Report on Conceptual Grounds and Common Understandings

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1. Introduction

1.1 Objectives of trans4num project

Nature-based solutions (NBS), such as bio-based fertilisers, enhanced agricultural practices and technologies etc., come with immense potential to positively change intensive agricultural land use in Europe and beyond: to move towards net-zero environmental impacts while achieving food and water security and meet climate goals (Iseman and Miralles-Wilhelm 2021). However, the application of NBS is still limited and, in some cases, declining for several reasons. The first reason is the insufficient exploration and limited experimentation of the often-complex practices, processes and technologies. Secondly, the lack of knowledge, skills and capacities for their situational adaptation and application in different situations. And thirdly, the social and societal-level deficits in acceptance, incentives and further institutional support. Additionally, the broader effects of NBS on e.g. climate resilience and crop productivity, including nutrient availability and interaction between nutrients and carbon cycles, are scarcely explored.

The overarching ambition of trans4num is to substantiate and broadly promote the NBS approach for sustainable agricultural practices in Europe and China with a particular focus on nutrient management (bio-based nutrient sources, sustainable crop rotations, integrated management practices). To do so, trans4num will develop and implement a social-ecological transformation (SET) approach tailored for the inter- and transdisciplinary research on NBS for a more sustainable nutrient management in regions with intensive farming systems. In particular, trans4num will:

- Develop a disaggregated understanding of NBS potentials for achieving sustainable agricultural practices;
- Understand and analyse the complex interdependencies of applying NBS;
- Develop a dynamic, smart nutrient management tool to support decision making for optimal nutrient supply;
- Assess the (net) impact of technological and social innovations as well as policies related to NBS.

Specific objectives of trans4num

It is the overall objective of trans4num to develop and test innovative NBS practices and pathways that contribute to a socio-ecological transformation of existing intensive agriculture systems towards an increasingly sustainable nutrient management. The overall objective will be achieved through a number of specific ones:

- Specific objective (1): develop, practice and assess inter- and transdisciplinary, systemic research conducive for a transformative learning approach towards sustainable agricultural practices. Transformative learning needs encompass the acquisition and the sharing of new knowledge, and of values and behavioural changes' requirements for a wider implementation of NBS, they will become apparent through trans4num's inter- and transdisciplinary cooperation. Crosscutting insights will be obtained from numerous collaborative activities among the project partners and in cooperation with wider stakeholder communities related to the NBS sites; they will be systematically documented (based on D1.1-D1.4) and comparatively analysed for the wider audience (D5.3).

- Specific objective (2): develop a differentiated understanding of NBS potentials for sustainable agricultural practices in the context of intensive farming systems. For seven selected regions in Europe and China, trans4num will characterise, test and assess both mono-nutrient and multi-nutrient NBS through case studies investigating nutrient flows, management options and policy interventions for a selection of agricultural products in different biophysical and farming systems' contexts at multiple intervention levels (field, farm, farming system), and address the aspects of nutrient deficit, surplus and/or loss (D2.1-D2.8).
- Specific objective (3): understand and analyse the complex interdependencies of applying NBS as well as their effects for multi-level nutrient management. For a selection of promising NBS and comparatively across the selected NBS sites, trans4num will use the Agricultural Knowledge and Innovation System (AKIS) framework to analyse the respective innovation processes with an actor-centred approach, thus emphasising the actor-agency rationale of sustainable practices, identifying and fostering actor coalitions and promising innovation support measures and entry-points for a wider dissemination (D2.9, D4.4).
- Specific objective (4): develop a dynamic and smart nutrient management tool to support decision making for optimum nutrient supply in diverse agricultural practices and at multiple intervention levels. trans4num will demonstrate, advance and evaluate a range of innovative monitoring techniques and models to enhance the adoption of decision support systems that can help optimisation of NBS at a regional level for the sustainable use of nutrients with inter- and transdisciplinary approaches (D3.1-D3.3).
- Specific objective (5): provide an integrated assessment of food systems, value chains and policy levels' leverage points for a robust transition to nature-based nutrient management in Europe and China. Based on agent-based impact simulations and food-system level biophysical mass- and nutrient-flow models, trans4num will measure the sustainability impact and upscaling potential of key nature-based nutrient management strategies for farming systems and along value chains and identify options for transformational change at the food-system level. trans4num will develop a multi-level, multi-actor exchange and assessment approach to comprehensively investigate and evaluate the process, dimensions and the impact of technological and social innovations as well as policies contributing to promising NBS related social-ecological transformation pathways. (D4.1-D4.4).
- Specific objective (6): develop evidence-based knowledge, create awareness for necessary conditions in a food system context, disseminate, up- and out-scale information and recommendations related to the design, development and implementation of NBS in different farming systems of intensive production character.
  o A broad range of outputs in different formats per NBS site will inform and sensitise various target groups and the wider public for the potentials and advantages that come with NBS innovations;

- A range of dissemination and exploitation activities will demonstrate NBS advantages and the strengths of a multi-level, multi-actor social-ecological transformation (SET) approach in European and other international professional networks and conferences; o A series of policy briefs will reach political decision makers and regional management bodies with situationally adjusted and institutionally adapted recommendations (D5.2-D5.5).
- Specific objective (7): enhance Europe - China exchange and learning processes and promote synergy and alignment of agenda-setting on sustainable agricultural practices in intensive farming systems. trans4num will create numerous opportunities for European and Chinese academicians and practitioners to deepen their understanding of NBS innovations and exchange knowledge through developing a joint strategy for promoting NBS for sustainable nutrient management. Taking the perspectives of SET, the project partners consider the Europe-China interaction as a high-level force of nudging system changes that would be otherwise locked in at the national, regional and local levels. There is an option to harmonize sustainability standards for increased transferability and transparency between China and Europe, and to jointly develop enhancing ecosystems and enabling environments for NBS innovations and societal changes.

1.2 Purpose and development procedure of Deliverable 1.1

In order to achieve the objectives of the project, it is necessary to look more closely at the definition of NBS in order to establish a common conceptual basis among the partner countries. For a better understanding, it is also useful to know how the concept of NBS has evolved and developed over time.

Trans4num's scientific partners have therefore provided a concise summary of the state of the art of empirical NBS research in their respective fields, highlighting the most recent and innovative findings. These findings provide the conceptual basis for the joint work and contribute to the overview of NBS that are appropriate to respond to the site-specific challenges where trans4num operates (D2.1, D3.2).

A common conceptual ground has been developed based on the state of the art by identifying and joining key concepts, definitions related to nature-based solutions, nutrient flow, climate change, agroecology, restorative ecology, regenerative/circular farming, ecosystems into a coherent framework. The aim is for project partners from different backgrounds to share a common understanding of the guiding concepts and principles, which will help them to communicate and collaborate effectively. The results are summarised in the current document, cross-checked and agreed by all partners.

The following NBS definition has been used as a basis throughout the development of trans4num project: “Nature-based solutions are defined as actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham et al. 2016).”

NBS have become a prominent concept in environmental management and policy-making over the past few decades. Today, NBS generally refer to the use of natural ecosystems and biodiversity to address various environmental and societal challenges such as climate change, biodiversity loss, and human health and well-being. The development of the NBS concept can be traced back to various fields of study such as ecology, restoration ecology, and ecosystem services.

Development procedure

The deliverable was developed as part of WP1, Task 1.1 (Develop a conceptual framework based on the state of the art) led by SZE. The basic structure and contents of the document were defined by SZE with the support of UHOH, WU, AU, RRes, FiBL, HCC, P4All, AII-CAAS, ICS-CAAS, SWU, HAAS, THU, AQSC, RCRE, HADFIC.

The document was shaped through several online meetings between the project partners, and the draft was uploaded to a common platform where partners could comment and add their input. The final document thus reflects the partners' shared insights on NBS and is suitable for developing a common understanding that will guide the implementation of further project activities.

In developing D1.1, all the academic partners provided a concise summary of the state of the art of empirical NBS research in their respective fields, highlighting the most recent and innovative findings. These findings provide the conceptual basis for the joint work and contribute to the overview of NBS that are appropriate to respond to the site-specific challenges where trans4num operates. The state-of-the-art work was carried out through desk studies and literature reviews.

Here we would like to clarify the spelling of "nature-based solutions'' and its abbreviation. Since the scientific literature on the subject and the international organisations concerned spell these terms differently, the spelling used in this paper follows the spelling used when writing the trans4num proposal. That is: nature-based solutions and NBS for short. The original spelling has been retained where it is quoted verbatim.

1.3 Structure of the document

The document is divided into four sections. In the first introductory section we describe the aims of the trans4num project, the purpose of the document, the process of its development and its structure.

The second section explores the concept of nature-based solutions. As the concept of NBS is relatively new, there is no generally accepted, well-established definition of it. One of the first steps in understanding the concept is to look at its origins, which are discussed in Development of the NBS concept (2.1). 2.2 gives further insight into the concept of NBS by exploring the possible typological classification. We collected different approaches, definitions of NBS (2.3) and key concepts connected to NBS (2.4). This section contains a list of key terms related to NBS as defined in the proposal, with the aim of developing a common understanding between the partners. Section 2.5 provides a brief introduction to the IUCN Global Standard (2.6), which is one of the most comprehensive attempts to develop a concept of NBS worldwide. Section 3 describes the role and potential of NBS in agriculture and the most commonly used NBS. Methods are discussed in terms of their application to agricultural production or the agricultural landscape.

2. What is NBS?

2.1 Development of the NBS concept

Human activity and intervention on earth have reached a level that has led to environmental changes, often irreversible, to which societies are responding with two types of solutions. One is increased reliance on technology, and the alternative is a shift towards natural solutions, reflecting a more complex approach (Eggermont et al. 2015). The term NBS itself suggests that nature can provide solutions to these global challenges and transform them into opportunities (EC 2021).

Often referred to as a "framework" (Cohen-Shacham 2019), the concept of NBS is in constant evolution (Dick et al. 2019; Dumitru et al. 2020; Davies et al. 2021). Many environmental scientists believe that nature-based solutions enhance community welfare, climate resilience and biodiversity.

Professionals, researchers and policy makers involved in the management of the natural environment have been regularly encountering new terminology and concepts since the last decades of the 20th century (Nesshöver et al. 2017). The idea of environmental or ecosystem services first appeared in the scientific literature in the 1970s. By the 1990s, there was a generally accepted need for a more systematic approach to the relationship between humans and nature (Cohen-Shacham et al. 2016). The term "sustainable development" was first defined by the UN Brundtland Commission in the late 1980s (Brundtland et al. 1987), followed by the emergence of "biodiversity" from conservation biology. During the last two decades an anthropocentric approach to natural resource management has been increasingly emphasized (Nesshöver et al. 2017).

The NBS concept emerged in the late-2000s as a way to bring together these various fields of study and practices (MacKinnon et al. 2008).

The specific term "nature-based solutions" was first used in the late 2000s (MacKinnon et al. 2008) in the context of mitigating and adapting to the impacts of climate change while "protecting biodiversity and improving sustainable livelihoods" (Eggermont et al. 2015).

The World Bank used the phrase first in 2008 (MacKinnon et al. 2008) and the International Union for Conservation of Nature (IUCN) in 2009 in a position paper for the United Nations Framework Convention on Climate Change (IUCN 2009), where NBS were defined as: “actions to protect, sustainably manage, and restore natural or modified ecosystems” (Eggermont et al. 2015). Figure 1 shows the main institutional developments associated with NBS (Cohen-Shacham et al. 2016).

