

What is the state of evidence on how Nature-based Solutions promote transformative change for the sustainable use and management of biodiversity in socio-ecological systems?



Document Information

Grant Agreement number:	101052342
Project acronym:	Biodiversa+
Project full name:	The European Biodiversity Partnership
Biodiversa+ duration:	7 years
Biodiversa+ start date:	<u>Start date:</u> 1 st October 2021
For more information about Biodiversa+	Website: http://www.biodiversa.eu/ Email: contact@biodiversa.eu Twitter: @BiodiversaPlus LinkedIn: Biodiversa+

Deliverable title:	D4.8 - A knowledge synthesis: “ <i>Do Nature-based Solutions promote transformative change for sustainable use and management of biodiversity in socio-ecological systems? An evidence based approach</i> ”
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Work package title:	WP4 Connecting R&I programmes, research, and results to policy
Task or sub-task title:	4.1.2 Desk studies and production of knowledge syntheses
Lead partner:	FRB
Date of publication:	March 2024
Disclaimer:	Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those

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What is Biodiversa+

The European Biodiversity Partnership, Biodiversa+, supports excellent research on biodiversity with an impact for policy and society. Connecting science, policy and practise for transformative change, Biodiversa+ is part of the European Biodiversity Strategy for 2030 that aims to put Europe's biodiversity on a path to recovery by 2030. Co-funded by the European Commission, Biodiversa+ gathers 81 partners from research funding, programming and environmental policy actors in 39 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

BTAP	Billion Trees Afforestation Project
CBD	Convention on Biological Diversity
CEE	Collaboration for Environmental Evidence
COP	Conference of the Parties
DOI	Digital Object Identified
GBF	Kunming-Montreal Global Biodiversity Framework
GBR	Great Barrier Reef
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
NbS	Nature-based Solutions
NCP	Nature's Contribution to People
NFCP	National Forest Conservation Plan
NGO	Non-governmental organisation
PES	Payment for Ecosystem Services
PIO-C	Population, Intervention, Outcome, Context
QoL	Quality of Life
REDD+	Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
SLCP	Sloping Land Conversion Programme
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme
UNEP-WCMC	United Nations Environment Programme World Conservation Monitoring Centre
WOSCC	Web of Science Core Collection

Executive Summary

Transformative change is a fundamental, system-wide reorganisation across technological, economic and social factors (IPBES 2019). It has been upheld as key to effectively addressing the current biodiversity decline, climate crisis, and other societal challenges. Nature-based Solutions (NbS) are an approach that can foster transformative change for achieving sustainable outcomes for nature and people. However, gaps in knowledge persist regarding how Nature-based Solutions support outcomes that lead to transformative change.

This report presents results of systematically mapping the outcomes of Nature-based Solutions interventions and assessing contributions to transformative change for sustainable use and management of biodiversity in socio-ecological systems. Following the guidelines from the Collaboration for Environmental Evidence, we conducted a search and extracted information from relevant literature. The results are synthesized in a database of relevant case studies. These are categorized by the type of intervention, the type of outcome, the type of biome, and the types of transformative change that occurred. The database contains seventy-one (71) case studies gleaned from forty-six (46) relevant academic literature articles. Separately, thirty-five (35) case studies are included from grey literature.

The case studies in academic literature cover all continents. Sub-Saharan Africa was the most represented sub-region. Tropical forests were the most represented biome, whereas some others (e.g. boreal forests) were not represented at all. Most case studies evaluated interventions that targeted environmental degradation. Interventions mostly consisted of actions to sustainably manage or restore nature, although the majority of studies were classified as more than one type of NbS intervention. Outcomes pertaining to quality of life were assessed more often than outcomes pertaining to biodiversity or Nature's Contributions to People. Most case studies provided qualitative, rather than quantitative evidence, even for biodiversity outcomes.

To define and assess transformative change, we adopted the framework developed by Palomo et al. (2021). Explicit assessment of transformative change was present in a minority of studies. We used indicators of transformative change defined from Palomo et al. (2021) to assess the evidence provided by articles. Evidence of transformative change was related to environmental trends, or human behaviour, rather than sustained long-term change, or multiscale, systemic change.

It should be noted that, as outlined in our methodology, we focused primarily on peer-reviewed literature on NbS and transformative change and did a supplementary review of 'grey data' on the Panorama Solutions database. This implies our results do not necessarily reflect ongoing efforts on NbS and transformative change, for instance current ongoing work from Horizon Europe projects [COEVOLVERS](#), [NATURESCAPES](#), [TRANS-Lighthouses](#).

We recommend that firstly there be increased clarity on what qualifies as NbS – and what does not – as this would help researchers and policy-makers understand, evaluate, and implement suitable NbS interventions. In addition, we recommend development of a more holistic, detailed, and clearly defined framework for evaluating transformative change in NbS interventions. This will facilitate a comprehensive assessment of outcomes i.e., assessing whether the outcomes align with the transformative change indicators.

1. Introduction

The triple planetary crisis of climate change, biodiversity loss and pollution are threatening the functioning of socio-ecological systems across the world (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES] 2019; Andersen 2020). Parties to the Convention on Biological Diversity (CBD) agreed on the Kunming-Montreal Global Biodiversity Framework (GBF; CBD 2022) at the fifteenth Conference of the Parties (COP15). The GBF aims to meet the overarching goal to halt and reverse biodiversity loss through transformative action, while meeting the 2030 Agenda for Sustainable Development. Nature-based Solutions (NbS) will play a key role in achieving this. They are explicitly mentioned in Targets 8 and 11 of the GBF.¹

The concept of NbS has developed as a comprehensive framework encompassing strategies that involve harnessing the capabilities of nature to foster sustainable socio-ecological systems while effectively addressing multiple societal challenges. NbS are increasingly being considered by researchers and policymakers as pathways to more sustainable use and management of natural resources and biodiversity. However, evidence gaps remain regarding their ability to foster transformative change in societies and economies, and their capacity to support long-term sustainability.

For some years now, transformation has been established as a holy grail for economic development and international development assistance, attracting the attention of researchers and practitioners across the international development community (Puri 2018). Yet, approaches to defining the desired transformative changes continue to evolve (O'Brian and Sygna 2013). The dynamic nature and characteristics of desired transformations have posed challenges in evaluating whether transformative changes are being achieved, how best to measure progress towards them, and what evidence is available so far.

Although a review of interventions for climate change adaptation (e.g. Doswald et al. 2020) found that Nature-based Solutions are the most studied intervention, other scientific reviews (e.g. Dick et al. 2020; Cheng et al. 2023) have shown that there is an inadequate evidence base to confirm if NbS create robust social and ecological outcomes.

As governments in Europe and other parts of the world scale up investments in NbS in line with the GBF and its targets, case studies on this topic can be expected to continue to expand further over the coming years. Hence, the objectives of this evidence synthesis are (i) to assess the available literature on the extent to which NbS support transformative change and enable the sustainable use and management of biodiversity in socio-ecological systems; and (ii) to understand which NbS have been particularly effective in bringing about transformative change, and which type of transformative change is most likely to occur. Documenting the evidence base will assist scientists and policymakers in identifying effective solutions for the sustainable use and management of biodiversity, as well as identifying areas where more research is needed regarding the effectiveness of NbS.

¹ Target 8: “minimise the impact of climate change and ocean acidification on biodiversity and increase its resilience ... including through Nature-based Solutions and/or ecosystem-based approaches”. Target 11: “Restore, maintain and enhance nature’s contribution to people ... through “Nature-based Solutions and/or ecosystem-based approaches for the benefit of all people and nature”.

2. Background

2.1 Defining Nature-based Solutions

Nature-based Solutions are defined, standardised, and classified in a variety of ways (e.g. Eggermont et al. 2015; Cohen-Shacham et al. 2016; International Union for Conservation of Nature [IUCN] 2020; United Nations Environment Programme [UNEP] and IUCN 2021; Anderson and Gough 2022). Existing typologies of NbS are often developed for different purposes and are not always consistent with each other. For example, UNEP and IUCN (2021) provide categories of NbS actions focused on climate change mitigation and Nehren *et al.* (2023) develop a typology of NbS for disaster risk reduction. It should be noted that NBS are often local and context specific interventions, and co-creation with local stakeholders is an important dimension when looking at transformative change - encouraging a system wide reorganisation.

For this study, we have employed the definition of Nature-based Solutions adopted by the United Nations Environment Assembly in 2022. This is a multilaterally agreed-upon definition. It defines NbS as “actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human wellbeing, ecosystem services and resilience and biodiversity benefits” (UNEA 2022, UNEP/EA.5/Res.5 paragraph 1).

2.2 Defining Transformative Change

Transformative change is an emerging theme in scientific discussions concerning sustainable development, yet it lacks a precise practical definition (Fedele *et al.* 2019). The diversity of interpretations surrounding this concept hinders effective communication among various stakeholders and often results in a vague application of the term. For this synthesis, transformative change is defined as the profound and disruptive alteration of social-ecological relationships, especially at personal, cultural, organisational, institutional, and systemic levels (Palomo *et al.* 2021).

We adopt the framework for evaluating transformative change established by Palomo *et al.* (2021), which is built on definitions of transformative change by O'Brien and Sygna (2013) and Fedele *et al.* (2019). Through a literature review of transformative change in socio-ecological systems, Fedele *et al.* (2019) identified six indicators that frequently characterise transformative change: *path-shifting*, *restructuring*, *innovative*, *multiscale*, *system-wide*, and *persistent*. Palomo *et al.* (2021) adopted these indicators as part of their framework (see Table 1 for descriptions).

Table 1: Descriptions of the six indicators of transformative change (adapted from Palomo *et al.* 2021).

Indicators of transformative change	Description of indicators
Path-shifting	Ecological or social transformations: change towards different pathways of sustainability, resilience, vulnerability, or equity. For example, reduced deforestation trends or increased water flows, empowerment, increased revenues, alternative livelihoods.
Restructuring	Change in the interaction between people and nature, e.g. through changing paradigms, mind-sets and practices, restructuring landscape through restoration, changing social cooperative structures.
Multiscale	Change at multiple systems' scales, e.g. co-engagement across different levels of governance.
Innovative	Re-evaluation and innovation in the relation between people and nature, e.g. new resilient crop varieties, novel financing mechanisms, new sources of income.
System-wide	Change at large-scale or systemic, e.g. basin-wide, lower watershed areas coordinating with upper watershed; involvement of foreign companies.
Persistent	Future-oriented and long-term change, which is not necessarily irreversible, e.g. evidence of long-term effect, legislative changes, government recognition, establishment of a reserve.

3. Methods

3.1 Primary question and scope of study

The evidence synthesis is intended to provide an overview of the existing literature cataloguing evidence of transformative change from the implementation of NbS (Figure 1 shows a conceptual diagram of this synthesis). The primary question of this study is: *What evidence exists demonstrating that Nature-based Solutions (NbS) contribute positively to transformative change for the sustainable use and management of biodiversity in social-ecological systems?*

The primary question is broken down into two sub-questions:

1. To what extent is there an assessment of the potential for Nature-based Solutions to contribute to transformative change?
2. Where assessed, is there evidence that Nature-based Solutions contribute positively to transformative change, and how?

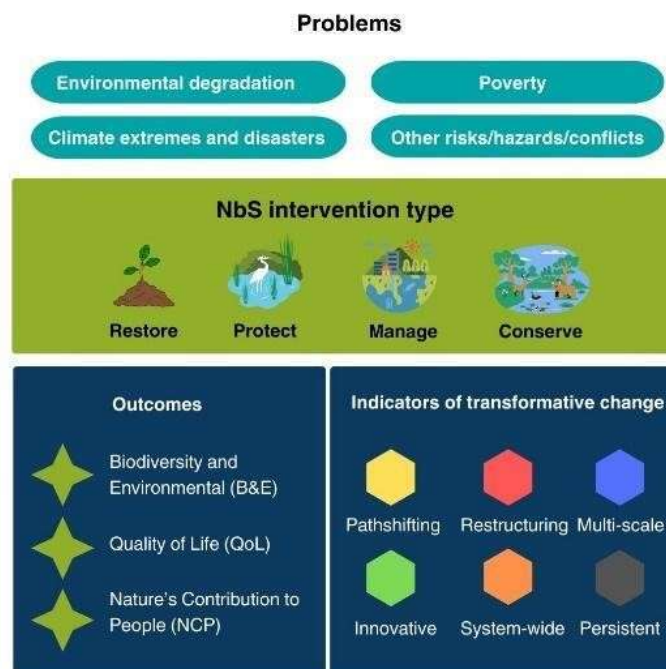


Figure 1: Schematic of the concept used in evaluating the contribution of Nature-based Solutions to transformative change.

