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Possible ways to foster the uptake of knowledge on Nature-based Solutions

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For more information about Biodiversa+	Website: http://www.biodiversa.eu/ Email: contact@biodiversa.eu Twitter: @BiodiversaPlus LinkedIn: Biodiversa+

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Authors:	Chiara Catalano, Alessandro Campiotti, Chiara Baldacchini
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What is Biodiversa+

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

Biodiversa+ aims to make the bridge between science, policy and practice as part of the European Biodiversity Strategy for 2030.

Biodiversa+ currently gathers 81 research programmers and funders and environmental policy actors from 40 European and associated countries to work on 5 main objectives contributing to a sustainable ecological transition in Europe:

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 transnational 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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Introduction

The term NbS was first introduced in the early 2000s, in the context of addressing future actions to mitigate the effect of climate change on ecosystems, biodiversity and people (Cohen-Shacham et al., 2019). Over time this concept has become more mainstream, and it is now evident that:

1. NbS should be considered as a key approach for tackling future societal challenges aiming to minimize the negative impacts while maximizing resilience;
2. NbS should be integrated into practices and policy at all scales;
3. There is a critical need for a shared and clear understanding of what NbS are, including a common terminology and definition.

Following, the initial attempt to define NbS by the World Bank, the development of a shared common, global framework involved several institutions worldwide, notably among them the European Commission (EC) (European Commission, 2015) and the International Union for the Conservation of Nature (IUCN) (IUCN, 2020).

On the 2nd March 2022, The United Nations (UN) introduced a commonly agreed definition for NbS (UNEA, 2022), which further supported the inclusion of NbS into 1) the most recent policies concerning the conservation of nature and biodiversity, such as the Kunming-Montreal Global Biodiversity Framework (CBD, 2022); and 2) the recently approved European Union (EU) Nature Restoration Law (European Commission, 2022b). In the former, NbS, together with other ecosystem-based approaches, are highlighted as the preferred strategies to address biodiversity threats (Target 8) and fulfil people's needs through sustainable utilisation and equitable benefits (Target 11); in the latter, NbS are seen as a fundamental mean against the climate crisis and are considered a crucial tool for adaptation strategy policy. They serve to counteract the degradation and loss of urban green the integration of green infrastructure into urban planning and design.

Nevertheless, moving beyond the basic definition of NbS, mainstreaming the NbS concept and its translation into policies and practices further requires several key elements:

- A universally agreed-upon taxonomy and definitional framework. This is a fundamental prerequisite for shared knowledge, especially when engaging stakeholders from very different contexts, as it happens in NbS projects;
- The establishment of a common impact evaluation method to assess the efficiency of NbS. These methods should facilitate comparisons across different implementations, identify the relation between NbS parameters and characteristics, consistently produce replicable results, and finally build evidence-based NbS knowledge.

Over the past decade, there has been extensive effort dedicated to constructing these frameworks, which trace their origins back to practical implementations of NbS, particularly those supported by the European Union. Indeed, with the introduction of NbS in the EU Research & Innovation (R&I) agenda, embracing other approaches such as green and blue infrastructure, and ecosystem services, the EU positioned itself as a pioneer and leader in this field since 2015, with the aim to greening the economy and achieving sustainable development fostering biodiversity and human well-being (European Commission, 2015). For

this reason, a huge effort has been made by the EC, in funding R&I programs to generate knowledge and theories and implement innovative approaches and best practices as well as disseminating and promoting NbS for the creation of new green “decent” jobs (Davies et al., 2021; ILO, UNEP, IUCN, 2022).

The five major targets (Faivre et al., 2017) formulated by the EU for the R&I agenda were (Fig. 1): 1) “Enhance framework conditions for NbS at EU policy level”; 2) “Develop the NbS community of innovators”; 3) Provide evidence-base and knowledge; 4) Advance development uptake and upscale, 5) Mainstream NbS within the international R&I agenda.

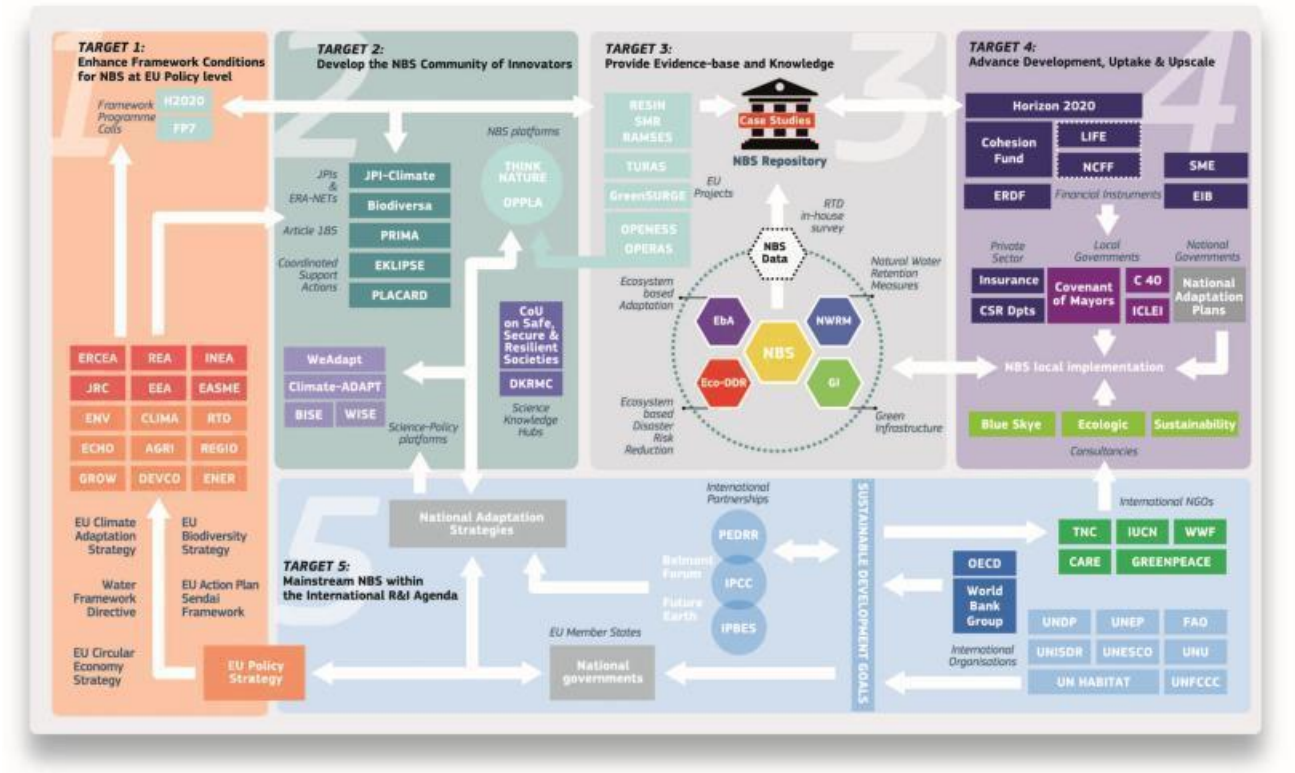

Figure 1 : Mapping of the targets of the Research & Innovation agenda for Nature-Based Solutions. From (Faivre et al., 2017).