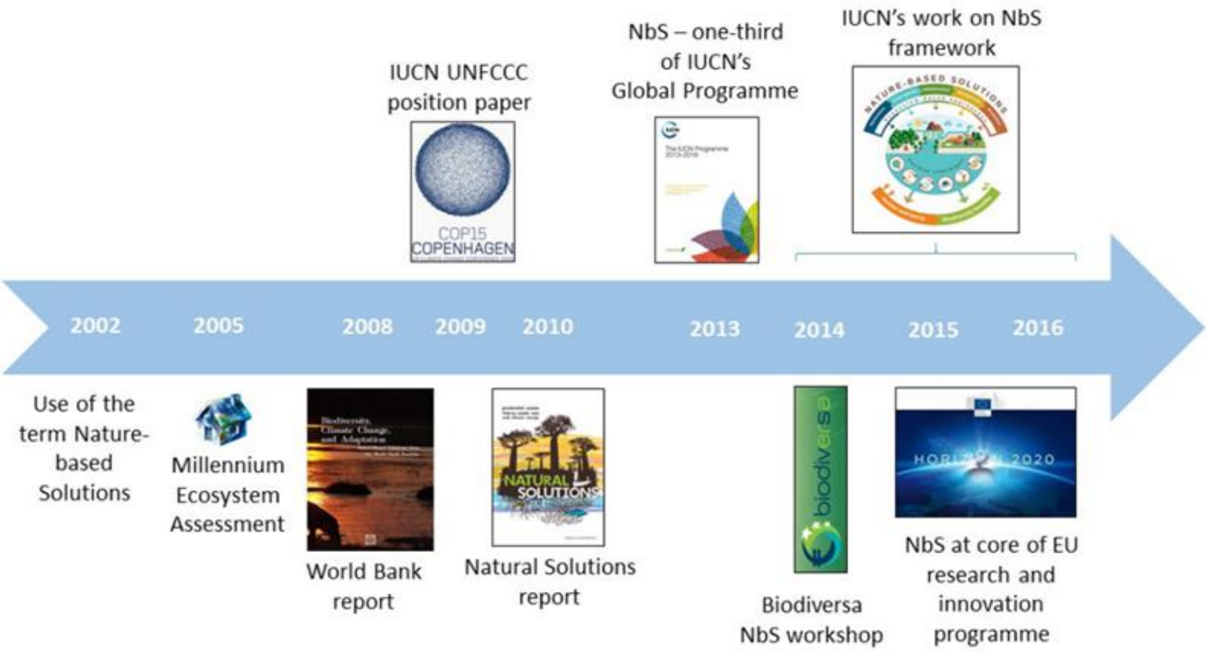

Figure 1 Timeline of the development of the NBS (Cohen-Shacham et al. 2016)

The Web of Science database was searched for publications after 2000 to find the number of publications containing the exact phrase "nature-based solutions" (Figure 2). This is a selected example from the Web of Science databases, but it illustrates the explosion in the number of publications dealing with NBS after the first appearance in 2009.

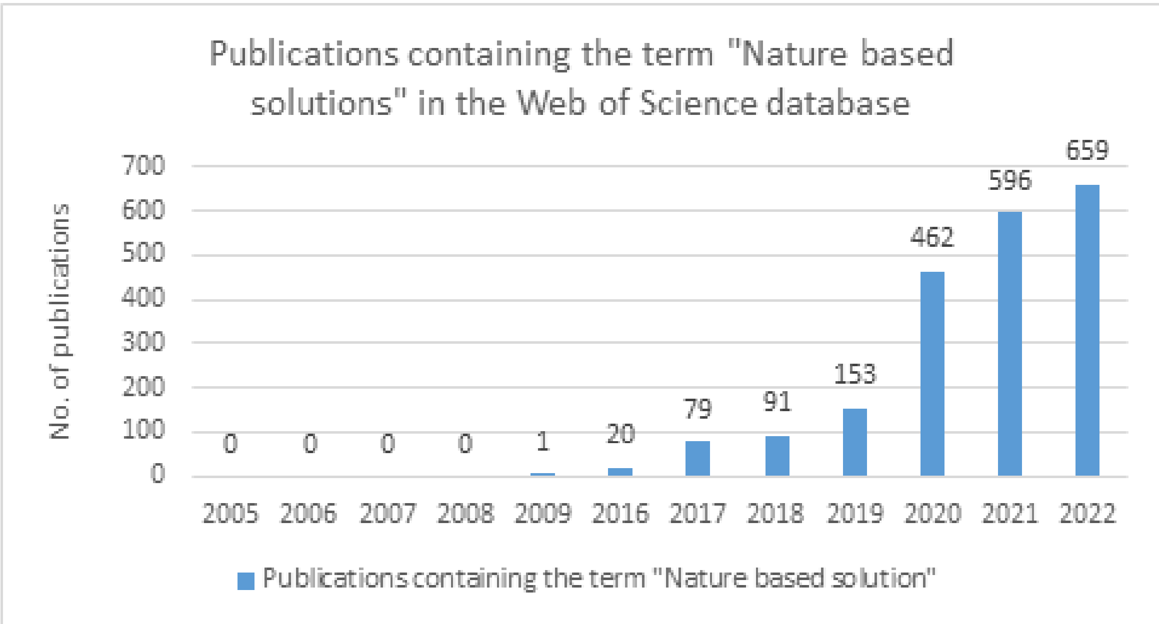

Figure 2 Publications containing the term "nature-based solutions" in the Web of Science database from 2005 to 2022

In 2013, the first NBS-focused research programme was launched. In 2015, the European Commission report on NBS and re-naturing cities (Bauduceau et al. 2015) called for research and innovation on NBS to examine their social, economic and environmental benefits (Sowińska-Świerkosz and García 2022).

In 2015, the NBS concept was included in the European Union's Horizon2020 call, in order to achieve the global goals on climate change and sustainable development and due to the popularity of related scientific research areas such as sustainability, biodiversity, ecosystem services and climate change (Li et al. 2021).

Based on a review of 20 definitions of NBS, Sowińska-Świerkosz and García (2022) found that the different definitions have 4 main characteristics in common: they "(1) are inspired and powered by nature; (2) address (societal) challenges or resolve problems; (3) provide multiple services/benefits, including biodiversity gain; and (4) are of high effectiveness and economic efficiency."

A study published in 2022 aimed at clarifying the concept of NBS by conducting a systematic review of publications and identifying key words used in the definitions (Figure 3). On 30 January 2021, Scopus was searched for publications including the term 'nature-based solution' in their title, abstract and/or keywords.

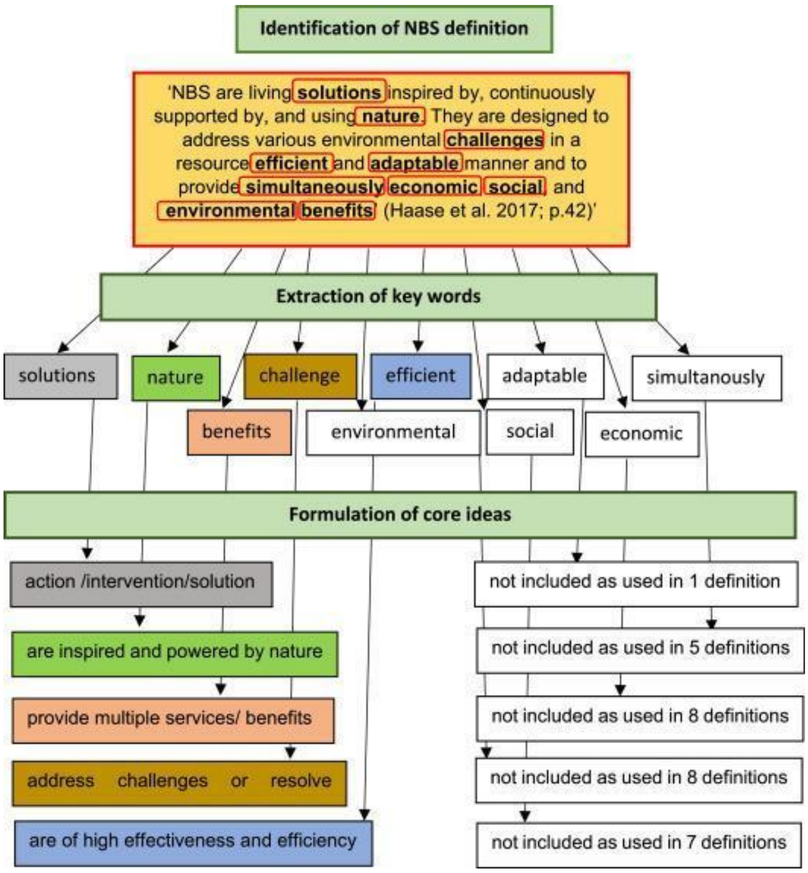

Figure 3 Identification of NBS definition (Sowińska-Świerkosz and García 2022)

Out of the 970 documents retrieved, the most relevant 200 were screened, 64 were detailed analysed and 20 documents contained a definition of NBS. The analysis revealed that the NBS concept is centred around an 'action'/'intervention'/'solution' term, along with key words related to the purpose (e.g. 'challenge', 'society', 'biodiversity') and style (e.g. 'powered by nature', 'sustainable', 'efficient/effective') of the action. Overall, NBS involves actions that are inspired and powered by nature, address societal challenges or resolve problems, provide multiple services/benefits (including biodiversity gain), and are highly effective and economically efficient (Sowińska-Świerkosz and García 2022).

NBS is now widely recognised as a means of addressing environmental and societal objectives. For example, the European Union has recognised NBS as a key strategy for achieving its biodiversity and climate objectives, and the United Nations has also identified NBS as a key strategy for achieving the Sustainable Development Goals (SDGs).

In conclusion, the development of the NBS concept has been influenced by a range of fields of study and practices, including ecosystem services, ecosystem-based management, and ecological restoration. NBS has become a prominent strategy for addressing environmental and societal challenges, but further research is required to ensure its successful implementation.

2.2 Typology of NBS

Clarifying the definition of NBS is closely linked to the question of how to categorise NBS. Several of the studies that have been carried out in order to develop a definition have also included the categorisation of NBS.

An example is the research by Castellar et al. (2021) to develop a common understanding of the nomenclature and typology of NBS. The research involved a review of 4 European research projects. After elicitation workshops to develop an integrative list of NBS, and a conceptual hierarchical classification, the NBS were clustered. An integrative assessment of NBS performance was developed, based on the qualitative evaluations from each project (Figure 4).

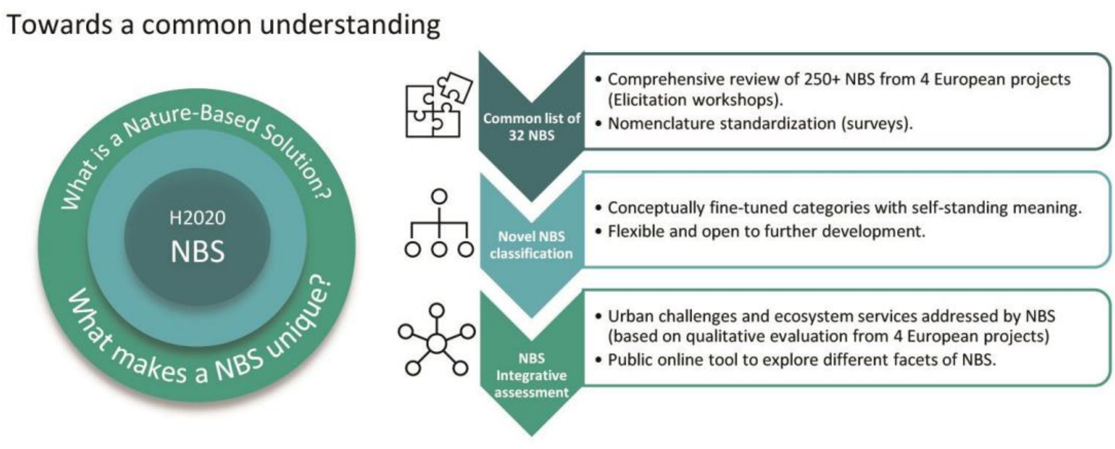

Figure 4 Research methodology to create the concept of NBS (Castellar et al. 2021)

The research resulted in the following hierarchical classification of NBS (Figure 5).