We followed the Guidelines and Standards for systematic reviews described by the Collaboration for Environmental Evidence (CEE 2022). Evidence maps are an established type of narrative synthesis for broad topics where the effects of intervention or exposure are not measured with quantitative methods.

We used a PIO-C framework (Table 2), where the primary question was broken down into “population”, “intervention”, “outcome”, and “context”. By context, we refer to the type of relevant literature, which was defined as case study. Case studies were from peer-reviewed articles and two grey literature databases (see section 3.5).

Table 2: The Population-Intervention-Outcome-Context framework used to conceptualise this study and develop the search terms and inclusion/exclusion criteria.

Population	Use and management of biodiversity in social-ecological systems
Intervention	Nature-based Solutions interventions
Outcome	Transformative change for the sustainable use and management of biodiversity
Context (study type)	Case studies (academic and grey literature)

As highlighted in the PIO-C framework, the question entails two key concepts – *Nature-based Solutions* and *transformative change* – both of which have been historically subject to a diversity of definitions (section 2). The challenge in determining the scope of the study emanated from the finding that interventions can be classed as *Nature-based Solutions* and effects as *transformative change* but are not always termed this way. This is partly because the uptake of both concepts in literature and policy has only gained momentum in the past decade (Li *et al.* 2021), even though NbS interventions have existed for centuries, and transformative change has occurred throughout human history.

To guide the framing of these concepts for the purpose of this synthesis, we considered relevant papers describing interventions that can be classified as Nature-based Solutions according to the definition adopted by the United Nations Environment Assembly (UNEA 2022, UNEP/EA.5/Res.5 paragraph 1; see section 2.1). We reviewed the interventions described within the articles and included them based on the above definition. In applying the definition to articles during screening, we used a conservative approach, only excluding articles where the intervention was clearly not in line with the definition.

3.2 Peer-reviewed literature search

We searched for relevant peer-reviewed literature in the Web of Science Core Collections (WOSCC) database, filtering out articles in languages other than English. No temporal limits were used in the search query.

The benchmark articles were selected through the course of an internal discussion of three reviewers based on a list of articles provided by Biodiversa+. These were found through a scoping search online as well as past publications by the United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC). Drawing on consultations with Biodiversa+, the selected three benchmark articles are:

- Scolobig *et al.* (2023). Transformative adaptation through Nature-based Solutions: a comparative case study analysis in China, Italy, and Germany. Regional environmental change.

- Short *et al.* (2019). Capturing the multiple benefits associated with Nature-based Solutions: Lessons from a natural flood management project in the Cotswolds, UK. Land degradation and development.
- Turpie, Marais, and Blignaut (2007). Working for Water programme: evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in Southern Africa. Ecological economics.

These articles were used to test the sensitivity of the search string, as per best practices recommended for evidence syntheses (CEE 2022).

Following from the PIO-C framework, we used the terms Nature-based Solutions, transformative change, sustainable use and management of biodiversity in social-ecological systems, and case studies/evidence, as well as related synonyms to develop our search string. This ensured that we encompassed different terminologies and perspectives to achieve a comprehensive coverage of the topics. Subsequently, we connected the search terms using the Boolean operators "AND" and "OR". After carefully examining the initial results, we refined the search string. In collaboration with Biodiversa+, we incorporated additional keywords into two new search strings.

The process of testing various search strings can be viewed in more detail in Annex 1. Our final search string (Table 3) generated 1,175 results, including all three benchmark articles. This search string was subsequently approved by Biodiversa+ and the article metadata was downloaded on 14 August 2023.

Table 3: The final search string used to query on the Web of Science Core Collections is as follows. It includes additional terms to help capture all four benchmark articles, the search string also introduces wildcards to allow for regional variations of spelling and removes redundant terms.

```
TS = (((("nature-based solution*" OR "NbS" OR "ecosystem-based" OR "green infrastructure" OR
"ecosystem service*" OR "renaturali?ation" OR "renaturing" OR "nature-based strateg*" OR
"nature-based mitigation" OR "ecosystem-based mitigation" OR "nature-based adaptation" OR
"ecosystem-based adaptation")
AND ("Transformative change$" OR "governance" OR "Socioeconomic impact$" OR "Behavioral
change*" OR "Policy change*" OR "Policies change*" OR "Institutional change*" OR "Societal
change*" OR "Social benefit*" OR "Knowledge typ*" OR "personal belief*" OR "Collective belief*"
OR "Political instrument*" OR "Economic instrument*" OR "Cultural element*" OR "Legal
instrument*" OR "Technical element*" OR "transformative adaptation" OR "transformative societal
change$" OR "transformational adaptation" OR "social transformation" OR "transformative
behaviour$" OR "transformational change$" OR "novel business model$" OR "financing
mechanism$" OR "technological innovation$" OR "systemic solution$" OR "transformative impact$"
OR "institutional framework$" OR "policy action$" OR "policies action$" OR "implementation
action$" OR "practical implementation$" OR "human-nature relationship$" OR "economic
instrument$" OR "financial instrument$" OR "legal instrument$" OR "regulatory framework$" OR
"community engagement" OR "rights-based instrument$" OR "customary norms" OR "crosssectoral
collaboration" OR "co*management" OR "government-funded")
AND ("case study" OR "case studies" OR "empirical evidence" OR "research findings" OR
"scientific studies" OR "proof*of*concept" OR "project" OR initiative*)
AND (biodiversit* OR "sustainabl* manag*" OR "biodiversit* conservat*" OR "biodiversit* manag*"
OR "environment* impact*" OR "sustainable* use" OR "sustainabl* develop*" OR conserv* OR
preserv* OR restor* OR "ecological* sustainabilit*" OR "natural" NEAR "capital"))))
```

3.3 Criteria for study eligibility

The PIO-C framework (section 3.1) was also used to standardise the screening process. Criteria for inclusion and exclusion of articles were developed for each of the four question elements (Table 4). Firstly, two reviewers looked at 20 sample papers to pilot the screening criteria. Where reviewers were uncertain of whether an article should be included or not, discussion between the reviewers took place and inclusion criteria made more granular if necessary.

Table 4: Criteria used to include and exclude articles based on the Population-Intervention-Outcome-Context framework defined above. These criteria were used for the evidence maps of both the peer-reviewed and grey literature.

Question Element	Inclusion Criteria	Exclusion Criteria
Population	Article deals with the use and management of biodiversity (species, habitats, terrestrial and marine ecosystems) in socialecological systems.	Article does not mention biodiversity or related concepts (e.g. species, habitats, ecosystems).
Intervention	Article deals with the implementation of specific and described Nature-based Solutions.	- Article focuses on processes prior to actual interventions (planning, attitudes, narratives, mapping, prioritisation, power dynamics between stakeholders). - Article focuses on the creation of a theoretical framework. - Article does not describe the intervention. - The intervention is not NbS according to the UNEA definition (section 2.1).
Outcome	Article provides primary evidence of the outcome of the described NbS intervention, related to the six transformative change indicators (section 2.2).	- Article does not describe outcomes. - Article provides outcomes that are modelled or projected. - Article provides outcomes with descriptions that are not detailed enough to be coded.
Context: Study type	Article focuses on one or more case studies - from academic peerreviewed literature and grey literature- with evidence provided for each case study.	- Article is a review, opinion piece, book, or book chapter. - Article relies on research conducted by other peer-reviewed studies in order to assess evidence.

3.4 Screening process for peer-reviewed articles

Following the development of the eligibility criteria, screening of the peer-reviewed literature was conducted firstly on titles, then abstracts, and finally on full texts of the articles. At each stage, agreement between reviewers was determined through calculating the Cohen's kappa (McHugh 2012). The approach to exclusion was conservative at all stages prior to full text. Where the Cohen's kappa was

below 0.6, reviewers discussed points of disagreement and refined the eligibility criteria where appropriate.

Title screening stage: we excluded titles that clearly communicated a theoretical approach (for example, where the title contained words like ‘conceptual framework’, ‘mapping approach’, ‘index’ or ‘model’), or a focus on interventions that cannot be qualified as Nature-based Solutions (e.g. ‘grey’ or fully-engineered solutions, which are “built structures and mechanical equipment” such as sea walls; Browder *et al.* 2019).

Abstract screening stage: we expanded on our approach during the title stage. We excluded papers whose abstracts made no mention of biodiversity or related concepts (e.g. nature, species, ecosystems, etc.). We excluded abstracts where the focus of the paper was not outcomes of an NbS intervention, for example where the subject was perceptions or attitudes about ecosystem services, or assessment of landscape prior to any intervention taking place. We also excluded papers where the abstract clearly specified that the paper is focused on projected outcomes or various stages of projects prior to implementation, including stakeholder engagement, modelling, and prioritisation. Review papers were also excluded as this would risk including a case study more than once. Through discussions with Biodiversa+ we decided to include some papers focusing on NbS policy, for example articles on payment for ecosystem services (PES) schemes.

Full-text screening stage: we employed the above approaches, in addition to evaluating outcomes of implemented NbS. Four reviewers conducted the full text screening and performed consistency checks by engaging in discussions with each other whenever there was uncertainty about whether an article should be excluded or included. We concurrently screened the full text while coding the papers retained (see 3.6). During this stage we also excluded papers that lacked descriptions or evaluations of outcomes (see Table 4).

3.5 Screening process for grey literature

In addition to the peer-reviewed literature, we conducted a supplementary review of two databases of Nature-based Solutions: The Panorama database and the Global Program on Nature-based Solutions for Climate Resilience Knowledge Hub. The grey literature review was conducted to provide a broader variety of NbS interventions. The Panorama database contains a total of 1423 NbS interventions and case studies from around the world and aims to inspire and possibly replicate some of the solutions. The Global Program on Nature-based Solutions for Climate Resilience Knowledge Hub provides a collection of 43 cases, briefing notes, guidance, and technical reports. This review of grey literature aimed to answer the same primary question, followed the same PIO-C framework and applied the same inclusion and exclusion criteria.

We used a geographical reach filter in the Panorama database to concentrate cases in European regions. This was done to widen the representation of NbS interventions in Europe, the focus region for Biodiversa+. By applying the geographical reach filter, we were provided 197 case studies. When reviewing the Global Program on Nature-Based Solutions for Climate Resilience database, we kept the search global as the database was much smaller.

3.6 Coding strategy

A similar coding strategy was used for both the peer-reviewed and the grey literature, although it was initially developed based on trials with the peer-reviewed literature. Coding from peer-reviewed literature was conducted at the same time as full-text screening.

Metadata were coded in an Excel workbook. The initial coding sheet was trialled by three researchers (FR, MA, MH) on one article. It was then further adapted with consultation with Biodiversa+ and re-trialled by one researcher (MH) on the three benchmark articles. We assigned numerical IDs to each article and separately to each case study. We extracted the following categories of information from articles:

- Bibliometric information.
- Case study details.
- Evidence of outcomes.
- Evidence of transformative change.

In addition to the coding sheet, an exclusion sheet contained the same bibliometric information, alongside a reason for exclusion and the category of the PIO-C framework (see supplementary database).

3.6.1 Coding of bibliometric information

For the peer-reviewed articles, the authors, title, year of publication, journal of publication, and DOI were coded. These categories were used across the coding sheet and the separate exclusion sheet. Due to the nature of the grey literature, different bibliometric information was extracted: the database title, the case study title, link to the case study, author, and associated institution.

3.6.2 Coding of case study details

Five types of information were extracted about the case studies: geographical information (country and biome of intervention), funding type, time since implementation, the problem addressed by the intervention, and the intervention type.

Country of intervention was extracted from the articles and coded using the names as defined by the United Nations Statistics Division in the M49 Standard (UNSD 2024). For the biome classification, we used the four main ‘natural’ biome types from the UNEA definition of NbS – terrestrial, freshwater, coastal, and marine. We supplemented this by defining two ‘modified’ biomes – urban and agricultural landscapes. Terrestrial biomes were further classified using an adapted version of the ecoregion biome classification (Dinerstein *et al.* 2017; see Annex 2). This resulted in fifteen biome categories. Interventions could be in multiple biome categories.

For the problem addressed, we used the three problems defined in Palomo *et al.* (2021) – environmental degradation, climate extremes and disasters, other risks/hazards/conflicts (Table 5).² We also used the category of *poverty* to capture the use of NbS primarily for socio-economic solutions.