The implementation of such a strategy by the EC led to a strong increase in the funding dedicated to NbS-related projects (Wild et al., 2020, Annex 1) considering that 76 R&I projects were funded by the H2020 and Horizon Europe from 2016 to 2023. Consequently, the generated knowledge on NbS significantly increased, as demonstrated by the publication rate on Web of Science (Wild et al., 2020).

There is an undeniable relationship between R&I and policies implementation of NbS, the first enabling the advancement of the second across EU scales and sectors while initiating a virtuous feedback loop among stakeholders, policy development, legal frameworks, collaborative governance, and international agendas (EL Harrak & Lemaître, 2023).

The latest Joint Research Centre (JRC) report mapped the relationship between EU-funded research projects and EU policy priorities according to the four pillars of the EU Biodiversity Strategy 2030 (Parracciani et al., 2022): 1) Protect nature; 2) Restore ecosystems; 3) Enable transformative change; 4) Ensure a high level of EU ambition and mobilise all efforts for the good of the world’s biodiversity. The

results of this investigation showed different trends, such as the decrease of funded projects related to the effective management of protected areas (pillar 1 of the Strategy and type 1 of NbS); an increased number of projects focusing mainly on marine and forest ecosystems thus neglecting other ecosystems and habitats; the agrobiodiversity is covered under the biodiversity restoration context (pillar 2); the transformative change (pillar 3) is only partially a thematic focus for EU-funded research projects.

Report aim

The objective of this report is to explore the possible ways to foster the uptake of knowledge on NbS. Specifically, it aims to investigate the processes that can promote the mainstreaming of NbS and help the incorporation of research findings and scientific knowledge into policies, practices, and decision-making, with the final aim of achieving positive impacts on biodiversity and human well-being.

Starting from the analysis of the most recent policy reports published by relevant stakeholders, such as IUCN and EU, along with the strategies employed by single projects and by wider initiatives to disseminate knowledge on NbS, we have identified three critical processes that underpin the uptake of knowledge on NbS (Fig. 2):

1. Establishing a shared understanding of what NbS are (taxonomy and definitions) and how their benefits and co-benefits can be measured (indicators, monitoring);
2. Disseminating the developed knowledge on NbS to a wide range of potential stakeholders, either by sharing the research findings through multiple channels, such as workshops and public outreach events (hereafter called direct dissemination activities), or by virtual sources of knowledge, such as scientific publications, reports, platforms, repositories, and tools;
3. Fostering cooperation by facilitating the exchange of experiences among different countries and regions within the context of joint projects, engaging stakeholders along the NbS life cycle (design/planning, implementation, follow-up/monitoring), and employing an effective capacity-building strategy to train researchers and practitioners, enhancing their skills and competencies in the realm of NbS.

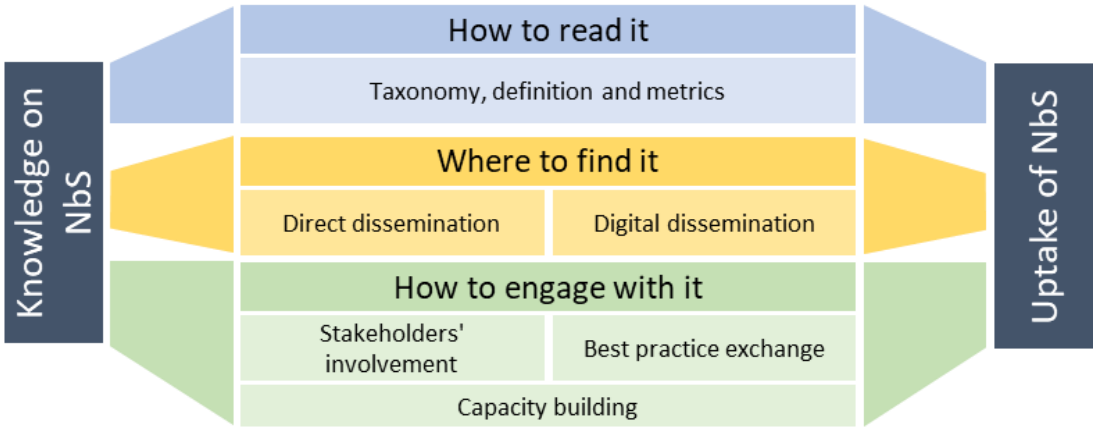

Figure 2 : Factor affecting the uptake process

Furthermore, a more in-depth examination was conducted on the Biodiversa funded projects, to obtain descriptions of success stories, with the further identification of synergies among the ways to uptake the knowledge that has led to a boost in the dissemination action.

Who should read this report?

This report is intended to be dedicated to two different target readers:

1. Stakeholders such as policymakers, planners willing to work with NbS, and citizens interested in improving their accessibility to knowledge on NbS;
2. Stakeholders such as scientists, NbS-specialised companies, and planners working with NbS, are interested in maximising the impact of the knowledge they contributed to among the NbS community and in the policy and practice world.

1. Knowledge on NbS and how to read it

A shared, common, agreed taxonomy is essential for establishing a common foundation of knowledge, particularly when engaging stakeholders from diverse backgrounds. This is crucial in scenarios such as NbS planning, design, and implementation, and even more so in fostering effective collaboration among science, policy, and practice (Nesshöver et al., 2017).

1.1 NbS definition and taxonomy

Both the definition and the taxonomy of NbS are constantly evolving as new approaches and innovations are developed to address environmental challenges and promote sustainable development. While it is challenging and potentially risky to categorize NbS singularly due to the vast array of scenarios and pertinent factors affecting their effectiveness, it is essential to ensure that any interventions are accurately aligned with the varied aspects of NbS. This ensures that interventions are appropriately classified as NbS, while also defining the boundaries of the NbS concept (Sowińska-Świerkosz & García, 2022).

According to the latest definition by (UNEA, 2022), NbS " […] are actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits […]".

Various classifications (taxonomy) exist for ecosystem-based approaches beyond NbS and the challenges they should address. Among these, the most commonly utilised classifications are likely those outlined in the Global Standard for NbS by the International Union for Conservation of Nature (IUCN, 2020). However, very recently, within the framework of NetworkNature, such categories have been merged with those emerging within the EU context, obtaining a total of 6 ecosystem-based approaches and 13 challenges (EL Harrak & Lemaître, 2023). Figure 3, shows the disruption of the EU project funder from 2012-2020 by types of ecosystems approaches and societal challenges addressed.

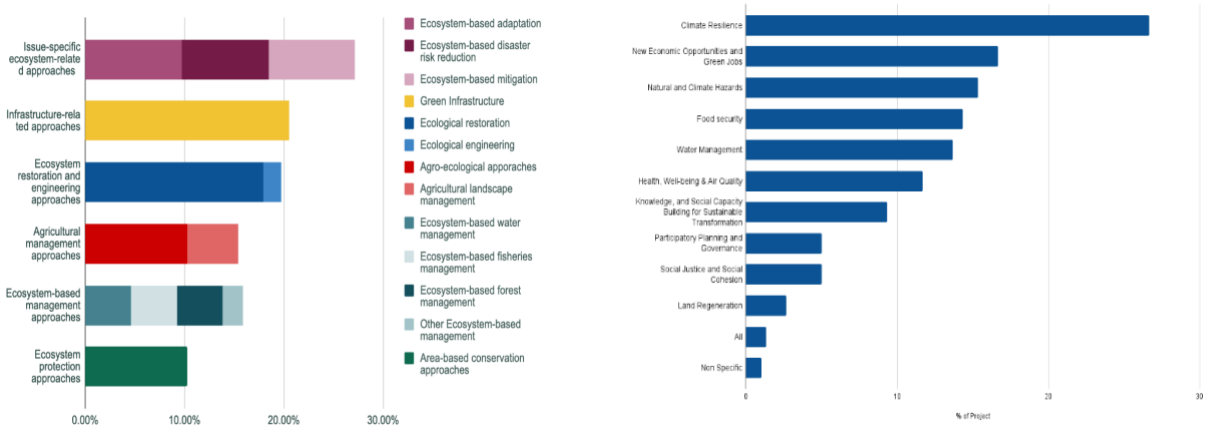

Figure 3 : Types of ecosystem-based approaches followed (left) and of challenges addressed with NbS (right) (EL Harrak & Lemaître, 2023).