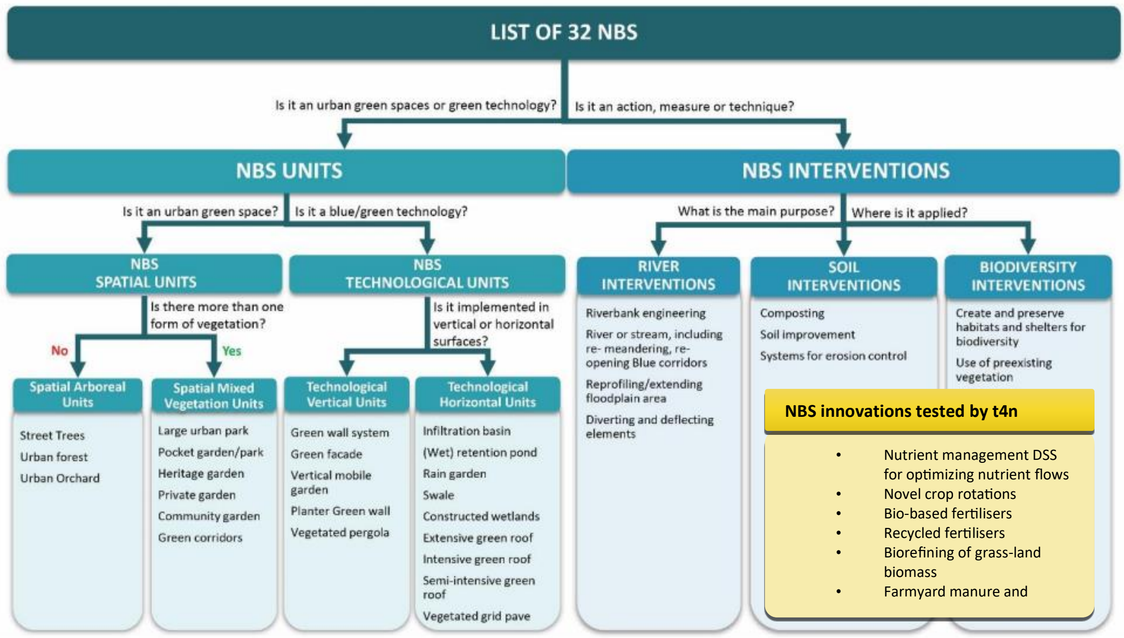

Figure 5 A possible hierarchical classification of considered NBS (Castellar et al. 2021) and NBS innovations tested in trans4num

Figure 5 is complemented with innovative NBS that are being tested in the trans4num project. The methods to be tested are basically classified in the above categories of NBS interventions, including "soil interventions" and "biodiversity interventions". We have not divided the methods used into soil and biodiversity interventions, as these interventions tend to overlap. For example, crop rotation can be a soil intervention but can also enrich the biodiversity of the area, or various soil improvement interventions can increase soil biodiversity.

According to the above classification, methods belonging to the categories "soil interventions" and "biodiversity interventions" will be tested in trans4num test sites, such as novel crop rotations, bio based and recycled fertilizers, biostimulants.

Another typology by Eggermont et al. (2015) to characterize NBS along two gradients (Figure 6):

1. How much engineering of biodiversity and ecosystems is involved in NBS?

2. How many ecosystem services and stakeholder groups are targeted by a given NBS?

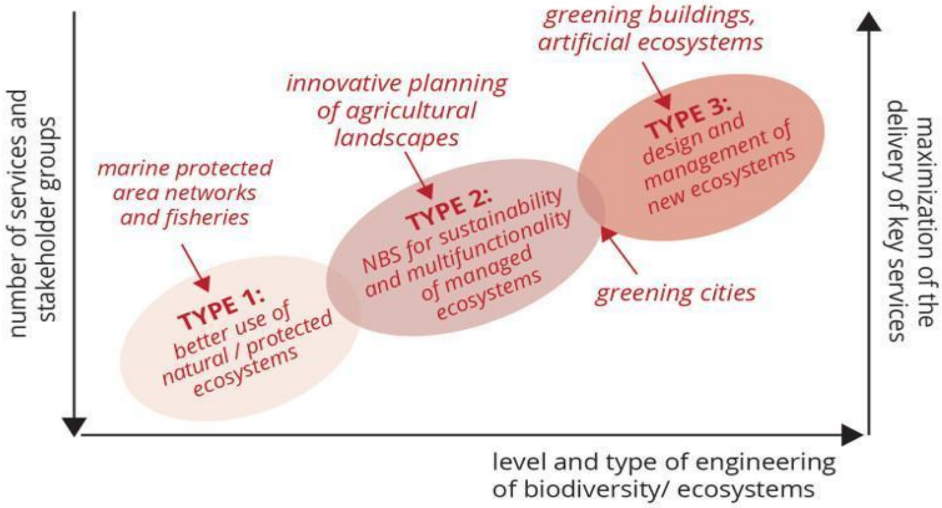

Figure 6 Schematic representation of the range of NBS approaches (Eggermont et al. 2015)

The NBS tested in trans4num (e.g. crop rotation, no tillage, cover crops, biostimulants) can be classified as type 2, NBS for sustainability and multifunctionality of managed ecosystems.

Anderson and Gough (2022) used the IUCN framework and its key categories as a starting point to categorize NBS (Figure 7), to show how each application behaves as a complex intervention to address societal challenges.

Figure 7 illustrates the five categories defined by IUCN with general examples, while also illustrating specific NBS applications and their associated benefits.

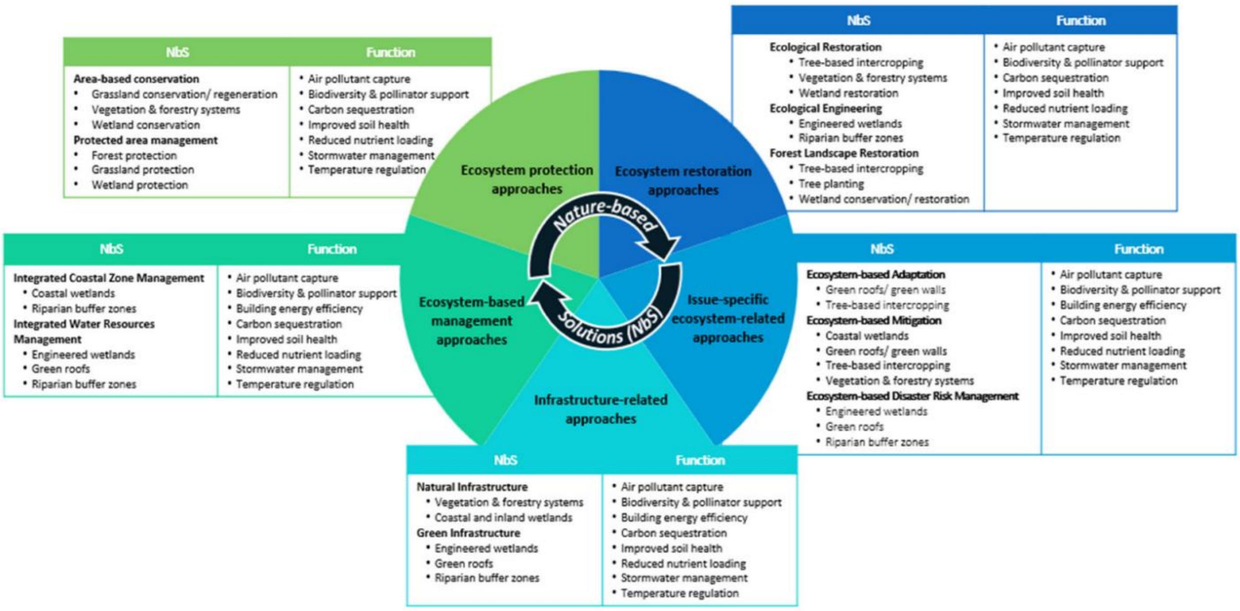

Figure 7 Linkage of IUCN NBS categories and generic examples to specific NBS and associated functions (Anderson and Gough 2022)

2.3 Different approaches and definitions of NBS

Based on a targeted literature review, four different approaches to describe and define NBS can be distinguished:

1. **The ecosystem perspective**: At the heart of this definition is the need for strong ecosystem management and restoration at local, regional, landscape and national level (UNEP 2022; Cohen-Shacham et al. 2016). The effective use of ecosystems and their services should in turn contribute to meeting general societal challenges such as food security, climate change, social and economic development and many more by simultaneously ensuring the local communities' needs. NBS is therefore used as an umbrella term for referring to ecosystem related approaches managing societal challenges. In practice, examples for this perspective are often characterised by minimal interventions in ecosystems, highlighting preservation such as protection of mangroves or coastal areas (Eggermont et al. 2015). IUCN (2020a) proposed a standard for NBS with 8 criteria and 28 indicators to precise and clarify the concept for a common understanding (Figure 8). Through the standard, the extent to which a proposed solution qualifies as an NBS can be assessed. It also identifies actions that can be taken to further strengthen the robustness of the interventions, using a scale of: strong, adequate, weak and insufficient. This tool enables purposeful design solutions and to adhere to the criteria and indicators. At the same time, it allows for building in adaptive management mechanisms that maintain the relevance and robustness of the solution through its lifespan.

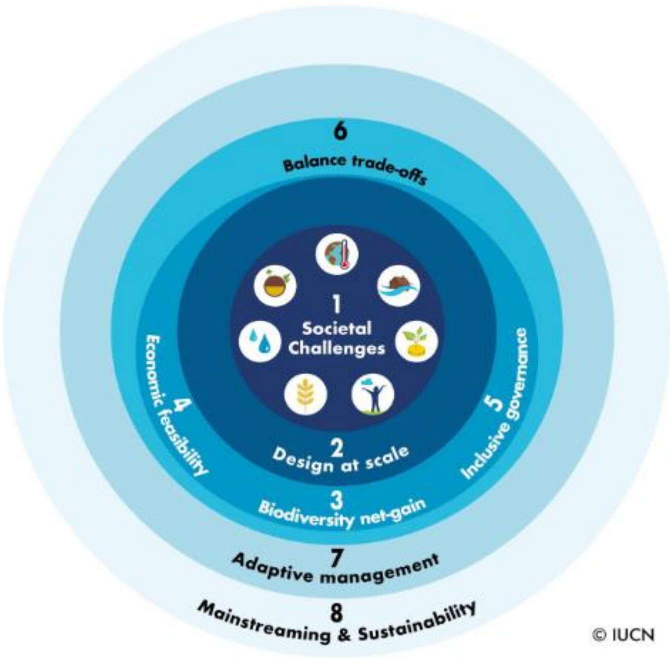

Figure 8 Criteria for NBS (IUCN, 2020a)

2. **The economical perspective**: From the European Commission's (EC) perspective, NBS are expected to contribute to more resilient economies that warrant people's needs also in times of climate change and other risks. In practice this approach focuses on development and management of sustainable and multifunctional ecosystems to

improve its delivery, such as increasing multifunctionality of agricultural landscapes or enhancing tree genetic diversity in forests for increased resilience to climatic developments (Eggermont et al. 2015). Further an aim is to create new ecosystems, for instance, roof gardening, green and blue infrastructure and restoration of degraded and polluted areas as source for green growth and development (Eggermont et al. 2015). Research in this regard, shall provide and improve framework conditions for NBS at EU policy level (Wild et al. 2020). This approach contributes to the development of a European research and innovation community and mainstreams NBS in international research and innovation. Research is therefore expected to advance the development, uptake and upscale of innovative NBS in the light of strong (European) economies. The updated version of EC's definition more strongly emphasises a more passive and "natural" development of economy and habitats such as cities, land- and seascapes compared to the original definition (EC 2022).

