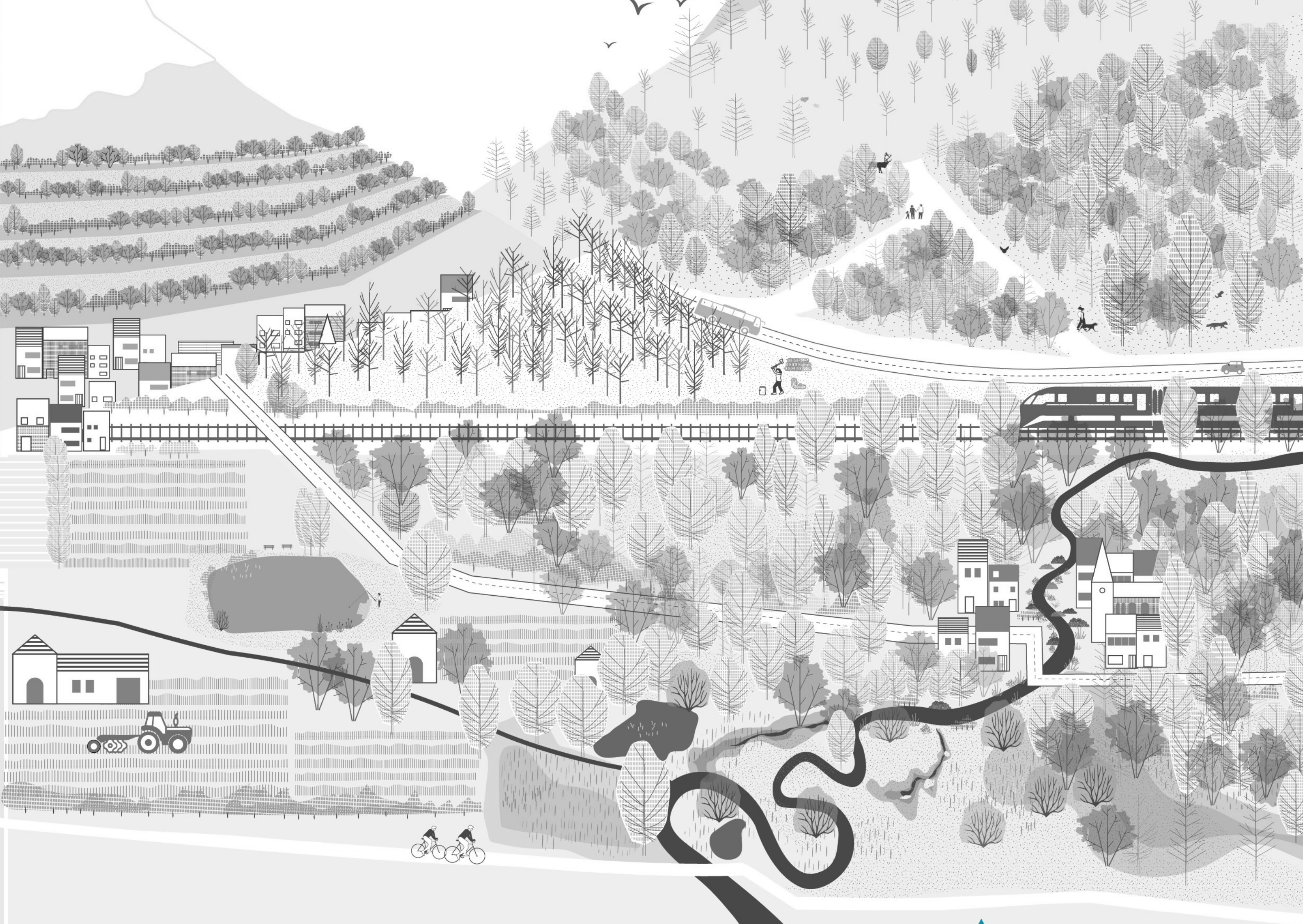
According to nature

Towards nature-based solutions as a design attitude

A NBS guidebook for designed landscapes in rural areas from a river basin perspective

April 2025



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PHUSICOS

Colophon

ACCORDING TO NATURE -
Towards nature-based solutions as a design attitude

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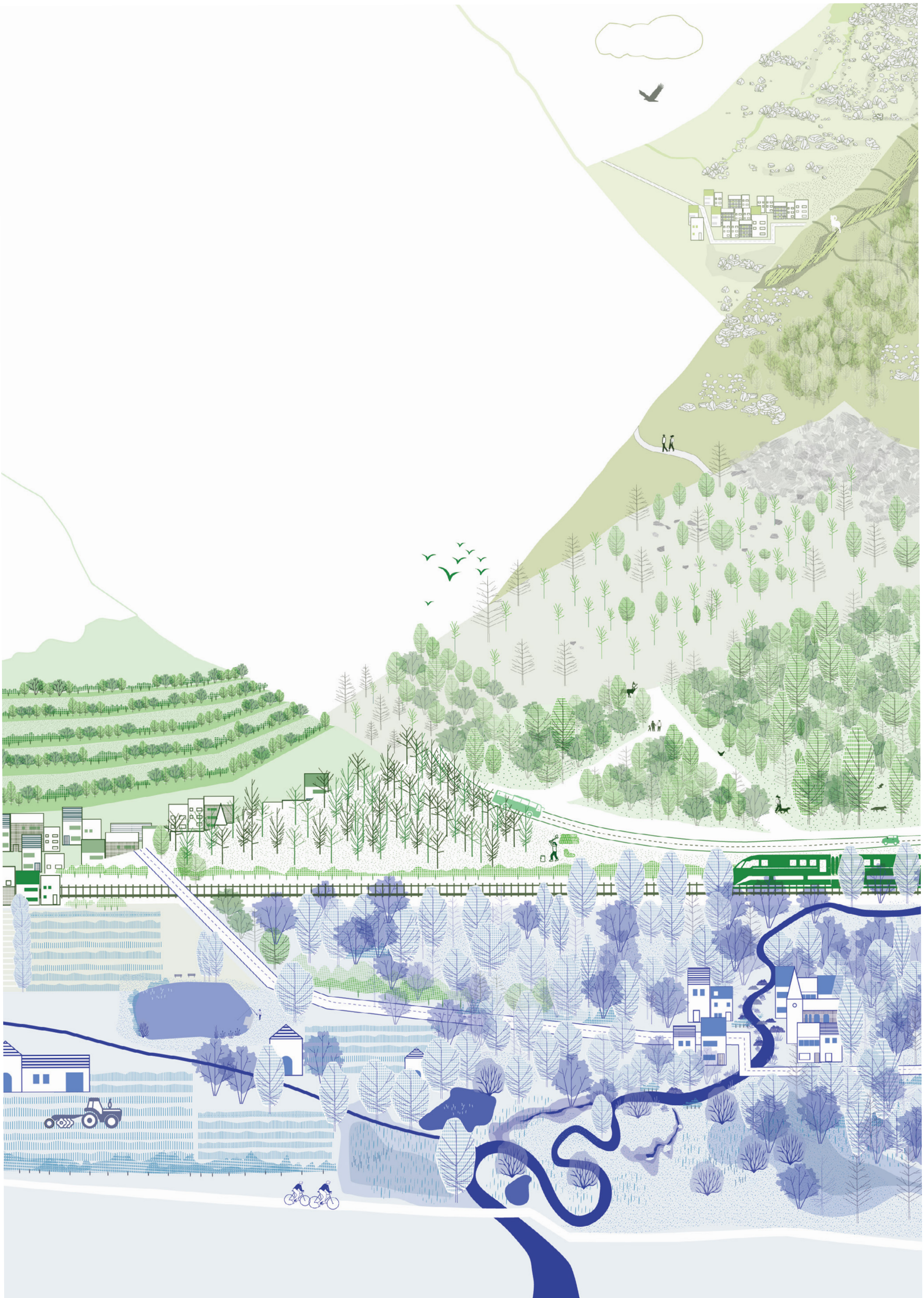


Foreword

Nearly 50% of the rural areas in the world are classified as mountainous regions and are exposed to risk from geological and hydro-meteorological hazards. Mountains tend to amplify these risks, and even more so under extreme weather events. However, rural mountainous regions do not receive the same attention as densely populated urban areas in national disaster risk reduction (DRR) plans. National DRR plans focus mainly on regions with the highest population density, which tend to be urban and/or coastal areas.

The PHUSICOS project has focused on investigating the use and benefits of nature-based solutions in rural mountainous areas by implementing demonstrator cases. Our sister project OPERANDUM has developed complementary experience through their focus on open air laboratories in rural natural areas. The PHUSICOS and OPERANDUM teams have collaborated on compiling these experiences in this NBS guidebook. Initially planned as an overview of possibilities and conditions from the project sites themselves, the guidebook has evolved to become a much broader document that aims to inspire designers, local policy makers and others to implement NBS in a broad spectrum. It provides insight to the suitability of certain NBS in the different landscapes or ecosystems and their effectiveness for climate resilience.

We hope this guidebook can inspire anyone to work with NBS to address resilience on various scales. Let this be an invitation to discover, understand, but most importantly act according to nature.

April 2025

A. Introduction

A1. General introduction

The increasing frequency and severity of hydro-meteorological events on land and sea have a high impact globally. Hydro-meteorological events such as flooding, landslides, cyclones and intense storms, as well as severe temperatures and droughts are more likely to become more frequent and more extreme because of climate change. Nature-based solutions (NBS), interventions that are inspired and supported by nature, are being recognized as having the potential to reduce the risk of these extreme hydro-meteorological events (Ruangpan et al., 2020).

As an umbrella concept, NBS are now formally defined by the United Nations Environment Assembly as 'actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits' (UNEA-5, 2022). As such, NBS represent the unifying concept to prioritize nature, it is compelling in its intuitive construct and is gaining traction in both the public and private sector (Cohen-Shacham et al., 2019; UNEP, 2021). NBS for hydro-meteorological risk reduction 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).

The European Commission's Research and Innovation agenda on NBS has positioned the EU as a leader to mainstream NBS. Through the EU's Horizon 2020 (H2020) Work Programme several NBS projects have been funded to advocate its further implementation and provide proof-of-concept for the replication and upscaling of NBS. This has included the support of research and innovation action projects that design, implement and evaluate innovative and locally attuned NBS for hydro-meteorological risk reduction at the watershed and landscape scale. Two of these projects, PHUSICOS and OPERANDUM, which focus on large-scale demonstrations to verify proof-of-concept and the upscaling potential of NBS to the regional landscape scale are showcased in this guidebook.