1.1.1 NbS types from Eggermont et al.

Another shared, well-agreed classification of NbS is based on the cross-relation of the intensity of the NbS impact on the ecosystem and NbS-provided services (also including the number of stakeholders involved). This classification was first proposed by Eggermont et al. (2015) but it is still the most used to classify the type of NbS intervention. In such classification, three types of NbS are identified (Fig. 4):

Type 1 consists of no or minimal intervention in ecosystems, with the objectives of maintaining or improving the delivery of a wider range of ES, both inside and outside of these preserved ecosystems, providing multiple but not intensive ES yet addressing multiple beneficiaries.

Type 2 corresponds to the definition and implementation of management approaches that develop sustainable and multi-functional ecosystems and landscapes (extensively or intensively managed), which improves the delivery of selected ES compared to what would be obtained with a more conventional intervention.

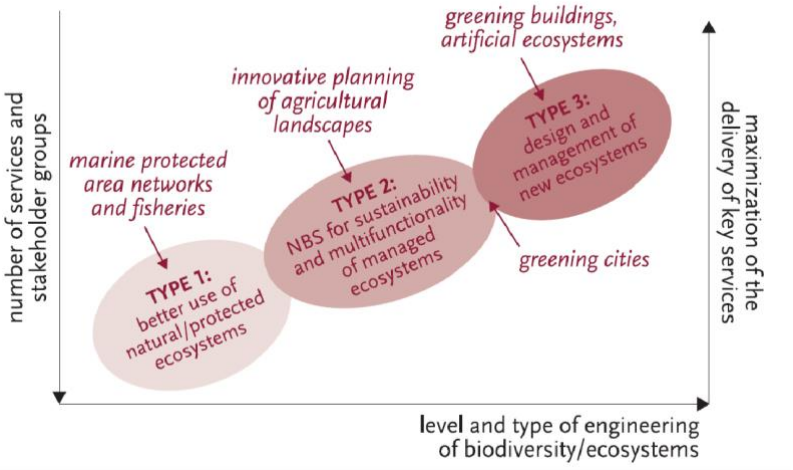

Figure 4 : NbS type classification from Eggermont et al., 2015.

Type 3 consists of managing ecosystems in very intrusive ways or even creating new ecosystems (e.g., artificial ecosystems with new assemblages of organisms for green roofs and walls to mitigate city warming and clean polluted air). In this last type, the impact in terms of new services provided to humans and nature is maximised, being generally very low in the pre-intervention status.

It is worth noting that, up to date, type 2 and type 3 NbS are the most frequently studied at least at the EU level (EL Harrak & Lemaître, 2023), likely due to the strong focus devoted to urban and peri-urban NbS in the EU context, and the lack of accounting of socio-economic properties and effects of what could otherwise potentially be considered NBS type 1 interventions (e.g. protected areas).

1.1.2 Other NbS Categories

Following the IUCN framework, (Anderson & Gough, 2022) identified five NbS categories namely ecosystem protection approaches, ecosystem restoration approaches, issue-specific ecosystem-related approaches, infrastructure-related approaches, and ecosystem-based management approaches, connected to a series of NbS and associated functions (Fig. 5).

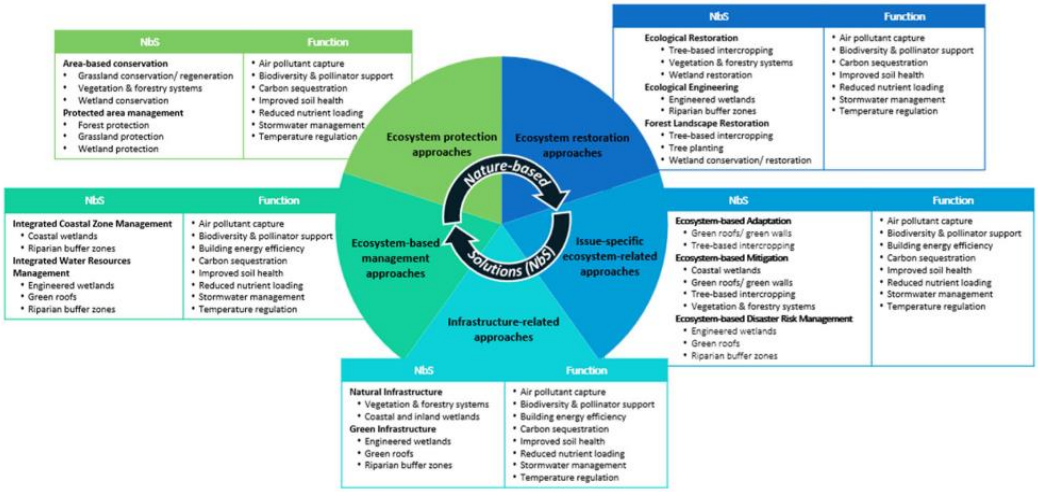

Figure 5 : NbS categories and general examples established by the IUCN, are connected to a series of specific NbS and associated functions. From Anderson & Gough (2022).

The wide range of NbS interventions realised in the urban context also led to the appearance of urban-specific classifications. For instance, within the context of the EdiCitNet project and based on the screening of 250 NbS interventions in the dissemination documents of the projects Urbangreenup, Unalab, Nature4cities, Thinknature (Castellar et al., 2021) proposed a novel hierarchical classification (Fig. 6), based on 32 different types of NbS, which are firstly grouped into NbS Units and NbS Intervention.

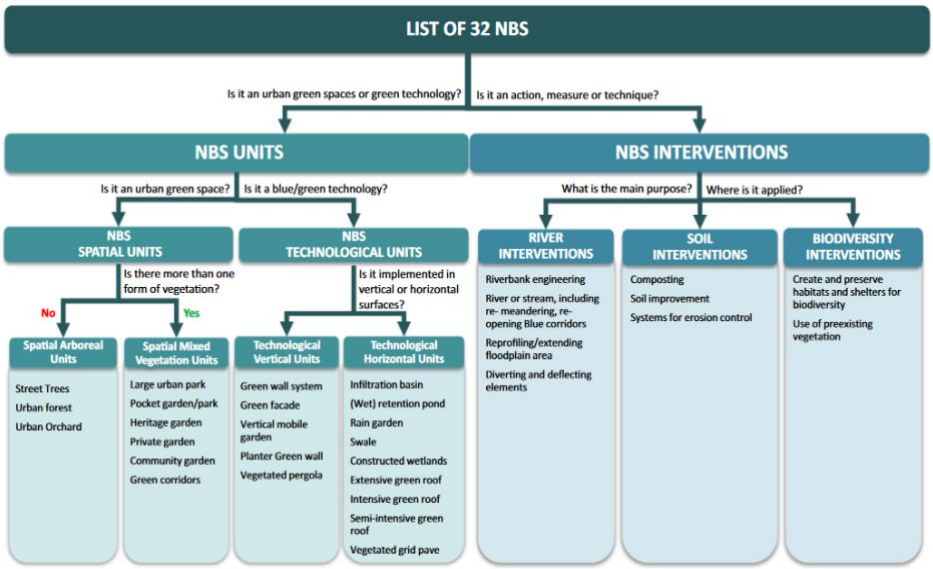

Figure 6 : Novel hierarchical classification as proposed by Castellar et al. (2021).