3. **The agricultural perspective**: In this perspective agricultural practice and producers are put in the centre by highlighting "cost-effective interventions that can enhance resilience in agriculture and food production, while mitigating climate change and enhancing nature and biodiversity" (Iseman and Miralles-Wilhelm 2021). A critical role for the development of landscapes and managing of climate and environment challenges is seen for agricultural producers as they directly work with and depend on land and water resources. They can have a positive role as they finally implement NBS but also a destructive role in a way that many inhibiting factors beforehand such as initial costs, risk perception and willingness to change have to be overcome for the adoption of NBS. To support the implementation, direct economic and broader societal benefits to producers in agricultural production and grazing management need to be created. Nevertheless, implementation at landscape scale should be done by diverse stakeholders to maximise benefits and scale up impacts. Policy could enable and guide this development through different tools such as law and regulation, economic incentives, capacity building and communication.
4. **The agri-ecological perspective**: Simelton et al. (2021) see "the use of natural processes or elements" as the starting point to improve "ecosystem functions of environments and landscapes affected by agricultural practices" by at the same time "enhancing livelihoods and other social and cultural functions, over various temporal and spatial scales". Meeting these challenges in landscapes through the use of NBS, a framework was designed. The categorise of the framework sustainable practices, green infrastructure amelioration of environmental factors and conservation are proposed to add functionality, purpose and scale in designing projects.

Summarising the above-mentioned approaches NBS are environmentally friendly practices and natural infrastructures derived from site-specific experimentations and problem-solving processes in intensive agri-food systems and rural landscapes, which can provide low-risk and cost-effective solutions for simultaneously gaining socio-economic, natural and cultural benefits.

Based on project-internal work, further understandings of NBS were presented. For instance, from a practitioner perspective, NBS in the context of nutrient management, is the standard fertilisation for the future that keeps yields and quality at the level we are used to, based on local circularity. In a modelling perspective, NBS can be a decision-support system that estimates the effect of using bio-based fertilisers, green refining biomass, and crop rotations for optimal nutrient (i.e., N and P) management options, both in conventional and organic farms and at landscape and regional scales.

NBS definitions

"Actions to protect, sustainably manage, and restore natural and modified ecosystems, that address societal challenges effectively and adaptively, simultaneously" benefiting people and nature (IUCN 2016; Cohen-Schacham et al. 2016).

Nature-based agriculture is a form of sustainable agriculture and part of a resilient ecosystem and food system. It makes optimal use of ecological processes and integrates them into farming practice. Nature-based agriculture also directly contributes to the quality of the natural environment itself, producing food within the boundaries set by the environment and having a positive impact on biodiversity (van Doorn et al. 2016).

UN environment assembly: "Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits" (UNEP 2022)

"NBS are solutions that can transform environmental and societal challenges into innovation opportunities, by turning natural capital into a source for green growth and sustainable development" (EC 2015).

"Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions." (EC 2022)

"NBS are cost-effective interventions that can enhance resilience in agriculture and food production, while mitigating climate change and enhancing nature and biodiversity" (Iseman and Miralles-Wilhelm 2021).

"NBS are measures that protect, sustainably manage or restore nature, with the goal of maintaining or enhancing ecosystem services to address a variety of social, environmental and economic challenges." (OECD 2020).

Examples of NBS definitions and use in some trans4num partner countries

Czech Republic

Climate change has an effect on a number of areas and sectors in everyday life and also in economies. Besides direct impacts on the community of cities and villages such as, for example heat waves, drought, floods, diseases and internal migration, climate change affects all national economies, including agriculture. Agriculture is a very sensitive sector to climate change because of the significant effect of climate change on agricultural production and ecosystems as well as for landscape and soil. These challenges need to be solved also by the Czech Republic (Ministry of the Environment in 2017). To answer these challenges adequately, the Czech Republic must introduce new measures, agricultural practices and mindset for their farmers that contribute to solving problems that have been overlooked or handled inadequately due to limited resources (erosion, soil removal, water quality, etc.).

In the Czech Republic, most nature-based solutions are limited to cities based on the available information. The previously discussed natural phenomena caused by radical environmental changes influence the quality of life in cities and impact infrastructure, human health and city life (EEA, 2017). The green buildings (ESB-magazin 2017; Zelene Strechy 2017; Inspirace 2016), different educational programme (Křenovská I 2014; Lipka 2015), the renovation and revitalization of nature in public places (Denik 2012; City of Brno 2017; Centrum News 2020; Water in Brno, 2020) as urban nature-based solutions are well discussed in literatures (Badura et. al., 2021; Vojvodíková et. al., 2022), but there is less discussion on nature-based solutions used in agriculture sector in Czech Republic.

Territorial System of Ecological Stability - An interconnected complex of natural, or even modified, though nearly natural, ecosystems which are capable of maintaining a natural balance. There are local, regional and supraregional systems.

Denmark

There is no policy or law in Denmark that mentions NBS, so there are many different definitions in academia, however the IUCN definition and the EU definition seem to be the ones used mostly. The Nordic Council of Ministers has just recently initiated a program on this, and published a report:

https://norden.diva-portal.org/smash/get/diva2:1724385/FULLTEXT01.pdf: they use this definition: "definition of NBS as actions based in nature to address societal challenges and that NBS imitate and enhance natural processes and mechanisms"

England

“Ways of working with natural processes to provide benefits to people and nature” (EA 2022)

Specifically, in relation to climate change: A collection of approaches that offer the potential to reduce and remove emissions by “enhancing the ability of ecosystems” to sequester carbon dioxide (by capturing, removing and storing carbon dioxide from the Earth’s atmosphere), or by “reversing the degradation of an ecosystem” so that it no longer emits greenhouse gas emissions."

Hungary

The H2020-funded NATURVATION project carried out a study in 2017 on EU and national policy instruments and relevant national policy discourse and developments on NBS.

Interviews conducted during the study revealed that while the term NBS rarely appears at the national level (neither in policies nor in discourses), it has emerged in recent years in local discussions. Other related concepts have been around for over 10 years, with terms like GI more recently being integrated into sectoral discourses, national strategies, and informational campaigns. ‘Sustainable management’ is the term that is estimated to have been used most frequently in the past on the whole within different sectoral discussions, but more recently the ‘green (and blue) infrastructure’ or ‘ecosystem-based approaches’ have gained in usage within nature conservation discussions.” (Davis et al., 2017)

Hungary's Fundamental Law lays the foundations for the regulation of the NBS: “Natural resources, in particularly arable land, forests and water resources, biodiversity, in particular native plant and animal species, and cultural values are the common heritage of the nation, which the state and all of us have the duty to protect, maintain and preserve for future generations.” (Hungary's Fundamental Law).

The current environmental policy does not sufficiently support the use of these approaches. The concept of NBS is reflected in several horizontal and sectoral policies and partially in regulations, but the regulatory environment for implementation and the institutional system is still lagging.

Switzerland

The government talks here and there about NBS - but remains rather vague in general - or then specifies it for concrete cases, c.f. e.g. a talk by the director of BAFU (Federal Office for the Environment). Other organisations also use their definitions, but all remain rather general. Business uses the following definition (Swiss Business Network 4 Nature, https://sb4n.ch/ - a business network with many larger companies as members, e.g. Holcim: concrete production, etc.): "What are Nature-based Solutions?

Nature-based Solutions are actions that work with and enhance nature to help address societal challenges. The concept is grounded in the knowledge that healthy natural and managed ecosystems produce a diverse range of services on which human wellbeing depends.

We believe that mainstreaming nature conservation into key economic sectors is essential. Increasingly, governments and business alike recognise that NBS are not only useful tools, but imperative for addressing the dual global crises on biodiversity loss and climate change." - In this generality, it is rather void of contents, though.

China

China's five-year development strategy for green agriculture was announced by the Chinese government in 2021. The plan, jointly issued by six ministries including the Ministry of Agriculture and Rural Affairs, identified resource protection, pollution control, restoration of agricultural ecology and development of a low-carbon agricultural industrial chain as key tasks for 2021-2025.

The plan identified the following challenges for the development of green agriculture in China:

- Awareness and perception
- Extensive production through intensive use of external inputs
- Insufficient supply of quality products and poor sustainability standards
- Governance issues (e.g. incentives and regulations)

The plan identified the following objectives and possible outcomes (Table 1).

Table 1 Objectives and anticipated outcomes of the agenda and planning

Objectives	**Specific outcomes**
Improving efficiency of nature resource use	Land and water use efficiency
Bettering environmental quality and **pollution**-mitigation	**Fertilizer** and **pesticide** efficiency; integrative **straw** use; **manure** use efficiency; retrieving field film; soil conditioner and biological fertilizer; recycling **residuals**
Strengthening **ecosystem** (e.g. biodiversity, forestry, grassland)	**Minimise of land degradation**; recovery of 'black soil' (chernozem) in Northeast China
Enhancing **supply chain** capacity (e.g. quality supply, branding)	**Certification** to organic and PGI; **ecolabel**
Carbon sequestration and mitigation	Ecosystem **valuation**; **monitoring and surveillance**

Regional and territorial consideration:

- Peri-urban animal husbandry, especially for large-scale farms
- Peri-urban aquaculture and water pollution
- Straw mulching: major grain production areas (i.e. Northeast, North China Plain, Yangtze River)
- Fallow and rotation: Northeast; North China Plain (Yellow River Basin); Yangtze River
- Farming-pastoral or mixed/integrating crop-livestock: North; Northwest; importantly, for counties with large livestock and major crop production
- Ecosystem approaches and management: Yellow River Basin (mountains, rivers, forests, farmlands, lakes and grasslands)
- Integrated rice and aquaculture farming: Yangtze River; Pearl River Delta

Governance and institutions:

- Green supply chain (e.g. infrastructure; e-commerce; standards and eco-label; consumption)
- Innovation platform and farmer entrepreneurship
- Smallholder family farmers (e.g. advisory services; integrated services; extension; capacity development)
- Digital tools and digital services
- Watershed approaches and management (in reference to management by administrative areas)
- Payment for ecosystem services and protection

2.4 Key concepts connected to NBS

In order to have a coherent approach to the NBS examined in the framework of the trans4num project, several target areas/concepts have been identified, the preliminary definition of which is critical in the light of the interpretation of the expected results. These target areas are the following: **nutrient flow, climate change, agroecology, restoration ecology, regenerative farming and ecosystems.** In the next chapter, the definitions of these target areas will be clarified by monitoring their changes over time.

Climate change

Climate change and its impact on the environment, ecology, society, political decisions and economy have long been researched (Adger et al. 2005; Leal Filho et al. 2021; Feliciano et al. 2022). The interpretation of the concept of climate change has changed slightly over time, and additional concepts with slightly different meanings such as Global Warming or Climate Emergency have been introduced for its comprehensive understanding (Munasinghe 2010; Kyte, 2014; Princiotta and Loughlin, 2014; Martens et al., 2016). The study of the impact of human activity on the environment has become an increasingly popular research topic since the 1950s (Pierrehumbert 2010; Peterson et al., 2008).

In 1992, the official concept of climate change was designed by The United Nations Framework Convention on Climate Change (UNFCC). Accordingly, Climate change means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and is in addition to natural climate variability observed over comparable periods (UNFCCC, 1992). According to the Intergovernmental Panel on Climate Change (IPCC), the Climate change is a long-term change in the typical or average weather of a region. Supplementing the UNFCCC concept, the attention was raised not only the human but also to the industrial activities that have led to gradually accelerating changes in the climate in the last few decades, including an annually incremental increase in the average surface temperature, which has been defined as climate change (IPCC, 2014). In 2018, IPCC reformed the previous definition as “a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period” (IPCC, 2018).