NbS interventions were classed into four categories, using the four main types in the UNEA definition

² We use italics throughout this document to refer to the different categories that we used to characterise the case studies.

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– *Protect, Restore, Conserve, and Manage* (see Table 5 for definitions). Although more detailed classifications do exist (e.g. Eggermont *et al.* 2015; Cohen-Shacham *et al.* 2016), these were deemed not to fit the purpose of our study.

Table 5: The categories used for, and their definitions, for selected variables extracted about the case study details. 'Problem addressed' is adapted from Palomo *et al.* (2021). Intervention types are adapted from the United Nations Environment Assembly definition of Nature-based Solutions.

Variables	Categories	Definition
Funding type	Public	Domestic or foreign investment by a nation or multilateral public funding body (e.g. World Bank, African Development Bank, Green Climate Fund)
	Private	Investment by a company or private investment fund
	Blended	Funding provided by both public and private institutions.
	Unknown/Not applicable	Paper does not state funder type.
Problem addressed	Environmental degradation	e.g. deforestation, hunting
	Climate extremes and disasters	e.g. extreme heat, sea level rise
	Other risks/hazards/conflicts	e.g. landslides, flooding
	Poverty	e.g. threats to livelihood, food insecurity
Intervention type	Protect	e.g. protected areas
	Restore	e.g. reforestation, afforestation, wetland restoration
	Manage	Sustainable use and management, such as payment for ecosystem services
	Conserve	Protection of natural resources, e.g. protection of animal nesting
Time passed since intervention	<2 years	As explicitly mentioned by the article or inferred from the difference between data collection (or article date if not provided) and date of intervention.
	2-5 years	
	5-10 years	
	10+ years	
	Unclear/unspecified	

3.6.3 Coding evidence of NbS outcomes

We coded whether case studies assessed three types of outcomes of NbS: *biodiversity and environment*, *quality of life*, and *Nature's Contribution to People* (Palomo *et al.* 2021). Palomo *et al.* (2021) adopted these terms from the IPBES conceptual framework (Díaz *et al.* 2015). *Biodiversity and environment* refers to the “diversity of living organisms and their interactions among themselves and with their environment” (Díaz *et al.* 2015, p. 4). *Nature's Contribution to People* refers to “the benefits that humanity – individuals, communities, societies, nations or humanity as a whole – obtain from nature” (NB. This can include ecosystem goods and services i.e. provisioning, regulating and cultural services) (Díaz *et al.* 2015, p. 6). Finally, *quality of life* refers to the “achievement of a fulfilled human life” through various factors including, but not limited to: access to food and water, livelihood security, equity, and participation in society (NB these are multidimensional, including material, as well as non-material benefits) (Díaz *et al.* 2015, p. 7).

For each of these outcome categories, we categorised the state of evidence in a hierarchy (Figure 2): whether evidence had been assessed for each outcome; if so, whether there was positive, mixed, negative, or no discernible change. By mixed change, we refer to case studies where evidence was provided for both positive and negative change for the outcome category.

Where evidence was provided, it was further categorised as quantitative, qualitative, or mixed evidence. Mixed evidence refers to evidence provided for a certain outcome that was both quantitative and qualitative.

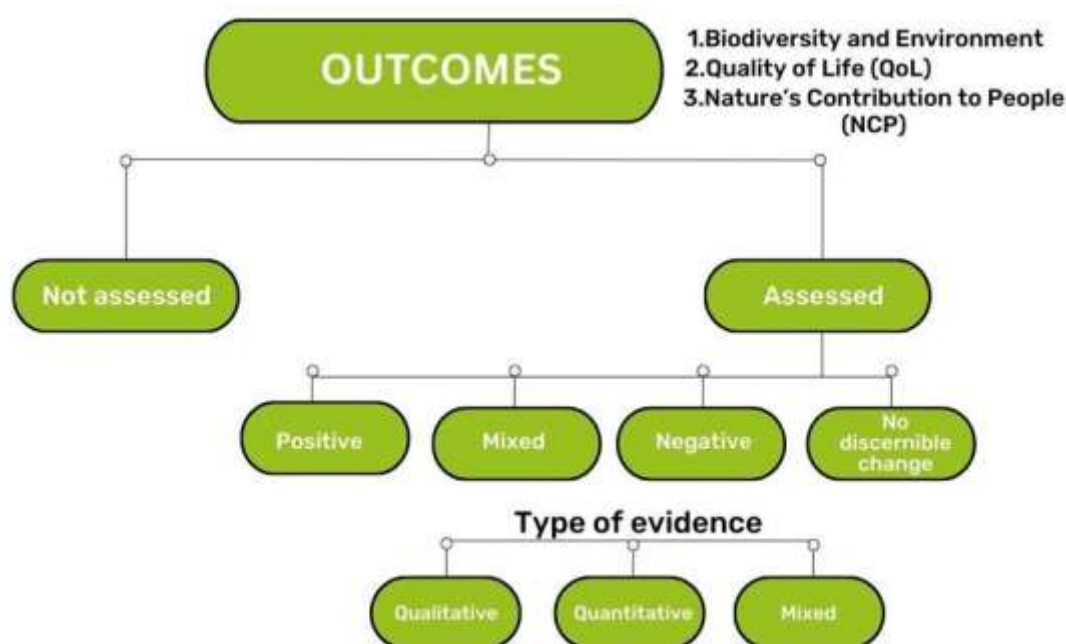


Figure 2: Flow diagram presenting the hierarchy of categories used to assess outcomes of Nature based Solutions.

3.6.4 Coding evidence of transformative change

Assessment of the evidence of transformative change was approached in a similar way, using a hierarchy of the state of evidence. We assessed whether an article provided evidence of transformative change in two ways (Figure 3).

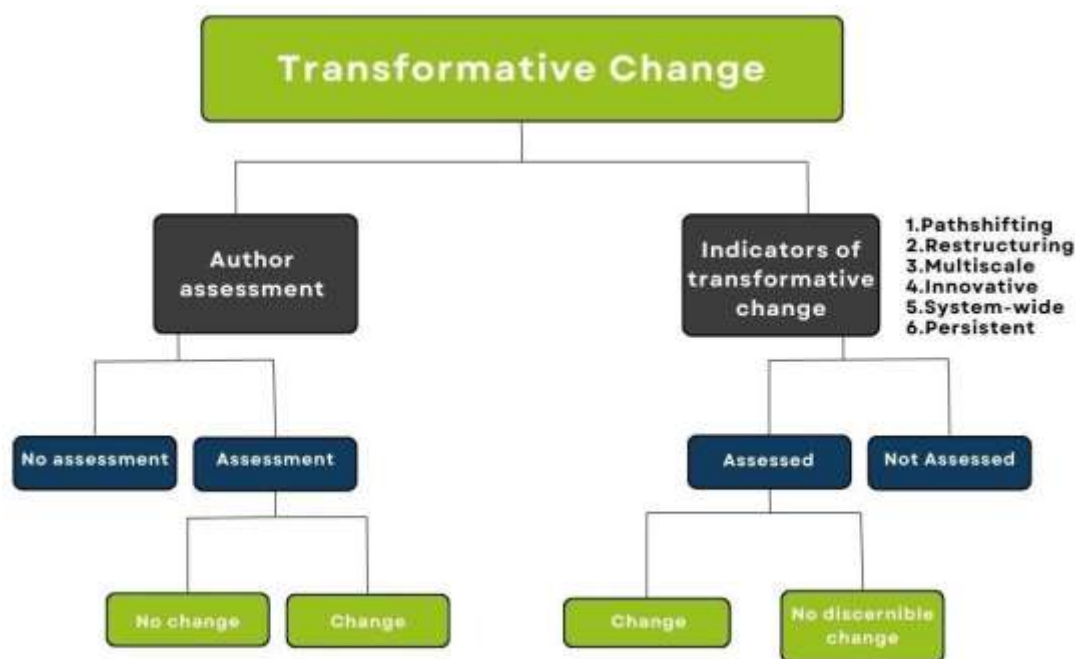


Figure 3: Flow diagram showing the hierarchy of categories used to assess transformative change in case studies.

First (Figure 3, left-hand branch), author(s) of a case study were considered to explicitly evaluated transformative change if they used the phrase ‘transformative change’, any related phrases (such as systemic change), or words related to or similar to the six indicators (e.g. “path shift”, “mental shift”, “system-wide”). If one of these criteria was met, the assessment was categorised as either i) there was transformative change or ii) there was not transformative change. In the context of this evidence map transformative change only referred to positive change. Therefore, any change that was interpreted as negative was categorised as no transformative change occurred.

Second (Figure 3, right-hand branch), we broadened the assessment of transformative change to apply the six indicators (Palomo *et al.* 2021; our Table 1). Rather than requiring explicit evaluation of these indicators, which was covered by the above, we assessed whether the author(s) provided evidence that could have been interpreted as transformative change under each of the six indicators.

Three main types of information were extracted regarding evaluating transformative change indicators. Firstly, we assessed whether the reviewer explicitly evaluated transformative change. Then, for each of the six transformative change indicators, we assessed whether the author(s) provided evidence that could be interpreted as assessing transformative change. If there was no evidence provided by the author(s) for a particular indicator, it was recorded as ‘not assessed’. If evidence was provided for the indicator, it was classified as either i) change in the indicator did occur (*change occurred*), or ii) it did not (*no discernible change*).

4. Results from peer-reviewed evidence map

4.1 Overview of screening process

The results of the screening process are illustrated in the ROSES flow diagram (Figure 4). 1,175 records were retrieved from WOSCC using the search string (Table 3). After title screening, 566 articles were retained for abstract screening (~48%). 351 articles were excluded at the abstract screening stage (see section 3.3 for eligibility criteria). Therefore, 215 articles were retained for fulltext screening, of which 46 (21%) met the inclusion criteria and were retained for coding metadata.

Three articles were not accessible to the authors and the remaining 166 articles were excluded. Reasons for exclusion at the full text stage were documented and classified according to the PIO-C framework as outlined in the methodology (section 3.1). No articles were excluded based on the *population* category. The *intervention* and *outcome* categories were the reasons for exclusion of 71 and 67 articles, respectively. Articles excluded for the *intervention* reason did not analyse an NbS intervention (e.g. focused on ecosystem services, interventions did not meet our criteria for NbS) or focused on something other than the outcomes of the NbS (e.g. the governance systems, power relations, or challenges of implementation). Articles excluded for the *outcome* reason passed the *intervention* criteria but did not present outcomes as required by our evidence map. Some articles presented modelled or “potential” outcomes, some articles did not provide any outcomes, and some did not provide any assessment of transformative change. Twenty-eight articles were excluded for *context* reasons. These included articles that were not in English or were books or book chapters. Furthermore, review articles and linked data (i.e. two articles analysing the same data) were not retained. These were excluded to avoid risks of duplicating evidence, and to focus solely on primary empirical evidence. However, articles that used evidence from grey literature (such as policy documents, institutional reports, or project documents) were included.