1.2 NbS upscaling

An essential element of NbS design involves determining the spatial and temporal scales of intervention and the anticipated impact. This aspect has undergone extensive deliberation in the context of categorization.

Merging the experiences reported in several Horizon2020 projects, four main **spatial scales** have been identified (Dumitru & Wendling, 2021):

- Local or element or NbS-level (building, public space, including street or pedestrian);
- neighbourhood or district or Living Lab level;
- city level;
- regional or landscape level.

The scale at which the impact of an NbS can be expected (and, thus, evaluated) is strongly affected by the spatial scale at which it is implemented (Vincent et al., 2022). Local, spotted interventions very likely will have only very local, often barely assessable impact. On the other side, larger scale intervention, i.e., city-scaled, more reasonably will produce a measurable impact at the same scale. Nevertheless, significant impact at larger scales can be obtained if local interventions are upscaled and networked.

It is then necessary to adopt a landscape approach to consider the connectivity among interventions and their ability to create an ecological network (Calliari et al., 2019). However, scaling up certain NbS might not be the best and feasible solution for any context, especially where there are strong spatial constraints; as in cities; or in the case of small-scale interventions (such as hedgerows, buffer strips and reforestation) which might be less effective to tackle certain challenge (for example flood) when upscaled (Collentine & Futter, 2018). In the latter case, the upscaling can be intended as replication in the same or another city, with the same or a new partnership (van Winden & van den Buuse, 2017).

The definition of the **temporal scales** of interest deserves importance in connection with both NbS lasting and needed maintenance as well as expected impact, which are somehow connected. In this regard, three broad categories have been identified (Raymond, Berry, et al., 2017): short (within 5 years), medium (5-10 years), and long-term (over 10 years). Time scales are more often determined by the NbS funding duration, which hinders the evaluation of the impact as they are likely to be better understood in the long term, since some impacts, such as social or health ones (e.g., reduction in the prevalence or incidence of different illnesses), require a longer time to become apparent, while others, mainly environmental ones, can be verified almost immediately (e.g., the reduction of local temperature through green walls).

1.3 NbS impact assessment and related metrics

According to the UNEA definition, once the site of intervention, with its environment, the ecosystem-based approach to follow and the societal challenges to address have been defined, a crucial aspect in characterising the proposed intervention as a Natural-Based Solution is ensuring the challenges are resolved "**effectively and adaptively"**.

«**Effectively**» means that the impact of the NbS on the identified challenges needs to be proved.

«**Adaptively**» means that, if the target has not been reached, the implementation must be updated.

Thus, impact monitoring and assessment are integral components of the planning and implementation process in the NbS life cycle (Dumitru & Wendling, 2021). Furthermore, many more lessons could be learned if such evaluations were performed within a common impact assessment framework. This has been a key objective of the EU since 2015, as it could facilitate the development of evidence-based knowledge and enhance overall efficiency.

Starting from the input of the seminar work of the EKLISPE Expert Working Group (Raymond, Berry, et al., 2017; Raymond, Frantzeskaki, et al., 2017), which firstly focused on the importance of common indicators to be used to assess the benefits and co-benefits provided by NbS in urban areas, the EU developed a strategy to strengthen the NbS concept and make it a reality on the ground (Faivre et al., 2017).

In this strategy, the cornerstone process resolves around data collection on NbS impact. To achieve this, numerous R&I projects focused on NbS have been funded since 2016, to implement NbS across Europe and evaluate their performances. As part of these efforts, involved researchers collaborated within thematic Taskforces; coordinated by NetworkNature, to develop fundamental tools for the future implementation of efficient NbS intervention. One of these tools is a Handbook designed to guide stakeholders in applying a standardised impact evaluation framework (Dumitru & Wendling, 2021).

The Handbook compiles insights gathered from various projects that have monitored and assessed the impact of implemented NbS. It offers an array of options for selecting indicators to monitor and evaluate the impacts of NbS, provides guidance in developing holistic plans for impact evaluation that consider multifunctionality and supports efforts for sound evaluation, leading to the accumulation of evidence. Lastly, it offers decision-making support to local authorities.

The impact evaluation framework proposed is composed of a categorization of the societal challenges that an NbS should aim to address, matching those listed in the previous chapter about NbS taxonomy, except for “Food security”, which is missing. For each challenge, a specific list of key performance indicators, and related methods, are provided, divided into “Recommended” (up to 10 per each challenge) and “Additional” (up to 39 per each challenge), to obtain an assessment as holistic as possible. Both quantitative and qualitative, measured, and modelled indicators are present in all categories.

The indicators have been selected with the aim of:

- Ensuring a robust scientific framework for evaluation within a comprehensive context, including the consideration of trade-offs, to evaluate the multifunctionality of NbS;
- Enabling comparability and standardization – to facilitate the accumulation of evidence;
- Maintaining neutrality – encompassing both positive and negative outcomes
- Being capable of measuring impacts on different social groups and across spatial scales and, when appropriate, providing long-term evaluation.

From the ecosystem services (ES) – provisioning, regulating, cultural, supporting – of a set of NbS typologies taken from different catalogues derived by EU projects (Urban GreenUP, Nature4 Cities, Urbinat, etc.), Francés et al. (2021) identified a set of Key performance indicators (KPI) to assess their multiple benefits at the urban level. Similar Environmental Indicators were developed within the Connecting Nature project for an urban environment, distinguished into core indicators (relevant to all NbS), feature indicators (relevant to specific cities) and other indicators (relevant to specific projects) (Connop et al., 2020).

Other assessment frameworks have been proposed in the last few years. For example, Rödl & Arlati (2022) suggested a procedure to identify indicators for evaluation and monitoring of NbS projects consisting of five phases, namely 1) definition of assessment targets, 2) description of the assessed object, 3) determination of suitable criteria and indicator, 4) data collection and quantification of indicator values, 5) evaluation. Regarding the selection of criteria and indicators, they refer to both results and processes (co-creation), including the 1) definition of the spatial and temporal scales (how big, for how long, and when?), 2) the target of the assessment (evaluation or monitoring?), 3) the benefits to be achieved in relationship to the challenges, and finally 3) the target group benefiting.

Based on previous frameworks which account simultaneously for economic, social and environmental benefits, as well as multi-stakeholder engagement (Liquete et al., 2016; Raymond, Berry, et al., 2017) Calliari et al. (2019) proposed a new one considering also the impact of climate change for the ex-ante assessment of benefits/costs and co-benefits/costs of NbS, by integrating system analysis and backcasting.

