rockfalls across the French Alps: Influence of forest diversity. Forest Ecology and Management, 382, pp.269-279.	NBS2	x	x	x				
5	FAIRCHILD, T.P., WEEDON, J. & GRIFFIN, J.N., 2022. Species diversity enhances perceptions of urban coastlines at multiple scales. *People and Nature*, *4*(4), pp.931-948.	NBS4		x					x
6	POORTER, L., CRAVEN, D., JAKOVAC, C. C., VAN DER SANDE, M. T., AMISSAH, L., BONGERS, F., CHAZDON, R. L., FARRIOR, C. E., KAMBACH, S. & MEAVE, J. A. 2021. Multidimensional tropical forest recovery. *Science*, 374, 1370-1376.	NBS3	x	x		x			

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
7	BIGOT, C., DORREN, L.K. & BERGER, F., 2009. Quantifying the protective function of a forest against rockfall for past, present and future scenarios using two modelling approaches. *Natural hazards*, *49*, pp.99-111.	NBS5.3	x	x					
8	MOOS, C., TOE, D., BOURRIER, F., KNÜSEL, S., STOFFEL, M. & DORREN, L., 2019. Assessing the effect of invasive tree species on rockfall risk–The case of Ailanthus altissima. *Ecological engineering*, *131*, pp.63-72.	NBS2	x	x	x				
9	DEVKOTA S, BABU, S. U., SANJEEV, P. & PRASAD, C. R. 2022. Mushrooms in the Mountains: Assessing the Role of Fungi on the Ecosystem-based Adaptation (EbA) Practices in Nepal Himalaya. *Journal of Resources and Ecology,* 13, 1030-1036.	NBS5.1			x				
10	SIKORSKI, P., GAWRYSZEWSKA, B., SIKORSKA, D., CHORMAŃSKI, J.,	NBS5.4		x	x	x			x

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
	SCHWERK, A., JOJCZYK, A., CIĘŻKOWSKI, W., ARCHICIŃSKI, P., ŁEPKOWSKI, M. & DYMITRYSZYN, I. 2021. The value of doing nothing–How informal green spaces can provide comparable ecosystem services to cultivated urban parks. *Ecosystem services,* 50, 101339.								
11	WU, C., LI, J., WANG, C., SONG, C., HAASE, D., BREUSTE, J. & FINKA, M. 2021. Estimating the Cooling Effect of Pocket Green Space in High Density Urban Areas in Shanghai, China. *Frontiers in Environmental Science*, 181.	NBS4	x	x	x	x	x		
12	TRIBOT, A.S., DETER, J., CLAVERIE, T., GUILLHAUMON, F., VILLÉGER, S. & MOUQUET, N., 2019. Species diversity and composition drive the aesthetic value of coral reef fish assemblages. *Biology Letters*, *15*(11), p.20190703.	NBS1		x	x	x			x

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
13	AUSTEN, G.E., DALLIMER, M., IRVINE, K.N., MAUND, P.R., FISH, R.D. & DAVIES, Z.G., 2021. Exploring shared public perspectives on biodiversity attributes. *People and Nature*, *3*(4), pp.901-913.	NBS2							x
14	BROUGHTON, R.K., BULLOCK, J.M., GEORGE, C., GERARD, F., MAZIARZ, M., PAYNE, W.E., SCHOLEFIELD, P.A., WADE, D. & PYWELL, R.F., 2022. Slow development of woodland vegetation and bird communities during 33 years of passive rewilding in open farmland. *Plos one*, *17*(11), p.e0277545.	NBS1		x	x				
15	RAHMAN, M.M., ZIMMER, M., AHMED, I., DONATO, D., KANZAKI, M. & XU, M., 2021. Co-benefits of protecting mangroves for biodiversity conservation and carbon storage. *Nature communications*, *12*(1), p.3875.	NBS1	x	x	x	x			
16	KENNEDY, H., PAGÈS, J.F., LAGOMASINO, D., ARIAS-ORTIZ, A., COLARUSSO, P., FOURQUREAN, J.W.,	NBS1	x	x		x			