Researchers have further specified the concept of climate change according to its impacts. It is considered that it can be characterised based on the comprehensive long-haul temperature and precipitation trends and other components such as pressure and humidity level in the surrounding environment. Besides, the irregular weather patterns, retreating of global ice sheets, and the corresponding elevated sea level rise are among the most renowned international and domestic effects of climate change (Lipczynska-Kochany 2018; Michel et al. 2021; Murshed and Dao 2020).

Climate change is a phenomenon, or rather a set of phenomena, which has almost unanimously been recognized as being practical and affecting the environment and populations globally (Kellstedt et al. 2008).

Agroecology

The term agroecology, which appeared primarily as a natural science field at the start of the 20th century, had its scope continuously widened, expanded and changed in different continent during the last 100 years (Wezel et al. 2009; Argüello 2015, Altieri et al. 2017, Toledo et al. 2017). The word agroecology has been first introduced in the scientific publications by Bersin (1928, 1930) and despite the growing number of publications, there is still debate on its exact definitions.

At the genesis of agroecology, it focused mainly on the farm level solutions, or the farm agroecosystem. This approach encouraged farmers to substitute the inputs and practices of conventional monoculture-based industrial farming and move towards certifiable organic production systems (Bersin 1928, 1930).

From the 1990s, the definition of agroecology included the ecology of the entire food system. By its meaning, the agroecosystem was no longer just the farm, but needed to include all aspects and participants in the food system (Francis et al. 2003). The finding of Gliessman (2007), agroecology became a way of building integrated, interlinked and relationship-based market systems that are equitable, just, and accessible for all. As Wezel et al. (2009) advocated later that agroecology comprises three interlinked and complementary approaches: agroecology "as a scientific discipline," "as a set of practices," and "as a movement." According to FAO. (1996) and Fischer et al. (2005), the concept of agroecology is a relatively standardised biophysical climate-soil-landscape framework that may benefit long-term agricultural production. Others stated that it is a much broader approach which helps to achieve sustainable food systems through ecological principles (Francis et al. 2003).

As the concept of agroecology has been strengthened during the last decades, thus the agroecology has taken a political economy focus in order to confront and develop alternatives to the political and economic power that has created the "lock-ins" (IPES-Food 2016) that keep food systems from changing (Gliessman 2015).

The official definition of agroecology has evolved to the following (Gliessman 2018):

"Agroecology is the integration of research, education, action and change that brings sustainability to all parts of the food system: ecological, economic, and social. It is transdisciplinary in that it values all forms of knowledge and experience in food system change. It is participatory in that it requires the involvement of all stakeholders from the farm to the table and everyone in between. And it is action-oriented because it confronts the economic and political power structures of the current industrial food system with alternative social structures and policy action. The approach is grounded in ecological thinking where a holistic, systems-level understanding of food system sustainability is required."

Regenerative/Circular farming

1979 was the year when the definitions of regenerative agriculture (RA) were first introduced by Gabel (1979) and then Rodale in 1983 further articulated the concept of regenerative farming. They found that RA includes **(i)** avoiding or reducing tillage of soil, **(ii)** using cover crops for maintaining and boosting the soil quality, **(iii)** fostering plant diversity, and **(iv)** harmonising the livestock and cropping system. The new holistic approach with a focus on environmental and social improvements considered the use of "internal" resources available on the farm instead of imported energy "external" resources including chemical fertilizers and pesticides (Rodale 1985, 1986).

Since the introduction of the first definition, other concepts of RA have been developed by various researchers. Francis et al. (1986) proposed again that RA emphasises the use of resources found on the farm while restricting the use of synthetic inputs. The result of Duchin (2017) uses the term to refer to annual cropping systems including at least four of six sustainable practices. According to Sherwood and Uphoff (2000) and Rhodes (2017), RA is a biological principles-based system enhancing not only environmental management but also productivity.

RA is a tool for using different farming techniques (Duncan 2015) in order to restore and realise the potential of damaged landscapes (Francis and Harwood 1985; Massy 2013, 2017; Wahl 2016). Later and Malik (2014) and Elevitch et al. (2018) highlighted that RA is a dynamically advanced modified agricultural technique involving the use of organic farming methods while supporting the capacity for self-renewal and resiliency, contributing to soil health, increasing water percolation and retention, enhancing and conserving biodiversity, and sequestering carbon by the soil.

There is currently no uniformly accepted definition on regenerative agriculture therefore four widely-used, and accepted definitions on regenerative agriculture were identified by trans4num project which cover all aspects of RA:

1. *"Regenerative organic agriculture is marked by tendencies towards closed nutrient loops, greater diversity in the biological community, fewer annuals and more perennials, and greater reliance on internal rather than external resources." (Rodale Institute 2014).*

2. *"Regenerative agricultural includes the following: **(i)** contribute to generating/building soils and soil fertility and health; **(ii)** increase water percolation, water retention, and clean and safe water runoff; **(iii)** increase biodiversity and ecosystem health and resiliency; and **(iv)** invert the carbon emissions of our current agriculture to one of remarkably significant carbon sequestration thereby cleansing the atmosphere of legacy levels of CO_2." (Kastner 2016).*

3. *"Unifying principles consistent across regenerative farming systems include: **(1)** abandoning tillage (or actively rebuilding soil communities following a tillage event); **(2)** eliminating spatio-temporal events of bare soil; **(3)** fostering plant diversity on the farm; and **(4)** integrating livestock and cropping operations on the land." (LaCanne et al. 2018).*

4. *Schreefel et al. (2020) proposed a provisional definition of RA as "an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting services, with the objective that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production".*

Restoration ecology

Restoration ecology is a scientific discipline that focuses on restoring ecosystems that have been damaged or destroyed by human activities, natural disasters, or other disturbances. The goal of restoration ecology is to return a damaged ecosystem to a state that is as close as possible to its original, pre-disturbance condition. This involves not only restoring the physical and biological components of the ecosystem, but also restoring the ecosystem's function and resilience (Cairns and John 1996).

Restoration ecology draws on principles from ecology, biology, geology, hydrology, and other fields to develop strategies for restoring ecosystems. These strategies may involve reintroducing native species, managing invasive species, altering physical features of the landscape (such as hydrology), and other techniques. Restoration ecologists also consider the social and economic context in which restoration is taking place, and work to engage stakeholders and build support for restoration efforts (Howell and John 2012).

Restoration ecology is important because human activities have caused widespread damage to ecosystems around the world. By restoring damaged ecosystems, we can help to reverse some of the negative impacts of human activities, such as habitat loss, fragmentation, and degradation, and promote biodiversity, ecological functioning, and resilience.

The goal of restoration ecology is not just to return an ecosystem to its pre-disturbance state, but also to restore its ecological functions and services, such as nutrient cycling, carbon sequestration, and water filtration. Restoration ecologists work to identify the causes of ecosystem degradation and develop strategies to address these causes, such as controlling invasive species, reducing pollution, or reintroducing native species (Falk et al. 2006).

Restoration ecology also recognizes the importance of engaging with local communities and stakeholders in the restoration process. Successful restoration efforts often require the cooperation and support of a wide range of actors, including landowners, government agencies, NGOs, and the broader public. Restoration ecologists work to build relationships with these stakeholders and to develop strategies that are socially and economically viable, as well as ecologically sound (Balaguer et al. 2014).

Overall, the concept of restoration ecology is based on the recognition that humans have had a profound impact on the world's ecosystems, and that we have a responsibility to work towards repairing the damage that has been done. By restoring ecosystems, we can help to promote biodiversity, ecological functioning, and human well-being, and create a more sustainable and resilient future for all.

Nutrient flow

Nutrient flow is a term used to describe the movement of essential nutrients, such as carbon, nitrogen, phosphorus, and potassium, through ecosystems. This flow is fundamental to the functioning of ecosystems as it provides the nutrients necessary for the growth and survival of plants and animals. The flow of nutrients through ecosystems is a cycle, which involves both biotic and abiotic processes (Bormann and Likens 1967).

In the biotic process, plants absorb nutrients from the soil through their roots and use them to grow and reproduce. Animals, in turn, consume plants and other animals, thereby obtaining nutrients. When plants and animals die, their bodies decompose, releasing nutrients back into the soil where they can be taken up by other plants. This process of nutrient flow is known as the biogeochemical cycle, which is an essential component of the overall functioning of ecosystems (Lavelle et al. 2005).

Abiotic processes also influence nutrient flow. Weathering and erosion, for example, can cause the release of nutrients into the environment. Nutrients can also be taken up by water and carried through aquatic ecosystems, where they play a critical role in the growth and reproduction of aquatic organisms.

Human activities can disrupt nutrient flow and lead to nutrient imbalances in ecosystems. The use of fertilizers in agriculture can cause an overabundance of certain nutrients, such as nitrogen and phosphorus, which can contribute to harmful algal blooms in aquatic ecosystems. Similarly, urban development can disrupt the natural flow of nutrients and contribute to nutrient pollution (Smaling et al. 1999).

It is essential to understand nutrient flow and its importance in ecosystem functioning to promote sustainable land use practices. By maintaining a balance of nutrients in ecosystems, we can help to promote biodiversity, ecological functioning, and human well-being. Sustainable land use practices, such as sustainable agriculture, conservation, and restoration, can help to maintain healthy nutrient flows in ecosystems (Ohkuma 2003).

In summary, nutrient flow refers to the movement of essential nutrients, such as carbon, nitrogen, phosphorus, and potassium, through ecosystems. It is a critical process in ecosystem functioning and involves both biotic and abiotic processes. Human activities can disrupt nutrient flow, but sustainable land use practices can help to promote healthy nutrient flows and maintain the overall health of ecosystems.

(Agro)ecosystem

The concept of agroecosystem refers to the dynamic and interconnected system that encompasses all the biotic and abiotic components within a specific agricultural landscape. An agroecosystem is managed by humans to produce food, fibre, and other agricultural products. The management practices of an agroecosystem can impact the health of the soil, water quality, biodiversity, and the overall sustainability of the agricultural landscape.

The concept of agroecosystem management focuses on optimizing production while minimizing negative impacts on the environment and enhancing the well-being of the people who rely on these systems for their livelihoods. This can be achieved through various management practices, such as crop rotations, intercropping, integrated pest management, and conservation tillage (Cordoba et al. 2020).

Agroecosystems can vary in scale and complexity, from small-scale subsistence agriculture to large-scale commercial farming. They can also vary in terms of the types of crops and animals grown, the use of inputs such as fertilizers and pesticides, and the level of mechanization.

The concept of agroecosystem recognizes that agriculture is not just about producing food, but also about maintaining the health of the soil, water, and biodiversity, and contributing to the social and economic well-being of the communities involved in agricultural production (McPhee et al. 2021).

Agroecosystems can vary in scale, from small-scale subsistence agriculture to large-scale commercial farming, from monoculture to diverse cropping systems, and from conventional to organic and agroecological practices. The goal of agroecosystem management is to optimize production while minimizing negative impacts on the environment, and to enhance the well-being of the people who rely on these systems for their livelihoods.