It is then possible to distinguish four types of frameworks which follow the four main phases of urban planning: 1) strategic planning, 2) implementation, 3) maintenance and 4) evaluation (Wickenberg et al., 2021) and 5) stewardship (Collier et al., 2023). These frameworks can assure the selection of cost/effective NbS able to tackle selected challenges when including their monitoring and the assessment of their actual effectiveness, in an optic of adaptive management. It is then crucial that these tools are used at a planning stage engaging policymakers, planners, and citizens among other stakeholders while assuring the implemented solutions are evidence-based.

2. Knowledge on NbS and where to find it

Dissemination is a strategic process that facilitates the uptake by ensuring that the right information reaches the right audience at the right time. This aspect pertains to the identification of stakeholders, as a well-crafted strategy goes beyond merely targeting an academic audience and strives to promote awareness and engagement. Nevertheless, a crucial role in **building awareness and trust** is played by sound scientific research which aims to elucidate the quantitative and qualitative services, benefits, and co-benefits of NbS. This knowledge empowers a broader audience to consider adopting or accepting NbS as viable solutions for addressing similar issues, instead of more common or conventional approaches.

Therefore, effective dissemination involves the **transfer of knowledge or information** in a clear understandable and practical manner so that individuals, organisations, practitioners, policymakers and others can grasp how to use or implement recommended NbS to address relevant social and environmental challenges.

In the dissemination phases, it is necessary to reduce the **information asymmetry** which occurs when some individuals or groups have access to more information than others, which instead must be accessible to all stakeholders while promoting equal opportunities for uptake. However, it is important to tailor the **dissemination to specific targets** or demographics, by understanding the unique needs and concerns of different groups.

An effective method is **demonstrating the value and the benefits** of NbS by presenting case studies, testimonials, demonstrations, or data that highlight positive results. Collecting feedback is essential for refining and enhancing the proposed solutions, addressing aspects like acceptance, and overcoming barriers such as cost, cultural resistance, or regulatory challenges.

Finally, dissemination is essential when an innovation or idea needs to be **scaled up** from a pilot or small-scale implementation to a larger, more widespread application by reaching a broader audience and thus a broader impact.

As highlighted in the European Roadmap to 2030 for Research and Innovation on NbS (EL Harrak & Lemaître, 2023), four strategic actions were identified, setting the priorities towards an effective NbS knowledge uptake, that are 1) advancing NbS knowledge and data; 2) closing the NbS research-innovation gap; 3) mainstreaming the role of R&I in NbS policy; 4) exchange, capacity building and awareness.

The roadmap underscores the crucial role of research and innovation (R&I) in making NbS knowledge accessible and actionable. Specifically, R&I is deemed essential for closing the gap between knowledge

and implementation, particularly by developing tools to facilitate the incorporation of NbS into planning and policy frameworks, establishing standards and technical guidelines, and creating platforms for knowledge sharing are vital components in this effort.

2.1 Direct dissemination activities

Direct (on-site) dissemination activities, involving in-person gatherings, such as conferences, workshops, and world café, facilitate the exchange of knowledge among various stakeholders Conferences typically cater to a broader, often international audience, with a focus on specialised topics. Workshops, on the other hand, target a mixed audience, encompassing both specialised individuals and general participants, including laypeople. For example, the BiodivERsA Strategic Foresight workshop titled 'Nature-Based Solutions in a BiodivERsA context' Brussels June 11-12 2014, played a pivotal role in defining NbS and initiated the development of a conceptual framework (Balian et al., 2014). When possible, these events should be organised within the local community context, in collaboration with authorities, NGOs or other entities, depending on the main stakeholder involved.

2.2 Digital resources

Virtual resources are intended to be web-based, interactive and dynamic tools such as platforms, databases, and networks. The development of such digital resources, a common feature in EU-funded projects (European Commission, 2020a), is aimed at facilitating the dissemination of information about the benefits of Nature-Based Solutions (NbS) and fostering the exchange of knowledge (Tab. 1).

Table 1. EU-funded project tools, documents, and initiatives fostering the knowledge uptake of NbS. Data from European Commission (2022a). As example, only projects targeting climate and water resilience issue in cities are shown here.

Focus	Topic	Project name	Years	Main outputs fostering NbS uptake	Output Type / Format / Accessibility
Urban	CLIMATE AND WATER RESILIENCE	Connecting Nature	2017-2022	Webinar & Community Workshop	Video recordings / YouTube / Freely accessible
				Environmental Indicators Review	Document / .pdf. / Free download
				Nature-based enterprises Platform	Tool / Web-based / Registration needed
		Urban GreenUP	2017 - 2023	NbS selection tool	Tool / .xlsx / Free download
				NbS scenario generation	Tool / .xlsx / Free download
				NbS KPI and NbS evaluated	Document / .pdf / Free download
				Videos and Webinars	Video recordings / YouTube / Freely accessible
				NbS catalogue	Document / .pdf / Free download

		Grow Green	2017 - 2022	Cost-Benefit tool	Tool / Web-based / Free access
				NbS Business Models search engine	Tool / Web-based / Free access
		UnaLab	2017 - 2022	Co-creation tool	Tool / Web-based / Free access
				NbS Simulation Visualisation Tool	Tool / Web-Based / Free accessible
				Open Nature Innovation Arena	Tool / Web-Based / Free available

2.2.1. Reports and scientific publications repositories

The evolution of knowledge related to Nature-Based Solutions (NbS) is monitored through an extensive collection of scientific research papers and reports (Tab. 2).

Table 2. Main databases collecting dissemination documents (not exhaustive).

Organisation	Repository name	Description
NetworkNature	knowledge database	Mappings of European research, policy, projects, and marked-based tools including stakeholders involved and topics covered focused on NbS
Oppla	Oppla marketplace	Online platform promoting products (including datasets and software), various documents, services on NbS
World Bank	Open Knowledge Repository	World bank open access repository for its research outputs and knowledge products
SciencePo	Science Po papers collection	EU chair for sustainable development and climate transition

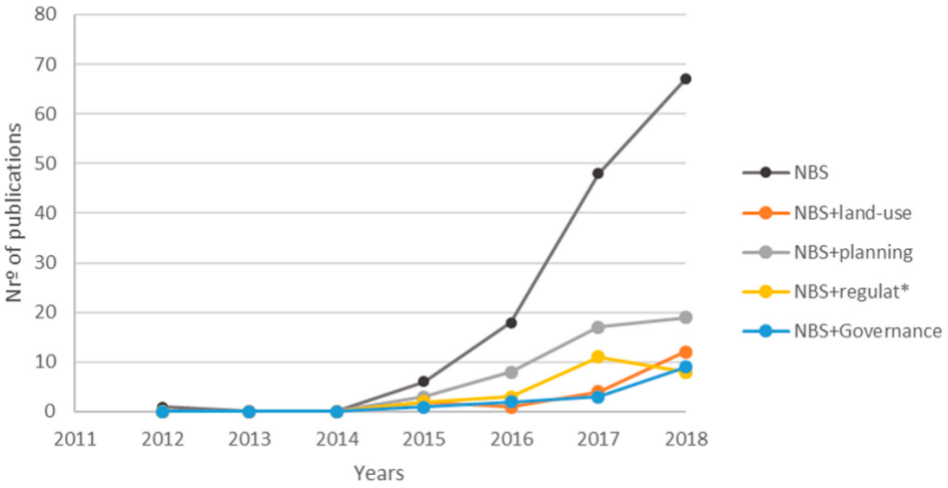

Figure 7 : Temporal evolution of the number of articles addressing the issue of nature based-solutions (NbS); NbS and land-use; NbS and planning; NbS and regulations; and NbS and governance. From Mendes et al. (2020)

Bibliometric analysis revealed that NbS made its debut in academic literature in 2012 (Fig. 7), subsequently, there was a notable surge in the number of articles on NbS starting from 2015, culminating in over 100 publications by 2018 (Mendes et al., 2020).

