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# Soil and Water Bioengineering (SWB) is and has always been a nature-based solution (NBS): a reasoned comparison of terms and definitions

Federico Preti[a,c,d], Vittoria Capobianco[b,c,*], Paola Sangalli[d,e]

[a] University of Florence, Department of Agricolture, Food, Environment and Forest Science & Technology (DAGRI), Via delle Cascine, 5, 50144 Firenze FI, Italy
[b] Norwegian Geotechnical Institute, Natural Hazards division, NGI, P.O. Box. 3930 Ullevål Stadion, Oslo, Norway
[c] Associazione Italiana per l'Ingegneria Naturalistica (AIPIN), Via San Bonaventura 13, 50145 Firenze, Italy
[d] European Federation of Soil and Water Bioengineering EFIB
[e] Sangalli Coronel y Asociados SCIA S.L, Paseo de Lugaritz 25 Bajo, 20018 Donostia-San Sebastián, Spain

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ABSTRACT

Nature-based solutions (NBS) is a collective term for solutions that are based on natural processes, in healthy or restored ecosystems, and their services to address the three pillars of sustainability, including climate-related challenges. Soil and Water Bioengineering (SWB or SWBE) is a hazard mitigation and restoration discipline formally established and structured since the aftermath of World War II, but finding its roots in age old applications, which have many objectives in common with NBS. However, a structured comparison of SWB and NBS terminologies and objectives is lacking, and this is much needed to highlight that SWB are amenable to the concept of NBS in the context of climate change adaptation and disaster risk reduction (DRR). This work presents a comparison between the definition of SWB, NBS, and other terminologies that fall under the NBS concept. A matrix was created to compare NBS and NBS-related terminologies with the three main aspects of the SWB practice: "main aims", "fields of application" and "other objectives". Results from the comparison confirm that NBS is a unifying concept to prioritise nature to integrate climate change adaptation, mitigation, and disaster reduction efforts, embracing also many aspects of SWB criteria and applications. Thus, SWB can and should be recognized as having always been an NBS.

## 1. Introduction

Climate change impacts on the planet are unequivocally and dramatically increasing. The risks posed from this climate crisis are identified as: (1) risk by impact; and (2) risk by likelihood over the next 10 years (WEF, 2020). In the last decade many extreme and destructive weather events were recorded all over the world. One of the main concerns for Europe are floods initiated by extreme storms, potentially triggering landslides. It is also expected that extreme events will result in more extreme dry periods which in turn may result in severe droughts and consequently wildfires (Blöschl et al., 2019). The other dramatic challenge that our generation is facing is biodiversity loss. There is an increasing awareness that climate change and loss of biodiversity are closely connected or even inseparable. Thus, integrated policy frameworks for contrasting both are becoming urgent (IPCC, 2019; Turney et al., 2020; IPCC, 2021).

Massive and rapid interventions are needed to tackle the climate crisis but also to mitigate the effects of this crisis. In order to achieve net zero, the clear message for society and industry is to drastically reduce the emissions of $CO^2$ and other gasses (climate change mitigation actions). Nature-based Solutions (NBS) can help achieve this goal as more recently climate solutions explicitly addressing NBS for carbon storage have been indicated (Seddon et al., 2020). This focus is encouraging as the adoption of NBS provides an important opportunity to integrate climate mitigation with adaptation efforts, while also preventing biodiversity loss.

Nature-based solutions imply solutions to societal challenges that involve working with nature as an integrated approach that could address the twin crises of climate change and biodiversity loss (Seddon et al., 2020). NBS for climate change adaptation can involve conserving or rehabilitating natural ecosystems and/or the enhancement or creation of natural processes in modified or artificial ecosystems, applied both at micro- or macro- scales (UNESCO, 2018). Thus, NBS focus on processes for ecosystem protection and restoration, to address societal

* Corresponding author at: Norwegian Geotechnical Institute, Natural Hazards division, P.O. Box. 3930 Ullevål Stadion, Oslo, Norway.
*E-mail address:* vittoria.capobianco@ngi.no (V. Capobianco).

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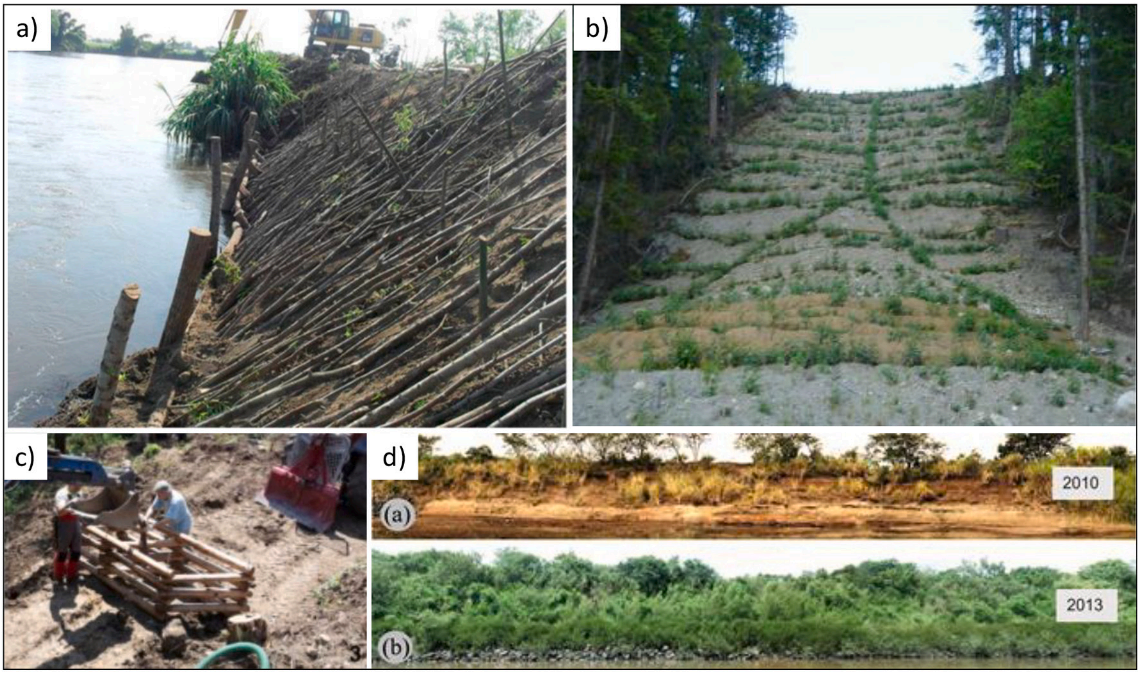


**Fig. 1.** Examples of soil-bioengineering solutions for soil erosion and bank stabilization in different climatic areas: a) SWB construction at La Nueva Concepción (Guatemala) single walled crib wall at the base and living branches at the slope (Maxwald et al., 2020); b) Live pole drains and lateral drain fascines along a slope in Walker's Landing Road, British Columbia, Canada (Stokes et al., 2014); c) Prefabricated wooden structure for reinforcement of a reshaped slope in Italy (photo: F. Preti) (Rey et al., 2019); d) Embankment in Southern Brazil before and after the implementation of reinforcement works (Rauch et al., 2014; Hörbirnger, 2021).

challenges, while improving human well-being and biodiversity (Cohen-Shacham et al., 2016). The societal challenges that NBS aim to address are very actual and can vary from natural hazards, global warming, water management, food and agriculture, among others.

Recently NBS have been increasingly receiving attention as no-regret measures for natural hazards mitigation and hydro-meteorological risk reduction, since they not only buffer hydro-meteorological hazards at different scales, but also provide a wide range of direct benefits and co-benefits to the environment and the human well-being, quantifiable through modelling methods (Kumar et al., 2021).

As an overarching concept, NBS covers established ecosystem-based approaches such as ecosystem-based adaptation (EbA), ecosystem-based disaster risk reduction (eco-DRR), natural, green, as well as blue-green infrastructure (Cohen-Shacham et al., 2016; Ruangpan et al., 2020).

Although some of the recent SWB literature is making references to NBS, currently no direct comparisons have been documented in literature. SWB describes the use of nature or natural materials, particularly plants and vegetation, to restore fragmented habitats or to mitigate natural hazards. SWB techniques are rooted in the engineering practice, having been extensively adopted since the last century, but with traces dating back as far as the first Century BC (Evette et al., 2009).