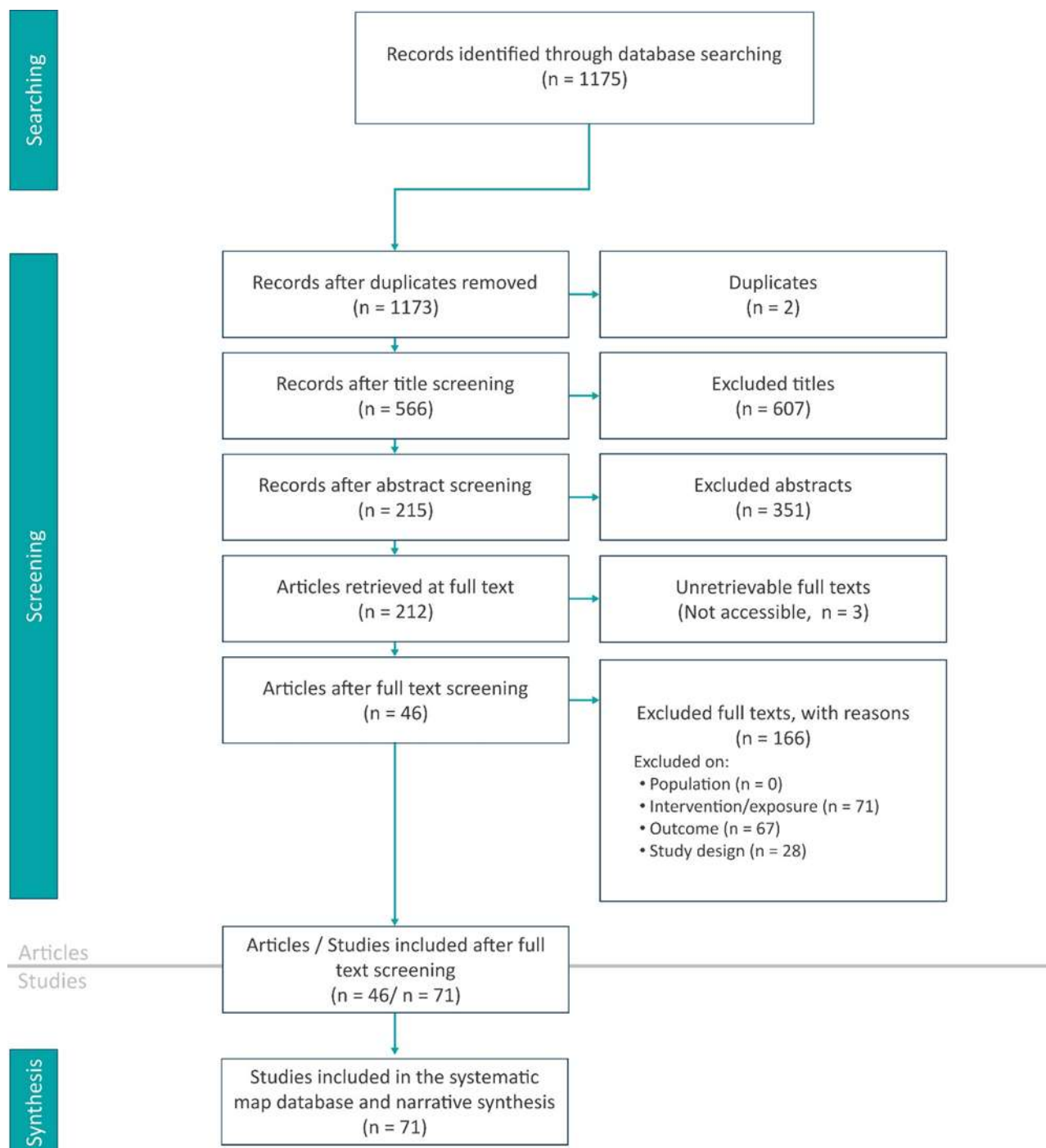


Figure 4: ROSES flow diagram illustrating the searching, screening and synthesis process for the evidence map of peer-reviewed literature. Adapted from Haddaway et al. (2017). Note the change from 'articles' to 'studies' after the screening process. Multiple studies could be in one article.

4.2 Case study details

From the final 46 articles, 71 case studies were coded with corresponding metadata. Fourteen articles contained more than one case study (with between two and eight case studies per article). Two articles assessed different aspects of the same NbS intervention (but with different data). This was coded as one case study.

All articles were published between 2007 and 2023 (up until the date of extraction from WOSCC – August 2023; Figure 5). Over half the articles (53%) were published since 2020.



Figure 5: Temporal spread of the 46 articles included after full-text screening (green line) and the 71 case studies extracted from these articles. Note that 2023 is not a full year because the search was conducted on 14 August 2023.

4.2.1 Geographic spread of case studies

The included case studies covered 30 countries, across 11 sub-regions and all continents (Figures 6a, b).³ The assignment of marine interventions was based either on where the land-based research was conducted (e.g. the effects of a marine protected area on Indonesians), or on the closest country to the intervention (the Great Barrier Reef Marine Park was designated Australia, and the intervention in the Southern Ocean was designated Antarctica).⁴ *Sub-Saharan Africa* and *Latin America and the Caribbean* were the most represented regions, with 28% and 21% of case studies based in these locations, respectively. The *Australia and New Zealand* and *Antarctica* sub-regions each had only one case study. Three case studies were cross-border (though in the same subregion), covering the Kenya-Tanzania borderlands.

Case studies covered 10 of the 15 biome categories (as well as one unclear study), with the most extensively covered being *tropical forests*, *agricultural landscapes*, *coastal*, *freshwater*, and *marine areas* (Figure 6c). Sixteen case studies were categorised as multiple biomes (Table 6). These were primarily when the location of the NbS intervention was classified as both a modified biome and a natural biome (e.g. tropical forest and agricultural landscape), or when the intervention was considered multiple water-based biome (e.g. marine and coastal). The biome type was unclear in one case study. No case studies described NbS interventions in *temperate forests*, *boreal forests*, *tundra*, *Mediterranean*, or *wetland* biomes.

³ By sub-region, we refer to the seventeen sub-regions defined by the UN Statistics Division M49 Standard (UNSD 2024). By continents, we refer to: Asia, Africa, North America, South America, Europe, Oceania and Antarctica. These are different to the continental regions defined by the UNSD. Antarctica is considered both its own sub-region (although not in the UNSD Standard), a continent, and a country for simplicity.

⁴ We did not consider the Exclusive Economic Zone (EEZ) when classifying these marine interventions.

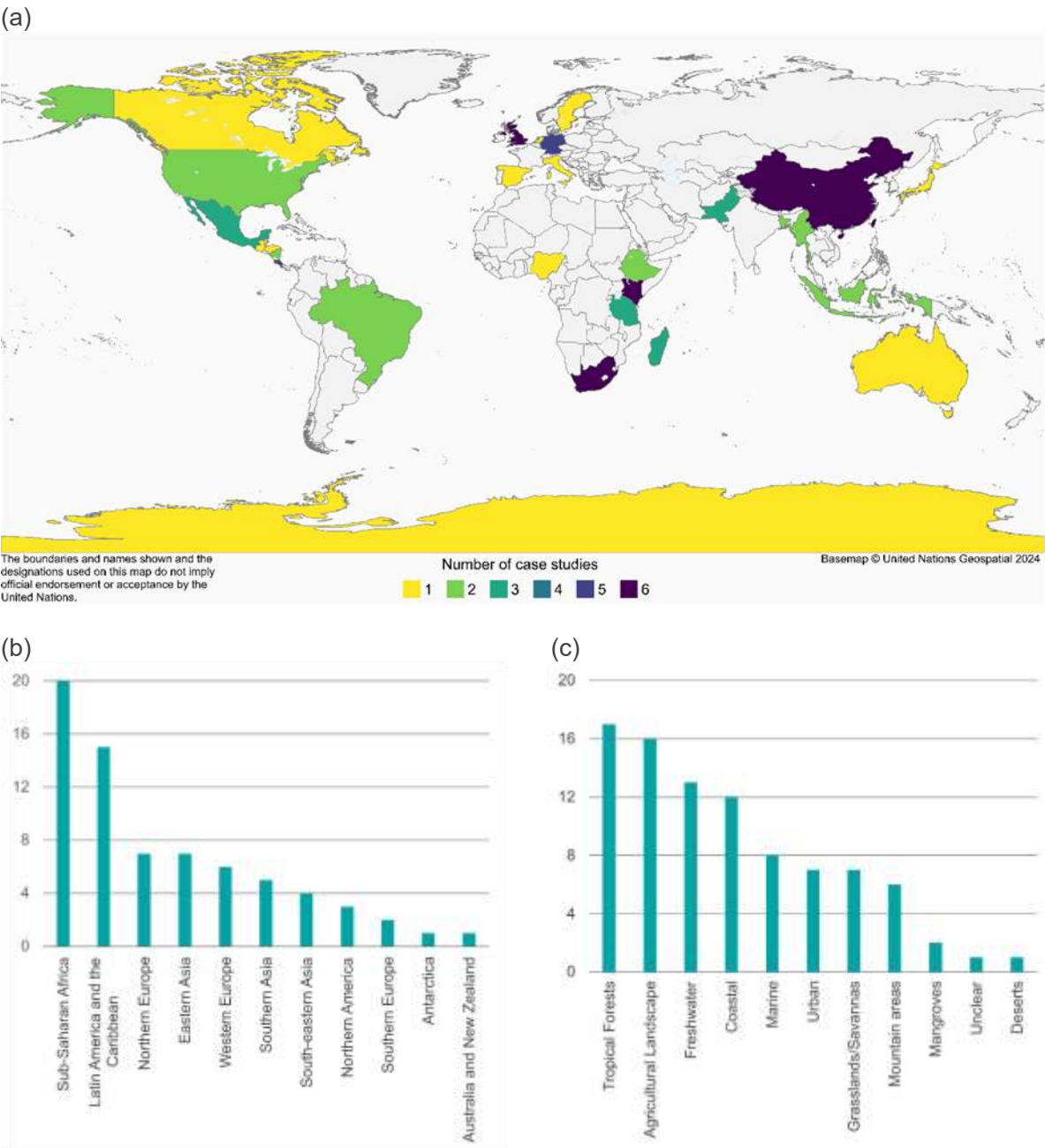


Figure 6: (a) Choropleth map of case study frequency per country. Three case studies were crossborder (Kenya-Tanzania borderlands). Marine interventions were assigned to the country where land-based research was conducted or the closest country to the intervention. (b) frequency of case studies for each sub-region (defined by UNSD M49 Standard, except for Antarctica). There were no case studies for seven sub-regions. (c) frequency of case studies for each biome. The biome was unclear in one case study. There were no case studies in five biome categories. The boundaries and names shown, and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Table 6: Number of case studies for each combination where case studies were categorised as multiple biome types. Terrestrial biomes are adapted from Dinerstein *et al.* (2019); see Annex 2.

Multiple biome combinations	Number of case studies
Agricultural Landscape, Grasslands/Savannas, Tropical Forests	3
Coastal, Freshwater	1
Freshwater, Agricultural Landscape	1
Mangroves, Coastal	2
Marine, Coastal	3
Tropical Forests, Agricultural Landscape	1
Urban, Freshwater	4
Urban, Tropical Forests	1

4.2.2 Problems addressed by Nature-based Solutions

Across all case studies, NbS was overwhelmingly used to address *environmental degradation* (Table 7). Of the 71 case studies, 63 interventions addressed *environmental degradation* at least in part, and 39 focused solely on *environmental degradation*. *Poverty* was addressed by 19 of the NbS interventions described, but only two of these addressed it as the sole problem. *Other risks/hazards/conflicts* and *climate extremes* and *disasters* were addressed by 14 and seven interventions, respectively. However, they were each addressed as the sole problem by only three case studies and one case study, respectively. Therefore, over a third of case studies (37%) aimed to address more than one problem. The most common combination was *environmental degradation* and *poverty*. Thirteen case studies had interventions classified as addressing only these two problems, and in three others, interventions addressed additional problems as well. In four case studies, interventions addressed three problems, and in one, the intervention addressed all four problems.

Interventions were classified as addressing multiple problems where the focus of the implementation aimed to, for example, reduce degradation whilst improving livelihoods. It was not classified as addressing both if there were co-benefits (when outcomes were coded), but it was not the aim of the intervention. For example, the Integrated Ocean Management of the Bohai Sea that focused on reducing pollution led to economic and social development (Xue *et al.* 2022) but reducing poverty was not the focus of the intervention.

These categories were extracted from the description of the NbS intervention. Therefore, when we refer to “problem addressed” it does not necessarily mean the intervention was successful. We did not detail the synergies or trade-offs when addressing multiple problems.

Table 7: Frequency of case studies that described interventions that addressed in part (top row) or solely addressed (bottom row) each of the four “problem” types (adapted from Palomo *et al.* 2021). As interventions could address multiple problems, the sum of each row does not equal the total number of case studies.

Problem addressed	Environmental degradation	Climate extremes and disasters	Other risks/hazards/ conflicts	Poverty
Addressed in part	63	7	14	19
Solely addressed	39	1	3	2

4.2.3 Type of Nature-based Solutions intervention

NbS interventions classified as *Manage* and *Restore* were the most represented across case studies (Table 8). Of the 71 case studies, interventions were classified as *Manage* or *Restore* 40 and 30 times respectively. This includes case studies where interventions were classified as more than one of the four types. Considering case studies where interventions were classified as only one of these types, 19 were classified as *Manage* and 18 as *Restore*. *Conserve* and *Protect* intervention types were less well represented. Interventions were classified as *Conserve* and *Protect* in 17 and 15 case studies respectively. They were the sole intervention type in three and seven case studies respectively.