A few definitions of agroecosystem were determined:

1. The Food and Agriculture Organization (FAO) of the United Nations defines an agroecosystem as "a spatially and functionally coherent unit of agricultural production, along with its associated biodiversity and environmental resources." This definition emphasizes the interconnectedness of different components within an agroecosystem (FAO, 2014).
2. The United States Department of Agriculture (USDA) defines an agroecosystem as "a dynamic, complex of plant, animal, and microorganism communities interacting with the non-living environment as a functional unit." This definition highlights the fact that an agroecosystem is not just about the crops or animals being produced, but also includes the broader environment and ecological processes (USDA, 2007).
3. According to the Encyclopedia of Ecology, an agroecosystem is "a managed ecosystem that includes agricultural crops and/or animals, as well as the physical and biotic components that interact with them." This definition emphasizes the human management and intervention involved in shaping agroecosystems.
4. “The science and practice of applying ecological concepts, principles and knowledge (i.e., the interactions of, and explanations for, the diversity, abundance and activities of organisms) to the study, design and management of sustainable agroecosystems. It includes the roles of human beings as a central organism in agroecology by way of social and economic processes in farming systems. Agroecology examines the roles and interactions among all relevant biophysical, technical and socioeconomic components of farming systems and their surrounding landscapes” (IPBES, 2018).
5. “Agroecology is understood here as “the science of applying ecological concepts and principles to the design and management of sustainable food systems” (Gliessman, 2007). It encompasses various approaches to maximise biodiversity and stimulate interactions between different plants and species, as part of holistic strategies to build long-term fertility, healthy agro-ecosystems and secure livelihoods. It also represents a social movement; this usage will be specified where relevant” (IPES-Food, 2016).
6. “Agroecology is considered jointly as a science, a practice and a social movement. It encompasses the whole food system from the soil to the organization of human societies. It is value-laden and based on core principles. As a science, it gives priority to action research, holistic and participatory approaches, and transdisciplinarity that is inclusive of different knowledge systems. As a practice, it is based on sustainable use of local renewable resources, local farmers’ knowledge and priorities, wise use of biodiversity to provide ecosystem services and resilience, and solutions that provide multiple benefits (environmental, economic, social) from local to global. As a movement, it defends smallholders and family farming, farmers and rural communities, food sovereignty, local and short food supply chains, diversity of indigenous seeds and breeds, healthy and quality food. Agroecology acknowledges that the whole is more than the sum of its parts and hence fosters interactions

between actors in science, practice and movements, by facilitating knowledge sharing and action" (Agroecology 2018).

7. "Agroecology is an alternative model for developing agriculture. The model is based on each farm being an integrated ecosystem, in which crops, plants and animals interact to create favourable conditions for cultivation. This alternative is knowledge-intensive, requiring farmers to have a lot of knowledge about the functioning of various components in the ecological system, as well as an ability to create synergies between plants, insects, crops and soil fertility. The model also rests on traditional farming methods. Agroecology is a real alternative to conventional agricultural production, and a model that safeguards both the climate and social development. However, it requires civil society to push for change from the bottom up in Uganda, and for markets worldwide to transition to supporting alternative ways of farming the land" (Lund University 2018).

Overall, an agroecosystem is a highly interconnected and managed system that includes crops, animals, soil, water, and other environmental factors, all of which interact with each other in complex ways.

Socio-ecological and socio-economic contexts

Nature-based solutions offer a range of socio-economic benefits that can help address environmental and societal challenges while promoting sustainable development. Nature-based solutions can enhance ecosystems and species by increasing habitat diversity, restoring aquatic ecosystems and wetlands and improving the quality and reliability of water (Abell et al. 2017).

Socio-ecological context

The socio-ecological context of NBS refers to the interaction between social and ecological systems. NBS are often designed to address environmental problems, such as climate change and biodiversity loss, but they must also take into account the social and cultural contexts in which they are implemented. For example, urban green spaces can provide multiple benefits, such as improved air quality and climate regulation, but they also play an important role in community building and social cohesion (Pataki et al. 2011).

Additionally, the success of NBS is often dependent on the ecological context in which they are implemented. For example, the restoration of degraded ecosystems can provide multiple benefits, such as carbon sequestration and improved water quality, but the success of restoration efforts is often dependent on the availability of suitable habitats and the presence of key species (Chapin et al. 2010).

A few examples:

1. Green jobs: NBS can create new employment opportunities, particularly in rural areas. For example, the restoration of degraded landscapes, such as forests or wetlands, can create jobs in tree planting, soil conservation, and ecological monitoring.
2. Payment for ecosystem services (PES): PES schemes reward individuals or communities for providing ecosystem services such as carbon sequestration, water filtration, or biodiversity conservation. These schemes can provide a source of income for landowners and contribute to the conservation of natural resources.

3. Ecotourism: NBS can create opportunities for nature-based tourism, generating revenue for local communities. For example, the establishment of nature reserves or the restoration of degraded habitats can attract visitors interested in wildlife watching, hiking, or birding.
4. Co-benefits: NBS can deliver multiple benefits beyond environmental outcomes. For example, urban green spaces can provide recreational opportunities, improve mental health, and reduce urban heat island effects.
5. Social equity: NBS can address social and economic inequalities by providing access to natural resources and ecosystem services for marginalized communities. For example, the restoration of urban parks or green corridors can enhance the quality of life in low-income neighbourhoods.
6. Livelihood diversification: NBS can provide alternative sources of income for communities that rely on natural resources for their livelihoods. For example, sustainable forestry practices can provide income from non-timber forest products such as mushrooms, berries, or medicinal plants.
7. Green infrastructure: NBS can provide cost-effective solutions for infrastructure development. For example, using natural systems such as wetlands or mangroves for coastal protection can be cheaper and more effective than building seawalls.

In 2017, study of Davis et al. identified key concepts and terms related to NBS aimed at improving human well-being through the appropriate management of ecosystem services and natural capital (Potschin et al. 2016). The concepts and terms identified were as follows (Table 2).

Table 2 Concepts related to NBS and societal challenges addressed. Source: Davis et al. (2017)

Concepts and terminology relating to NBS	**Societal challenges potentially addressed by NBS (adapted from the SDGs and Raymond et al. 2017 for use in NATURVATION)**
• Green (and blue) infrastructure • Ecosystem-based adaptation • Ecosystem-based mitigation • Ecosystem-based approach • Natural water retention measures • Ecological engineering • Working with nature • Nature-based infrastructure	• Climate action for adaptation, resilience and mitigation • Water management • Coastal resilience and marine protection • Green space, habitats and biodiversity • Environmental quality, including air quality and waste management • Regeneration, land use and urban development • Inclusive and effective governance • Social justice, inequality and social cohesion • Health and well-being • Economic development and decent employment • Cultural heritage and cultural diversity • Sustainable consumption and production

Socio-economic context

The socio-economic context of NBS refers to the social and economic factors that influence the success of NBS. For example, the availability of financial resources can be a critical factor in determining whether NBS are implemented and maintained over time. In addition, the cultural and institutional context in which NBS are implemented can play an important role in their success. For example, in some cases, traditional ecological knowledge can be an important factor in the success of NBS (Berkes et al., 2000).

Another important socio-economic factor is the involvement of stakeholders in the planning and implementation of NBS. Stakeholder involvement can help ensure that NBS meet the needs of the local community and are supported by key stakeholders (Borgström et al. 2015).

2.5 Scientific areas related to NBS

In 2016 the International Union for Conservation of Nature and Natural Resources (IUCN) defined nature-based solutions as an overarching concept that encompasses approaches from many different areas of scientific research, practice or policy, but with a common characteristic of focusing on ecosystem services and addressing societal challenges (Cohen-Shacham et al. 2016).

A Web of science query by SZE in March 2023 resulted in 2,182 publications containing the term "nature-based solutions" (Figure 9). The distribution of these by scientific area is shown in the figure below. It can be seen that the majority of the results, about 50%, are from the fields of environmental sciences and environmental studies (25%), with other prominent fields being Green Sustainable Science Technology (22%), Water Resources (19%), Environmental Engineering (almost 12%) and Ecology (11%). Other fields below 10% cover topics ranging from e.g. Ecology to Urban Studies, Meteorology and Forestry. (Remark: The Web of Science database does not explain the difference between the terms "environmental sciences" and "environmental studies", nor does it specify their definition.)

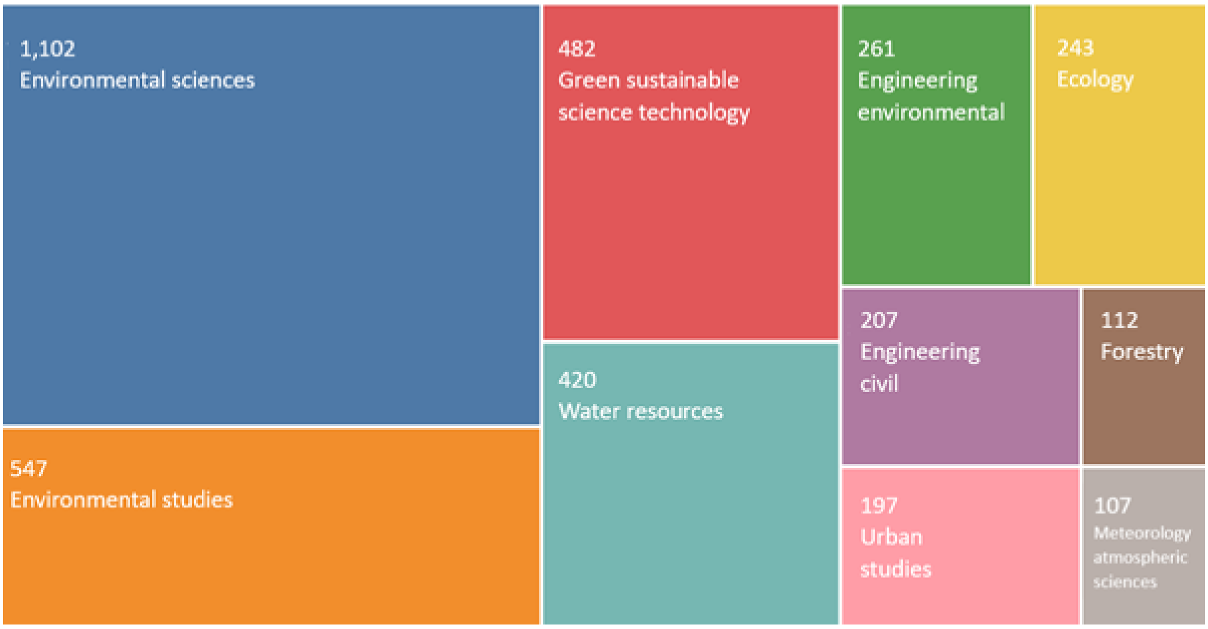

Figure 9 Web of science query 2023.03.28 (The areas on the chart are not strictly proportional to the values of each entry)

2.6 IUCN Global Standard for NBS

One of the world's most comprehensive and inclusive international initiatives to create a standardised global NBS definition was launched by IUCN in 2020. IUCN members are states, government agencies, subnational governments, political/economic integration organisations, national and international NGOs, and other organisations committed to the conservation of nature.

The aim of creating the Global Standard was to create a common, user-friendly framework for the verification, design and scaling up of Nature-based Solutions.

"Nature-based solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits." (IUCN 2016)

About IUCN

"IUCN is a membership union made up of government and civil society organizations that helps promote human progress, economic development, and nature conservation. It was established in 1948 and is now the world's largest environmental network, with over 1,400-member organizations and 15,000 experts. It provides conservation data, assessments, and analysis, and serves as a trusted repository of best practices and international standards." (IUCN 2020b)

IUCN's innovative conservation initiatives for protecting, managing and restoring the environment over decades are delivering tangible and sustainable benefits for people. This approach has become known as nature-based solutions (Figure 10).

Figure 10 "Nature-based Solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits" (IUCN 2020b)

Development of the global standard

The IUCN first referred to NBS in a position paper for the United Nations Framework Convention on Climate Change (IUCN 2009), after which the term has been quickly taken up by policy, viewing NBS as an innovative mean to create jobs and growth part of a green economy (Eggermont et al. 2015).

The introduction to the IUCN Global Standard for NBS points out that there was an urgent need for a standardised framework for nature-based solutions to ensure consistent and effective implementation of NBS projects. Without such a standard, NBS applications could be inconsistent and ungrounded (IUCN 2020b).