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
	GITHAIGA, M.N., HOWARD, J.L., KRAUSE-JENSEN, D., KUWAE, T. & LAVERY, P.S., 2022. Species traits and geomorphic setting as drivers of global soil carbon stocks in seagrass meadows. Global Biogeochemical Cycles, 36(10), p.e2022GB007481.								
17	GRAVES, R.A., PEARSON, S.M. & TURNER, M.G., 2017. Species richness alone does not predict cultural ecosystem service value. *Proceedings of the National Academy of Sciences*, *114*(14), pp.3774-3779.	NBS1		x	x				x
19	ADHIKARI, S., ADHIKARI, A., WEAVER, D. K., BEKKERMAN, A. & MENALLED, F. D. 2019. Impacts of Agricultural Management Systems on Biodiversity and Ecosystem Services in Highly Simplified Dryland Landscapes. Sustainability, 11.	NBS2		x					
20	BENAYAS, J. M. R. & BULLOCK, J. M. 2012. Restoration of Biodiversity and Ecosystem Services on Agricultural Land. *Ecosystems,* 15, 883-899.	NBS5.3					x		

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
21	BIANCHI, F., MIKOS, V., BRUSSAARD, L., DELBAERE, B. & PULLEMAN, M. M. 2013. Opportunities and limitations for functional agrobiodiversity in the European context. *Environmental Science & Policy*, 27, 223-231.	NBS5.3			x				
26	HARIK, G., ALAMEDDINE, I., MAROUN, R., RACHID, G., BRUSCHI, D., GARCIA, D.A. & EL-FADEL, M., 2017. Implications of adopting a biodiversity-based vulnerability index versus a shoreline environmental sensitivity index on management and policy planning along coastal areas. *Journal of environmental management*, *187*, pp.187-200.	NBS2	x	x			x	x	
27	FELIX, G. F., SCHOLBERG, J. M. S., CLERMONT-DAUPHIN, C., COURNAC, L. & TITTONELL, P. 2018. Enhancing agroecosystem productivity with woody perennials in semi-arid West Africa. A meta-analysis. *Agronomy for Sustainable Development*, 38.	NBS2		x					

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
28	FRANZLUEBBERS, A. J., BROOME, S. W., PRITCHETT, K. L., WAGGER, M. G., LOWDER, N., WOODRUFF, S. & LOVEJOY, M. 2021. Multispecies cover cropping promotes soil health in no-tillage cropping systems of North Carolina. *Journal of Soil and Water Conservation,* 76, 263-275.	NBS2		x					
29	GARCIA, D., MINARRO, M. & MARTINEZ-SASTRE, R. 2021. Enhancing ecosystem services in apple orchards: Nest boxes increase pest control by insectivorous birds. *Journal of Applied Ecology,* 58, 465-475.	NBS2			x				
30	HASSELQUIST, E. M., KUGLEROVA, L., SJOGREN, J., HJALTEN, J., RING, E., SPONSELLER, R. A., ANDERSSON, E., LUNDSTROM, J., MANCHEVA, I., NORDIN, A. & LAUDON, H. 2021. Moving towards multi-layered, mixed-species forests in riparian buffers will enhance their long-term function in boreal landscapes. *Forest Ecology and Management,* 493.	NBS3		x					

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
31	MARTINELLI, F., VOLLHEYDE, A. L., CEBRIAN-PIQUERAS, M. A., VON HAAREN, C., LORENZETTI, E., BARBERI, P., LORETO, F., PIERGIOVANNI, A. R., TOTEV, V. V., BEDINI, A., MORELLI, R. K., YAHIA, N., REZKI, M. A., OUSLIM, S., FYAD-LAMECHE, F. Z., BEKKI, A., SIKORA, S., RODRIGUEZ-NAVARRO, D., CAMACHO, M., NABBOUT, R., AMIL, R., TRABELSI, D., YUCEL, D. & YOUSEFI, S. 2022. LEGU-MED: Developing Biodiversity-Based Agriculture with Legume Cropping Systems in the Mediterranean Basin. *Agronomy-Basel,* 12.	NBS2		x					
33	REDLICH, S., MARTIN, E. A. & STEFFAN-DEWENTER, I. 2021. Sustainable landscape, soil and crop management practices enhance biodiversity and yield in conventional cereal systems. *Journal of Applied Ecology,* 58, 507-517.	NBS2			x				