A third of case studies (34%) described interventions classified as more than one type. The two most common combinations of intervention were *Manage* and *Conserve* (7) and *Manage* and *Restore* (6). Three case studies were classified as three types and two case studies were classified as all four. For example, the Billion Trees Afforestation Project (BTAP) in Pakistan (Ullah *et al.* 2022) that aimed to afforest large areas (*Restore*), *Conserve* and *Protect* existing forests, and engage the rural poor in management actions (*Manage*). Similarly, the National Forest Conservation Plan (NFCP) in China (Scolobig *et al.* 2023) was implemented in a protected area (the Wolong Nature Reserve; *Protect*), includes afforestation and restoration actions (*Restore*), has a logging ban (*Conserve*) and has a payment for ecosystem services (PES) scheme (*Manage*).

Table 8: Frequency of case studies where interventions were classified as each intervention type. As interventions could be categorised as more than one type, the sum of each row does not equal the total number of case studies. The bottom row includes any case studies where interventions were classified as only that intervention type.

	Manage	Protect	Restore	Conserve
Classified	40	15	30	17
Solely classified	19	7	18	3

4.2.4 Problems addressed by NbS intervention types

In case studies where interventions addressed *poverty*, 48% described interventions classified as *Manage* (Table 9). The majority of interventions that addressed *other risks/hazards/conflicts* were classified as two intervention types: 42% as *Manage* and 42% as *Restore*. In studies where interventions addressed *climate extremes and disasters*, 54% were classified as *Restore*.

Table 9: The percentage of case studies that addressed each problem by the intervention type. Percentages do not add to 100% because case studies could have interventions classified as multiple types and/or addressed multiple problems.

	Environmental degradation	Climate extremes and disasters	Other risks/hazards/ conflicts	Poverty
Manage	37%	31%	42%	48%
Protect	16%	8%	11%	12%
Restore	29%	54%	42%	15%
Conserve	18%	8%	5%	24%

4.2.5 Funding type and time since implementation

In addition to the above information, we extracted the type of funding and the time passed since implementation. Over a third of case studies (24) had *unclear/unspecified* types of funding. Only five case studies had *blended* finance. The rest were equally split between *public* and *private* (both 21 case studies).

Almost half of the case studies (30) conducted research *at least 10 years* after the intervention began. 14 were conducted *five to ten years* since the intervention began, 11 *two to five years*, and only two *less than two years*. 14 case studies had *unclear/unspecified* time since implementation.

4.3 Evidence of Nature-based Solutions outcomes

We evaluated the extracted case studies to ascertain the presence of three types of outcomes resulting from NbS interventions (Palomo *et al.* 2021; our Figure 1 and Figure 2): *biodiversity and environment*, *quality of life*, and *Nature's Contributions to People*. As outlined in section 3.6.3, we documented whether the outcome was assessed. If it was assessed, we documented whether the change was i) *positive*, ii) *negative*, iii) *mixed*, or iv) had *no discernible change*; and whether it was assessed using i) *quantitative*, ii) *qualitative*, or iii) *mixed* evidence.

Quality of life was the outcome most frequently assessed, referenced in 44 case studies, followed by *biodiversity and environment* with 33 case studies and *Nature's Contribution to People* with 28 case studies (Figure 7a). 19 case studies did not assess any of the three outcomes but still provided evidence of transformative change. 18 case studies assessed all three outcomes. Of these 18 case studies, 10 found *positive* change in all three outcomes.

Evidence for these outcomes was not always mutually exclusive. For example, Scolobig *et al.* (2023), in their assessment of the National Forest Conservation Plan (NFCP) in China, described the successes in “maintaining forest cover” (*biodiversity and environment*), “which serves as an essential NBS [sic] for flood and landslide protection” (*Nature's Contribution to People*), “biodiversity by assuring panda habitat” (*biodiversity and environment*), “and ecotourism” (*quality of life*). This highlights the interaction between all three outcomes. Likewise, Krause *et al.*'s (2019) evaluation of a pilot project for community-based forest and wildlife management in Nigeria, and its impact on primates found *negative biodiversity and*

environment outcomes (less primate sightings and more deforestation) with *no discernible change* in *quality of life* or *Nature's Contribution to People* outcomes as there were no results-based payments and old forest practices continued.

When outcomes were assessed, they were often *positive*. *Nature's Contribution to People* outcomes had the highest proportion of *positive* change (71% of case studies assessed, compared to 64% and 59% for *biodiversity and environment* and *quality of life* respectively). *Mixed* evidence was the next most likely evaluation: 24%, 30%, and 21% for case studies assessed for *biodiversity and environment*, *quality of life*, and *Nature's Contribution to People*.

For all three outcomes, there was more *qualitative* evidence than *quantitative* evidence (Figure 7b). Nevertheless, *biodiversity and environment* outcomes had the largest proportion of *quantitative* and was almost equally assessed by *quantitative* and *qualitative* evidence (39% and 42% of all case studies where *biodiversity and environment* was assessed respectively). *Nature's Contribution to People* was assessed much less by *quantitative* evidence (21% of all case studies where it was assessed), followed by *quality of life* outcomes (only 9%). Given the inherent differences between the three variables, this overall pattern is not surprising. However, the low proportion of *quantitative biodiversity and environment* outcomes is perhaps unexpected. While some studies provided data on, for example, increased forest cover, many relied on qualitative evidence such as interviews to communicate change in species diversity (e.g. Zuniga *et al.* 2023) or a decrease in water pollution levels (e.g. Davids *et al.* 2021) rather than field measurements.

Broadly, there was not a noticeable relationship between the type of change and the type of evidence. The proportion of *quantitative* and *qualitative* evidence assessment of *positive* change is similar for all three outcomes. Mixed change in *Nature's Contribution to People* had a similar proportion of *quantitative* and *qualitative*. The three case studies that provided evidence of *negative* change for *biodiversity and environment*, and the one case study for *Nature's Contribution to People*, used *qualitative* evidence. For *negative* change in *quality of life*, one case study provided *qualitative* evidence and two provided *mixed* evidence.

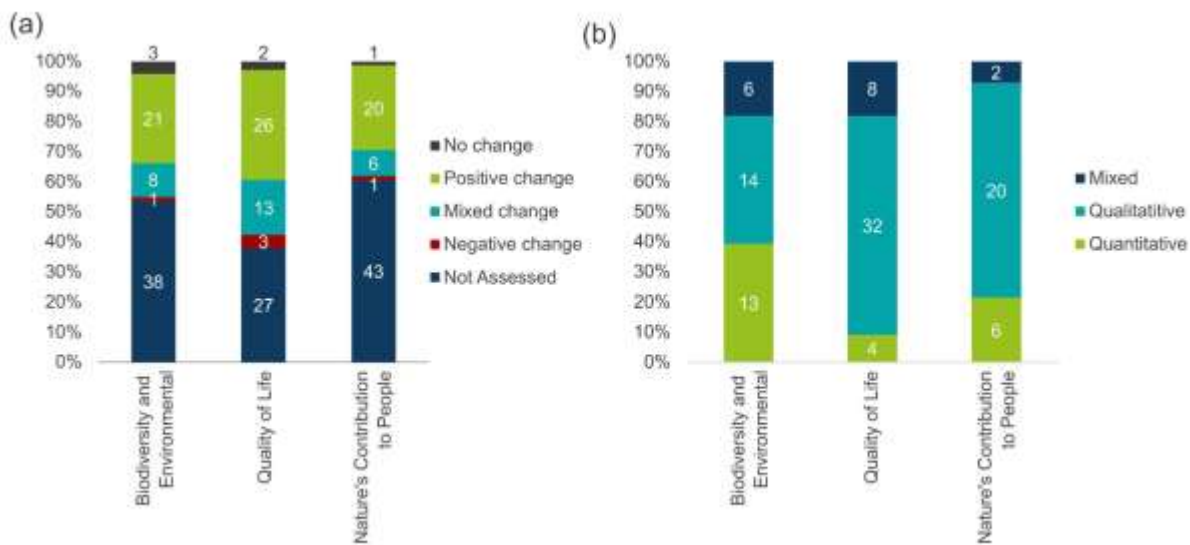


Figure 7: (a) Distribution of case studies across the five 'evidence' categories: not assessed, and positive, negative, mixed, and no change. (b) Distribution of evidence type for case studies where each outcome was assessed. The vertical axis in (a) shows the proportion of all case studies. The vertical axis in (b) shows the proportion of case studies that assessed that outcome. Bars are labelled with the frequencies of each category.

4.4 Assessment of Transformative Change

We assessed the potential for transformative change in two different ways (section 3.6.4; Figure 3): (a) whether the author(s) explicitly stated that transformative change occurred; and (b) whether the authors provided evidence that could be interpreted as transformative change under the six indicators defined by Palomo et al. (2021; our Table 1; section 2.2).

4.4.1 Explicit author evaluation

Most case studies (79%) did not assess transformative change explicitly (56 case studies). Of those where transformative change was explicitly evaluated (total 15), 14 found that *transformative change did occur*, and one that it did not.

Examples of statements that transformative change did occur include that “*systemic socio-ecological outcomes* [were] observed” (Davenport *et al.* 2017, emphasis added) and that “this process could be described as a *mental shift*” (Schultz *et al.* 2015, emphasis added). The one study that found that transformative change did not occur stated “the PES [Payment for Ecosystem Services] project alone is not enough to *break with historically evolved practices*” (Van Hecken *et al.* 2019, emphasis added).

4.4.2 Evidence for each transformative change indicator

Path-shifting and *restructuring* indicators were the most assessed across all case studies (79% and 72% respectively; Figure 8). *Multiscale* was the next most assessed (42%) followed by *persistent* (35%), *innovative* (31%) and *system-wide* (30%). When each indicator was assessed, the proportion of case studies that provided evidence of change in the indicator was different across the indicators. Assessment of the *innovative*, *system-wide* and *persistent* indicators often found that *change did occur* (91%, 81%

and 80% of case studies where the indicator was assessed respectively). Evidence for change in *path-shifting* was slightly lower (71% of those assessed). Evidence of change in *restructuring* was the lowest (59% of those assessed).

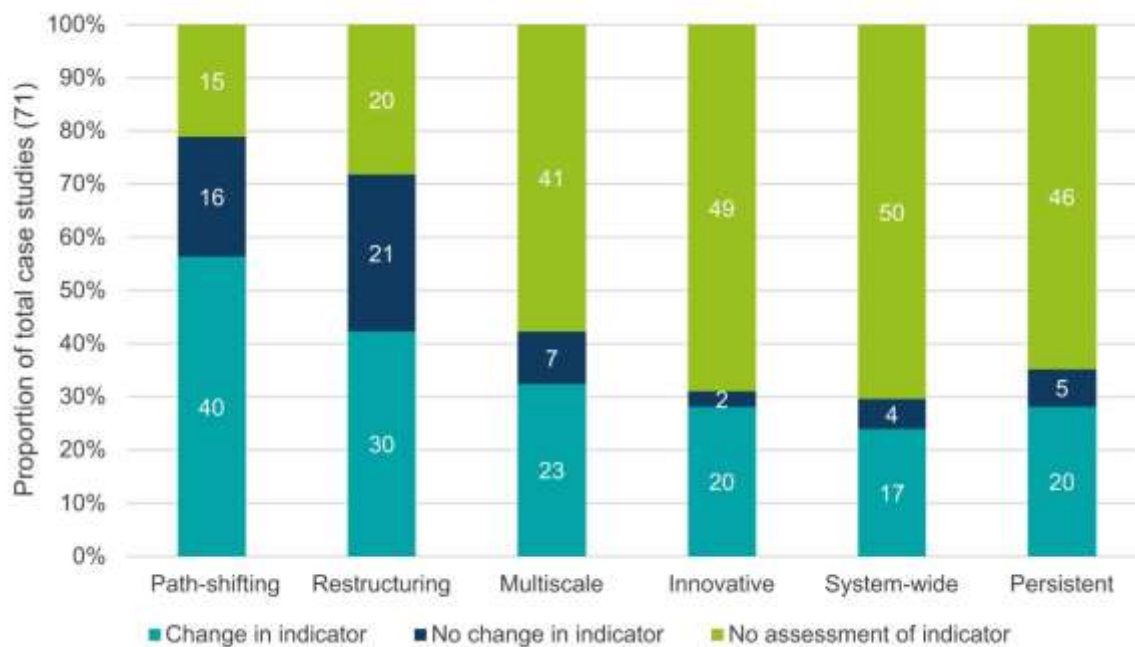


Figure 8: Distribution of the three evidence categories across the six indicators of transformative change defined by Palomo *et al.* 2021. Proportion of total case studies refers to the proportion of case studies where the reviewer found that the article provided evidence that could be used to assess the indicator.