The IUCN Global Standard for Nature-based Solutions provides a systematic learning framework that enables lessons to improve and evolve applications, leading to greater confidence among decision-makers. The Standard also provides an opportunity to create a global user community that can guide implementation on the ground, accelerate policy development and generate conservation science on NBS. Ultimately, the Standard aims to provide a common understanding and shared vision of NBS to achieve a just and sustainable world (IUCN 2020b).

The document Guidance for using the IUCN Global Standard for Nature-based Solutions discusses how several conservation approaches developed since the 1990s, including Forest Landscape Restoration, Sustainable Land Management, and Ecological Restoration, have been able to deliver conservation outcomes that provide tangible benefits to society, such as jobs, improved land productivity, erosion control, and carbon sequestration. The NBS concept „was developed as part of an ongoing paradigm shift that began in the 1980s in which people are viewed as proactively protecting, managing, or restoring ecosystems to address major societal challenges".

Over the past decade, NBS has gathered momentum and has been incorporated into policy, economic plans, and national strategies for biodiversity and climate change. With this growing appreciation and investment, there was an increasing need to define the term. The document highlights the importance of the IUCN Global Standard for NBS in providing a standardized framework, which will help to ensure consistent and effective deployment of NBS projects, leading to greater confidence among decision-makers and a shared vision for a just and sustainable world (IUCN 2020b).

Aim of the IUCN Standard

"The Standard will enable practitioners to standardise the design and implementation of NBS, by: 1) Setting a common basis of understanding for what an NBS is and is not; 2) Contributing to transformational changes, by improving NBS practice, and supporting the clarification and development of NBS-related policy" (IUCN 2020b)

The Standard helps users design and verify NBS to solve societal challenges. It is a facilitative Standard that avoids rigid normative framing and definitive thresholds. Instead, it supports users to continuously improve the effectiveness, sustainability, and adaptability of their NBS interventions based on feedback from actual and potential users (IUCN 2020b).

The Standard consists of 8 criteria and 28 indicators built on the concept's principles and feedback from consultations with stakeholders and refer to the following aspects (Sowińska-

Świerkosz and García 2022): "(1) address societal challenges; (2) landscape scale of intervention; (3) biodiversity gain; (4) economic viability; (5) governance capability; (6) equitably balance trade-offs; (7) adaptive management; (8) mainstreamed within an appropriate jurisdictional context."

3. NBS in agriculture

3.1 The role and potential for NBS in agriculture

According to (Miralles-Wilhelm 2021) NBS encompass a broad range of practices that can be deployed directly in the context of the production of food and fibre, either by agricultural practitioners or on lands or waters used for production.

Van Doorn et al. (2016) stated that nature-based agriculture is a form of sustainable agriculture and part of a resilient ecosystem and food system. It makes optimal use of ecological processes and integrates them into farming practice. Nature-based agriculture also directly contributes to the quality of the natural environment itself, producing food within the boundaries set by the environment and having a positive impact on biodiversity.

Agriculture NBS (Ag-NBS) are an effective, long-term, cost-efficient approach to tackling sustainable land and water resources management and climate change. These practices can help improve water availability and quality as well as restore ecosystems and soils worldwide, while offering substantial health co-benefits and achieving global food security. These strategies can contribute to the attainment of multiple goals of the 2030 Sustainable Development Agenda.

Farmers and food producers are important stewards of our ecosystem and on the frontlines of climate change, and play an important role in developing and implementing environmental and agriculture solutions. They can help address the planet's water challenges and unearth sustainable alternatives to producing our food. Farmers are great drivers of Ag-NBS as they can combine their traditional knowledge with new skills and training to safeguard the ecosystems on which our food production depends (Iseman and Miralles-Wilhelm 2021).

According to the FAO knowledge products addressing NBS in agriculture says that Agriculture Nature-based Solutions can provide a triple benefit: improving the livelihoods of farmers and the resilience of agriculture, mitigating and adapting to climate change through soil, wetlands and forests carbon sequestration, and enhancing nature and biodiversity. In order to sustain the future of food systems, agricultural producers around the globe are poised to lead a transition to production practices that regenerate and restore nature while enhancing efficient and sustainable food systems (Iseman and Miralles-Wilhelm 2021).

Resilient food production

Nature-based solutions can help farmers adapt and ensure food production is more resilient to future weather extremes like droughts, heavy storms, or coastal flooding by enhancing soil health and water retention, reducing soil erosion and buffering shorelines, as well as enhancing food and nutrition security through diversified production systems and sources of income. They can reduce use of chemical additives, which reduces production costs and creates safer foods.

Mitigating climate change

Nature-based solutions can reduce carbon emissions from the food sector and store carbon, most significantly by avoiding deforestation and conversion of natural habitat, by conserving, restoring and sustainably managing aquatic ecosystems (e.g. watersheds, wetlands, coastal mangroves, seagrass meadows and coral reefs) to enhance their role in carbon sequestration, and also by changing crop residue, cover crop and tilling practices in ways that enhance the carbon retained in plants and soils (Griscom et al. 2017).

Enhancing nature and biodiversity

Nature-based solutions can enhance ecosystems and species by increasing habitat diversity, restoring aquatic ecosystems and wetlands and improving the quality and reliability of water (Abbel et al. 2007).

3.2 Dimensions of NBS in agriculture

According to van Doorn et al. 2016 the NBS in agriculture has the following dimensions:

Biodiversity contributes to implementing a resilient agriculture and food system through developing new innovative farming practices, including natural prevention of disease and pests, pollination, the supply and treatment of water, maintain of natural soil fertility and a good soil structure. In the line with these practices, the nature-based agriculture offers different tools to the farmers in the field of conservation, improvement and exploitation of functional agro-biodiversity and the ecosystem services, thus helping the renew of industrialised agricultural ecosystem.

By capitalizing the tools of functional agro-biodiversity and ecosystem services helps to aim at the close the carbon loops with more efficient use of natural resources including the introduction of decreased farming practices. Thus, resulting minimum environmental impact on natural environment causing by farming practices, and indicating positive consequences for specific species on the farm and in the surrounding countryside.

By boosting the implementation of the green infrastructures at farms, contributes to maintaining the construction and conservation of landscape elements (important for flora and fauna). The agricultural built environmental and its management contributes to the survival of meadow and farmland birds and other farmland species.

The figure below shows that a significant aspect of the application of NBS is the consideration of cost-effectiveness (Figure 11) while protecting and improving biodiversity. The use of NBS can lead to an improvement in biodiversity on the farm and in the area, which contributes to an increase in the resilience of farming and thus to a sound income model.

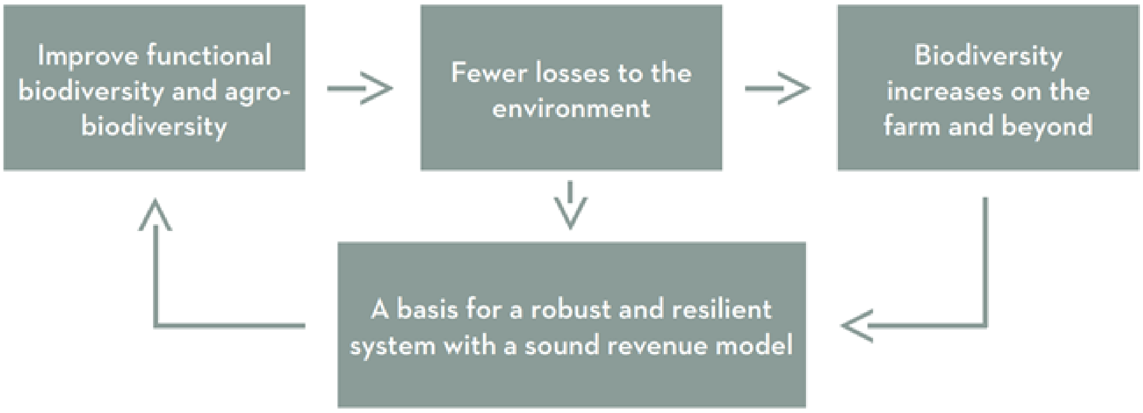

Figure 11 Links and interactions of nature-based agriculture (Erisman et al. 2017)

According to the FAO knowledge products, addressing NBS in agriculture that include a literature review of more than 300 papers, agricultural nature-based solutions can be divided into 2 dimensions if it is implemented in at production or at landscape or ecosystem scale (Iseman and Miralles-Wilhelm 2021). According to EU supporting policy the above-mentioned FAO document is proposed as main resources so the above mentioned 2 dimensions: agriculture production and agricultural landscapes are used as main pathways in this document.

3.3 NBS in agricultural production

NBS in Agricultural Production (including Forestry, Fisheries and Aquaculture)

Numerous Nature-Based Solutions are witnessed in agricultural production and pasture management domains and are predominantly executed by farmers or growers, as illustrated in Figure 12. These endeavours could also entail significant economic gains for cultivators in terms of amplified crop yields and reduced expenses, alongside wider-ranging societal advantages. If the advantages gathered by landlords prove to be satisfactory, the provision of technical guidance and interim financing might be adequate to yield a sustainable impact. A multitude of such practices are consonant with the nascent domain of praxis referred to as regenerative agriculture. The concept of conservation agriculture is widely recognized and encompasses a repertoire of agricultural techniques including the cultivation of cover crops and transitioning to farming methods that involve minimal or zero tillage. The aforementioned techniques are implemented on an estimated global scale of 125 million hectares, as suggested by Friedrich et al. (2012). In conjunction with regenerative agriculture, the aforementioned practices endeavour to optimize the innate processes which serve as the groundwork for agricultural efficacy. These practices form an essential component of extant sustainable management strategies and environmentally conscious methodologies targeting climate change mitigation. Agriculturists have the potential to enhance nutrient management processes via diversification of crops, specifically by incorporating legumes into their farming practices. Furthermore, biochar has demonstrated exceptional efficacy in terms of augmenting carbon sequestration and storage in soil. In addition, integrating trees within cultivated land can prove beneficial and contribute positively towards sustainable agricultural practices. The agricultural practices of grazing and animal husbandry entail various measures, including optimizing grazing intensity, incorporating forest grazing as a means of providing sustenance for the animals, installing shelter and barriers for shielding them, integrating legumes within pastures, and enhancing forage quality. Furthermore, it is worth considering nature-based strategies, specifically those related to enhancement. Overall, the aforementioned measures serve to mitigate carbon emissions and enhance soil carbon sequestration, all the while yielding considerable advantages in terms of water quality and availability, habitat preservation, and air quality. Within the realm of forestry and diligent wood handling, there exist diverse natural approaches capable of enhancing productivity and fostering advantageous social outcomes. The management of natural forests entails the implementation of several strategies, such as elevated logging rotation, adoption of low-impact logging approaches, and voluntary certification practices aimed at promoting environmental sustainability. There exist several practices that can enhance the management of plantations. These include employing multicropping instead of monocropping, selecting native over exotic plant species, incorporating repeating disturbance patterns, extending the duration of crop rotations, and advocating for early thinning. Finally, the utilization of more efficient cookstoves and alternate sources of fuel can be considered as a viable solution to prevent the act of deforestation attributed to wood fuel, consequently preserving the natural material of woodlands for the sustenance of biodiversity and human livelihood. In addition to arable land, there exist nature-oriented approaches that can be utilized within freshwater, coastal, and marine ecosystems to enhance food production and promote carbon sequestration. The farming of mussels and seaweed provides a worldwide opportunity to reinstate coastal habitats and its related ecosystem functions, along with catering to the food security objectives of low- and middle-income nations, as illustrated by Theuerkauf et al. (2013). In the year 2019, significant events occurred, warranting extensive analysis and discussion within academic circles. Within the Mediterranean region, planners collaborated closely with artisanal fishers in order to formulate an approach to managing fisheries that is grounded in the fundamentals of ecosystem preservation alongside the preservation of commercial resources.