Briefly, PHUSICOS, meaning 'According to nature' in Greek, demonstrates how NBS provide robust, sustainable and cost-effective measures for reducing the risk of extreme weather events in rural mountain landscapes. Mountains amplify risks, and even more so under extreme weather events; however, mountainous regions have not received the same attention as densely populated urban areas in European disaster risk reduction plans. PHUSICOS's underlying premise is that nature itself is a source of ideas and solutions for reducing the risk posed by climate-driven natural hazards.

OPERANDUM (OPEn-air laboRAtories for Nature baseD solUtions to Manage hydro-meteorisks) has focused on mitigating risks of severe hazards by delivering the tools and methods for the validation of NBS to enhance resilience in European rural and natural territories. In the OPERANDUM project, site-specific and innovative NBS are co-designed, co-developed, deployed, tested and demonstrated with partners and local stakeholders in open-air laboratories. These open-air laboratories (OALs) are natural and rural Living Labs that cover a wide range of hazards with different climate projections, land use and socio-economic characteristics.

Both the PHUSICOS and OPERANDUM projects represent robust, transdisciplinary consortia comprising partners with extensive expertise and a long track record of experience from public authorities, research institutes and universities as well as private enterprises. The expertise covers the fields of natural hazards and disaster risk reduction, climate scenarios modelling, GIS capabilities, geoinformatics and remote sensing, landscape architecture, landscape planning, nature conservation, economics and ecosystem services, , governance as well as knowledge brokering to improve stakeholder involvement.

Both projects have been working closely together to ensure that NBS are technically viable, socially acceptable, cost-effective and implementable at the regional scale and that the benefits of NBS are inclusive by increasing the ecological, social and economic resilience of local communities. Several NBS interventions to tackle different hydro-meteorological risks have been co-designed and co-developed with local stakeholders and subsequently implemented in a total of 15 different case study sites in 13 countries throughout Europe as well as China and Australia. Selected examples are illustrated in this guidebook to exemplify the multiple benefits of NBS and to support their widespread implementation.

Through the lens of PHUSCIOS and OPERANDUM, we aim to inspire the NBS community of practitioners and facilitate knowledge exchange, enable synergies, and contribute to wider policy initiatives and community engagement across all of Europe and globally.

A2. Inspiring with a guidebook

This guidebook is set up to be first and foremost a source of inspiration. By taking the experiences of the PHUSICOS and OPERANDUM projects and framing those within a wider, more general perspective, overall insights can be formulated. Policy makers, designers, technicians, researchers and others interested in NBS can be inspired by the solutions proposed to prevent hazards or to mitigate their consequences.

The guidebook is designed for visual impact, aiming to comprehensively illustrate the NBS, their spatial impact and the consequences vis-à-vis grey solutions. Even though every NBS will have to be evaluated from various points of view (technical, financial, etc.), a very fundamental element is also determined by its spatial impact on a landscape and territory. By illustrating the opportunities and added value of NBS as landscape interventions, this guidebook seeks to broaden perspectives and ambitions for the territorial landscape to become a driver for risk reduction and mitigation.

While certainly not aiming to be an exhaustive overview of all possible NBS, the guidebook provides a consistent compilation of strategies, every time in relation to a specific landscape. In the following chapters these landscapes and a selection of NBS will be further detailed and explained. The guidebook takes specifically the starting point of rural areas, in relation to the focus of the PHUSICOS project.

Finally, the guidebook aims to be complementary to other literature and online platforms on NBS. Recently, more and more publications and sources are becoming available with regards to NBS, their implementation and their importance in relation to hazards, risk reduction and mitigation. Many of these sources provide either very general overviews or are focusing specifically on urban NBS. By providing the perspective of rural landscapes, the guidebook can offer an alternative overview and can inspire for specific landscape conditions. With this document at hand, anyone involved in the specific development of a rural territory can pick up elements and ideas for NBS that can reinforce its resilience.

B. Towards nature-based solutions as a design attitude

B1. A river basin perspective

The river basin as a starting point

Mountains amplify risks, and even more so under extreme hydro-meteorological events where the impact of these events in mountain areas can affect entire river basins. As such, hazards initiated upstream in a river basin can also impact more densely populated urban and coastal areas downstream. For example, flash floods that begin in hilly and mountainous regions can trigger landslides with massive movement of sediment and debris that can subsequently damage infrastructure or result in dam failure releasing large amounts of water downstream and causing additional flooding. The force of these events can also lead to significant erosion, damaging ecosystems such as wetlands and coastal habitats.

PHUSICOS leverages multiple levels of innovation to increase the capacity of rural mountain areas to apply nature-based and nature-inspired solutions to reduce risks associated with extreme hydro-meteorological events. Further to application in mountainous areas, these multiple levels of innovation are relevant for implementing NBS in non-mountainous contexts within the river basin, as well as in coastal and urban areas. This river basin perspective lends us an approach to i) understand the interconnectedness of the entire ecosystem and the landscape of the river basin, and ii) identify potential NBS that consider the complexities of the local context.

This guidebook showcases NBS for relevant natural hazards by highlighting the spatial placement of the NBS interventions relative to the river basin. The intention is to easily identify potential sites for replicating and upscaling successful NBS, favoring them over traditional grey infrastructure measures such as pipes and concrete structures. Furthermore, the river basin perspective also emphasizes the importance of considering the long-term impacts of NBS, the time needed for them to reach maturation, the maintenance required and subsequently their ability reduce the impacts of extreme hydro-meteorological events which are becoming more frequent and more severe in the face of climate change.

In summary, the river basin perspective integrates ecological, social, and economic considerations emphasizing long-term sustainability. This approach ensures that NBS reduce the risk of natural hazards from the mountainous areas upstream to the coastal areas downstream, that NBS are managed effectively, and that NBS contribute to a healthy and resilient ecosystem.

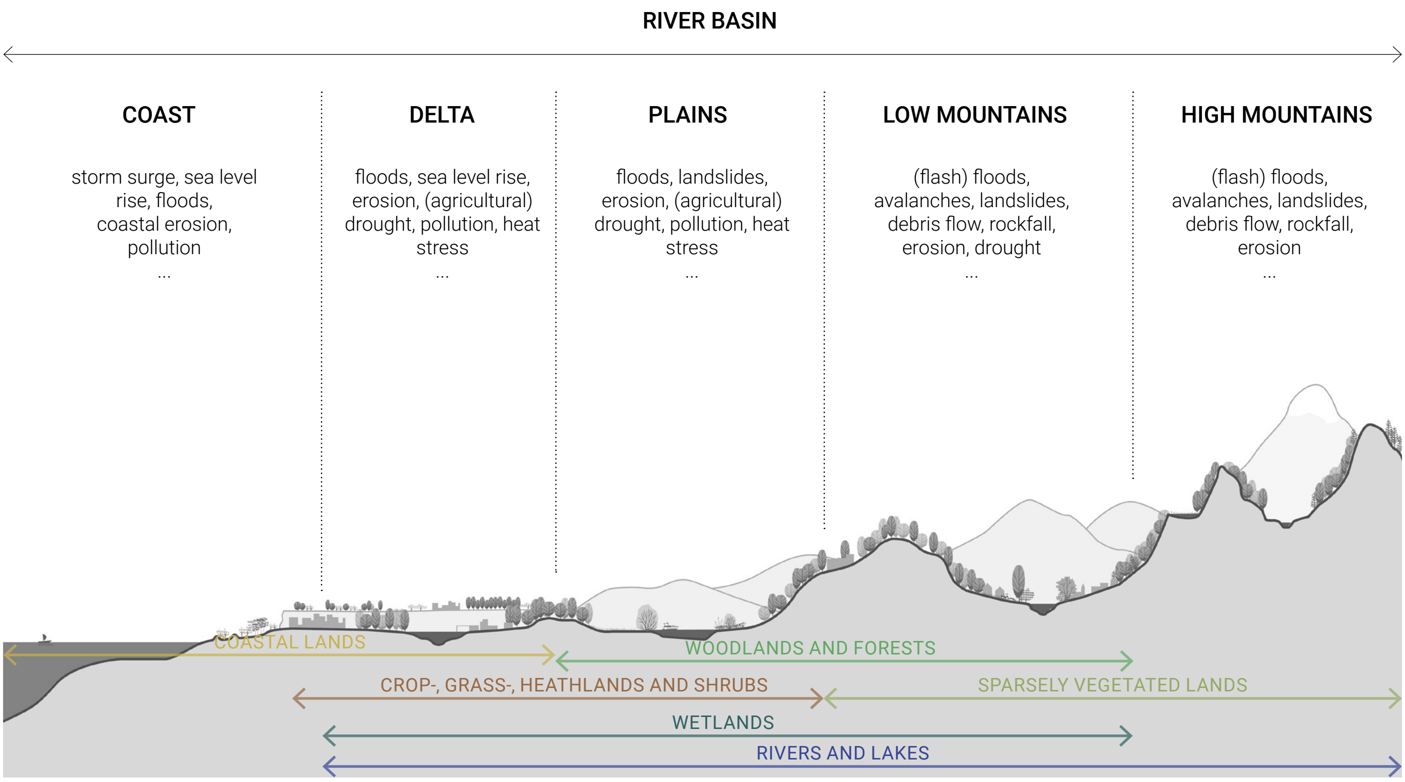


Figure B-1: Illustration of the entire river basin

Six ecosystems as narratives

The river basin perspective includes a variety of conditions. For the purposes of this guidebook these are grouped into six ecosystems based on distinctive spatial and ecological characteristics, including topography, vegetation, land-use, and climatic conditions. Although, each ecosystem faces unique hazards and challenges, they also share common features which support their grouping into pairs.

Every ecosystem in the guidebook is developed as a landscape narrative, where the qualities, spatial relations and transformations, ecosystem services, possible NBS and their specific implementation are highlighted. This approach allows for a coherent vision between different NBS within one determined landscape or territory. By laying out a spatial strategy for the entire area, the socio-ecological benefits of the NBS can also be reinforced and promote a more resilient landscape.