Some of these results are less surprising than others. The definitions of *path-shifting* and *restructuring* used in this synthesis (adapted from Palomo *et al.* 2021) overlap with whether NbS achieves particular outcomes. NbS interventions that achieved reductions in deforestation, successfully reduced flood risk, or provided new income sources to local communities would have achieved *path-shifting*. Similarly, *restructuring* (changes in the relationship between people and nature) was considered in two ways: restructuring of the physical environment e.g. “bank vegetation had long since been re-established and the river and its surroundings had lush vegetation” (Aberg *et al.* 2013); or changes in paradigms, structures and practices, e.g. farmers changing from traditional practices and engaging with the regional government “asking for more cropland to be converted under” China’s Sloping Land Conversion Plan (SLCP; He 2021). Some NbS interventions are, therefore, inherently *restructuring*: restoration of a river or forest entails restructuring of the environment and creating a new marine management area entails changing in the structures and practices that link society with nature.

Similarly, the lower rates of the other four indicators may be explained by their associations with the nature of NbS interventions. *Multiscale* and *system-wide* indicators are related to the institutional and physical scale of the NbS intervention. NbS interventions implemented at a local scale are inherently not *system-wide* and may not involve multiple levels of governance, as is required for *multiscale* change. Implementing well-evidenced NbS interventions would not be considered *innovative*. However, this does not mean that they cannot be transformative in other indicators.

For the *persistent* indicator, there would need to be long-term monitoring of the intervention and evaluation of its effects. Indeed, of the case studies that conducted their assessments between *two to five years* and between *five to ten years*, 64% and 79% did not provide evidence that assessed the *persistent* indicator. In contrast, 60% of case studies conducted *more than 10 years* after implementation provided evidence that assessed the *persistent* indicator, e.g. “that over a decade has passed since the initiation of the project, allowing co-benefits to develop and flourish.” (Scolobig *et al.* 2023). Furthermore, where assessment took place, change in the indicator was more common in studies conducted *more than 10 years* after implementation (53% of those case studies) compared to *five to ten years* (7%) and *two to five years* (27%). Of the 14 case studies where the time since implementation was *unclear/unspecified*, none evaluated the *persistent* indicator. Neither of the two case studies that were conducted *less than two years* after implementation assessed the *persistent* indicator.

Only five case studies assessed all transformative change indicators. In two of these, the author(s) provided an explicit evaluation of transformative change, demonstrating, for example, how “grassroots community organisations” “have been transformed into a strong local governance mechanism” (Zafar *et al.* 2023). All case studies provided evidence of change in the *path-shifting*, *restructuring*, and *persistent* indicators. For example, in Xue *et al.* (2023), integrated ocean management was implemented in the Bohai Sea, resulting in transformative change in the region. This change was brought up by ecological transformations such as the enhancement of “the marine water quality” and social transformations achieved through “unprecedented economic development” (*path-shifting* transformation). *Restructuring* transformation was obtained through significant restoration of the landscape which improved the “ecological landscape of key node projects” as well as the “river and lake environment.” The results of this transformation have persisted over “almost two decades of changes, with ongoing changes and good outcomes” (*persistent* transformation).

Of the five articles mentioned above, three showed change in the *multiscale* indicator. For example, Scolobig *et al.* (2023), “a coalition was formed that rallied many different environmental NGOs”, while four showed *system-wide* or *innovative* change.

4.5 Links between outcomes of NbS and the potential for transformative change

Of the 10 case studies that reported positive change in each of the three outcome categories (*biodiversity and environment*, *quality of life*, and *Nature’s Contribution to People*), two explicitly evaluated transformative change. This is the same proportion across all case studies. However, these case studies assessed, and found change in, almost all the indicators of transformative change more often than across all case studies (Table 10). *Restructuring* was the only indicator which was almost equally assessed (72% across all case studies, and 80% across these 10), but also found change in the indicator more often than across all case studies. This highlights the synergies between positive outcomes of NbS and the contribution of NbS to transformative change.

Table 10: Evaluation of transformative change indicators for the 10 case studies that assessed positive change in all three outcome categories.

	Path-shifting	Restructuring	Multiscale	Innovative	System-wide	Persistent
Change in indicator	100%	70%	60%	60%	50%	50%
No change in indicator	0%	10%	0%	0%	10%	0%
Not assessed	0%	20%	40%	40%	40%	50%

4.6 Context of transformative change

To further explore the potential for NbS to create transformative change, we looked at the assessment of transformative change across different biomes and for different intervention types. As the focus of this study is on transformative change, we have not assessed outcomes across biomes.

4.6.1 Biome assessment

A heatmap of the assessment of the transformative change indicators across biomes is presented in Figure 9. The results for case studies designated as *mangroves*, *deserts* and *unclear* are not discussed as there were too few case studies to draw meaningful results. The general patterns observed in previous sections hold true across all ecosystems: transformative change is rarely explicitly evaluated and *path-shifting* and *restructuring* indicators tend to be assessed more than the other four.

	Number of case studies*	Author evaluation	Path-shifting	Restructuring	Multiscale	Innovative	System-wide	Persistent
Tropical Forests	17	12%	88%	53%	18%	18%	12%	29%
Agricultural Landscape	16	25%	50%	88%	25%	25%	25%	6%
Freshwater	13	15%	92%	62%	46%	38%	46%	38%
Coastal	12	0%	92%	58%	83%	42%	25%	67%
Marine	8	38%	88%	100%	63%	38%	50%	75%
Grasslands/Savannas	7	0%	57%	71%	29%	29%	57%	14%
Urban	7	14%	100%	29%	14%	14%	14%	43%
Mountain areas	6	50%	67%	83%	50%	33%	67%	33%
Mangroves	2	0%	100%	50%	50%	50%	0%	50%
Deserts	1	0%	100%	100%	0%	0%	0%	0%
Unclear	1	100%	100%	100%	100%	100%	100%	0%
All Biomes	71	21%	79%	72%	42%	31%	30%	35%

Figure 9. Heatmap showing the assessment of transformative change across biome. The 'Author evaluation' column refers to the proportion of articles that explicitly assessed transformative change. The last six columns show the proportion of case studies in each biome provided evidence that each of the six indicators of transformative change was assessed. *As case studies could be in multiple biomes, the sum of case studies across biomes does not equal the total number of case studies.

There was a lot of variation between biomes on the assessment of each indicator, compared to the assessment across all case studies. Case studies in *agricultural landscapes*, *grasslands/savannas*, and *mountain areas* assessed the *path-shifting* indicator much less often relative to all the case studies. Case studies in *urban* areas assessed the *path-shifting* and *persistent* indicators much more often (100% and 43% of *urban* case studies compared to 79% and 35% across all biomes). However, case studies in *urban* areas assessed the *restructuring* indicator less often (29% compared to 72%), and, to a lesser extent, the *multiscale*, *innovative* and *system-wide* indicators.

There are other notable deviations from the general pattern. Case studies from *coastal* and *marine* areas assessed the *multiscale* and *persistent* indicators more often. The higher assessment of *multiscale* perhaps reflects the complex governance of these areas. For instance, Schultz *et al.* (2015) conducted a study on the Great Barrier Reef (GBR) Marine Park in Australia and described the governance type as a "comanagement [sic] arrangement" that "involv[ed] a range of stakeholders, to achieve substantial change in anthropogenic nutrient, sediment, and pesticide runoff." Another example is the project discussed in Suedel *et al.* (2022) that used placement of dredged sediment for the restoration of a coastal habitat and "involved numerous federal, state, and regional partners" Additionally, case studies from

mountain areas and *grasslands/savannas* assessed the *system-wide* indicator more often. Meanwhile, case studies from *agricultural landscapes* assessed the *restructuring* indicator more often.

It is important to not only assess the indicators, but also to understand how often the assessment of that change occurred. Figure 10 shows the number of case studies for each ecosystem that provided evidence of change in each indicator. The colours indicate the proportion of assessment of the indicator per ecosystem: dark green represents a high proportion of assessments, showing that change occurred (starred ones indicate 100% of assessments), and light green/white a low proportion. Due to the high proportion of case studies that rarely assessed the indicator for each biome, the number of 100% change occurred is not that informative. However, the relatively low proportion of assessments of *restructuring* (similar to results discussed above for all case studies) is notable. Additionally, there is low proportion of assessment that *multiscale* change occurred for case studies in *mountain areas* and *tropical forests*. Indeed, interventions in *mountain areas* appear to fare badly, with a low proportion of assessment that change did occur in three of the six indicators (*restructuring*, *multiscale* and *system-wide*).

	Path-shifting	Restructuring	Multiscale	Innovative	System-wide	Persistent
Tropical Forests	8	4	1	2	2*	3
Agricultural Landscape	5	10	3	4*	4*	0
Coastal	10	6	9	5*	3*	7
Freshwater	9	5	5	4	4	5*
Marine	5	5	5*	3*	4*	5
Urban	5*	1	1*	1*	0	3*
Grasslands/Savannas		3	2*	2*	4	1*
Mountain areas	4*	2	1	2*	2	2*
Mangroves	1*	0	0	1*	0	0
Unclear	1*	1*	1*	1*	1*	0
Deserts	1*	1*	0	0	0	0

Figure 10: The number of case studies for each biome that provided evidence of a change in each transformative change indicator. Colours refer to the proportion of change: dark green colours refer to areas where a high proportion of case studies where the indicator was assessed found change, and light green/white a low proportion. Stars highlight case studies where 100% of case studies assessed found change in the indicator; most of these only assessed the indicator in one or two case studies which is too low to draw conclusions.

4.6.2 Transformative change compared to intervention type

Patterns of assessment of the transformative change indicators by intervention type are similar to the general results (Figure 11): *path-shifting* and *restructuring* are assessed more than the other indicators across all four intervention types. There are, however, a few notable patterns. Case studies of interventions classified as *Restore* or *Protect* assessed *path-shifting* slightly more often than *Manage* and *Conserve*. Interventions classified as *Conserve* assessed the *multiscale*, *innovative* or *persistent* much less often.

	Path-shifting	Restructuring	Multiscale	Innovative	Systemwide	Persistent
Manage	87%	67%	47%	40%	30%	43%
Protect	75%	78%	45%	33%	38%	35%
Restore	93%	80%	40%	33%	27%	47%
Conserve	76%	76%	24%	18%	29%	24%

Figure 11: Heatmap showing the proportion of case studies in each intervention type that provided evidence that assessed each of the six indicators of transformative.

Looking at how often change in the indicator was found highlights an additional interesting pattern. Figure 12 (as in section 4.6.1) shows the number of case studies for each intervention type that found change in each indicator. The shading shows the proportion of the case studies assessed for each intervention and indicator, with dark green highlighting a high proportion of case studies finding change in the respective indicator and light green showing a low proportion of case studies finding change in the indicator. *Restructuring* occurred less often in interventions classified as *Protect* and *Conserve*. All the *Restore* interventions where the *innovative* indicator was assessed as change occurring, this perhaps reflects the novelty of restoration interventions. Case studies evaluating *Conserve* interventions appear to find that there is change in the indicator less often than all other intervention types. Interventions classified as *Manage* or *Restore* found change in *path-shifting* indicator more often.

	Path-shifting	Restructuring	Multiscale	Innovative	Systemwide	Persistent
Manage	23	18	13	11	12	12
Protect	8	5	5	4	4*	5
Restore	19	13	13	12*	8	11
Conserve	7	6	2	2	3	2

Figure 12: The number of case studies for each intervention type that provided evidence of a change in each transformative change indicator. Colours refer to the proportion of change: dark green colours refer to areas where a high proportion of case studies where the indicator was assessed found change, light green where a low proportion found change in the indicator. Stars highlight case studies where 100% of case studies assessed found change in the indicator.

5. Results from the grey literature evidence map

For grey literature, we screened 240 cases from the Panorama database⁵ (197) and the Global Program on Nature-Based Solutions for Climate Resilience Knowledge Hub⁶ (43), of which 35 were included while the remaining 205 cases were excluded.

Excluded articles primarily focused on NbS intervention methods, language of the text and policy recommendations. For example, introducing new support system/warning systems, assessment and monitoring, recommendations to develop solutions, educational programmes, and capacity building exercises were excluded. Technical reports and guidance documents were also excluded as the evidence map primarily focused on finding case studies demonstrating NbS outcomes and whether they led to transformative change and not tools, guidance documents and/or other resources. Some case studies provided projected benefits, and therefore were also excluded.

Among the excluded articles, 12 case studies were excluded as they were not written in English. This also led to an issue of duplication of articles. Some articles were uploaded in multiple languages on the databases, which made evaluation challenging, especially when they provided evidence of NbS for transformative change.