The term Soil Bioengineering ranks among the most frequently mentioned NBS for addressing surface erosion and shallow landslide stabilization in a selection of peer-review literature performed by de Jesús Arce-Mojica et al. (2019).

Recently, Sangalli et al. (2021) presented the main objectives and main applications of SWB in urban and peri-urban areas, with some examples from European case study sites where SWB have been implemented as NBS, indeed providing also several ecosystem services to the environment and society (Escobedo et al., 2019; Giambastiani et al., 2021).

Efforts have been made to include also SWB techniques as part of the new category "NBS for erosion control" in the database of structural landslide risk mitigation measures within the LaRiMiT webportal – Landslide Risk Mitigation Toolbox, for the selection of the most suitable mitigation measure for a specific landslide case (Capobianco et al., 2022).

Furthermore, SWB practice has been defined as the pioneer of NBS for landslide protection and riverbank erosion control (e.g. Forzieri et al., 2011; Preti et al., 2011; Preti, 2013; Preti et al., 2022; Capobianco et al., 2021), since it provides environmental-friendly and cost-effective solutions in accordance with the principles of NBS actions "inspired by, supported by or copied from nature" (Kalsnes and Capobianco, 2019).

A similar observation appears in the report by UNESCO (2018), in which also Green Infrastructure are considered an application of NBS.

However, no direct comparisons between SWB and NBS definitions have been conducted, to understand to what extent they overlap in terms of objectives and applications. This is not only important to understand overlaps, but also when definitions are linked to legislations and funding mechanisms. Therefore, it results extremely useful to conduct a structured comparison of terminologies and objectives (Fernandes and Guiomar, 2018; Rey, 2021).

This work aims to systematically compare the definition of NBS, and other terminologies that fall under the NBS concept, with the definition of SWB, with a special focus on flood risk mitigation, ecosystem restoration, landslide and erosion mitigation. A comparison matrix is proposed and developed with the scope to find points in common of SWB practices with newer terminologies and highlight where these differ. In addition to NBS, terminologies that are analysed include: Watershed Management or hydraulic-forestry arrangements (WM), NBS, Green/blue Infrastructure (GI), Urban Forestry (UF), Ecological Engineering (EE), as well as Ecosystem-based Disaster Risk Reduction (Eco-DRR).

## 2. Overview of definitions and commonly used terms

### 2.1. Soil and Water Bioengineering

#### 2.1.1. Definition of Soil and Water Bioengineering

Soil Bioengineering is the equivocal English translation for the German "Ingenieurbiologie", coined in the early 50s in the homonymous book by forester Arthur von Kruedener (Evette et al., 2009). The aim of the discipline was explained in the book to be "the conciliation between the technology (and its impacts) and environmental and landscape concerns" (Bischetti et al., 2014).

The word "Soil" was added to the literal English translation for avoiding any misunderstanding with other medical and genetic disciplines (Stiles, 1988; Barker, 1997).

Other European countries have instead tried to translate the term more literally from German. An example is given by Italy, where the term "Ingegneria Naturalistica" (which translated to English would be "naturalistic engineering"), is commonly used, also in legislations.

According to the European Federation of Soil and Water Bioengineering -EFIB – (http://www.efib.org/), SWB is a specific discipline. Its definition is provided by Sangalli et al. (2021) as "*Biology-oriented Engineering, in which native plants and plant fragments are used as living building material which together with the improvement of soil quality can significantly contribute to human safety and face all forms of erosion. In other words, Bioengineering is a discipline that uses plants as element of environmental construction and reconstruction*". Thus, the term "engineering" refers to "*the use of well-established technical and scientific solutions for building, stabilization and erosion control deriving from civil and geotechnical engineering.* The term "bio" is related both *"to the nature of the building materials used (i.e. mostly native plants with appropriate biotechnical characteristics), and to the purpose of rebuilding ecosystems and increasing biodiversity"*.

A significant dissemination of this discipline can be attributed to the work of Hugo Meinhard Schiechtl, who published an important book highlighting the potential of green technologies, receiving attention worldwide and redefining the fundaments of the modern SWB (Bischetti et al., 2014; Schiechtl, 1980).

### 2.1.2. SWB solutions as multi-purpose solutions

In the modern times SWB applications have been successfully adopted both in Alpine (e.g. Bischetti et al., 2009; Giupponi et al., 2017) and Mediterranean areas (e.g. Sauli and Cornelini, 2011; Rey et al., 2013; Palmeri et al., 2006), as well as outside Europe in Canada (e.g. Stokes et al., 2014), Nepal (e.g. Lammeranner et al., 2005), Brazil (e.g. Rauch et al., 2014) and other humid tropical areas (e.g. Petrone and Preti, 2010; Preti and Petrone, 2013; Maxwald et al., 2020; Castelli et al., 2021): Fig. 1.

SWB implies using plants not only for their *technical* functions, in terms of stabilization properties and erosion protection, but also for their multiple purposes, including *ecological* functions, through the development of plant communities, carbon storage and habitat protection. Hence, SWB fulfils a significant function for the ecosystem in which it is inserted, recovering ecosystem services of public interest (Santolini

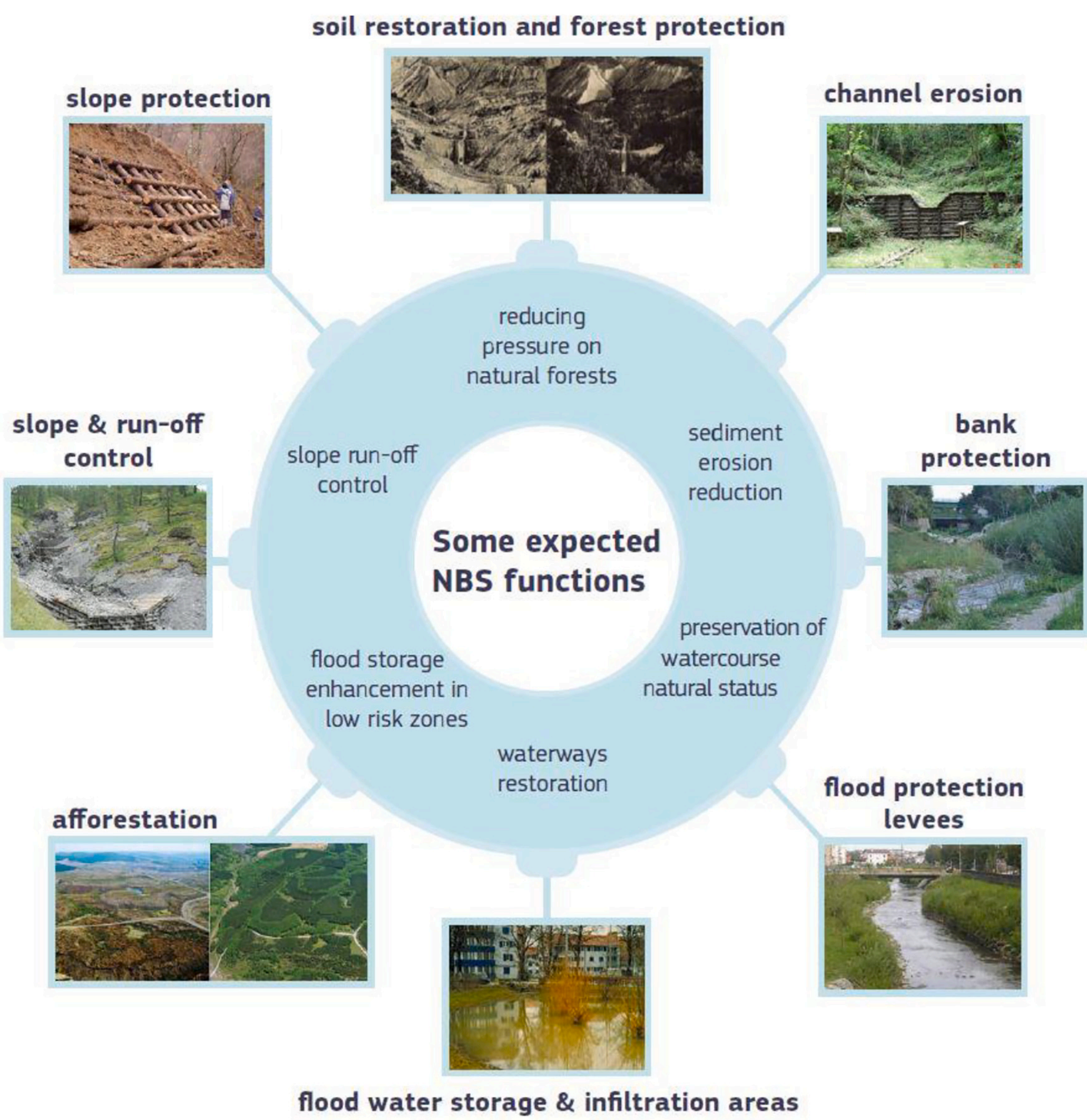


**Fig. 2.** NBS used for hydrometeorological risk management (source: EC - European Commission, 2021 with contribution of EFIB).