The ecosystems and their pairs are defined in this guidebook as:

WATERSCAPES

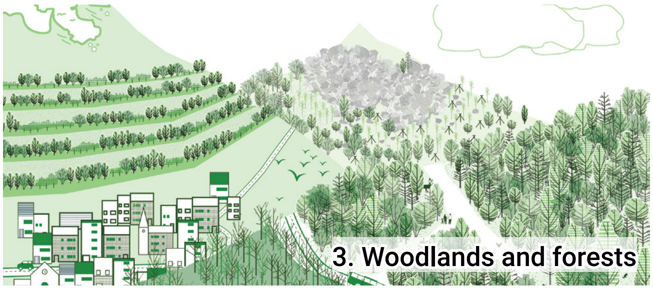
1. Rivers and lakes
2. Wetlands

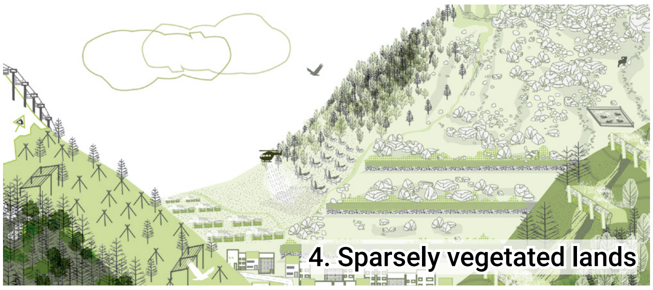
(VEGETATED) SLOPES

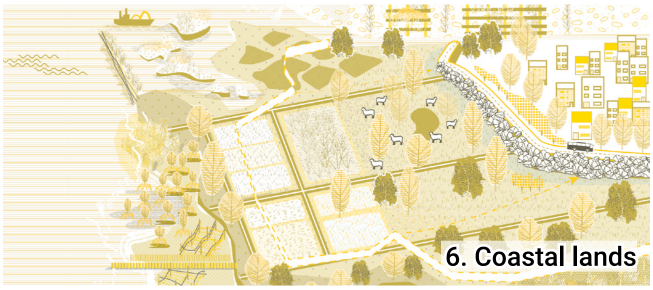
3. Woodlands and forests
4. Sparsely vegetated lands

DYNAMIC LOWER LANDS

5. Crop-, grass-, heathlands and shrubs
6. Coastal lands







B2. Parameters defining NBS

Approaches

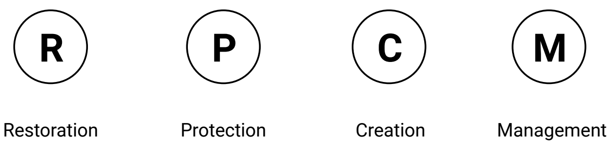
The guidebook also indicates different types of NBS approaches in the context of a landscape synthesis as well as for each specific NBS. Four categories are identified under the NBS umbrella:

- Restoration: rehabilitating degraded ecosystems to regenerate functions and benefits
- Protection: sustaining existing NBS and protecting specific areas from direct hazards
- Creation: create new NBS to address hazards or to prevent from potential hazards
- Management: implement a sustainable management of existing valuable ecosystems and NBS

Hazards

A wide range of expected hazards are represented in this guidebook. They are very specific to each of the ecosystems and may occur simultaneously at a given location. The hazards are influenced by the variations of the territorial landscapes and are ranging from threats specific for mountainous areas, water- or soil-related risks to more specific challenges like wildfires or heat stress. Multiple hazardous events can also trigger in a cascading way like a series of toppling dominoes, such as flooding and landslides that occur after extreme rain events. Cascading events may begin in small areas but eventually intensify and spread over larger areas which can influence an entire catchment.

DIFFERENT TYPES OF NBS APPROACHES



HAZARDS

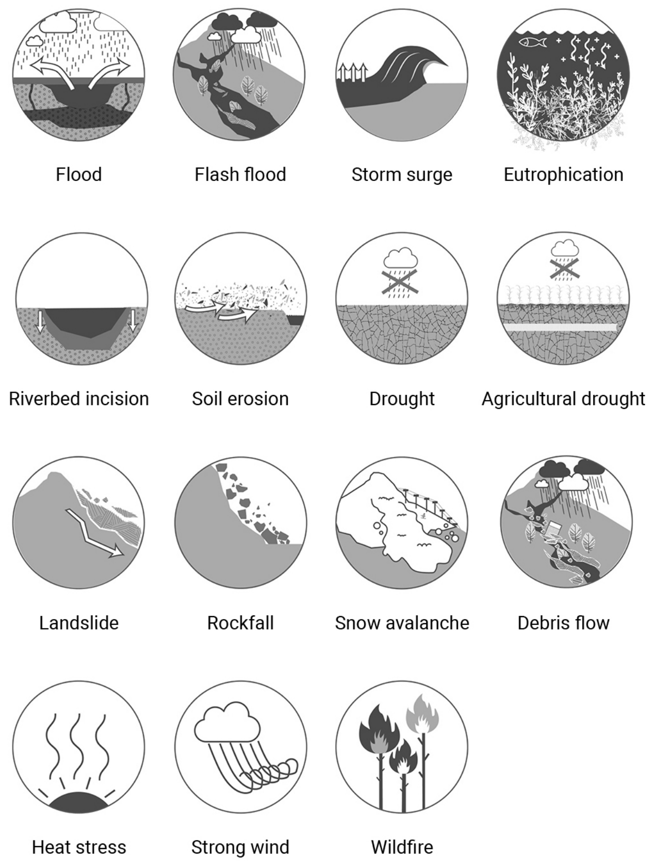


Figure B-2 Iconography for indicating NBS approach, hazards, functions and benefits.

Functions

Each of the NBS aims for a specific set of functions to be achieved. They represent the desired results after implementation. They can describe the management of potential natural hazards, but also the regulation of other ecosystem services.

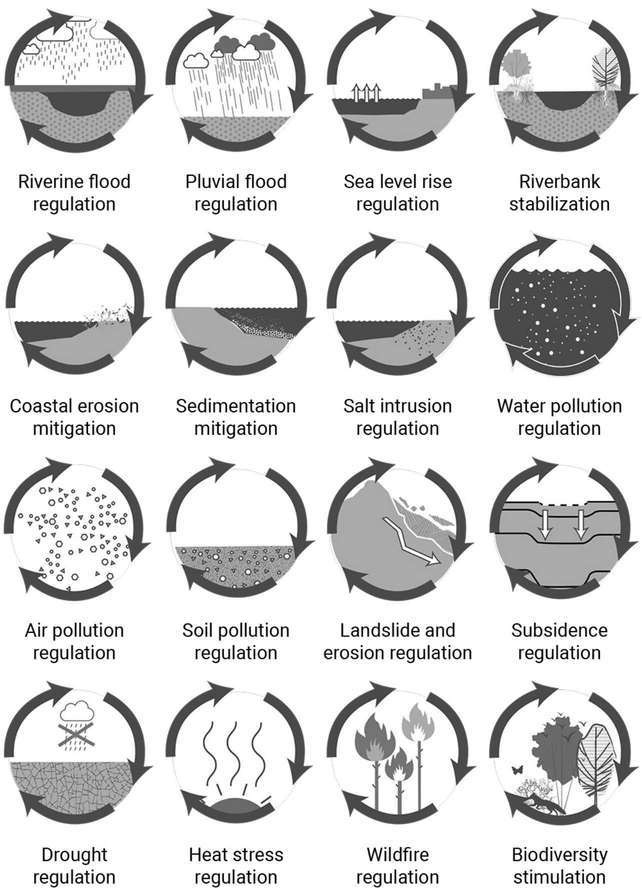
For each of the ecosystems the importance and relevance of the functions are represented in a graph. Furthermore, the main functions are represented for each of the specifically highlighted NBS in the different chapters.

Benefits

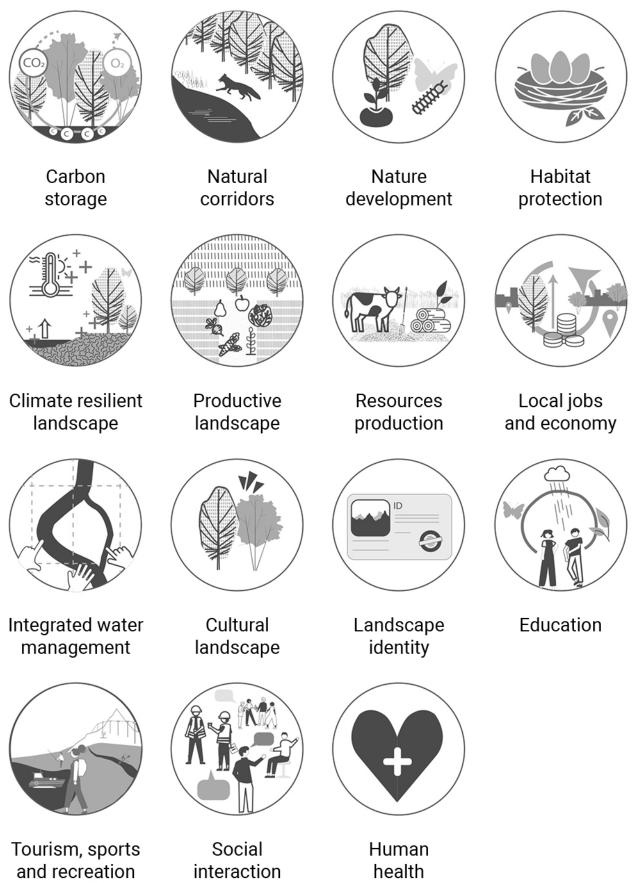
Nature-based solutions provide various socio-ecological benefits in addition to the direct reduction of natural hazard impacts. These range from more direct and tangible benefits (for example resources production or habitat protection) to indirect or abstract benefits (for example landscape identity or human health). The impacts of these are relevant for a variety of societal challenges.

The benefits highlighted by the iconography below are also illustrated in a graphical format for each of the ecosystems in this guidebook. The descriptions of the showcase NBS presented include a description of the main benefits provided by these.

FUNCTIONS



BENEFITS



B3. Enablers for implementation

Governance issues relating to NBS are increasingly recognized as an important emerging theme. They are also appearing on an ever-expanding number of political agendas, most recently and noteworthy on the Convention on Biological Diversity's Kunming-Montreal Global Biodiversity Framework and the UNFCCC Conference of the Parties (COP) 27 decision text. Despite NBS' increasing political traction and recognition in Europe and beyond, information is still fragmented on how NBS can successfully be implemented in different governance settings, and what stands in the way of their realization.