5.1 Case study details

The case studies were often classified as *urban*. Of the total 35 case studies, 16 were conducted in urban areas. The problem addressed by the interventions was mainly *environmental degradation* and *climate extremes and disasters*. Most intervention types were *Restore* and *Manage* (17 and 15 case studies, respectively). Some studies described interventions that could not be easily categorised as *Conserve*, *Restore*, *Manage* or *Protect*. For example, there were some doubts to understand the type of NbS intervention for a case study outlining a biophilic design in the city of Milan⁷. A total of 17 studies did not

⁵ Panorama. Solutions for a healthy planet. Available at: <https://panorama.solutions/en>

⁶ The Knowledge Hub. Global Program on Nature-Based Solutions for Climate Resilience. Available at: <https://naturebasedsolutions.org/knowledge-hub>

⁷ From a case study titled "Bosco Verticale, architectural biodiversity – a new alliance between forests and architecture" in the extraction sheet. Available at: <https://panorama.solutions/en/solution/bosco-verticale-architectural-biodiversity-new-alliance-between-forests-and-architecture>

specify the source of funding. While 11 studies described interventions that occurred *five to ten years* prior to the case study being published, they lacked an assessment of the impact in the long term.

5.2 Evidence of outcome

Biodiversity and environment was the most frequently reported outcome, assessed in 25 case studies, followed by *quality of life* and *Nature's Contribution to People*, in 20 and 18 case studies, respectively. Only nine case studies provided supporting evidence for *positive* outcomes and one study did not provide evidence for any of the outcomes resulting from NbS interventions. Evidence for *biodiversity and environment* outcomes was predominantly *quantitative*, with 14 of the total 25 showing *quantitative positive* outcomes while 11 provided *qualitative positive* outcomes. For *quality of life* and *Nature's Contribution to People*, evidence provided was primarily *qualitative*. Of the 20 and 18 case studies assessing these outcomes, 15 and 14 respectively found *positive* change using *qualitative* evidence. Only five and three case studies for *quality of life* and *Nature's Contribution to People*, respectively, were assessed using *quantitative* data.

5.3 Evidence of Transformative Change

5.3.1 Explicit case evaluation

Only one case study explicitly evaluated transformative change. The study described how NbS outcomes have helped and will continue to help enhance green spaces in the urban setting, improve institutional capacity, bring together communities, and scale up restoration to alleviate climate risks.

Path-shifting and *restructuring* were the most assessed indicators in the case studies. 31 of the 35 studies provided evidence of *path-shifting* and 26 provided evidence of *restructuring*. Evidence of *path-shifting* frequently aligned with positive outcomes, mainly showing reduction in biodiversity loss, socio-economic improvements, and positive restoration results for the landscape or seascape and for people. The *restructuring* indicator was typically assessed for interventions that applied restoration methods to address environmental degradation, extreme disasters, and socio-economic benefits. For instance, a project “focused its efforts on restoring vegetation in the upper catchment and high-slope areas identified, along with the support of a tool, to address flood risk, landslide susceptibility, and threats to the water supply⁸.”

The *multiscale*, *innovative* and *persistent* indicators were assessed in 19, 10, and 16 case studies, respectively. Assessment of the *multi-scale* indicator typically aligned with *restructuring*, providing evidence of co-engagement across multiple levels of government and external organisations. Evidence of community-based interventions to address environmental degradation were assessed in eight cases. Evaluating the *innovative* indicator was challenging as many studies provided only a vague mention of the term and/or were not sufficiently explicit when describing the intervention.

Assessment of the *persistent* indicator was difficult as most of the case studies did not provide a clear timescale. Case studies mostly implied the possibility of long-term impacts based on projected outcomes of a given project. However, projected outcomes are not evidence of the intervention being *persistent*, or successful.

⁸ From a case study titled “Toward a Resilient Urban Sierra Leone” in the extraction sheet. Available at: <https://www.naturebasedsolutions.org/index.php/knowledge-hub/62-toward-resilient-urban-sierra-leone>

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The *system-wide* indicator was the least assessed, with only eight out of 35 case studies providing evidence. Assessing the *system-wide* indicator was particularly challenging because there were overlaps in terms of the perception of what the indicator means and how it is distinguished from the other five indicators. Indeed, as stated by Palomo *et al.* (2021), “system-wide perspectives are anchored on a social-ecological perspective”. This definition could overlap with other indicators of transformative change, such as *multiscale* and *restructuring*, making it difficult to evaluate.

6. Limitations of the evidence map

While our review of both the grey and scientific literature offers valuable insights into various aspects of the potential for transformative change by NbS, it is crucial to acknowledge and discuss its limitations.

The search methodology used in our literature review was limited: i) the search was conducted in English only, which may have influenced the geographic scope of the evidence map; ii) the search was conducted in one database (the Web of Science Core Collection), which, although comprehensive, may not represent the full extent of scientific literature on this subject. Equally our primary focus was on peer-reviewed articles, which implies that results do not necessarily reflect ongoing efforts on NbS and transformative change (cf. currently ongoing work from Horizon Europe projects [COEVOLVERS](#), [NATURESCAPES](#), [TRANS-Lighthouses](#)).

Some limitations were inherent in this review, given the novelty of the topics being discussed. This was clearly demonstrated by the difficulty in assessing whether some case studies fit the UNEA definition for NbS and a broader discussion on this topic was held to correctly categorise the case studies. This difficulty in assessing what is NbS was recently reflected at a global level in the UNEP NbS Consultations (Valverde and Egbuwalo 2023).

During the data coding stage, some additional constraints emerged, notably the absence of certain information in most case studies. This was particularly the case for the funding type, which often was not described in the articles assessed. Evaluating the time elapsed between the implementation of the intervention and the assessment of outcomes was also challenging, as most articles did not explicitly provide this information. This hindered the assessment of the *persistent* indicator of transformative change, which is closely linked to the timescale of the projects described.

We followed the framework by Palomo *et al.* (2021) to assess whether the Nature-based Solutions described in the case studies contributed to transformative change, evaluating the presence of the indicators provided in the framework and whether the authors explicitly evaluated transformative change. Although an evaluation of this framework is not within the scope of this study, we outline some limitations. Notably, the overrepresentation of *path-shifting* and *restructuring* indicators is perhaps due to the similarity between their definitions and the criteria for NbS projects. This observation was also made concerning grey literature. Ecological transformations and restoration, prevalent objectives in NbS projects, make these indicators more likely to be met. Clear definitions of the indicators and better differentiation between them would make them more practical.

7. Conclusions and Recommendations

Despite the importance of transformative change for resolving the combined crises facing the world, our evidence map showed that there is limited assessment of the potential for NbS to contribute to transformative change. But there is rising evidence presented from peer-reviewed literature showing that NbS can contribute to elements of transformative change.

We operationalised a framework from Palomo *et al.* (2021) for assessing the contribution of NbS to transformative change. This defined six indicators of transformative change: *path-shifting*, *restructuring*, *multiscale*, *innovative*, *system-wide* and *persistent*. After applying our screening criteria, we reviewed 46 peer-reviewed articles (with a total of 71 case studies) that evaluated NbS interventions and assessed evidence of transformative change to some degree. This was supplemented by a review of two grey literature databases which resulted in 35 additional case studies. Only 15 case studies from peer-reviewed literature and three from grey literature explicitly evaluated transformative change.

Using the six indicators of transformative change defined by Palomo *et al.* (2021), we broadened our evidence map to assess whether case studies provided evidence that could be considered transformative under each of the indicators. The 46 peer-reviewed and 35 grey literature case studies were included because they provided evidence for at least one of the indicators. Evidence of *path-shifting* and *restructuring* was provided most often. This differed between case studies looking at interventions in different biomes with, for example, the *multiscale* indicator assessed much more often in *coastal* ecosystems, and the *system-wide* indicator assessed more often in *mountain areas*. Our results showed that NbS projects categorized as *Manage* were more frequently associated with change of at least one transformative change indicator, and the *path-shifting* and *restructuring* indicators were the most recurrent across all NbS types.

The results of the evidence map highlight a series of evidence gaps on which future research could focus. The primary evidence gap is the lack of explicit or implicit evaluation of whether NbS contributes to transformative change. Related to this, assessment of change at multiple geographical scales (e.g. local, basin-wide, national, regional), between multiple levels of governance (local and national; private and public institutions), and over long-periods of time is lacking. Considering the results of the evaluation of the assessment of the three types of outcomes of NbS [section 4.3], (that may or may not be considered transformative), *Nature's Contribution to People* (NCP), and to a lesser extent *biodiversity and environment*, outcomes appear to be less in evidence, at least in studies that evaluate transformative change. For *Nature's Contribution to People*, this may be due to a less-established but growing evidence base and challenges in evaluating outcomes that depend on the direct relationship between society and nature. Insufficient detail on the context of NbS interventions (e.g. the lack of information on funding type) makes it challenging to assess the factors that affect the success of NbS. Furthermore, we found geographical biases within our evidence (limited coverage of some biomes, such as *mangroves*, *deserts*, and *boreal forests* as well as limited coverage of sub-regions including *Eastern Europe*, *Western Asia* and *Northern Africa*). However, this may partly reflect one of the limitations of our evidence map: we only looked at case studies in English from one peer-reviewed and two grey literature databases.

While conducting this evidence map, we faced multiple challenges in understanding and applying the definitions of both NbS and transformative change. Evaluating a term as complex as transformative change will require a clear and comprehensive assessment framework. Although the framework used by

Palomo *et al.* (2021) here allowed us to evaluate, at least partially, the potential for NbS to contribute to transformative change, more work is needed to develop this. We found that there was overlap between some of the indicators defined by Palomo *et al.* (2021) and the inherent outcomes of NbS. Some of the indicators appeared to be more about the nature of the intervention (e.g. *innovative*) than the (transformative) outcomes of NbS. Furthermore, we noticed in our review that there was limited explicit recognition of key considerations such as gender equality and inclusion of local communities and how NbS can address inequalities and contribute to social change. Additionally, despite being defined to assess transformative change in socio-ecological systems, the indicators appear mostly socio-political rather than ecological.

Based on our review and these evidence gaps, we provide a series of recommendations below that can help develop the evidence based for and implementation of NbS for the sustainable use and management of biodiversity in socio-ecological systems.

7.1 Recommendations

Overarching recommendations from this study are that (i) increased clarity on what qualifies as NbS – and what does not – would help researchers and policy-makers understand, evaluate, and implement NbS and (ii) a holistic, more detailed, and clearly defined framework for evaluating transformative change in NbS interventions needs to be developed. Creation of such a framework, which could then be adopted by the research community and practitioners who design, implement, and monitor NbS interventions, would enhance the understanding of how NbS can contribute to transformative change in a measurable way. Given this overarching recommendation, we also provide additional suggestions for research and policy.

7.1.1 Recommendations for research

- Research on the impacts of NbS should consider how they can lead to transformative change. This should include impacts on both people and nature.
- New assessments should consider the factors that facilitate or hinder the potential for NbS to create transformative change, including ways of funding NbS, the types of landscapes where they are applied, or the problems they are intended to tackle.
- Examining the interconnectedness of change across various spatial scales (local to regional, watershed to continental) and governance scales (local to international governance) would be particularly important.
- More studies that monitor the impacts of NbS for many years after the intervention and determine whether they persist over long timescales are necessary for assessing transformative change, including assessment of their resilience to external factors.
- Future evidence maps and syntheses should consider non-English literature, as well as additional sources of information, to correctly assess the geographical spread of the evidence base. Some countries and biomes were scarcely represented, or not represented at all, within our evidence map. Although this may partly be rectified by expanding the review to more languages and databases, it is likely that there will still be geographical biases whose identification that can help direct research toward knowledge gaps.

7.1.2 Recommendations for policy

- NbS policies, plans and strategies should articulate what they mean by transformative change and how transformative outcomes can be delivered by NbS.
- Transformative change indicators should also be recognized as outcomes for Nature-based Solutions and embedded into global and national standards, including for public funding. Hence, NbS should not only deliver measurable environmental and social co-benefits, but could also actively contribute to system-wide positive shifts.
- Research and innovation funding that support the scaling of NbS should promote trans- and interdisciplinary research approaches to assess the full contribution of NbS to transformative change.
- Frameworks for monitoring, evaluating and reporting on the outcomes of NbS, including transformative change, need to include qualitative and quantitative evidence across outcomes for people and nature and should be incorporated into the design of NbS interventions.
- Governments and funders of NbS implementations should ensure that there are sufficient technical and financial resources for planning, monitoring and reporting on NbS and its outcomes to allow for a detailed evaluation over a period that is long enough to provide evidence of the ways in which NbS contributes to transformative change.