and Morri, 2017; CCN - Comitato Capitale Naturale, 2019). An ecosystem is a system, or a group of interconnected elements, formed by the interaction of a community of organisms with their environment in a unit of space, creating a self-sufficient system in thermodynamic equilibrium (Tansley, 1935). For instance, using wooden logs together with live cuttings for stabilizing a slope, allows to trigger the natural recovery process and therefore the exchange of energy and matter within the ecosystem, by increasing the ecological niches available and the consequent biodiversity and biomass, thus reducing the entropy. Alternatively, a traditional grey solution for slope stabilization, such as reinforced concrete wall, represents a closed system comprising different components (i.e., concrete, steel) which does not interact with the surrounding environment. For example, the wall will heat up, without however exchanging energy with the external system, changing the living conditions in the ecosystem and consequently increasing entropy.

In addition to the ecological function exerted by both native plants and natural materials used, SWB fulfils several other objectives, such as: (1) *landscape* objectives, with the maintenance of aesthetic and perceptive functions (cultural ecosystem services) of landscape integrity (2) *social* functions, by creating recreational areas and healthier spaces, and (3) *economic* functions, by reducing the costs of construction and maintenance, and involving local communities both for supplying local materials and for manual effort in the construction phase with the introduction of "green jobs" (Bloemer et al., 2015; Sangalli et al., 2021; Maxwald et al., 2020). Additionally, Sangalli et al. (2021) defines SWB also as "Socio-cultural based solution" in the sense that its origins, development and application derive from a strong relation between human societies and their cultural history, the surroundings environment and its processes and components.

Thus, it is widely recognized that SWB represents a multi-purpose solution requiring a multi-disciplinary approach, under the auspices of the UN Sustainable Development Goals (SDGs). Recently, Mickovski (2021) mapped 22 reported cases of SWB in the Mediterranean region, implemented within the EU financed project Erasmus plus ECOMED (https://ecomedbio.eu/). He concluded that most of the cases analysed contributed towards achieving many of the goals set by the United Nations (i.e. SDG3 – good health and wellbeing, SDG9 – Industry, innovation, infrastructure, SDG11 – Sustainable cities and communities, SDG13 – climate action, SDG15 – life on land, SDG17 partnerships for the goals), highlighting that not all the UN SDGs could be addressed due to the scale of the projects. Thus, the potential for upscaling results is of high importance.

## 3. NBS in a global and European perspective

The term NBS was firstly used in the early 2010 by the International Union for Conservation of Nature (IUCN, 2012, 2016), mostly in a restoration practice perspective. The term referred to ecosystem-based approaches for protection and restoration management, that address societal challenges while improving human well-being and biodiversity. A more detailed history on the origins on NBS is found in Seddon et al. (2021).

In 2015, a European expert group was established within the research community establishing an NBS perspective at continental scale, with a strong focus on interventions in the built environment. Indeed, a first wave of European HORIZON 2020 funded projects focused on NBS in the urban environment (i.e., NBS as green spaces with benefits to the health and the society).

Starting from 2018, a series of European projects focused on demonstrating the effectiveness of NBS in reducing the hydro-meteorological risk also in rural landscapes, where the risk is amplified.

The projects financed during this period with NBS for hydro-meteorological risk mitigation included: OPERANDUM, PHUSICOS, and RECONECT.

Briefly:

**Table 1**
Definitions of nature-based solutions and related used terms that fall under the umbrella of NBS, with a focus on the scope of SWB applications.

| NBS and NBS related term | Definition | References |
|---|---|---|
| Watershed Management (WM) | The integrated use of land, vegetation, and water in a geographically discrete drainage area for the benefit of its residents, with the objective of protecting or conserving the hydrologic services that the watershed provides and of reducing or avoiding negative downstream or groundwater impacts. | Schiechtl (1985); Darghouth et al. (2008) |
| Nature-based solutions (NBS) | Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human wellbeing and biodiversity benefits. | Cohen-Shacham et al. (2016); IUCN (2012) |
| | NBS aim to help societies address a variety of environmental, social and – Europe EC (2015) solution economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature, both using and enhancing existing solutions to challenges as well as exploring more novel solutions. | EC (2015) |
| Green/blue Infrastructure (GBI) | A strategically planned and managed, spatially interconnected network of multi-functional natural, semi-natural and man-made green and blue features including agricultural land, green corridors, urban parks, forest reserves, wetlands, rivers, coastal and other aquatic ecosystems. | European Commission (2013) |
| Urban Forestry (UF) | The art, science, and technology of managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic, and aesthetic benefits tree provide society. | Konijnendijk et al. (2006) |
| Ecological Engineering (EE) | The design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both. | Odum (1962); Mitsch and Jørgensen (2003) |
| Ecosystem-based Disaster Risk Reduction (Eco-DRR) | The sustainable management, conservation, and restoration of ecosystems to reduce disaster risk, with the aim of achieving sustainable and resilient development. | Estralla and Saalismaa (2013); PEDDR (2010); UNDRR (2020) |

- OPERANDUM (https://www.operandum-project.eu/)is developing a set of co-design, co-developed, deployed, tested and demonstrated innovative NBS for the management of the impact of hydro-meteorological risks (HMRs), especially focused in European rural and natural territories, facilitating the adoption of new policies for the reduction of HMRs via NBS and their promotion.
- PHUSICOS (https://phusicos.eu/)is demonstrating the effectiveness of NBS and their ability to reduce the impact for small, frequent events (extensive risk) in rural mountain landscapes.

**Table 2**
Comparison matrix between the aspects of SWB and the other NBS-related terminologies: Watershed Management (WM), Nature-based solutions (NBS), Green-blue Infrastructure (GBI), Urban Forestry (UB), Ecological Engineering (EE); Ecosystem-based Disaster Risk Reduction (Eco-DRR). [1]IUCN, 2016; [2]EU(2015); [3]Science for Environment Policy (2021); [4]Naumann et al. (2011); [5]The World Bank – GFDRR – Deltares https://naturebasedsolutions.org/; [6]Konijnendijk et al. (2006); [7]Heathcote (2009); [8]Darghouth et al. (2008); [9]Balian et al. (2014); [10]Raymond et al. (2017); [11]Kalsnes and Capobianco (2019); [12]Tzoulas et al. (2007); [13]Benedict and McMahon (2006); [14]Mitsch (2012); [15]Stokes et al. (2010); [16]Stokes et al. (2014); [17]Mickovski (2014); [18]Paris Tormo et al. (2008); [19]van Bohemen (2005); [20]Moos et al. (2018); [21]Renaud et al. (2013); [22]EEA (2021); [23]UNESCO (2018).