For NBS to meet their promise of addressing global societal challenges, we need to better understand the governance drivers, frameworks, strategies and instruments that have enabled or impeded NBS. Another key factor to consider when exploring NBS governance is the stage in the NBS life cycle and how these enablers and barriers can vary for the contextual pre-conditions and subsequently the initiation, planning, design and implementation of NBS (figure B-3). The monitoring and maintenance aspects are fundamental to NBS and should be addressed already during the design and planning phase. This can ensure that required resources are allocated in time and monitoring can start immediately after the implementation is completed.

Further to novel governance frameworks and adaptive policies, stakeholder involvement is identified is an influential parameter for the success of NBS implementations. A thorough design process with the various stakeholders (professional as well as inhabitants) will not only enrich the design itself, but also its integration in the inhabited landscape. The co-creation process can lead to fundamental ownership of the NBS and the landscape integration.

Finally, a successful implementation of NBS requires the necessary technical approaches across the NBS life cycle to provide fundamental insights before, during and after the construction of the NBS. These technical approaches are summarized as the "3M's": modelling, maintenance and monitoring. Modelling provides a method to document the effectiveness of the NBS and to assess and adjust the implementation within the landscape dynamics. Monitoring is an essential element of evaluating and documenting the effectiveness as well as the co-benefits of the NBS intervention. It increases the NBS evidence base and builds confidence in NBS for their upscaling and widespread application. Maintenance is also a key to success to ensure the long-term functionality of the implemented NBS. Not only should NBS maintenance be carefully planned for during the design process, but it also needs to be prioritized over the life of the NBS.

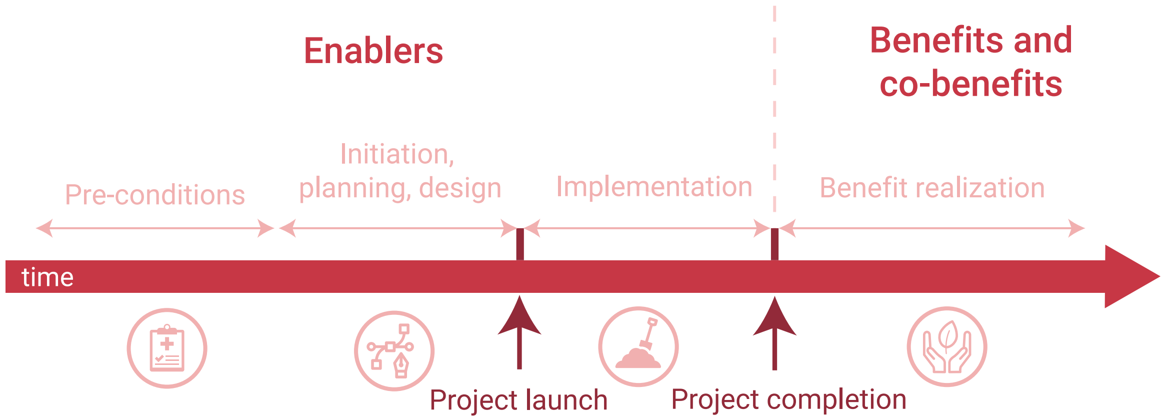


Figure B-3: Illustration of the process of a NBS implementation

Governance and stakeholder approaches

The NBS landscape in Europe is characterized by a policy-action and implementation gap (i.e., the mismatch between NBS ambitions and on-the-ground implementation). Most NBS policies are based largely on voluntary action and lack quantitative and measurable targets for NBS deployment and quality evaluation. Furthermore, the complexity and sheer number of policy instruments addressing NBS in Europe (figure B-4) can lead to confusion among decision-makers, fragmented governance and eventually, policy stalemates. Further alignment of sectoral policy instruments is also needed to facilitate cross-sectoral governance arrangements for NBS.

At the EU country level, multiple policy instruments explicitly acknowledge NBS and related concepts, sometimes even including them in their strategic objectives (e.g., German Green and White Papers on Urban Green, Federal Strategy on green infrastructures, Spanish National Natural Heritage and Biodiversity Law). However, this has not yet translated into their widespread implementation.

It is critical to better understand NBS enablers and barriers to promote the uptake of NBS as key options in fighting climate change, biodiversity loss and reducing disaster risk.

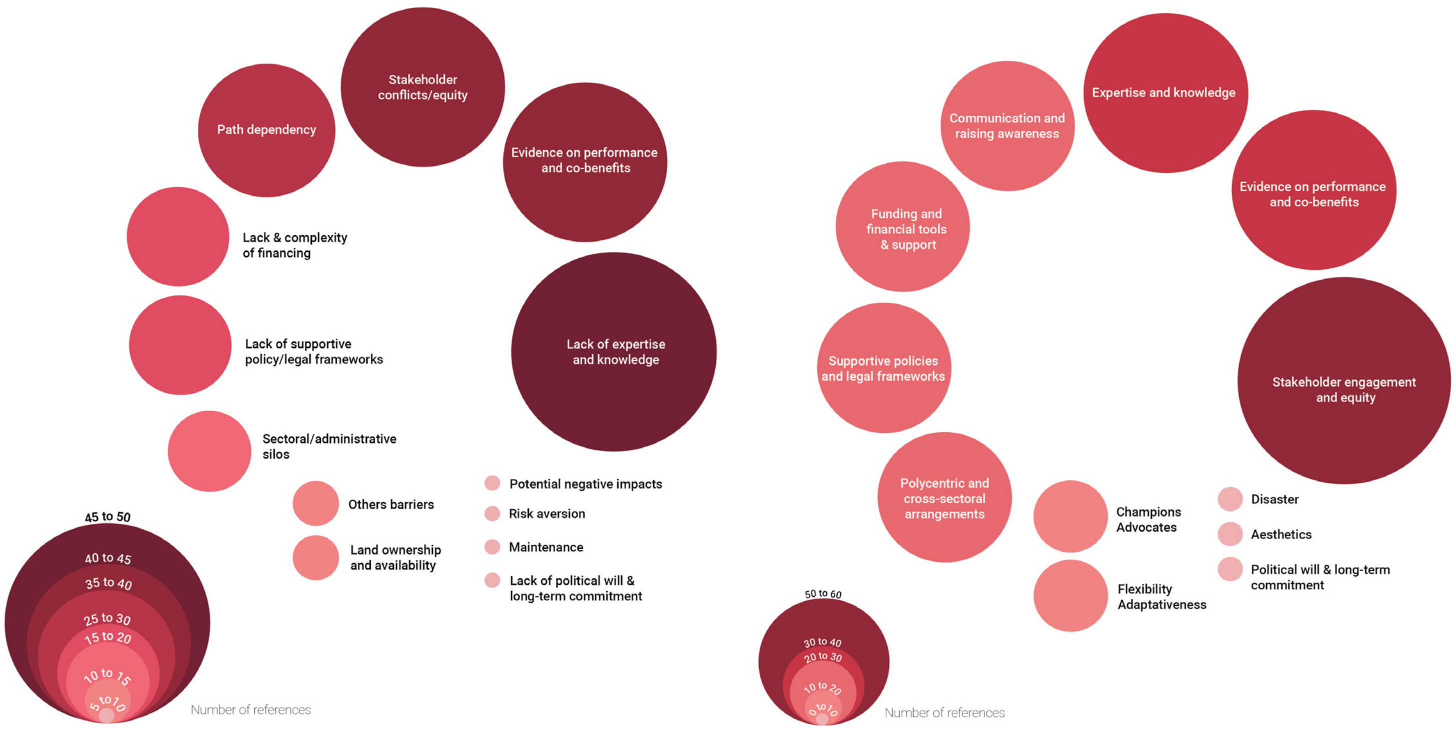


Figure B-4: Barrier (left) and enabler (right) themes identified in literature and workshop sessions (results from Martin et al. submitted)

Figure B-4 highlights the most important institutional, legal, regulatory, social and economic opportunities, as well as the key barriers to NBS implementation. Interestingly, barriers and enablers are remarkably similar, which can be attributed to the fact that many enablers represent the counterpart of barriers, and vice-versa.

Barriers to NBS implementation are manifold. Lack of equity (both in stakeholder engagement and in NBS benefit distributions) is a key barrier to successful NBS implementation. Stakeholder conflicts were among the most cited hurdles. This emphasizes the importance of inclusive engagement of stakeholders in the NBS design, planning and implementation process. One way to tackle this challenge is through true co-design and co-creation processes, which also emerged as key enablers of NBS.

The existence and further development of an evidence base on NBS performance and their benefits is also a critical NBS enabler.

"Having proof is a barrier. I know if I buy concrete, the engineers would tell me exactly what it will stop, but you guys cannot. So that is a big problem." (Consultant)

BOX B-1: Stakeholder opposition to NBS at Gudbrandsdalslågen

Stakeholder economic interests played a pivotal role in the flood-mitigation NBS proposed for Jorekstad in the Norwegian valley of Gudbrandsdalen. The catchment of the river, Gudbrandsdalslågen, and its tributaries drain large areas of glacial tills. This results in severe erosion leading to transport and deposition of large amounts of sand and gravel downstream, which is the basis for local companies retrieving and selling this resource. Gravel out-take after flooding events is therefore an important additional income for landowners along the rivers, and this has given rise to a potential barrier for implementing flood-reduction measures of any type.

Contrary to most European countries, where rivers are the property of the public, in Norway they are the property of the riparian landowners. This enables private property owners to significantly influence measures that impact the river, and in this case, gravel deposition in the river.

Poorly staffed municipalities with little experience or expertise with NBS combined with a dearth of evidence on their effectiveness and benefits, appear to be the norm.

> "Still today our main problem is having people that can work with us and sometimes we need to tell our customers that we cannot do the work because we do not have the right people." (Design/construction company)

Indeed, further studies are needed on the long-term benefits of NBS in comparison to grey solutions. In particular, more quantitative cost-benefits analyses capturing the multiple values of solutions are required.

Another common theme across enablers and barriers is the lack of knowledge products and NBS-specific expertise. Possible solutions include the creation of educational programs and trainings that are specific to NBS design (mainly targeting landscape architects and designers) and implementation (targeting contractors). The further development of nationally (and ideally, internationally) agreed technical standards, guidelines and legal norms for NBS implementation can also help surmount this challenge. Lack of capacity and knowledge is compounded by a lack of funds earmarked for NBS, and there is a fundamental problem in attracting private financing given the public-good nature of NBS and thus the shortage of bankable projects and business models.