2.2.2. Data repositories and case study catalogues

Case study catalogues and data repositories are crucial for capacity building, sharing knowledge and building upon it (Tab. 3). Oppla and Urban Nature Atlas (open-ended output of the EU-funded project "Naturvation") constitute not only consistent repositories but also an attempt to centralise the information, which otherwise would be fragmented and less accessible.

Table 3. Case study catalogues and data repositories on NbS (not exhaustive).

Project or Repository	Repository name	Description / Scale of impact
OPPLA	Case studies database	Case studies compiled by Directorate-General for Research and Innovation of the European Commission
NetworkNature	Case studies database	Case studies across the globe on NbS
	Projects databases	European R&I projects on NbS from BiodivERsa, Horizon 2020, FP7, Interreg and LIFE over the years 2011-2021
Naturvation	Urban Nature Atlas	NbS from European cities and beyond / globe
Nature-based Solutions Initiative	NbS Case Study platform	Examples of best practice Nature-based Solutions from around the globe
	The NbS Evidence Platform	Typology and matrix of nature-based solutions for climate adaptation

Nature4Climate	Natural Climate Solutions Global Atlas	Atlas of natural climate solutions (NCS) as a subset of NbS targeting climate change mitigation
	Nature in action case studies	NbS actions worldwide
Nature4Cities	Geocluster4NbS	Nature4Cities project observatory and pre-selection tool of NbS typologies
Urban GreenUP	Access to data	Datasets free to download related to the Urban GreenUP project and case study

2.2.3. Decision and design supporting tools

Several tools were developed as a result of EU-funded projects to assess, plan, and implement NbS (Tab. 4). To decide which tool alone or in combination to use, it is important to set goals and targets.

Table 4. decision and design supporting tools on NbS (not exhaustive)

Project or Initiative	Tool name	Description
UnaLab	Tool for co-creation	It includes a suite of co-creation tools for Need Finding, Ideation, Strategy planning, Experimentation and Feedback gathering. The tools come in a wide range of formats from games, workshops to templates
UrbanGreenUP	NbS Selection Tool	Decision support tool designed to help local governments choose the right NbS (excel to download)
Naturvation	Urban Nature Explorer	A simulation game to address sustainability challenges through nature-based solutions.
EuPOLIS	NbS Preliminary Selection Tool	Supporting tool designed for urban planners to support them in the preliminary selection/prioritisation of possible NbS
Connecting Nature	CO-IMPACT	Tool to create your Nature-based Solutions / project evaluation and monitoring plan
Greater London Authority (GLA)	Green-Infrastructure Focus	Composite indicator map for the city of London to help London's decision-makers identify where green infrastructure improvements and investments might be best targeted, and what kind of interventions might be most useful for the needs of a specific area
REACHOUT	Climate Resillient City Toolox	To explore which adaptation measures can better protect a neighbourhood, neighbourhood, site or street against flooding, drought, and extreme heat.

Envision Tomorrow	Geodesign	Open-access scenario planning package that allows users to analyse how their community's current growth pattern and future decisions impacting growth will impact a range of measures from public health, fiscal resiliency, and environmental sustainability
Nature4Cities	Nbenefit$	To support decision-making on NbS by allowing the simulation and visualisation of ecosystem service-based costs & benefits scenarios through a graphical user-friendly interface
Cerema	Sesame	A tool for integrating trees into your urban renaturation projects
Florintesa	Anthosart	Tool to select Italy's spontaneous plant species for green spaces species based on the aesthetic and physiognomic characteristics (user oriented) and the ecological, edaphic and climatic characteristics (place oriented)
GreenInUrbs	Specifind	Searching for arboreal plants from which you can get more benefits
EdiCitNet	NbS performance assessment	Scores visualisation of a specific NbS along with its description, as well as the visualisation of different NbS' scores regarding an individual UC or ES. This allows experts and practitioners to explore the co-benefits of any NbS or identify the NbS that best addresses a specific issue
Natural England	Biodiversity Metric 4.0	Biodiversity accounting tool that can be used for the purposes of calculating biodiversity net gain in any development project, for terrestrial and/or intertidal habitats
Policysupport	Co$tingNature	Conservation prioritisation and Ecosystem Services mapping

2.2.4. Modelling tools

Several modelling tools are available for estimating and simulating the impact of NbS (Tab. 5). These tools help assess the potential outcomes and benefits of implementing NbS in various environmental and societal contexts.

Table 5. Modelling tools (not exhaustive)

Name	Description
InVest	Integrated Valuation of Ecosystem Services and Tradeoffs

iTree	Tool for assessing and managing forests and community trees
Envi-Met	Microclimatic analysis and simulation for urban planning
Dessin	Ecosystem Services Valuation Toolkit

3. Knowledge on NbS and how to engage with it

Capacity building is a crucial element in the uptake process. It involves enhancing the knowledge, skills, resources, and capabilities of individuals, organisations, or communities to effectively adopt, implement, and sustain Nature-based Solutions. **Knowledge and skills development** is done by providing training and educational resources to stakeholders involved in the uptake process such as end-users, employees, partners, or community members and also by providing frameworks and tools for the effective selection and implementation of the right NbS.

Given the technological innovations embedded in certain Nature-Based Solutions (NbS), it is equally crucial to ensure that users possess the **technical competence** needed to operate, maintain, and address any issues. This approach helps minimise the risk of disruptions to ecosystems. To the latter point, the **adaptive management** of NbS is essential to empower individuals and organisations to cope with the new ways of working or thinking, for example providing training in change resilience, leadership, and communication skills to facilitate a smooth transition. For this reason, it is necessary to **allocate human and financial resources** (such as funding, and supporting structures) to support the uptake process (for example establishing training programs, or hiring skilled personnel), and **institutionalise** them by their integration into existing systems, policies, and practices.

Potential challenges must be addressed to **mitigate risks** associated with the uptake of NbS by educating stakeholders on how to address them, reducing the likelihood of setbacks or failures, creating **feedback loops** for continuous improvement, and fostering a culture of innovation and learning. Finally, capacity-building efforts should be **measurable and subject to evaluation** to assess their impact.

Nature-based enterprises are key to the implementation and delivery of NbS (McQuaid et al., 2021). Increased awareness (willingness to pay), the incorporation of NbS into policies (SDGs) and economic instruments (such as public funding, subsidies, and tax incentives) are decisive factors in market growth, together with the development of industry standards as well as tools to measure the impact, training, and skills (McQuaid et al., 2021).

3.1 Stakeholder engagement and co-creation

A stakeholder is any person or group who influences or is impacted by the research (directly and indirectly), therefore identifying stakeholders, why to involve them, and how and when to engage with them is crucial to enhance the credibility, relevance, and legitimacy of the research (Durham et al., 2014; Jolibert & Wesselink, 2012).