| | | From AIPIN Statute | WM | NBS | GBI | UF | EE | Eco-DRR |
|---|---|---|---|---|---|---|---|---|
| Aims | Technical aim | Erosion control, stabilization and consolidation of slopes | *Growing crops across slopes to reduce erosion & increase infiltration[1] Providing riparian buffers to maintain water quality & reduce erosion [1]* | *NBS for surface protection and erosion control - Living Approach, 2. NBS for surface protection and erosion control – Living/Not living Approach [11]* | | | *Ecoengineering is described as the long-term, ecological and economic strategy to manage a site with regard to natural or man-made hazards[15]* | *mountain forests for slope stability and avalanche protection[20]* |
| | Ecological aim | Ecological restoration of natural or modified ecosystems | | *Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges, simultaneously providing human well-being and biodiversity benefits[1]* | *[…] which enhance ecosystem health and resilience, contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services [4]* | | *Using vegetation in ecological rehabilitation or restoration projects will promote the recovery of ecosystem structures and functions, in addition to general ecological infrastructure.[16]* | *The protection and restoration of ecosystem services can be an important step towards enhancing disaster mitigation. Protected areas provide an effective mechanism for maintaining natural habitats and ecosystem function.[21]* |
| | Landscape aim | To connect the surrounding landscape and to minimize the impact of the systems | | *Better use of existing ecosystems by minimizing the impact on the systems themselves[9]* | *The network of natural and semi-natural areas, features and green spaces in rural and urban, and terrestrial, freshwater, coastal and marine areas [..] [4]* | *The art, science, and technology of managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic,and aesthetic benefits tree provide society [6]* | *Using vegetation in ecological rehabilitation or restoration projects will promote the recovery of ecosystem structures and functions, in addition to general ecological infrastructure.[16]* | |
| | Socio-economic aim | Enhancing the human capital, with the creation of new green jobs | *Today it is widely recognized that social and economic systems are an integral part of the watershed ecosystem, affecting […] the attitudinal and economic forces so central to succesful implementation of water management actions[7]* | *"simultaneously provide [..] and economic benefits and help build resilience"[2] "[..] and they provide jobs and business opportunities." [3]* | | *[..] ecological, economic, and sociological elements, and is inclusive of people from cities to suburbs to ruralcommunities [6]* | *eco-engineering or ground bio-engineering is based on a sustainable geotechnical design where the vegetation, apart from fulfilling an engineering function, contributes towards positive environmental and social impact at a relatively low cost.[17]* | *Ecosystem-based Disaster Risk Reduction in mountains h is the sustainable management, conservation and restoration of ecosystems to reduce (disaster) risk to achieve sustainable and resilient development[21]* |
| Fields of application | | Hydro-meteorological risk mitigation, hydraulic and forest management, management of water system at the catchment scale, erosion and shallow landslide protection along slopes, | *Watershed management is the integrated use of land, vegetation and water in a geographically discrete drainage area for the benefit of its residents, with the objective of protecting* | *Large-scale NbS can also enable natural processes that are beneficial for the maintenance of safe physical environments, such as hydrogeological* | *Green infrastructure is becoming increasingly recognized as an important opportunity for addressing the complex challenges of water management [..][23]* | | | |

(*continued on next page*)

**Table 2** (*continued*)

| | From AIPIN Statute | WM | NBS | GBI | UF | EE | Eco-DRR |
|---|---|---|---|---|---|---|---|
| | waterways management, restoration and reopening of waterways, coastline and seabed restoration | *or conserving the hydrologic services that the watershed provides and of reducing or avoiding negative downstream or groundwater impacts.*[8] | *stability to protect against erosion and landslides.*[22] | | | | |
| | Rewilding, contribution to the recovery of degraded areas, conserving ecosystems, preventing and reversing the land degradation process, post fire interventions | | *Nature-based solutions basically cover the full scope of using ecosystems to address hazards, making use of natural processes and ecosystem services for functional purposes, such as decreasing flood risk, erosion, and landslide risk.*[5] | *NI is defined as a "strategically planned and managed network of natural lands, such as forests and wetlands, working landscapes, and other open spaces that conserves or enhances ecosystem values and functions and provides associated benefits to human populations*[13] | | *Ecoengineering is described as the long-term, ecological and economic strategy to manage a site with regard to natural or man-made hazards*[15] | *Examples of Eco-DRR include the renaturation of rivers, where addi-tional flooding space is (re-) created in river beds, or dunes and saltmarshes that provide protection against coastal floods, as well as foreststhat mitigate mass movements in steep environments*[20] |
| | Slope revegetation along linear infrastructure, environmental requalification (roads, railways, pipeline, electric infrastructure, quarry, landfills) regreening, vertical green walls, green covers, bio-filters and natural depuration, requalification of anthropogenic, urban and industrial sites | | *[..] Renaturing landfill sites, brownfields and river corridors.*[4] | | | *Road building produces large amounts of unvegetated soilsoften forming embankments. […] revegetation of these slopes is fundamental since theyare very vulnerable to erosion*[18] | |
| | | | *Use of vegetation in urban areas* (e.g. *street trees, grassland, green roofs and facades, infiltration gardens and urban forests).*[10] | *solutions that involve creating new ecosystems* (e.g. *establishing green buildings (green walls, green roofs)).*[1] | | *Vegetation as bio-filter for air pollution*[19] | |
| Other objectives | Connecting fragmented habitats through the use of natural materials which help the restoration | | *NBS are systemic and will also increase the resilience of increasingly fragile nature reserves threatened by climate change. [..] (re) introducing green corridors. [..] 4* | *The green infrastructure concept emphasises on the quality as well as quantity of urban and periurban green spaces, their multifunctional role, and the importance of interconnections between habitats 12* | | *the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both14* | |
| | rewilding aimed at creating new habitats for the fauna and flora to thrive | | *NBS are systemic and will also increase the resilience of increasingly fragile nature reserves threatened by climate change. [..] (re) introducing green corridors. [..] 4* | *The green infrastructure concept emphasises on the quality as well as quantity of urban and periurban green spaces, their multifunctional role, and the importance of interconnections between habitats 12* | | | |

**Table 3**
Summary of the comparison matrix where the green coloured cells represent matches of NBS-related definitions with SWB definitions. The three different intensities of the colour indicate the level of importance for each NBS-related term in the authors' subjective assessment, from the darker (high importance) to the lighter (low importance). The NBS-related terms used in the table are: Watershed Management (WM), Nature-based solutions (NBS), Green-blue Infrastructure (GBI), Urban Forestry (UB), Ecological Engineering (EE); Ecosystem-based Disaster Risk Reduction (Eco-DRR).

| | From AIPIN Statute (and EFIB directives) | | WM | NBS | GBI | UF | EE | Eco-DRR |
|---|---|---|---|---|---|---|---|---|
| AIMS | Technical aim: | Erosion control, stabilization and consolidation of slopes | High | Medium | | | High | High |
| | Ecological aim: | Restoration of natural or modified ecosystems | | High | Medium | | Medium | High |
| | Landscape aim | To connect the surrounding landscape | | Medium | Medium | High | Low | |
| | Socio-economic aim: | Enhancing the human capital, with the creation of new green jobs | Medium | Medium | | Low | Low | Low |
| FIELDS OF APPLICATION | hydro-meteorological risk mitigation | | High | Medium | Medium | | | |
| | Rewilding and ecosystem restoration | | | Medium | Medium | | Medium | Medium |
| | Regreening | | | Medium | High | | Medium | |
| OTHER OBJ. OBJECTIVES | Connecting fragmented habitats | | | Medium | Medium | | Medium | |
| | Rewilding aimed at creating new habitats | | | Medium | Medium | | | |

| High | Medium | Low |
|---|---|---|

- RECONECT (http://www.reconect.eu/) aims to rapidly enhance the European reference framework on NBS for hydro-meteorological risk reduction by demonstrating, referencing, upscaling and exploiting large-scale NBS in rural and natural areas;

Within these three projects, many of the NBS that are proposed, especially for rockfall, avalanches and landslide risk mitigation, were adopted from already well-established techniques that find their roots in SWB practice (Solheim et al., 2021). Examples of NBS for hydrometeorological risk reduction are shown in Fig. 2.

In 2020, the EU definition was improved to also include a specific reference to enhancing biodiversity, in line with the IUCN Global Standard (IUCN, 2020). The European NBS definition now explicitly states that "NBS must benefit biodiversity", thus implying the importance to additionally monitor and assess the increased biodiversity when implementing NBS.