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
34	MOLINA, G. A. R. & PUGLIESE, D. E. V. 2022. Redesign the agroecosystem through biodiversity: revising concepts and integrating visions. *Agroecology and Sustainable Food Systems,* 46, 1550-1580.	NBS2							
36	STATON, T., WALTERS, R. J., BREEZE, T. D., SMITH, J. & GIRLING, R. D. 2022. Niche complementarity drives increases in pollinator functional diversity in diversified agroforestry systems. Agriculture Ecosystems & Environment, 336.	NBS2				x			
37	LU, Y., RANJITKAR, S., HARRISON, R.D., XU, J., OU, X., MA, X. & HE, J., 2017. Selection of native tree species for subtropical forest restoration in Southwest China. *PloS one*, *12*(1), p.e0170418.	NBS3	x						
38	HOEK VAN DIJKE, A.J., HEROLD, M., MALLICK, K., BENEDICT, I., MACHWITZ, M., SCHLERF, M., PRANINDITA, A., THEEUWEN, J.J., BASTIN, J.F. & TEULING, A.J., 2022.	NBS3	x		x				

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
	Shifts in regional water availability due to global tree restoration. *Nature Geoscience*, *15*(5), pp.363-368.								
39	ILSTEDT, U., BARGUÉS TOBELLA, A., BAZIÉ, H.R., BAYALA, J., VERBEETEN, E., NYBERG, G., SANOU, J., BENEGAS, L., MURDIYARSO, D., LAUDON, H. & SHEIL, D., 2016. Intermediate tree cover can maximize groundwater recharge in the seasonally dry tropics. *Scientific reports*, *6*(1), pp.1-12.	NBS2				x			
40	SCYPHERS, S.B., POWERS, S.P., HECK JR, K.L. & BYRON, D., 2011. Oyster reefs as natural breakwaters mitigate shoreline loss and facilitate fisheries. PloS one, 6(8), p.e22396.	NBS4	x						
41	NARAYAN, S., BECK, M.W., REGUERO, B.G., LOSADA, I.J., VAN WESENBEECK, B., PONTEE, N., SANCHIRICO, J.N., INGRAM, J.C., LANGE, G.M. & BURKS-COPES, K.A., 2016. The	NBS1, NBS3	x						

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
	effectiveness, costs and coastal protection benefits of natural and nature-based defences. *PloS one*, *11*(5), p.e0154735.								
42	SOLAN, M., BENNETT, E. M., MUMBY, P. J., LEYLAND, J. & GODBOLD, J. A. 2020. Benthic-based contributions to climate change mitigation and adaptation. *Philosophical Transactions of the Royal Society B-Biological Sciences,* 375.	NBS1, NBS2, NBS3				x			
43	ZHANG, L., SONG, L., ZHANG, L., SHAO, H., CHEN, X. & YAN, K., 2013. Seasonal dynamics in nitrous oxide emissions under different types of vegetation in saline-alkaline soils of the Yellow River Delta, China and implications for eco-restoring coastal wetland. *Ecological engineering*, *61*, pp.82-89.	NBS3			x				
44	SAS, H., KAMERMANS, P., ZU ERMGASSEN, P.S., POGODA, B., PRESTON, J., HELMER, L., HOLBROOK, Z., ARZUL, I., VAN DER HAVE, T., VILLALBA, A. & COLSOUL, B., 2020.	NBS3		x					

ID	Article	NBS type	Biodiversity metric						
			Bio	Div	Eco mp	EF & PD	Lstruc	Cons	P/ Expe
	Bonamia infection in native oysters (Ostrea edulis) in relation to European restoration projects. *Aquatic Conservation-Marine and Freshwater Ecosystems*, *30*(11), pp.2150-2162.								
45	SHAO, P., LIANG, C., LYNCH, L., XIE, H. & BAO, X., 2019. Reforestation accelerates soil organic carbon accumulation: Evidence from microbial biomarkers. *Soil Biology and Biochemistry*, *131*, pp.182-190.	NBS3	x	x	x	x			