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Annexes

Annex 1: Search string development process

A1.1 Initial search string

The systematic review process for our project began with a careful analysis of the question elements. Our aim was to identify four key concepts: nature-based solutions, transformative change, sustainable use and management of biodiversity in social-ecological systems, and case studies/evidence. To facilitate this, we brainstormed and connected search terms using Boolean operators (AND and OR) in a search on the Web of Science Core Collection (Table A1.1).

Table A1.1: Search terms proposed after the division of the main question into question elements.

Elements of the primary question	Search Terms	Search String
NbS	Nature-based solutions Ecosystem-based (approaches) Green infrastructure Ecosystem services Natural infrastructure Renaturalisation Renaturing Nature-based strategy Ecosystem based measure Nature based mitigation Ecosystem based mitigation Nature based adaptation Ecosystem based adaptation	("nature-based solution*" OR "NbS" OR "ecosystem*based" OR "green infrastructure" OR "ecosystem service*" OR "renaturalisation" OR "renaturing" OR "nature*based strateg*" OR "nature*based mitigation" OR "ecosystem*based mitigation" OR "nature*based adaptation" OR "ecosystem*based adaptation")
Transformative change	Transformative change Socio-economic impact Behavioral change Policy change Institutional change Societal change Social-ecological context(s) Social benefit Knowledge types Personal beliefs Collective beliefs Political instruments Economic instruments Cultural elements Legal instruments Governance Technical element Technological	("Transformative change*" OR "Socio*economic impact*" OR "Behavioral change*" OR "Policy change*" OR "Policies change*" OR "Institutional change*" OR "Societal change*" OR "Social-ecological" OR "Social benefit*" OR "Knowledge typ*" OR "personal belief*" OR "Collective belief*" OR "Political instrument*" OR "Economic instrument*" OR "Cultural element*" OR "Legal instrument*" OR "Governance" OR "Technical element*")
Sustainable use and management of biodiversity in socialecological systems	social benefit Social-ecological context Livelihood(s) Ecological systems Social inclusivity	("social-ecological context*" OR "social benefit*" OR "livelihood*" OR "ecological system*" OR "social inclusivity")
Case Studies	Case studies Research findings Empirical evidence Scientific studies	("case study" OR "case studies" OR "empirical evidence" OR "research findings" OR "scientific studies")

A1.2 Refining the first search string

Based on the initial article list, we evaluated titles, abstracts, and keywords to refine our search string. Feedback from collaborating partners suggested additional search terms. These suggestions were incorporated, and the search terms were combined using Boolean operators (Table A1.2).

State of evidence on how Nature-based Solutions promote transformative change

Table A1.2: First search string created using the search terms from Table A1.1 and number of results from the database Web of Science Core Collection.

String Number	Search String	# results in Web of Science
1	("nature-based solution*" OR "Nbs" OR "ecosystem*based" OR "green infrastructure" OR "ecosystem service*" OR "renaturalisation" OR "renaturing" OR "nature*based strateg*" OR "nature*based mitigation" OR "ecosystem*based mitigation" OR "nature*based adaptation" OR "ecosystem*based adaptation") AND ("Transformative change*" OR "Socio*economic impact*" OR "Behavioral change*" OR "Policy change*" OR "Policies change*" OR "Institutional change*" OR "Societal change*" OR "Social-ecological" OR "Social benefit*" OR "Knowledge typ*" OR "personal belief*" OR "Collective belief*" OR "Political instrument*" OR "Economic instrument*" OR "Cultural element*" OR "Legal instrument*" OR "Governance" OR "Technical element*") AND ("social-ecological context*" OR "social benefit*" OR "livelihood*" OR "ecological system*" OR "social inclusivity") AND ("case study" OR "case studies" OR "empirical evidence" OR "research findings" OR "scientific studies")	477 results

Iterative Process, Benchmarking and Final Search String

To ensure our search string is capturing relevant articles, we tested it against our benchmarking list. This was an iterative process which included amending the search terms and evaluating the article list. We explored the inclusion of broader terms, such as "governance," to capture variations of the search element representing transformative change. Additionally, we incorporated specific terms to capture our interest in case studies rather than purely theoretical papers. Through an analysis of titles, abstracts, and keywords, we developed a search string that successfully captured the benchmarking articles (Table A1.3; Table A1.4; Table A1.5).

Table A1.3: Search terms applied to final search string proposed, identified after iterative analysis of search terms, and resulting article list

Elements of the primary question	Search Terms	Search Strings
Nbs	Nature-based solutions Ecosystem-based (approaches) Green infrastructure Ecosystem services Renaturalisation Renaturing	Nature-based strategy Ecosystem based measure Nature based mitigation Ecosystem based mitigation Nature based adaptation Ecosystem based adaptation
Transformative Change	"Transformative change" Governance "Socioeconomic impact" "Behavioral change" "Policy change" "Policies change" "Institutional change" "Societal change" "Social benefit" "Knowledge typ" "personal belief" "Collective belief" "Political instrument" "Economic instrument" "Cultural element" "Legal instrument" "Technical element" "transformative adaptation" "transformative societal change" "transformational adaptation" "social transformation" "transformative behaviour" "transformative change"	"transformational change" "novel business model" "financing mechanism" "multi-level governance" "multi-stakeholder governance" "technological innovation" "systemic solution" "transformative impact" "institutional framework" "policy action" "implementation action" "practical implementation" "human-nature relationship" "economic instrument" "financial instrument" "legal instrument" "regulatory framework" "community engagement" "rights-based instrument" "co-management" "customary norms" "cross-sectoral collaboration"
Case Studies	Case studies Research findings Empirical evidence	proof of concept project Scientific studies
Sustainable use and management of biodiversity in socioecological systems	biodiversity sustainable management biodiversity conservation biodiversity management environmental Impact sustainable use	sustainable development conservation preservation natural capital ecological sustainability

Table A1.4: Second and third search strings created using the search terms from Table A1.3 and number of results from the database Web of Science Core Collection

Search String	Search String	# results in Web of Science
2	("nature-based solution*" OR "NbS" OR "ecosystem*based" OR "green infrastructure" OR "ecosystem service*" OR "renaturalisation" OR "renaturing" OR "nature*based strateg*" OR "nature*based mitigation" OR "ecosystem*based mitigation" OR "nature*based adaptation" OR "ecosystem*based adaptation") AND ("Transformative change*" OR "Socio*economic impact*" OR "Behavioral change*" OR "Policy change*" OR "Policies change*" OR "Institutional change*" OR "Societal change*" OR "Social-ecological" OR "Social benefit*" OR "Knowledge typ*" OR "personal belief*" OR "Collective belief*" OR "Political instrument*" OR "Economic instrument*" OR "Cultural element*" OR "Legal instrument*" OR "Governance" OR "Technical element*" OR "transformative adaptation" OR "transformative societal change\$" OR "transformational adaptation" OR "social transformation" OR "transformative behaviour\$" OR "transformative change\$" OR "transformational change\$" OR "novel business model\$" OR "financing mechanism\$" OR "multi-level governance" OR "multi-stakeholder governance" OR "technological innovation\$" OR "systemic solution\$" OR "transformative impact" OR "institutional framework\$" OR "policy action\$" OR "policies action\$" OR "implementation action\$" OR "practical implementation\$" OR "human-nature relationship\$" OR "economic instrument\$" OR "financial instrument\$" OR "legal instruments" OR "regulatory framework" OR "community engagement" OR "rights-based instrument\$" OR "customary norms" OR "technolog*" OR "strategic planning" OR Behaviour OR "cross-sectoral collaboration") AND ("case study" OR "case studies" OR "empirical evidence" OR "research findings" OR "scientific studies")	1719 results
3	("nature-based solution*" OR "NbS" OR "ecosystem*based" OR "green infrastructure" OR "ecosystem service*" OR "renaturalisation" OR "renaturing" OR "nature*based strateg*" OR "nature*based mitigation" OR "ecosystem*based mitigation" OR "nature*based adaptation" OR "ecosystem*based adaptation") AND ("Transformative change*" OR "Socio*economic impact*" OR "Behavioral change*" OR "Policy change*" OR "Policies change*" OR "Institutional change*" OR "Societal change*" OR "Social-ecological" OR "Social benefit*" OR "Knowledge typ*" OR "personal belief*" OR "Collective belief*" OR "Political instrument*" OR "Economic instrument*" OR "Cultural element*" OR "Legal instrument*" OR "Governance" OR "Technical element*" OR "transformative adaptation" OR "transformative societal change\$" OR "transformational adaptation" OR "social transformation" OR "transformative behaviour\$" OR "transformative change\$" OR "transformational change\$" OR "novel business model\$" OR "financing mechanism\$" OR "multi-level governance" OR "multi-stakeholder governance" OR "technological innovation\$" OR "systemic solution\$" OR "transformative impact" OR "institutional framework\$" OR "policy action\$" OR "policies action\$" OR "implementation action\$" OR "practical implementation\$" OR "human-nature relationship\$" OR "economic instrument\$" OR "financial instrument\$" OR "legal instruments" OR "regulatory framework" OR "community engagement" OR "rights-based instrument\$" OR "customary norms" OR "technolog*" OR "strategic planning" OR Behaviour OR "cross-sectoral collaboration") AND ("social-ecological context*" OR "social benefit*" OR "livelihood*" OR "ecological system*" OR "social inclusivity") AND ("case study" OR "case studies" OR "empirical evidence" OR "research findings" OR "scientific studies")	518 results

Table A1.5: Final search string used in this study.

TS = (((("nature-based solution*" OR "NbS" OR "ecosystem-based" OR "green infrastructure" OR "ecosystem service*" OR "renaturali?ation" OR "renaturing" OR "nature-based strateg*" OR "nature-based mitigation" OR "ecosystem-based mitigation" OR "nature-based adaptation" OR "ecosystem-based adaptation") AND ("Transformative change\$" OR "governance" OR "Socioeconomic impact\$" OR "Behavio\$ral change*" OR "Policy change*" OR "Policies change*" OR "Institutional change*" OR "Societal change*" OR "Social benefit*" OR "Knowledge typ*" OR "personal belief*" OR "Collective belief*" OR "Political instrument*" OR "Economic instrument*" OR "Cultural element*" OR "Legal instrument*" OR "Technical element*" OR "transformative adaptation" OR "transformative societal change\$" OR "transformational adaptation" OR "social transformation" OR "transformative behaviour\$" OR "transformational change\$" OR "novel business model\$" OR "financing mechanism\$" OR "technological innovation\$" OR "systemic solution\$" OR "transformative impact\$" OR "institutional framework\$" OR "policy action\$" OR "policies action\$" OR "implementation action\$" OR "practical implementation\$" OR "human-nature relationship\$" OR "economic instrument\$" OR "financial instrument\$" OR "legal instrument\$" OR "regulatory framework\$" OR "community engagement" OR "rights-based instrument\$" OR "customary norms" OR "cross-sectoral collaboration" OR "co*management" OR "government-funded") AND ("case study" OR "case studies" OR "empirical evidence" OR "research findings" OR "scientific studies" OR "proof*of*concept" OR "project" OR initiative*) AND (biodiversit* OR "sustainabl* manag*" OR "biodiversit* conservat*" OR "biodiversit* manag*" OR "environment* impact*" OR "sustainable* use" OR "sustainabl* develop*" OR conserv* OR preserv* OR restor* OR "ecological* sustainabilit*" OR "natural" NEAR "capital"))))

Annex 2: Simplified biome categories

Table A2.1. List of simplified and aggregated biome names and their original names as defined by Dinerstein et al. (2017).

Original name (Dinerstein <i>et al.</i> 2017)	Simplified name
Tropical & Subtropical Moist Broadleaf Forests, Tropical & Subtropical Dry Broadleaf Forests, Tropical & Subtropical Coniferous Forests	Tropical Forests
Temperate Broadleaf & Mixed Forests, Temperate Conifer Forests	Temperate Forests
Boreal Forests/Taiga	Boreal Forests
Tropical & Subtropical Grasslands, Savannas & Shrublands, Temperate Grasslands, Savannas & Shrublands	Grasslands/savannas
Flooded Grasslands & Savannas	Wetlands
Montane Grasslands & Shrublands	Mountain Areas
Tundra	Tundra
Mediterranean Forests, Woodlands & Scrub	Mediterranean
Deserts & Xeric Shrublands	Deserts
Mangroves	Mangroves