In 2020, a new international and highly multidisciplinary network was launched by the Norwegian Geotechnical Institute (NGI), with the aim to gather experts in the field of nature-based solutions, to create and promote interactions between experts with different scientific backgrounds (i.e. geotechnical engineering, hydrology, soil science, plant ecology, biodiversity, agronomy, protection forests), with a focus on use of vegetation to mitigate climate induced geo-hazards, including landslides, floods and erosion. The network is called PlaNet and promotes activities, conferences, and new research outcomes in the field of NBS (https://planetnetwork.eu/). In addition, the International EcorisQ Association (https://www.ecorisq.org/) is a global network in the field of natural hazard risks with the aim of promoting sustainable, where possible nature-based solutions for natural hazard risk reduction by bringing together science and practice for the development and dissemination of transparent tools for natural hazard and risk analyses.

As mentioned previously, NBS is currently considered an umbrella concept embracing all those disciplines involving the use of nature to address societal challenges. The majority of NBS applications, both in rural and in urban landscapes, essentially involves the management of vegetation, soils and/or wetlands, including rivers and lakes (UNESCO, 2018; WWAP (UNESCO World Water Assessment Programme), 2019). Table 1 lists the main terms that fall under the NBS concept, focussing on landslide and erosion protection, as well as flood mitigation and ecosystem restoration, which are also the pillars of SWB practice.

## 4. The comparison matrix

The comparison between SWB, NBS and related terminologies, was carried out by creating a matrix, where each row in the matrix represents each of the 3 main aspects of SWB practices: namely "main aims", "fields of application" and "other objectives"; and the matrix columns designate all the other terminologies, following the order listed in Table 1. The three main aspects of SWB practice were taken from the statute of the AIPIN – Italian Association of Soil and Water Bioengineering (http://www.aipin.it/), which is among the first established statues of SWB in Europe, following the Verein für Ingenieurbiologie

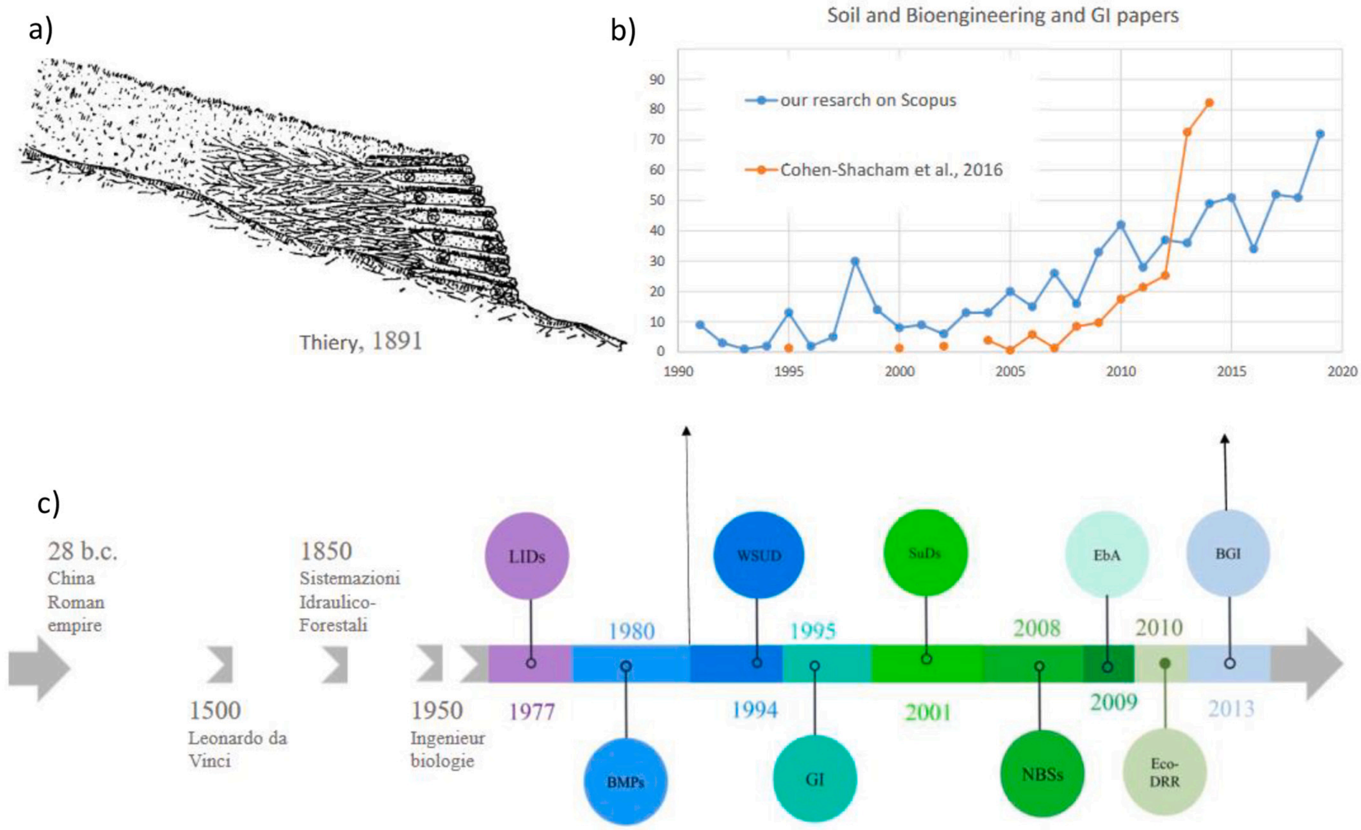


**Fig. 3.** a) Example of forest watershed management application from the late 1800's (Thiery, 1891); b) comparison between trend of international publications (source Scopus) on "SOIL" and "BIOENGINEERING" (where the peak of 1998 is of US origin) and trend of publications on "green and natural infrastructures" by Cohen-Shacham et al. (2016); c) timeline of historical milestones for SWB (Thiery, 1891; Hofmann, 1936; Evette et al., 2009; Bresci and Preti, 2010; Stokes et al., 2010; Preti, 2021) and year of origin of each NBS-related term (low-impact developments – LIDs, best management practices – BMPs, water-sensitive urban design – WSUD, green infrastructure – GI, sustainable urban drainage systems – SuDs, nature-based solutions – NBSs, ecosystem-based adaptation – EbA, ecosystem-based disaster risk reduction – Eco-DRR – and blue–green infrastructure – BGI) based on their appearance in publications (Ruangpan et al., 2020). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Switzerland) and Gesellschaft für Ingenieurbiologie (Germany). Thus, the statute reflects the current European directives EFIB (EFIB, 1996; Hacker, 2015; Sangalli et al., 2021). The aspects cover the following:

- *main aims*: the four main objectives of SWB; namely: technical, ecological, landscape and socio-economic objectives.
- *fields of application*: main domains of applications and fields of interventions, such as; *i)* slope stabilization, wetland restoration and streambank protection, coastal defence; *ii)* rewilding and contribution to ecological restoration of degraded areas; *iii)* environmental requalification;
- *other objectives*: the multi-purpose functions exerted by SWB.

Excerpts from relevant peer-review and grey literature as well as EU reports about NBS and related terms were included in the matrix to cross-check the 3 main aspects of the SWB practice. More emphasis was given to EU reports, which define what is and what is not an NBS, setting up the course for future legislations.

Table 2 shows the comparison matrix with these excerpts from literature for a specific NBS and related term, in correspondence with the three main aspects of SWB listed above.

## 5. Discussion

The main findings from this comparison are: (1) SWB approaches have at least 2 "aims" in common with all the terms; (2) all 3 main aspects are covered by the NBS definitions (Table 3). In terms of "fields of application", the highest number of similarities are found between SWB and EE, and, to a smaller extent, WM, GBI and Eco-DRR. Ecological engineering (EE) is indeed often considered a practice equivalent to SWB, using an ecosystem-based approach to manage hazards.

The category "other objectives" includes secondary scopes of SWB applications, such as rewilding, ecosystem restoration of fragmented habitats, and biodiversity protection. All of these represent important aspect of NBS practice and also pertain to the concepts of GBI (i.e., the use of green corridors) and EE. This confirms that SWB can be an effective tool for environmental improvement and recovery of biodiversity in degraded ecosystems (Sangalli et al., 2021).