> "Public projects have an administrative process that is quite different from the private one, it is more difficult and more constrained." (Designer)

> "They [infrastructure proposers] just ask what's the bare minimum to get them through planning (...). We have proposed options that are good for biodiversity, and sometimes they'll go “yes, but if it doesn't cost a lot of money, then that's fine”. But mostly, clients will complain if it's costing more money or delays." (EIA consultant)

A major factor limiting NBS implementation is path dependency, meaning the difficulty in breaking away from current legal and social norms which favor grey infrastructure. Moreover, politicians focus on short-term goals that bring voter support; yet NBS infrastructure has long-term impact and gestation periods.

Polycentric governance arrangements to overcome siloed administrations present an important enabler that appears somewhat unique to NBS implementation due to the often complex mosaic of actors, sectors and government levels involved in NBS projects. Polycentric governance arrangements, which foster cross-sectoral and cross-scale cooperation, offer an important opportunity to overcome these barriers. Nevertheless, such arrangements still lack practical operationalization in the NBS sphere.

Boosting NBS implementation

There is an urgent need for NBS projects to be embedded in broader agendas, bringing together different sectors and environmental issues. Novel governance arrangements, including polycentric arrangements to include various NBS benefits are therefore key for NBS uptake and contribution to transformative agendas.

> "I think we should start looking at the budget from a different angle in that respect, it will not be like "Oh, we don't have money". It is just investing your money differently and in a more intelligent way." (Designer)

Based on the recognized barriers and enablers of NBS, several actions that can help increase NBS in territorial, landscape and urban projects emerge (see figure B-5 below, and chapter D).

BOX B-2: Path dependency in the Serchio River Basin

In the PHUSICOS Serchio river Basin case, the responsible authority, the Autorita' di Bacino Distrettuale dell'Appennino Settentrionale (ADBS) maintains that to avoid grey measure path dependency it is essential to simplify the procedures for NBS approval.

Presently these procedures are the same as for grey measures. To exit this "lock-in", the recommendation is to promote technical self-certification schemes to be provided by the authorities in charge of NBS implementation.

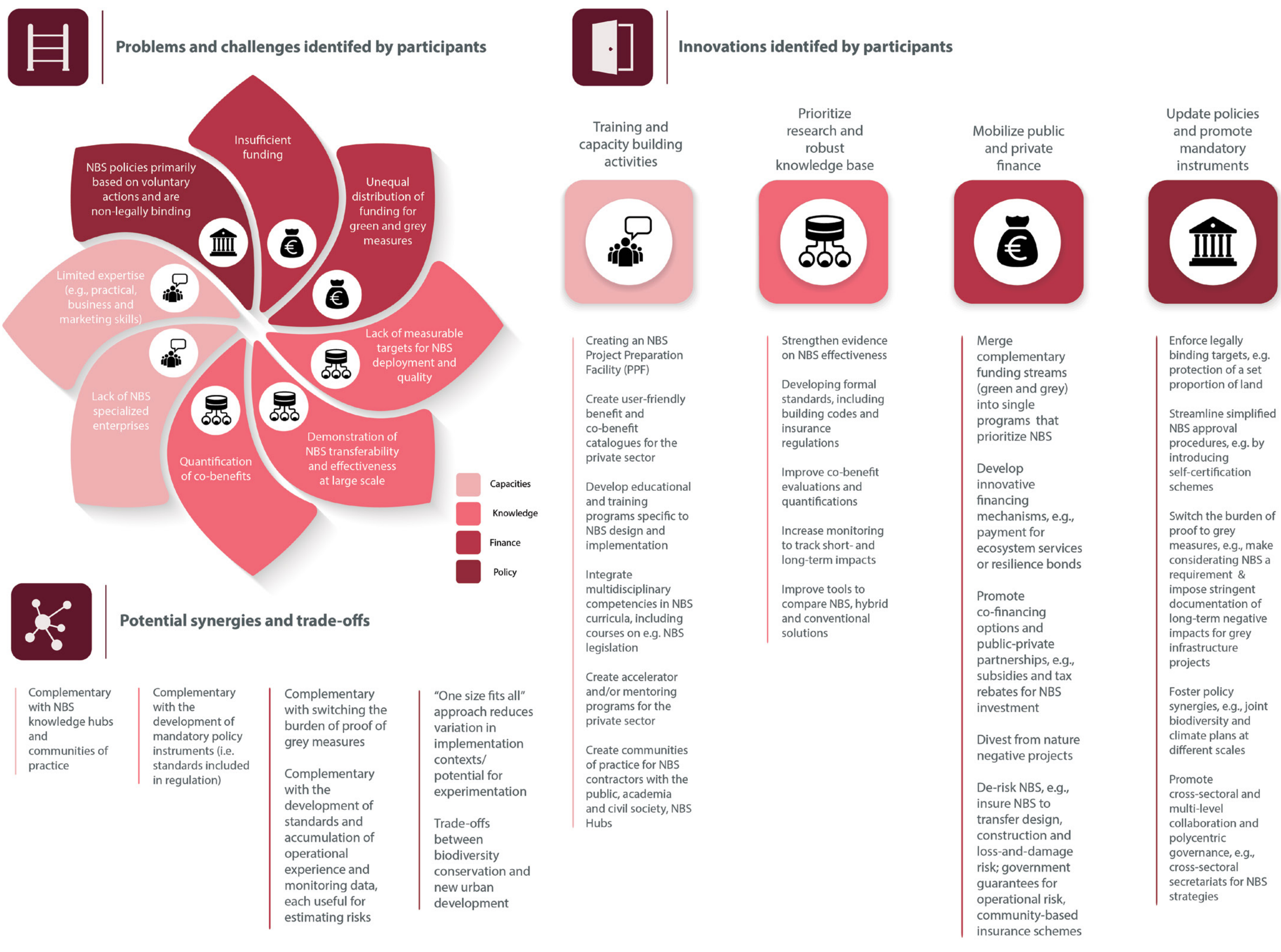


Figure B-5: Summary of the barriers, innovations, synergies and trade-offs identified from literature and stakeholder deliberations

Stakeholders as critical partners in developing NBS

Policies such as the UN sustainable development goals and the EU Green Deal envision sustainability, human well-being, justice, green growth and prosperity within the limits of the planet, safeguarding and enhancing biodiversity as well as to combat climate change. A key element of these strategies is evident in in the widespread implementations of NBS, not only in urban areas but in all ecosystems. Policies underscore the great potential released by co-creating NBS to achieve more sustainable planning designs. A broad range of stakeholders beyond the usual subjects work together on the co-design, co-implementation and co-monitoring. This helps to overcome bottlenecks implementing NBS resulting from silo-thinking, distrust and lack of knowledge by various actors. Collaborative approaches contribute to a better, more comprehensive understanding of natural hazards and related risks. The co-design of tailored solutions helps to address problems in a more comprehensive way and can lead to better solutions. Co-creation leads to a stronger sense of ownership for the solution and helps to better understand the potentials of NBS to address social, environmental and economic challenges to provide multiple benefits for both nature and all stakeholders.

Concepts that facilitate intense and inclusive multi-stakeholder collaboration have been recognized in recent years as progressive techniques to foster innovation and strengthen collaborative planning. Especially noteworthy is the concept of Living Labs as a systematic approach for multi-stakeholder collaboration, which has received significant attention from the European Union and its research and innovation agendas. Living Labs are recognized as progressive forms of experimental and inclusive modes of planning, project design, and implementation thus fostering innovation. A wide variety of activities are carried out under the umbrella term “Living Labs”. The common idea is to form partnerships between local governments, private companies, academia, and citizens providing an environment of innovation and creativity. A broad spectrum of participants with diverse backgrounds, lifestyles, ages, expertise, and experiences collaborate to create and develop new ideas.

The PHUSICOS Living Labs processes followed a stepwise approach that can be grouped according to three main categories; Purpose, People and Policy (Fohlmeister et al. 2018). Briefly, purpose focuses on the necessity of setting the objective and scope of the Living Labs process, people describes the key demands concerning the facilitator profile and possible tools for stakeholder identification and analysis, and policy hints at the relevant socio-cultural factors when planning for a Living Labs process. To operationalize the PHUSICOS Living Labs, the case study sites followed these general set of steps as described in more detail below, tailored to their specific cases.

PURPOSE

Before beginning more detailed planning of a specific Living Labs process, a fundamental preparatory step is to define the exact goal, scope and contextual setting of the intended stakeholder involvement. Key questions to ask are 'Why is the Living Labs process needed at the local case study site and what aspect does the process support to foster NBS innovation to reduce hydro-meteorological risk (e.g. NBS selection / design/ planning / implementation / performance evaluation)?' The scope of influence that the stakeholders in the Living Labs are intended to have must be defined as well as a preliminary assessment of their needs and knowledge demands.

PEOPLE

The next step is to use an adequate amount of time to determine who should participate in the Living Lab. Stakeholders are to be systematically identified using stakeholder mapping techniques to ensure a heterogeneous group of stakeholders representative of the community at the local case study site e.g. in terms of gender, age, disciplines, power and culture). The PHUSICOS stakeholder mapping focused on identifying participants from four core sectors: public, private, users and knowledge institutions. After stakeholders were identified, an assessment of their level of interest and influence for the objectives of the Living Labs at the case study site was conducted. This included identifying key players with a high level of influence due to their legitimacy. Strong networks and availability to resources were determined, as well as being aware of veto players to prepare for stakeholders that could obstruct the Living Labs processes. Based on the purpose of the Living Labs at the different case study sites, a selection of stakeholders was then made, and these stakeholders were recruited to participate. For the most part this was conducted through direct communication (e.g. email and telephone); however, is some of the larger Living Labs, announcements were made via social media and the local newspapers. A qualified facilitator was engaged to guide the discussions in the local language for the Living Labs processes. Ideally, the facilitator should be familiar with the local case study site. Most importantly, the facilitator should be a neutral player and perceived as trustworthy by the Living Labs participants.

POLICY

The final stage for operationalizing the Living Labs refers to being aware of the local context and the socio-cultural factors of the planning traditions, the hierarchical structures of the local institutions, and the roles of the stakeholder to include their self-understandings and worldviews. This overview has helped in the planning and execution of the Living Labs.

Together, Purpose, People and Policy provided a basis for the content of the Living Labs. Problems and needs to be addressed were identified and the stakeholders collaborated to create visions of local NBS, to co-design them and to support their implementation. Participants shared their knowledge and provided learning for others to spread the idea of NBS, supporting the replication, upscaling, adaptation and creation of new solutions elsewhere.