In European Union Framework Programs for biodiversity conservation projects, key stakeholder categories, listed in descending order of representation, comprise the following (Jolibert & Wesselink, 2012):

- Scientists (from public research institutes and universities to private consultants and experts)
- Policymakers (from EU institutions to national ministries)
- NGOs (from local to international)
- Managers (public and private)
- Private sector (including small and medium enterprises)
- Citizens (from amateur naturalists to representatives of consumer groups)
- Students (from primary schools to universities)
- Facilitators (social scientists and other mediators)
- Media (TV, radio, and newspapers)

The engagement of stakeholders happens at different magnitudes (from two to six categories at once) and stages yet is mainly confined to the end of the project, thus suggesting the disconnection between the social context and the research, the latter being self-referential (the issues are chosen by researchers and not influenced by the public).

The successful uptake of NbS requires multiple stakeholders across disciplines and sectors to be implicated in the design, implementation, financing and decision-making processes, including the development of innovative business and investment models, as well as legal and institutional frameworks (long-term financing) with the final aim of empowering and involving citizens (Davies et al., 2021; Faivre et al., 2017). Multistakeholder dialogues can be obtained via platforms such as NetworkNature, toolbox and strategies development and living labs (e.g., in Operandum, Urbact, Reconnect and Phusicos EU-funded projects) (Giordano et al., 2020; Lupp et al., 2021).

In BiodivERsA projects, stakeholders' (SH) engagement is monitored through form assessing the SH category, and timeframe of the engagement including dissemination activities and products intended for stakeholders (prior, during, and after). Here stakeholders are considered as non-academic exclusively.

In EU-funded projects, co-creation is encouraged to promote better governance, innovation, and societal well-being, promoting participatory democracy, and ensuring that policies and projects fit citizens and stakeholders. The co-creative process of NbS can be assessed (evaluated and monitored) and be measured in terms of stakeholders' involvement in the different phases: from (1) the definition of challenges and visions, embodied in the form of local and traditional knowledge, to (2) the planning/design and decision of the interventions, and (3) the implementation – the last two made jointly with residents and other local stakeholders – and (4) the follow-up, which shall inform the possible upscaling on the base of the monitoring results (Rödl & Arlati, 2022).

Co-creation process can also serve as a platform for capacity building, where stakeholders can learn from each other, share knowledge, and develop new skills.

The inclusive nature of NbS must be supported by new ways of co-creation, co-implementation and co-management, and avoiding mistaken co-creation with other forms of stakeholder involvement (Wilk et al., 2021). For example, among the lessons learned in the H2020 EU-funded projects PROGIREG, CLEVER CITIES, EDICINET, Wilk et al. (2021) highlighted the importance of 1) involving existing local associations

to gather needs and trust by the citizens, 2) supporting the uptake of new specialised skills by addressing them within the capacity building strategies, to assure long term autonomous maintenance and monitoring of NbS and 3) to involve people in data collection and knowledge sharing with citizen sciences activities.

3.2 Peer-to-peer best practice exchange

Peer-to-peer exchange is at the base of Taskforces (TF) such as the NbS Cluster Task Forces developed to "enable synergies, strengthen networks, share and synthesise knowledge, communicating and disseminating results with a wider impact, and save resources around common areas of work" (Network Nature, 2023). The main objective of the TF is to increase the project's impact on policy and practice while helping the process to fill the NbS knowledge and implementation gaps by building the evidence base in TF1) Data and Knowledge sharing (knowledge repository); TF2) Impact Assessment Framework; TF3) Governance, Business Models and Financial Mechanisms; TF4) NbS Communicators, TF5) NbS Education, and TF6) Co-creation and co-governance.

This exchange is also facilitated by the creation of European international partnerships (e.g., Biodiversa+, Water4all, DUT), NbS national and regional hubs, namely networks connecting practitioners, businesses, investors, policymakers, and researchers, as well as the creation of biodiversity centres at national and European levels such as the Italian National Biodiversity Future Centre (NBFC) and European Knowledge Center for Biodiversity (KCBD).

Furthermore, to better understand priorities and opportunities for cooperation as well as inform on R&I needs and support towards achieving policy goals by 2030, the regular and continuous mapping of R&I initiatives is among the goals of both Biodiversa (Goudeseune et al., 2018) and NetworkNature (EL Harrak & Lemaître, 2023). The Biodiversa database contains extensive information on research at least partially focused on biodiversity that can be considered representative enough to map the EU R&I landscape on NbS; while the European NbS R&I database powered by NetworkNature contains a repository mapping of R&I projects on NbS which is planned to be continuously updated during the NetworkNature+ and BiodivERsa+.

3.3 Higher-education and training

The scarce public awareness on biodiversity, exacerbated by the disconnection between people and nature due to the increased urbanisation, hampers its effective conservation and environmental protection (Prakash & Dubois, 2023). Education is crucial also to increase a sense of stewardship among citizens and to overcome the discrepancy between awareness and taking action. In this regard, UNESCO's education sector promotes the transition towards education for sustainable development (ESD) to equip all learners with the tools to tackle global challenges, empowering them to make informed choices, fostering action for societal change, and improving the cognitive, socio-emotional, and behavioural aspects of learning, making it an integral part of quality education (UNESCO, 2023). The role of education is also highlighted in the European Green Deal (European Commission, 2019), and it is a cornerstone of the 2030 Biodiversity Strategy (European Commission, 2020b). The alignment between job opportunities and people skills and aspirations, as well as providing reskilling opportunities are crucial

to implement the green and digital transition as highlighted in the European Year of Skills (European Union, 2023) and the Green Deal Industrial Plan (European Commission, 2023).

ICLEI, the global network of local governments for sustainability aiming at aligning strategic environmental planning at local levels with global goals, covers among others the 'knowledge role' as educators by training city officers on ES (Frantzeskaki et al., 2019). Moreover, ICLEI together with PPMI conducted a desktop study to map educational resources on NbS of EU-funded online repositories (e.g., Network Nature, Oppla, Urban Atlas, Scientix) as a deliverable of the Nature-Based Solutions Education Network (NBS EduWORLD) EU funded project (Mulvik et al., 2023). The outcome of the deliverable is the NbS edudirectory namely a repository of educational resources to be updated regularly.

At the European level, several initiatives and actions took place to support "green education" for a more sustainable future and to build the sustainability competence of learners (Prakash & Dubois, 2023): GreenComp, Education for Climate Coalition, and the EU learning corner. Among the EU R&I programs, Horizon Europe (HE) (2021-2027) supported biodiversity and education actions. For example, within Pilar I (excellent science), by fostering initiatives such as the annual "European Researchers' Night", "Researcher at Schools" and "European Year of Youth"; whilst within Pillar II (global challenges and European industrial competitiveness) of the HE the cluster 6 work programme funded the following topics on "addressing biodiversity decline and promoting NbS in higher education", "inside and outside: educational innovation with nature-based solutions", and "education on bioeconomy including bio-based sectors for young people in primary and secondary education in Europe".

Higher education should integrate NbS principles into their **curricula**, namely offering courses, programs, and degrees related to environmental science, ecology, conservation biology, landscape architecture, and sustainable development, with a specific focus on NbS concepts and practices. This would require **interdisciplinary collaboration** by engaging students from various disciplines to work together thereby developing a holistic understanding of the challenges and solutions proposed. Given the applied nature of NbS, universities and research institutions, shall develop **innovative solutions** through research projects and partnerships with industry and government agencies as well as promoting fieldwork, internships, and practical training in both natural settings and urban environments.