NBS is a relatively recent concept. As such, its definition has been and is being evolving with time as research on the topic increases and as scientists explore their disciplines' respective contributions to this multidisciplinary approach. This is also true for SWB, a discipline which has roots in ancient techniques, and which has been revised and re-proposed for current challenges. The timeline of historical milestones for SWB and the year of origin of each of NBS-related terms are shown in Fig. 3. SWB finds its roots in the beginning of the human transformation of the territory with the agriculture. There is evidence of such techniques also in the Chinese and Roman empire from 28 b.c. and 50 a.c. and 1 century a. c. (Lewis, 2000; Sauli et al., 2005; Stokes et al., 2010), and subsequently developed during the Renaissance with Leonardo Da Vinci (e.g. Sangalli et al., 2018), who introduced the concept of natural watershed management. In the second half of the 1800's, forest watershed management ("Sistemazioni Idraulico Forestali" in italian) started developing in Italy and Europe (Evette et al., 2009; Bresci and Preti, 2010) leading to the establishment of the "Ingenieurbiologie" discipline in the second part of XX century (Bischetti et al., 2014). An example of forest watershed management application is shown in Fig. 3a (Thiery, 1891). From then onwards, many other terms were introduced, as detailed by Ruangpan et al., 2020. Cohen-Shacham et al. (2016) have conducted a search of publications on " green and natural infrastructures" from the 90's until 2015 and concluded that there was an exponential increase of papers published on this topic starting from the 2010. However, by comparing it with the number of publications focusing on "Soil and Bioengineering" (source Scopus), from the year 1991 until 2020, this discontinuity does not appear to be so pronounced, as it seems that SWB applications have had a a continuity during the years starting from the early 90's, showing an increasing trend starting from middle 2010's (Fig. 3b). We therefore proposed a modified chronology of terminologies, where we introduced also the history of SWB until the 1950 in grey colour, to continue and complete what was started by Ruangpan et al., 2020 (Fig. 3c).

It is worth mentioning that the domains of applications of SWB are also changing over time, allowing space for new practices focusing on circularity and material recycling. The NBS concept is still under construction, and it is the responsibility of scientists and policy-makers, through sharing of experiences from the SWB discipline, to define how and to what degree SWB may form the foundations as well as fall under the NBS concept. Based on the main objectives of SWB, this discipline can be surely seen as an NBS tout court or a tool for NBS applications, representing a useful vehicle for implementing the umbrella function that the NBS need to fulfil. All these NBS-related terms most of the time represent the technical term for a specific application, which falls into the concept of NBS. Thus, also SWB is a supporting concept to NBS. In addition, although for example SWB for bank and slope stability does not address biodiversity as its primary objective, plants are an integral part of the SWB intervention that will eventually improve biodiversity, thus falling within the NBS concept.

This work serves to illustrate and provide documentation that SWB is an instrument to NBS, thus it is and it has always been an NBS. At the European level many legislations are being introduced including the concept of NBS, in accordance with the ambition for Europe for becoming the first carbon neutral continent within 2050. In Norway the NBS concept has explicitly been introduced in the climate adaptation legislation and "In municipal and regional planning, conservation, restoration or establishment of nature-based solutions should be considered". The evidence that green infrastructure (GI) lead to healthier cities (Trapani et al., 2021) are also moving policy makers to adopt regulations towards these NBS concepts (i.e., Germany has also adopted the national GI concept). Spain and Italy are also slowing going towards this direction. For instance, the regulations in Campania Region (southern Italy) are based on the "maximum applicability of the SWB" (Giunta regionale della Campania, Decreto del Presidente della Giunta Regionale n° 574 del 22 luglio 2002 - Emanazione Regolamento per l'attuazione degli interventi di Ingegneria naturalistica).

## 6. Concluding remarks

This work was carried out to illustrate and document that SWB discipline can be recognized as a concept falling under the NBS umbrella concept. It overlaps and, in some cases, compliments many NBS-related terminologies. These concepts strive to complement one another and are not conflicting, but rather supporting. The concept of NBS is being refined with use over time but requires further clarification and adaptation to history and different contexts. NBS is a unifying concept which prioritises nature to integrate climate change adaptation, mitigation, and disaster reduction efforts, also embracing many aspects of SWB applications. NBS finds inspiration from natural processes (for example wetlands, terraces, etc.), which are the product of a cultural heritage much older than the NBS definition. SWB discipline instead, is rooted in ancient techniques, revised and re-formulated for current challenges, with an exponentially growing technical-scientific interest. In conclusion, SWB is and it has always been a Nature-Based Solution.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References

Balian, E., et al., 2014. Outputs of the strategic foresight workshop "nature-based solutions in a BiodivERsA context" Brussels June 11-12 2014. In: BiodivERsA Report, 45 pp. Available at: http://www.biodiversa.org/687/download.

Barker, D.H., 1997. Editor's note. In: Schiechtl, H.M., Stern, R. (Eds.), Water Bioengineering Techniques for Watercourses, Bank and Shoreline Protection. Blackwell Science, Oxford, pp. xiii–xvi.

Benedict, M.A., McMahon, E.T., 2006. Green Infrastructure: Linking Landscapes and Communities. Island Press, Washington DC.

Bischetti, G.B., Chiaradia, E.A., Epis, T., Morlotti, E., 2009. Root cohesion of forest species in the Italian Alps. Plant Soil 324 (1), 71–89. https://doi.org/10.1007/s11104-009-9941-0.

Bischetti, G.B., Di Fi Dio, M., Florineth, F., 2014. On the origin of soil bioengineering. Landsc. Res. 39 (5), 583–595. https://doi.org/10.1080/01426397.2012.730139.

Bloemer, S., Fernandes, J.P., Florineth, F., Geitz, P., Gerstgraser, C., Graf, F., Witt, K.J., 2015. European Guidelines for Soil and Water Bioengineering.

Blöschl, G., Hall, J., Viglione, A., et al., 2019. Changing climate both increases and decreases European river floods. Nature 573, 108–111. https://doi.org/10.1038/s41586-019-1495-6.

Bresci, E., Preti, F., 2010. An historical survey on the evolution of some forest watershed management techniques (part ii: stream channel works). J. Agric. Eng. 41, 13–22. https://doi.org/10.4081/jae.2010.3.13.

Capobianco, V., Robinson, K., Kalsnes, B., Ekeheien, C., Høydal, Ø., 2021. Hydro-mechanical effects of several riparian vegetation combinations on the streambank stability—a benchmark case in southeastern Norway. Sustainability 13 (7), 4046. https://doi.org/10.3390/su13074046.

Capobianco, V., Uzielli, M., Kalsnes, B., Choi, J.C., Strout, J.M., von der Tann, L., Steinholt, I.H., Solheim, A., Nadim, F., Lacasse, S., 2022. Recent innovations in the LaRiMiT risk mitigation tool: implementing a novel methodology for expert scoring and extending the database to include nature-based solutions. Landslides 1–21. https://doi.org/10.1007/s10346-022-01855-1.

Castelli, G., Oo, W.M., Di Maggio, A., Fellin, L., Re, V., Bresci, E., 2021. Participatory analysis of sustainable land and water management practices for integrated rural development in Myanmar. J. Water Sanit. Hyg. Dev. 11 (1), 26–36. https://doi.org/10.2166/washdev.2020.166.

CCN - Comitato Capitale Naturale, 2019. Terzo Rapporto sullo Stato del Capitale Naturale in Italia. Roma. https://www.mite.gov.it/pagina/terzo-rapporto-sullo-stato-del-capitale-naturale-italia-2019 (in italian).

Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., 2016. Nature-Based Solutions to Address Global Societal Challenges. IUCN, Gland, Switzerland, p. 97. https://doi.org/10.2305/IUCN.CH.2016.13.en.

Darghouth, Salah, Ward, Christopher, Gambarelli, Gretel, Styger, Erika, Roux, Julienne, 2008. Watershed Management Approaches, Policies, and Operations : Lessons for Scaling Up. Water Sector Board Discussion Paper Series;No. 11. World Bank. World Bank, Washington, DC.

de Jesús Arce-Mojica, T., Nehren, U., Sudmeier-Rieux, K., Miranda, P.J., Anhuf, D., 2019. Nature-based solutions (NbS) for reducing the risk of shallow landslides: where do we stand? Int. J. Disast. Risk Reduct. 41, 101293 https://doi.org/10.1016/j.ijdrr.2019.101293.