A monitoring and evaluation scheme was also established to follow and learn from the Living Labs at the different case study sites. Surveys and in-depth interviews were used as the two main monitoring and evaluation methods to capture the various aspects of satisfaction with the Living Labs processes as well as stakeholder's NBS awareness and perception. The surveys, which included a basic set of questions about the purpose and content of the Living Labs, were distributed and completed by participants at the end of each Living Labs session. An online survey tool was also used to simplify data collection and handling. Furthermore, semi-structured interviews with selected stakeholders were carried out three times throughout the Living Labs process to better understand stakeholder views on NBS. The survey templates and interview questions are available in Lupp et al. (2023).

Based on the monitoring and evaluation results, Living Labs have proven to be a highly effective tool for engaging a broad range of stakeholders and generating knowledge about Nature-Based Solutions (NBSs). Stakeholders greatly appreciated working on hands-on cases, co-creating, and collaborating during the various phases of NBS development. However, challenges arose due to differing levels of knowledge, which interviewees felt slowed down the processes, particularly in later stages. Bringing together the right stakeholders with the appropriate authority to make decisions was not easy, especially when competencies were scattered among stakeholders or responsibilities overlapped. Systematic stakeholder mapping was found to be useful in identifying and mobilizing relevant stakeholders from the outset. Field trips or site visits to discuss risks and potential solutions on-site were seen as the most engaging Living Labs activities, significantly advancing the processes. An important success factor was the participation of experts, researchers, and students in the Living Labs, who discussed, shared, and developed new ideas. Remaining topics were related to the economic aspects of NBSs and creating value chains for maintenance and management as well as to upscale and disseminate solutions.

Figure B-6: The Living Lab approach as part of the different case-study sites in the PHUSICOS project.

Photo credits (left to right, top to bottom):

Photo 1, 3: Northern Apennine District Basin Authority (ADBS), Italy (Nicola Del Seppia)

Photo 2, 4, 5: OPCC-CTP

Photo 6: NGI

B4. Technical foundations: the 3Ms

Modelling the effectiveness of nature-based solutions

Risk is a combination of the hazard, which is related to the dynamics and probability of occurrence of a dangerous natural phenomenon, the exposure, and the vulnerability or coping capacity of the elements at risk (UNDRR, 2020). The coping capacity of elements at risk is in turn related to human assets and exposed activities. When the risk reduction interventions are oriented to decrease the frequency of natural phenomena, without intervening on exposed assets, then risk reduction is strictly related to hazard reduction. In the framework of the PHUSICOS project, the modelling activities are oriented to the hazard assessment, which represents the main risk component affected by NBS interventions.

The effectiveness of the intervention measures, from a technical perspective, can be assessed by modelling hazard scenarios before (baseline scenario) and after the NBS implementation. Furthermore, comparing hazard modelling results developed for different climatic scenarios can also be a useful approach to assess the effectiveness of the interventions for hazards that are driven by extreme weather events (e.g. rainfalls, snowfalls, temperature).

The choice of the methodological approach for hazard modelling should begin with a preliminary overall assessment of the following items:

- the hazardous event or natural disaster to be modelled
- the morphological, geological and hydrological characteristics
- data availability
- the triggering causes of hazardous phenomena
- the features of the potential NBS intervention
- the scale of assessment
- the climatic conditions

These elements are reflected in the general methodological framework (figure B-7) which illustrates the workflow to select the optimal approach for modelling the selected hazardous event. After the model is selected, the next step of modelling is to define the scenario for the specific hazard under consideration. This is ideally conducted together with site owners and local stakeholders using a multidisciplinary approach to collect all the necessary data and information that are available, as well as to explore potential triggering causes and relationships between these causes and climatic events.

The collected information allows the "Hazard scenario" (figure B-7) to be defined. The Hazard scenario is also essential for the "NBS design" to identify suitable countermeasures and to identify the modelling scale. Scale refers to both the scale of the phenomena and the implementation of NBS (here referred to as "Scale of assessment"). The effects of climate change must also be considered, here defined as the "Climate approach".

These four elements are the starting points for modelling:

- the baseline hazard or susceptibility, in the baseline scenario
- the residual hazard or susceptibility, in the NBS scenario under given climate conditions

Evaluating the trigger event is important when modelling the hazard onset. When factors leading to triggering events are associated with climatic events such as storms and droughts, a distinction is made between phenomena linked to single events, such as short-duration, high-intensity rainfall, and those related to long-lasting conditions, such as seasonal or annual variations. Hazard modelling can be conducted for single events by defining the relationship between intensity and probability of occurrence. For long-lasting events, only the intensity of the event is relevant. Since probability for these events is undefined, the modelling of long-lasting events is exclusively limited to susceptibility.

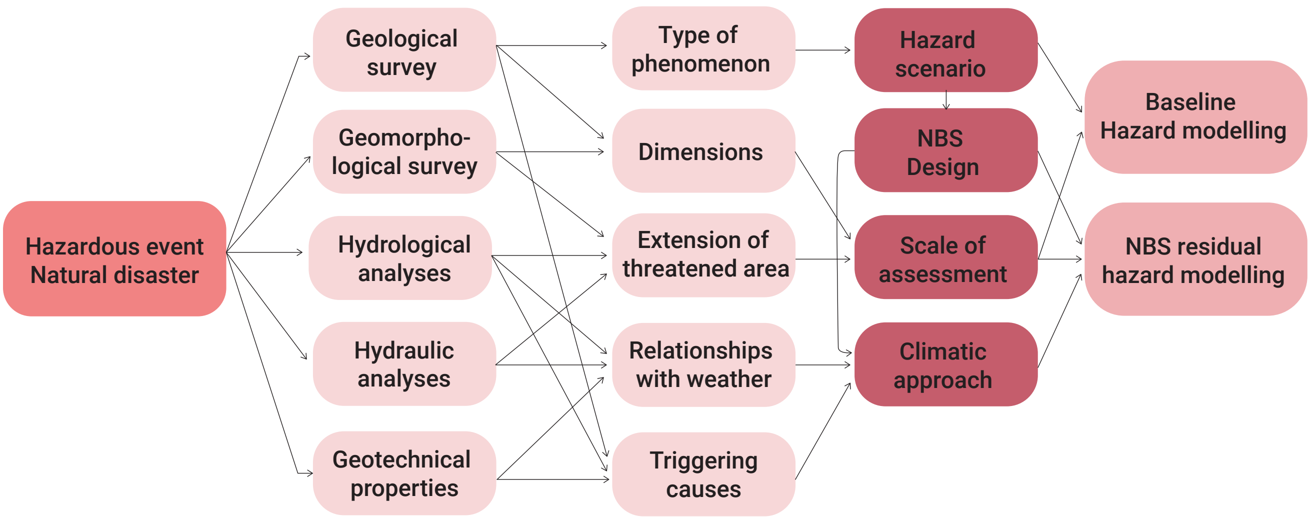


Figure B-7: General scheme for the definition of the modelling scenario.

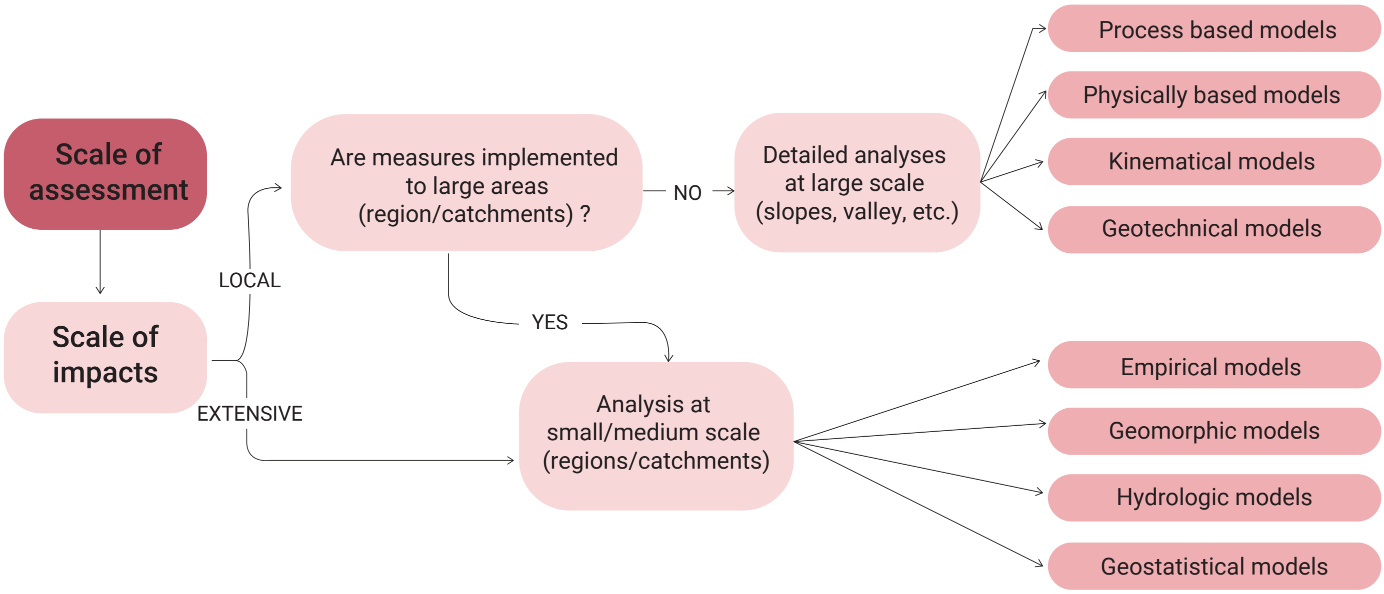


Figure B-8. decision-making process at the base of methodological framework focusing on the scale of assessment.

The modelling approach is also based on the most suitable scale of assessment, which is inherently connected to the scale at which the studied phenomena exhibit their effects (figure B-8). If the hazardous phenomenon impacts smaller landscape areas, it is feasible to carry out survey campaigns to collect geological, topographical, environmental, geotechnical and local weather data required for the detailed analysis. In such a case, physically based, site-specific models may be applied and detailed analysis may be developed by applying either deterministic or probabilistic approaches.

On the other hand, if the impact scale of the hazardous phenomenon is large (catchments, regions, countries, etc.), or if the NBS implementation is upscaled to large landscapes, then the modelling should be oriented to comparable scales. However, collecting detailed data for such extensive areas is often not feasible. In this case, some simplification and lower resolution must be accepted. Therefore, the choice of model is mainly oriented towards empirical heuristic models or geostatistical ones.