4. Biodiversa success stories regarding uptake of NbS

To bring the previously mentioned theoretical approaches on the ground, an analysis has been accomplished on the Biodiversa funded projects to evaluate their effectiveness regarding the uptake of knowledge on NbS. After a preliminary project screening devoted to the identification of the Biodiversa funded project including NbS implementations, a second screening has been performed to identify success stories, where synergies among the ways to uptake the knowledge have led to a boost in the dissemination action. The selection process and the identified success stories are described in this chapter.

4.1 Project Screening

A preliminary screening of all the projects funded by Biodiversa under the call 2013-2014, 2015-2016 and 2017-2018 has been performed to identify in which project NbS actions were put into place. A total of 18 projects were selected. Afterwards, an evaluation grid has been developed to select the success stories.

To provide a set of success stories as representative as possible of the different scenarios (i.e., ecosystems, challenges, typologies, etc…), the first part of the evaluation grid was composed of six screening criteria. Then four evaluation criteria have been adopted to rank the project in connection with i) the level of engagement of stakeholders during the project; ii) the type of knowledge on NbS produced by the project; iii) how much this knowledge is linked with efficiency in term of biodiversity increasing and provision of ES; iv) the type of dissemination actions put into action.

4.2 Success stories

Five success stories dealing with NbS (i.e. integrating ecological, social and economic aspects) have then been selected (Tab. 6) by considering both their representativeness of ecosystems involved and their impact on knowledge uptake (by assessing benefits, monitoring biodiversity, producing guidelines): REPEAT (REstoration and prognosis of PEAT formation in fens linking diversity in plant functional traits to soil biological and biogeochemical processes), PromESSinG (Promoting Ecosystem Services in Grapes), URBANGAIA (Managing urban Biodiversity and Green Infrastructure to increase city resilience), OSCAR (Optimising the configuration of woody riparian buffer strips along rivers to enhance biodiversity and ecosystem services) and RESERVEBENEFIT (Evaluating and managing connectivity in a network of Marine Protected Areas to maintain genetic diversity and deliver fish beyond protected limits). The selection was based on the different topics developed by each project on the theme of NbS. Particularly, it was considered the ecosystem involved in each NbS implementation, like agricultural, urban, marine, river and coastal ecosystems and their relative governance.

Table 6. Success stories selected

			Uptake Impact		
Project acronym	NbS type	What intervention in which **ecosystem**	Benefit assessment	Biodiversity assessment	Guidelines implementation
REPEAT	1	**Peatland** rewetting and delivery of fen ecosystem services.	• Increase research capacity • New method or technology development	• Vegetal biodiversity restoration • Animal and arthropodal biodiversity restoration • Structural and functional ecosystem connectivity and diversity	• NbS implementation • Benefits monitoring action

Prom ESSinG	2	**Non-crop vegetation** and effect of maintenance regimes between rows and under wines on pedofauna and grape quality; as well as bio vs. conventional treatment and type of surrounding habitats affecting the presence of solitary bees and spiders communities.	• Increase research capacity • New method or technology development • Tool development	• Vegetal biodiversity restoration • Animal and arthropodal biodiversity restoration • Structural and functional ecosystem connectivity and diversity	• NBS implementation • Participatory process • Benefits monitoring action • Policy development
URBAN GAIA	3	Management and governance tools in implementing **UGI** functioning and impact by involving citizens and other stakeholders (including planners and policy makers)	• Increase research capacity • New method, or technology development • Tool development	• Structural and functional ecosystem connectivity and diversity • Carbon stock and GHG effects mitigation	• NBS implementation • Policy development
OSCAR	2	Effect of trees buffers on **small rivers** functioning (reducing water temperature, retaining nutrients from agricultural areas, providing leaves and wood as food and habitat for aquatic insects and fish) and services (recreation)	• Increase research capacity • New method, data or technology development	• Vegetal biodiversity restoration • Animal and arthropodal biodiversity restoration • Structural and functional ecosystem connectivity and diversity	• NBS implementation • Benefits monitoring action
RESERVE BENEFIT	1	Role of **seascape** and protection measures (marine reserves) on fishery, biodiversity and genetic diversity outside protected boundaries.	• Increase research capacity • New method, data or technology development • New technical process development	• Animal and arthropodal biodiversity restoration • Structural and functional ecosystem connectivity and diversity	• NBS implementation • Benefits monitoring action

The projects had the common aim of improving the management of the different ecosystems they studied for the enhancement of ecosystem services, biodiversity conservation and environmental restoration. In

addition to the many environmental objectives, it was very important to pursue socio-ecological goals and knowledge. In this regard, the involvement of a very broad partnership, including local stakeholders, was pursued to start virtuous participation and co-creation actions and collaborative governance.

These pathways of collaboration and involvement were promoted through a dissemination strategy involving TV and radio broadcasts, conferences, and workshops in the focal countries of the different projects and Brussels, headquarters of the European Commission. The dissemination strategy also involved many different local stakeholders, and in some cases local communities and governments. The URBANGAIA project evaluated the results of its activities through interviews with stakeholders involved, and the results were used by local governments as a tool for improving the decision-making system for the management and planning of NbS in a collaborative governance style.

Moreover, these projects contributed to advancing scientific knowledge through collaborative efforts with partners from various experimental projects. This collaboration led to the generation of numerous scientific publications and databases, which informed the development of new NbS and associated policy frameworks. Additionally, the involvement of PhD and post-doctoral students facilitated the establishment of standardized methodologies for designing and evaluating ecosystem services produced by NbS.

One area for improvement in these projects could involve broadening the partnership beyond sole universities and research centres from the project's outset. Embracing the quadruple helix concept in NbS design would entail engaging academia, local government, the private sector, non-governmental organizations, and local communities from the start. By incorporating diverse stakeholder perspectives, the development and execution of NbS could be guided more effectively to attain social, economic, and environmental advantages. For example, the URBANGAIA project used citizen opinion as a tool of information to identify which ecosystem services they value the most. This will make it easier to identify the strengths and weaknesses of the different NbS actions so that they can be readapted to the changing context and the needs of each natural ecosystem and social community.

Conclusive remarks

NbS can be implemented alone or in an integrated manner with other solutions and should be executed at a landscape scale and seamlessly integrated into a broader framework of policies, measures, and actions designed to address societal challenges. The main barriers to the uptake and implementation of NbS are of a political, institutional, and knowledge-related nature (Sarabi et al., 2020). Additionally, the lack of consensus on the definition and scope of NbS further complicates their widespread adoption (Sarabi et al., 2019).

The strength of a multidimensional approach which is typical in Biodiversa+ funded projects, lies in its ability to address complex issues from various angles, promoting a comprehensive understanding and holistic solutions that address multiple dimensions of a problem simultaneously. This can lead to more effective and sustainable outcomes which can adapt to changing circumstances and evolving challenges by incorporating various perspectives and insights. For this reason, such projects must engage multiple stakeholders, including experts, affected communities, and policymakers, fostering inclusivity and diverse perspectives and encouraging innovative thinking by combining ideas and strategies from different domains. By doing so the risks associated with a project or initiative can be better identified and managed, reducing the chances of unexpected setbacks, and can lead to breakthrough solutions.

Funded projects play a crucial role in translating multifaceted strategies into actionable projects, offering essential resources to attain desired results and propel advancements in diverse domains. In addition to securing financial backing for research, development, and expanded implementation, funding facilitates the recruitment of skilled personnel, acquisition of technology, and comprehensive data collection. Funding can help ensure the long-term sustainability of projects, ensuring that they can continue to operate and make a positive impact over an extended period.

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