EC - European Commission, 2015. Nature-Based Solutions and Re-Naturing Cities, Final Report of the Horizon 2020 Expert Group on Nature-Based Solutions and Re-Naturing Cities. European Union, Brussels.
EC - European Commission, 2021. Evaluating the Impact of Nature-Based Solutions: A Handbook for Practitioners.
EEA, 2021. Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction. In: EEA Report.
EFIB, 1996. Statutes of the European Federation of Soil and Water Bioengineering. UBO register, Vienna-Austria. www.efib.org.
Escobedo, F.J., Vincenzo Giannico, C.Y., Jim, Giovanni Sanesi, Lafortezza, Raffaele, 2019. Urban forests, ecosystem services, green infrastructure and nature-based solutions: Nexus or evolving metaphors? Urban For. Urban Green. 37, 3–12. ISSN 1618–8667. https://doi.org/10.1016/j.ufug.2018.02.011.
Estralla, M., Saalismaa, N., 2013. Ecosystem-based disaster risk reduction (Eco-DRR): An overview. In: Renaud, F.G., Sudmeier-Rieux, K., Estrella, M. (Eds.), The Role of Ecosystems in Disaster Risk Reduction. United Nations University Press, 512 pp.
European Commission, 2013. Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions: Green Infrastructure (GI) –Enhancing Europe's Natural Capital (No. COM (2013). 249 Final).
Evette, A., Labonne, S., Rey, F., Liebault, F., Jancke, O., Girel, J., 2009. History of bioengineering techniques for erosion control in rivers in Western Europe. Environ. Manag. 43 (6), 972. https://doi.org/10.1007/s00267-009-9275-y.
Fernandes, J.P., Guiomar, N., 2018. Nature-based solutions: the need to increase the knowledge on their potentialities and limits. Land Degrad. Dev. 29, 1925–1939. https://doi.org/10.1002/ldr.2935.
Forzieri, G., Guarnieri, L., Vivoni, E.R., Castelli, F., Preti, F., 2011. Spectral-ALS data fusion for different roughness parameterizations of forested floodplains. River Res. Appl. 27 (7), 826–840. https://doi.org/10.1002/rra.1398.
Giambastiani, Y., Errico, A., Preti, F., Guastini, E., Censini, G., 2021. Indirect root distribution characterization using electrical resistivity tomography in different soil conditions. Urban For. Urban Green. https://doi.org/10.1016/j.ufug.2021.127442, 127442, ISSN 1618–8667.
Giupponi, L., Bischetti, G.B., Giorgi, A., 2017. A proposal for assessing the success of soil bioengineering work by analysing vegetation: results of two case studies in the Italian Alps. Landsc. Ecol. Eng. 13 (2), 305–318. https://doi.org/10.1007/s11355-016-0323-5.
Hacker, E. (Ed.), 2015. European Guidelines for Soil and Water Bioengineering. European Federation for Soil Bioengineering, Aachen. www.efib.org.
Heathcote, I.W., 2009. Integrated Watershed Management: Principles and Practice. John Wiley & Sons.
Hofmann, A., 1936. La sistemazione idraulica-forestale dei bacini montani. UTET, Torino.
Hörbirnger, S., 2021. Decision-Making Framework to Support Green-Blue Infrastructure Multifunctionality. Doctoral thesis. Boku University. https://boku.ac.at/en/baun at/iblb/news-archiv/doctoral-thesis-stephan-hoerbinger.
IPCC, 2019. Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems. Report. Intergovernmental Panel on Climate Change, Switzerland.
IPCC, 2021. In: Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., Zhou, B. (Eds.), Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
IUCN, 2012. The IUCN Programme 2013–2016.
IUCN, 2016. Nature-Based Solutions to Address Global Societal Challenges.
IUCN, 2020. IUCN Global Standard for NBS.
Kalsnes, B., Capobianco, V., 2019. Nature-Based Solutions. Landslides Safety Measures. Klima 2050 Report;16. SINTEF Academic Press. http://hdl.handle.net/11250/2617166.
Konijnendijk, C.C., Ricard, R.M., Kenney, A., Randrup, T.B., 2006. Defining urban forestry–a comparative perspective of North America and Europe. Urban For. Urban Green. 4 (3–4), 93–103. https://doi.org/10.1016/j.ufug.2005.11.003.
Kumar, P., Debele, S.E., Sahani, J., Rawat, N., Marti-Cardona, B., Alfieri, S.M., Zieher, T., 2021. Nature-based solutions efficiency evaluation against natural hazards: Modelling methods, advantages and limitations. Sci. Total Environ. 147058 https://doi.org/10.1016/j.scitotenv.2021.147058.
Lammeranner, W., Rauch, H.P., Laaha, G., 2005. Implementation and monitoring of soil bioengineering measures at a landslide in the Middle Mountains of Nepal. Plant Soil 278 (1), 159–170. https://doi.org/10.1007/s11104-005-7012-8.
Lewis, L., 2000. Soil Bioengineering an Alternative for Roadside Management a Practical Guide. USDA Forest Service.
Maxwald, M., Crocetti, C., Ferrari, R., Petrone, A., Rauch, H.P., Preti, F., 2020. Soil and Water Bioengineering applications in Central and South America: a transferability analysis. Sustainability 12 (24), 10505. https://doi.org/10.3390/su122410505.
Mickovski, S.B., 2014. Stabilisation of former trunk road embankment using combined structural and eco-engineering strategies. In: Proc. 3rd IntΓl Conf. on Road and Rail Infrastr. CETRA2014, Split, Croatia, pp. 28–30. April.
Mickovski, S.B., 2021. Re-thinking soil bioengineering to address climate change challenges. Sustainability 13 (6), 3338. https://doi.org/10.3390/su13063338.
Mitsch, W.J., 2012. What is ecological engineering? Ecol. Eng. 45, 5–12. https://doi.org/10.1016/j.ecoleng.2012.04.013.
Mitsch, W.J., Jørgensen, S.E., 2003. Ecological engineering and ecosystem restoration. John Wiley & Sons.
Moos, C., Bebi, P., Schwarz, M., Stoffel, M., Sudmeier-Rieux, K., Dorren, L., 2018. Ecosystem-based disaster risk reduction in mountains. Earth Sci. Rev. 177, 497–513. https://doi.org/10.1016/j.earscirev.2017.12.011.
Naumann, S., Davis, M., Kaphengst, T., Pieterse, M., Rayment, M., 2011. Design, Implementation and Cost Elements of Green Infrastructure Projects. Final Report. European Commission, pp. 138–Brussels.
Odum, H.T., 1962. Man in the ecosystem. In: Proceedings of Lockwood Conference onthe Suburban Forest and Ecology, Storrs, CT. Bull. Conn. Agric. Station, 652, pp. 57–75.
Palmeri, F., Sauli, G., Cornelini, P., 2006. A survey of experimental soil bioengineering works in Italian Mediterranean regions. In: Soil-bioengineering: ecological restoration with native plant and seed material. Conference, HBLFA Raumberg-Gumpenstein, Austria, 5–9 September, 2006. HBLFA Raumberg-Gumpenstein, pp. 43–52.
Paris Tormo, J., García-Fayos, P., Bochet, E., 2008. Relative importance of plant traits and ecological filters in road embankment revegetation under semiarid Mediterranean conditions. Ecol. Eng. 33 (3–4), 258–264. https://doi.org/10.1016/j.ecoleng.2008.05.002.
PEDDR, 2010. Demonstrating the Role of Ecosystem-Based Management for Disaster Risk Reduction. Partnership for Environment and Disaster Risk Reduction.
Petrone, A., Preti, F., 2010. Soil bioengineering for risk mitigation and environmental restoration in a humid tropical area. Hydrol. Earth Syst. Sci. 14 (2), 239–250. https://doi.org/10.5194/hess-14-239-2010.
Preti, F., 2013. Forest protection and protection forest: tree root degradation over hydrologicalshallow landslides triggering. Ecol. Eng. 61 (1 PARTC), 633–645. https://doi.org/10.1016/j.ecoleng.2012.11.009.
Preti, F., 2021. Soil and Water Bioengineering as Nature-Based Solution for Hill Slope and Bank Stability, Webinar Monday, 26 October 2020, 14:00–17:20 Beijing / 08:00–11:20 CETon Land Degradation, Soil Conservation and Sustainable Development - a Preview for LASOSU2021 (PLASOSU).
Preti, F., Petrone, A., 2013. Soil bio-engineering for watershed management and disaster mitigation in Ecuador: a short-term species suitability test. iForest 6, 95–99. https://doi.org/10.3832/ifor0636-006.
Preti, F., Forzieri, G., Chirico, G.B., 2011. Forest cover influence on regional flood frequency assessment in mediterranean catchments. Hydrol. Earth System Sci. 2011 15 (10), 3077–3090.
Preti, F., Dani, A., Noto, L.V., Arnone, E., 2022. On the leonardo's rule for the assessment of root profile. Ecol. Eng. 179 https://doi.org/10.1016/j.ecoleng.2022.106620.
Rauch, H.P., Sutili, F., Hörbinger, S., 2014. Installation of a riparian forest by means of soil bio engineering techniques—monitoring results from a river restoration work in Southern Brazil. Open J. For. 4 (02), 161. https://doi.org/10.4236/ojf.2014.42022.
Raymond, C.M., Berry, P., Breil, M., Nita, M.R., Kabisch, N., de Bel, M., Enzi, V., Frantzeskaki, N., Geneletti, D., Cardinaletti, M., Lovinger, L., Basnou, C., Monteiro, A., Robrecht, H., Sgrigna, G., Munari, L., Calfapietra, C., 2017. An Impact Evaluation Framework to Support Planning and Evaluation of Nature-Based Solutions Projects. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas. Centre for Ecology & Hydrology, Wallingford, United Kingdom.
Renaud, F.G., Sudmeier-Rieux, K., Estrella, M., (Eds.)., 2013. The Role of Ecosystems in Disaster Risk Reduction. United Nations University Press.
Rey, Freddy, 2021. Harmonizing erosion control and flood prevention with restoration of biodiversity through ecological engineering used for co-benefits nature-based solutions. Sustainability 13 (20), 11150. https://doi.org/10.3390/su132011150.
Rey, F., Louis, S., Burylo, M., Raymond, P., 2013. Improving soil bioengineering techniques to control erosion and sedimentation within the context of torrential Mediterranean climate: A French-Canadian experience. In: EGU General Assembly Conference Abstracts. April. (pp. EGU2013-8728).
Rey, F., Bifulco, C., Bischetti, G.B., Bourrier, F., De Cesare, G., Florineth, F., Stokes, A., 2019. Soil and water bioengineering: practice and research needs for reconciling natural hazard control and ecological restoration. Sci. Total Environ. 648, 1210–1218. https://doi.org/10.1016/j.scitotenv.2018.08.217.
Ruangpan, L., Vojinovic, Z., Sabatino, S.D., Leo, L.S., Capobianco, V., Oen, A.M., Lopez-Gunn, E., 2020. Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. Nat. Hazards Earth Syst. Sci. 20 (1), 243–270. https://doi.org/10.5194/nhess-20-243-2020.
Sangalli, P., Tardío, Guillermo, Peklo, Klaus, Stokes, Alexia, Fernandes, João Paulo, Freitas, Aldo, Oliveira, Ana, Faria, Sílvia, Marrone, Ettore, Salustri, Angela, Burricco, Giuseppe, Astarita, Vincenzo, 2018. Introduction to Soil and Water Bioengineering, ECOMED, Specialization Process for the Ecoengineering Sector in the Mediterranean Environment.
Sangalli, P., Fernandes, J.P., Tardío, G., 2021. Soil and water bioengineering as natural-based solutions. In: Urban Services to Ecosystems. Springer, Cham, pp. 317–332. https://doi.org/10.1007/978-3-030-75929-2_17.
Santolini, R., Morri, E., 2017. Criteri ecologici per l'introduzione di sistemi di valutazione e remunerazione dei Servizi Ecosistemici (SE) nella progettazione e pianificazione. In: La Dimensione Europea del Consumo di Suolo e le Politiche Nazionali, CRCS Rapporto 2017. INU ed, Roma, pp. 149–154 (in italian).
Sauli, G., Cornelini, P., 2011. The application of native species of shrubs rooted and as cuttings in soil bioengineering intervention in the mediterranean areas in Italy. In: ИнЖенерная биология в совреМенноМ Мире, pp. 228–229.
Sauli, G., Cornelini, P., Preti, F., 2005. Manuale di Ingegneria Naturalistica. Sistemazione dei versanti. Volume 3, Capitoli 1-7, Regione Lazio, 223 pages.
Schiechtl, H.M., 1980. Bioengineering for Land Reclamation and Conservation. University of Alberta Press, Edmonton.
Schiechtl, H.M., 1985. FAO Watershed Management Field Manual - Vegetative and Soil Treatment Measures, FAO Conservation Guide 13/1. Food and Agriculture Organization of the United Nations, Rome.