Another essential element of the general methodological approach is the climatic scenario, which is essential in modelling the residual hazard over time after the NBS implementation. When the triggering causes of hazardous phenomena are strictly weather related , the first step is to identify the most suitable climate change forecasting model for the area. Once the most suitable climate model is selected, and subsequently downscaled and bias-corrected, the climatic scenarios for evaluation of the NBS performance can be simulated.

Once the most suitable climate model is selected, and eventually downscaled and bias corrected, the climatic scenarios for evaluation of the NBS performance can be simulated.

The results of modelling the NBS implemented at the PHUSICOS case study sites show varying degrees of NBS effectiveness in reducing the hazard. At the Lake Massaciuccoli demonstrator site in Italy, the implemented NBS measures focus on mitigating the risk posed by soil erosion and farmland runoff. They comprise vegetated buffer strips (VBSs) and sediment retention basins for water purification, as well as revegetation with multiple vegetation layers, referred to as conventional agricultures (CAs) to reduce erosion using appropriate native plant species. The modelling results show that performance of the implemented NBS are strongly influenced by soil texture, organic content, water flow accumulation and rainfall intensity. In general, VBSs reduce both runoff and sediment losses. CAs are much more effective in reducing sediment losses but have only a secondary effect on runoff.

The NBS considered for the Jorekstad demonstrator site in Gudbrandsdalen, Norway, was designed for flood risk mitigation. The modelling results showed that the designed NBS would be highly effective in reducing the flood hazard even for extreme floods with return period of 1oo years when average soil moisture conditions were present. However, when soils were saturated, the designed NBS would lose its efficacy for floods with return period of 5 years or greater.

The NBS measures implemented at the case study sites in the Pyrenees are designed to reduce the risk of rockfalls, debris flows and snow avalanches. The modelling results show that the implemented measures are by and large effective in reducing the hazards associated with mass gravity flows in the location of where they are implemented. However, their effectiveness is very local; for a significant reduction in the hazard and associated risk within the study area, these measures need to be upscaled and implemented across numerous hazardous locations in the region.

Monitoring the performance of nature-based solutions

Effective monitoring is critical to the success of NBS projects and can help ensure that they are implemented to maximize their benefits for both people and the environment. Designing a robust monitoring system for NBS requires a multidisciplinary approach that integrates ecological, social, and economic considerations. The following key issues should be addressed when designing a monitoring system:

1. **Specifying the monitoring and evaluation objective(s):** The purpose of monitoring and evaluation is to quantify the effect that the NBS interventions have on addressing challenges and reaching certain objectives. The main objectives are usually to determine how effective the intervention is compared to alternatives (e.g. grey infrastructure or no intervention), and to assess maintenance or improvement needs.
2. **Engaging stakeholders in the monitoring process:** Stakeholders should be involved in both planning, deployment and operation of monitoring systems, as their perspectives are important to ensure that the monitoring results are relevant and useful. Monitoring the performance of NBS intervention is a long-term commitment and needs a sense of "ownership" from the stakeholders to succeed.
3. **Selecting indicators and data gathering methods:** The specific objectives of the monitoring program determine which indicators are appropriate and guide the development of the system to measure these. Once the indicators to be monitored are identified, one should ensure that data collection and analysis are adequate for evaluating the effectiveness of the NBS project and identify areas for improvement if needed.

The monitoring system for NBS needs to be adaptable and responsive to changing conditions. As the ecosystem evolves over time, the monitoring system needs to be able to capture these changes and adjust the monitoring indicators and methods accordingly. It is also useful to identify factors other than the implemented NBS that might produce the same outcomes in a given location and time period. Anticipating at least some of these factors will help with knowing which outcomes are directly attributable to the NBS and which are not.

The European Commission handbook on evaluating the impact of nature-based solutions (2021) provides recommendations for indicators associated with NBS in 12 societal challenge areas. The recommended core indicators are considered essential to mapping key outcomes of different types of NBS. The handbook also provides a set of additional indicators that might fit certain local contexts and types of NBS as well as guidance on implementing an effective and robust assessment process.

As an example, Table B-1 provides an overview of the monitoring program considerations for the PHUSICOS demo sites. This table illustrates how case-specific considerations are necessary, and given the diversity of NBS implementations, site conditions and stakeholder needs that it is necessary for a design and evaluation process in every case.

Table B-1:Suggested NBS-Monitoring program at the PHUSICOS case study sites

PHUSICOS CASE STUDY SITE	LOCATION/TYPE OF HAZARD TO BE MIGITATED	TYPE OF NBS IMPLEMENTED	INDICATORS MONITORED/ TO BE MONITORED	COMMENTS
Serchio River Basin, Italy [Crop-, grass-, heathland and shrubs]	Lake Massaciuccoli / Erosion	Buffer strips along canals	Rainfall, Water level, pH, Temperature, Conductivity, Redox potential, Dissolved O2, Turbidity, Nitrate, Ammonium, Solid transport, Game cameras and wild-life sample counts, Interviews with various stakeholders	Monitoring both by regular, manual sampling, and continuous, automatic probes
	Lake Massaciuccoli / Runoff of sediments and pollutants	Sedimentation Basin	Water level, pH, Temperature, Conductivity, Redox potential, Dissolved O2, Turbidity, Nitrate, Ammonium, solid transport	Two probes in the basin, for incoming and outgoing water. Automatic, continuous monitoring.
	Flooding, subsidence, state of crops	Whole intervened area	High resolution DTMs, Radar interferometry, Multi-sensor UAV	Repeated measurements from ground, air and satellites.
The Pyrenees, Spain-France [Woodlands and forests; Sparsely vegetated land]	Santa Elena / Unstable till slope	Terracing of slope and vegetation	Slope changes, blocks on the road, state of wood gabions, development of planted vegetation, sense of safety, creation of jobs	Webcam, visual inspections, reports from road users and maintenance personnel, interviews.
	Artouste / Rockfalls	Timber and/or stone structures to stabilise source areas and slowdown/divert falling rock blocks	Movement of blocks, blocks on the road, impact on road and on trees.	Visual inspections, reports from road users and maintenance personnel, interviews.
	Capet Forest / Snow avalanche	Afforestation and protection of plants by wooden tripods	Regular avalanche recording, impact forces on instrumented structures, state and mortality of plants, local economy, sense of safety	Visual inspection, pressure cells on structures, interviews with citizens, stakeholders and companies involved in construction and maintenance.
	Erill-la-Vall / Debris flow	Terracing of slope and vegetation	Precipitation, temperature, pore pressure, microseismic activity, stream turbidity and discharge, development of planted and natural vegetation, sense of citizen's safety, local economic effects.	Weather station. Piezometers in 55m deep borehole, microseismic network, flow- and turbidity meters in gullies, regular visits and interviews.
Gudbrandsdalen, Norway [Rivers and lakes]	Trodalen, Øyer / Flood	Re-opening of old creek, buffer zone for flood retention, erosion protection with vegetation	Precipitation, temperature, water level, turbidity, state of the interventions, plant growth, inhabitants' well-being, local economy	Weather station, instruments in the creek, visual/drone inspections, crowdsourcing, interviews.
	Skurdalsåa / Flood	Remediation of an old dam and spillway, selective clearing of vegetation	Precipitation, temperature, water level, flood damage, ecological state along the river, effects on sense of safety, water situation (irrigation), local economy	Weather station, water level sensor, visual inspection and physical sampling, interviews.

Maintaining the implemented nature-based solutions

Like all things, NBS require care and maintenance. NBS maintenance needs are different from other solutions and require new maintenance protocols (Kabisch et al. 2016). Regular maintenance will contribute to increasing the lifespan of the interventions (UNaLab 2021) and will contribute to effective and efficient operation. For example, a poorly maintained green roof has a reduced cooling effect compared to one that is well-maintained (Speak et al. 2013).

However, as much of the NBS research has focused on the implementation and the effect of NBS, little attention has been given to the practical challenges of how these solutions are to be maintained (Kabisch et al. 2016). Consequently, little information is found on this topic in the literature. Furthermore, the lack of guidelines and design standards both for construction and for maintenance is perceived as a barrier for implementing NBS (Solheim et al. 2021). Maintenance is an essential component of promoting NBS as a sustainable solution, necessitating greater focus on the practical maintenance needs, associated costs and resources required.

PLANNING

Since it often takes time before the effect of a NBS is realized, there is a risk that maintenance might be neglected before the NBS reaches its full potential. Therefore it is important to create a plan describing how the maintenance should be conducted and how is responsible .(PHUSICOS 2023, UNaLab 2021). This will ensure that the NBS is maintained throughout its lifetime, independent of short-term decision-making cycles (Kabisch et al. 2016). The entity responsible for maintenance may vary. For example, an NBS on public lands may be maintained by the local municipality, either directly by its own employees or by subcontractors operating on behalf of the municipality. Installations on private property may become the responsibility of the owner or assumed by another party through agreement. Another possibility is that third party interest groups might follow up maintenance of some implementations through voluntary engagement. There are many possibilities, but common to all is the need for proper planning.

In addition to planning for and assigning responsibility for NBS maintenance, it is also important to budget for maintenance early in the NBS planning phase (PHUSICOS 2023, UNaLab 2021). Financing maintenance has been identified as a barrier for implementing NBS (O'Donnell et al. 2017) and therefore estimating these costs in the beginning of the project is important.

METHODS

The maintenance required will depend on the selected NBS, its location and the type of hazard it addresses. An NBS implementation often includes several components, each with varying maintenance needs that can change over time. The varying needs for maintenance can be exemplified by the NBS implemented in PHUSICOS, all described in more detail in Deliverable D2.4 (PHUSICOS 2023).

- At the snow avalanche site in the Capet Forest, France, the implemented NBS consists of afforestation. The trees will need 20-30 years to grow sufficiently large to prevent avalanche release. The yearly maintenance during the growth period consists of replacing dying trees, thinning of trees (if needed) and general forest management. The tripod structures protecting the young trees will need maintenance until the trees are large enough.

- In the slope threatened by rock fall at Artouste, France, individual blocks have been secured by wooden structures, anchored to the ground. Yearly visual inspections should be done to check for rot in the wooden structures and to see that they are firmly anchored. Over time repairs may be needed to correct any problems detected.

- At Santa Elena, Spain the slope is reshaped through terracing with timber gabions and establishment of vegetation to stabilize the sediments. The initial maintenance needs will be more intensive the first years as the vegetation establishes itself and stabilizes the slope, but once the vegetation is well-established less maintenance should be necessary.