Grazing optimization

Grazing optimization defined as the offtake rate that leads to maximum forage production (Henderson et al., 2015). This prescribes a decrease in stocking rates in areas that are overgrazed and an increase in stocking rates in areas that are undergrazed, but with the net result of increased forage offtake and livestock production.

Improved rice cultivation in China

Water management techniques such as alternate wetting and drying and midseason drainage limit the time rice paddies spend in an anaerobic state thereby reduce annual methane emissions while at the same time saving water (Sander et al. 2016). Additional management techniques applied to upland rice such as fertilizer applications, residue and tillage management practices reduce the amounts of nitrogen and carbon emissions.

Biochar

Amount of crop residue available for pyrolysis, used as a soil amendment for both carbon sequestration and soil health benefits.

Cropland nutrient management

Business as usual nutrient budgets who use a range of development scenarios to project total food and feed demand to 2050 (Bodirsky et al. 2014).

Conservation agriculture

Cultivation of cover crops in fallow periods between main crops. Prevents losses of arable land while regenerating degraded lands. Promotes maintenance of a permanent soil cover, minimum soil disturbance, and diversification of plant species. Enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production.

Trees in croplands

Includes windbreaks (shelterbelts), alley cropping, and farmer managed natural regeneration (FMNR), each of which was restricted to non-overlapping relevant cropland areas.

Improved plantations

Extending harvest rotation lengths on intensively managed production forests (i.e. plantations) subject to even-aged stand management.

NBS IN AGRICULTURAL PRODUCTION

NbS Activity	01 GRAZING OPTIMIZATION	02 IMPROVED RICE CULTIVATION	03 BIOCHAR	04 CROPLAND NUTRIENT MANAGEMENT	05 CONSERVATION AGRICULTURE	06 TREES IN CROPLANDS	07 IMPROVED PLANTATIONS
Benefits							
Functions	Improve animal grazing intensity, pasture management and feed practices to reduce GHGs.	Adopt water management techniques, improve drainage, practice residue incorporation.	Increase use of biochar to increase carbon storage	Reduce excesive ferrtilizer and other additives and remove perverse incentives to increase fertilizer use.	Cultivate additional cover crops in fallow period; shift to reduced or zero tillage.	Promote integration of trees into agriculture lands to increase habitat value.	Extend harvest rotation lengths on intensively managed production forests.
Quantitive example of NbS benefits	**1.4B** head of cattle of potential; over **90% of cattle on earth**	**2.9:1** benefit-cost ratio water quality improved	**1,102M** tons CO_2/yr	**44M** tons of nitrogen per year reduction	**4.8B** hectares of conservation land	**1,040M** tons CO_2/yr	**257M** hectares potential

Figure 12 NBS in agricultural production (FAO, 2020)

3.4 NBS in agricultural landscapes

Alternative NBS are executed on a landscape or ecosystem level, along with various stakeholders encompassing governmental entities, corporate entities, and private landowners. The above-mentioned NBS continue to be of great importance in the field of agriculture, as they have the potential to deliver significant benefits in the areas of food and fibre production, with the active involvement of agricultural producers as partners in their implementation. Despite the implementation of NBS in a single farm or local project, it is crucial to plan the implementation of these solutions at the landscape level, in order to optimise the potential benefits and analyse the impacts when scaling up actions (Cohen et al. 2016).

As an example of landscape-level NBS, the conservation and safeguarding of ecosystems may be implemented to sustain their inherent functions and provision of services. The aforementioned comprises the potential preventive measures against grassland conversion, forest conversion, and associated impacts on wetlands as well as other aquatic ecosystems as posited by Narayan and colleagues in 2017. Frequently, these measures are achieved by means of establishing and enforcing areas that are safeguarded, although they may also be allocated on agricultural lands. Land managers have the ability to undertake various land management strategies such as reforestation, afforestation, fire management, and restoration of coastal wetlands, as well as aquatic ecosystems, peatlands, and forests on public, tribal, or private lands. In regards to marine environments, the employment of area-based fishery management strategies has the potential to enhance the cohesion and amalgamation of preservation seascapes on a larger spatial scope. The implementation of these measures can offer effective nature-based approaches to the conservation and restoration of ecosystems that sustain commercial fish production, safeguard the preservation or rehabilitation of population numbers and mitigate a diverse spectrum of anthropogenic stresses, where deemed necessary. The Food and Agriculture Organization (FAO) is extending its assistance to its Members by promoting cognizance regarding the efficacy of implementing spatial fishery management measures in augmenting the vigour, output, and adaptability of aquatic ecosystems. Whilst certain measures may be implemented in productive landscapes or seascapes, there is potential for trade-offs to occur. The implementation of these measures can yield significant gains for food production, particularly in the areas of water quality and regulation of flow. Nonetheless, their adoption is typically motivated by the more extensive societal benefits they generate, which can pose a considerable obstacle for producers. NBS in agricultural landscapes, even at the level of individual farms or localized initiatives, must also be planned with an eye to landscape-level deployment, which may involve foregoing production in certain areas, and often require funding and implementation that exceed the capacity and scope of an individual agricultural practitioner. Several of these measures conform to the standards and requirements of "other effective area-based conservation measures" (OECMs), which are spatial strategies intended to facilitate conservation of biodiversity in its natural habitat. This approach (Iseman and Miralles-Wilhelm 2021) is an essential component of the Aichi Target 11 of the Convention on Biological Diversity (CBD).

4. Conclusions

The goal of this document on conceptual grounds and common understandings is for project partners from different backgrounds to have the same understanding of guiding concepts and principles, which will help to communicate and cooperate effectively.

In the document we addressed

- Different approaches and definitions of NBS,
- Typology of NBS,
- Key concepts connected to NBS,
- The role and potential of NBS in agriculture,

- Different types of NBS in agriculture including agricultural production and agricultural landscapes.

The paper summarises the state of art in NBS and related fields, with the aim of facilitating the understanding between partners and contributing to specific objective interdisciplinary and transdisciplinary systemic research conducive to a transformative learning approach towards sustainable agricultural practices.

We have collected the concepts and areas discussed in the document, which are presented in the following context (Figure 14). The figure interprets NBS in the socio-ecological and socio-economic context. We have focused exclusively on the agricultural interpretation of NBS, including agroecology/agroecosystems and, more specifically, regenerative or circular farming. As a borderline, we have included restoration ecology, which also applies NBS, and the also overlapping area of organic farming.

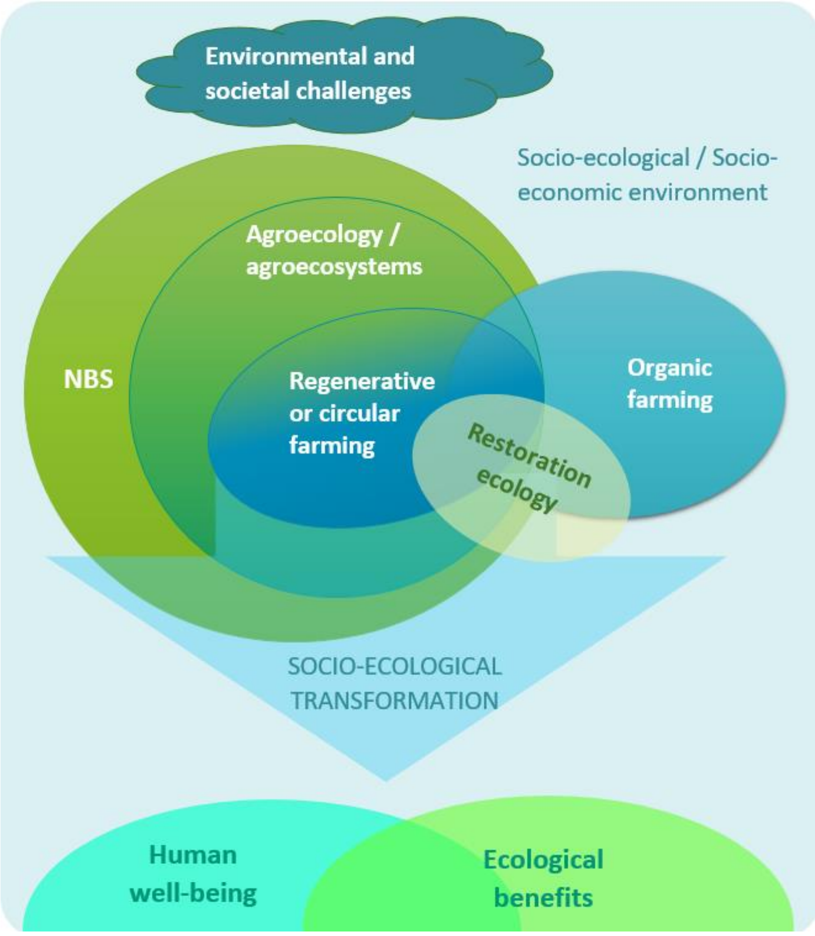

Figure 13 Conceptual framework of NBS in agriculture under the auspices of the trans4num project

4.1 Knowledge gaps connected to NBS in agriculture identified by trans4num project

As an emerging scientific concept, there is still a great deal of parallel, sometimes contradictory or unresolved, uncertain information about NBS. We have tried to summarise this to the best of our knowledge, but the complexity of the subject raises challenges:

1. NBS does not have a precise definition that is generally accepted in the scientific community yet. In this document, the most commonly cited definitions and presented some studies have been selected aimed at finding their common ground.
2. During the preparation of the document, questions were also raised as to which of the various NBS classifications and categorisations available should be presented, and into which classification the NBS methods to be tested in the trans4num project could be placed.
3. Enhancing comprehension of the connections among biodiversity, ecosystem functions, and ecosystem services is imperative in crafting NBS. The research agenda should prioritize aspects related to the efficiency and resilience properties of systems, surpassing its previous considerations. The utilization of genetic resources alongside the preservation of species and community diversity is advocated as a valuable means for deploying Nature-based Solutions that support adaptation and sustainability.
4. The examination of NBS from an economic perspective necessitates a comprehension of ecological production functions and associated uncertainties. Furthermore, the evaluation of NBS benefits typically spans a more extended time horizon compared to conventional approaches.
5. The domain of ecosystem functioning exhibits significant lacunae in our fundamental understanding. Specifically, uncertainties prevailing in this research area pertain to the durability of agro-ecological, forestry, and fishery management approaches envisaged on the principles of nature, principally stemming from the inadequacy of mechanistic and long-term data on biodiversity feedback, recycling loops, and trade-offs between various ecosystem functionalities.
6. The issue pertaining to the efficacy of interconnected small-scale NBS, colloquially referred to as "networks" in addition to their amalgamated configurations with large-scale NBS, is still indeterminate and must receive attention in subsequent studies.
7. One of the foremost challenges in the adoption of NBS is the concomitant management of diverse socio-ecological objectives such as the optimization of (1) biodiversity, specifically native species, species diversity, and endangered species; (2) regulatory services, including flood and erosion control, wildfire management, and pest outbreak prevention; and (3) cultural services, comprising recreational spaces, aesthetic landscapes, as well as zones for contemplative and meditative pursuits. Efficient management practices necessitate the adoption of a transdisciplinary approach, which involves the active engagement of natural and social scientists, land use managers, non-governmental environmental organizations, and local residents, among other relevant stakeholders. The overarching objective of this approach is to identify and blend diverse perspectives and goals, which may be potentially incompatible, in order to achieve a cohesive management strategy. A requisite element is a meticulously organized and compliant socio-ecological evaluation

structure, which employs techniques to amalgamate scientific knowledge and objectives alongside communal perspectives.

8. The present study contends that the evaluation plans for NBS must encompass a comprehensive appraisal of the positive and negative impacts, with due consideration to the degree of effectuation across diverse demographic and ethnic cohorts.

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