Science for Environment Policy, 2021. The Solution is in Nature. Future Brief 24. Brief Produced for the European Commission DG Environment. Science Communication Unit, UWE Bristol, Bristol.
Seddon, N., Chausson, A., Berry, P., Girardin, C.A., Smith, A., Turner, B., 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. Philos. Trans. R. Soc. B 375 (1794). https://doi.org/10.1098/rstb.2019.0120, 20190120.
Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., Turner, B., 2021. Getting the message right on nature-based solutions to climate change. Glob. Chang. Biol. 27 (8), 1518–1546. https://doi.org/10.1111/gcb.15513.
Solheim, A., Capobianco, V., Oen, A., Kalsnes, B., Wullf-Knutsen, T., Olsen, M., Strout, J. M., 2021. Implementing nature-based solutions in rural landscapes: barriers experienced in the PHUSICOS project. Sustainability 13 (3), 1461. https://doi.org/10.3390/su13031461.
Stiles, R., 1988. Engineering with vegetation. Landsc. Des. 172, 57–61.
Stokes, A., Sotir, R.B., Chen, W., Ghestem, M., 2010. Soil bio- and ecoengineering in China, past experience and present priorities. Ecol. Eng. 36, 247–257. https://doi.org/10.1016/j.ecoleng.2009.07.008.
Stokes, A., Douglas, G.B., Fourcaud, T., Giadrossich, F., Gillies, C., Hubble, T., Walker, L. R., 2014. Ecological mitigation of hillslope instability: ten key issues facing researchers and practitioners. Plant Soil 377 (1), 1–23. https://doi.org/10.1007/s11104-014-2044-6.
Tansley, A.G., 1935. The use and abuse of vegetational concepts and terms. Ecology 16 (3), 284–307.
Thiery, E., 1891. Restauration des montagnes. Correction des torrents. Reboisement. Baudry.
Trapani, F., Carrara, R., Chiara, G.D., Ferrara, L.M., Giudice, M., Pirrera, G., 2021. The necessary integration of green infrastructures in the public transport infrastructure design. In: Advanced Studies in Efficient Environmental Design and City Planning. Springer, Cham, pp. 317–331. https://doi.org/10.1007/978-3-030-65181-7_26.
Turney, C., Ausseil, A.G., Broadhurst, L., 2020. Urgent need for an integrated policy framework for biodiversity loss and climate change. Nat. Ecol. Evol. 4 (8), 996. https://doi.org/10.1038/s41559-020-1242-2.
Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kazmierczak, A., Niemela, J., James, P., 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: a literature review. Landsc. Urban Plan. 81 (3), 167–178. https://doi.org/10.1016/j.landurbplan.2007.02.001.
UNDRR, 2020. Ecosystem-Based Disaster Risk Reduction: Implementing Nature-Based Solutions for Resilience. United Nations Office for Disaster Risk Reduction – Regional Office for Asia and the Pacific, Bangkok, Thailand.
UNESCO, 2018. The United Nations World Water Development Report 2018: Nature-Based Solutions for Water.
van Bohemen, H. (Ed.), 2005. Ecological Engineering: Bridging between Ecology and Civil Engineering. Uitgeverij Æneas BV.
WEF, 2020. The Global Risks Report 2020. Insight Report, 15th edition.
WWAP (UNESCO World Water Assessment Programme), 2019. The United Nations World Water Development Report 2019: Leaving no One behind. UNESCO, Paris.