- At the demonstration case site Serchio River Basin, Italy, several different approaches have been implemented, each with its own need for maintenance. The buffer-strip vegetation needs to looked after and cut throughout the season and the need for new plants should be assessed annually. This is a continuous maintenance process throughout the growing season. In addition, the sedimentation basin may need emptying of sediments after extreme events with flooding and erosion.

- In Gudbrandsdalen, Norway, several NBS have been implemented to reduce flooding. In Trodalen, Øyer, a creek has been reopened and re-meandered. In addition, a sedimentation basin is constructed behind a weir in the creek. This solution needs little maintenance, but the basin needs to be checked periodically and emptied for sediments when needed, particularly after flooding events. Another measure, in Skurdalsåa, utilizes an old dam which has been modified to retain more water. Here one needs to ensure proper maintenance of the dam threshold, hence the maintenance here will likely increase with time.

REDUCING MAINTENANCE NEEDS

A well-designed NBS works with nature, and when done properly the solution might need less maintenance and improve through time as it interplays with the forces of nature (Kabisch et al. 2016, Keesstra et al. 2018). The required maintenance for an NBS implementation is affected by the choices that are made when designing and implementing it. For example, an NBS using vegetation as an important component must be based on species that are adapted to the area, have a good survival rate, and are reasonably resilient to climate changes. An example of working with nature is clearly illustrated in Den Hague where coastal protection works include dumping large volumes of sand offshore – the sand is transported by natural currents and are deposited on the beach and as sand dunes (Stive et al. 2013, van den Hoek et al. 2012).

The lack of available financial resources is a barrier for NBS implementation (Solheim et al. 2021), and this includes the costs for NBS maintenance. This underscores the need for a well-planned strategy for maintenance, including planning, budgeting and the assignment of responsibility already from early planning states. Minimizing needed maintenance is therefore essential, as reductions in maintenance need will often directly correlate with reduction in cost.

C. Six ecosystems

Reader's guide

In this chapter we explore six ecosystems, their exposure to specific hazards, and a selection of possible nature-based solutions (NBS) that mitigate those hazards while providing added value (co-benefits) to the living environment, natural habitats and landscape.

The chapter consists of six sections, each one representing a territorial ecosystem. The ecosystems are grouped in pairs, based on certain characteristics they share. The three pairs (waterscapes, (vegetated) slopes, and dynamic lower lands) cover together the different conditions within landscapes of the river basin. Each pair starts with a collective introduction and concludes with the results of relevant PHUSICOS case studies and their lessons learned in relation to the application of NBS.

The iconography defined in section B is used in diagrams grouping the distinct functions and benefits for each ecosystem. The position of the icons represent a general indication of their relevance with regards to this specific ecosystem – icons positioned more outwards on the circles represent functions or benefits that are considered more relevant. Further, these are grouped in categories in the diagrams using color nuances. These diagrams are preliminary and general indications, while every individual NBS related to a specific ecosystem will always need a more detailed evaluation of its specific functions and potential benefits.

This framing results in the following structure, with a reference color for each ecosystem.

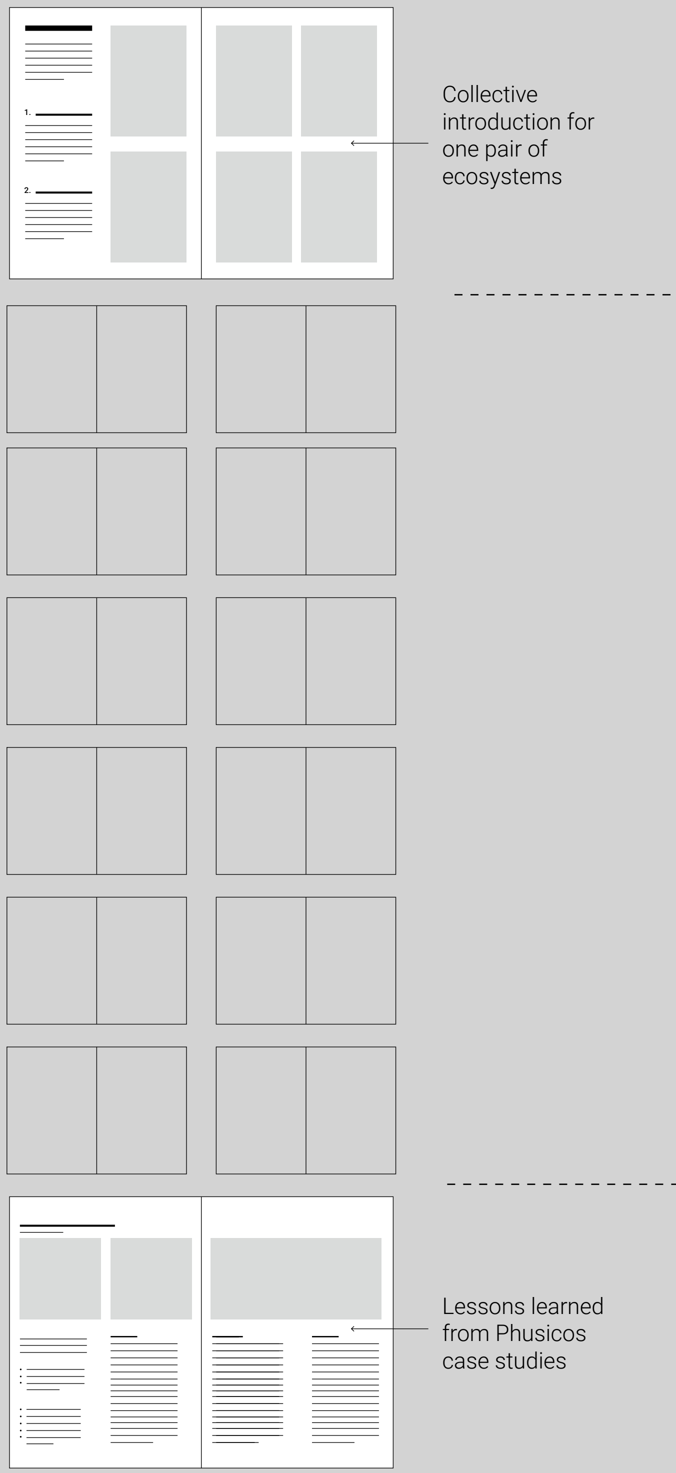
WATERSCAPES
1. Rivers and lakes
2. Wetlands

(VEGETATED) SLOPES
3. Woodlands and forests
4. Sparsely vegetated lands

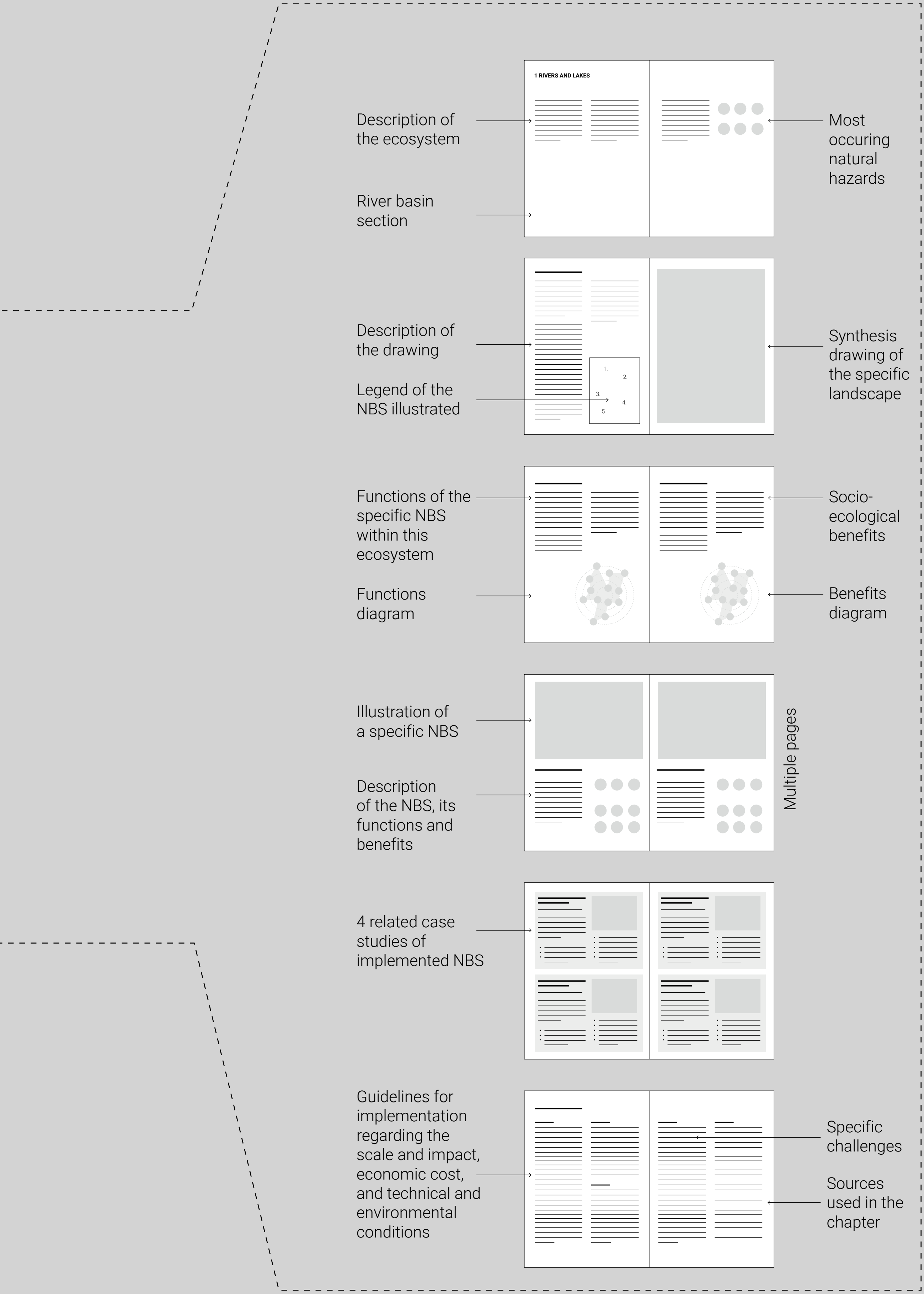
DYNAMIC LOWER LANDS
5. Crop-, grass-, heathlands and shrubs
6. Coastal lands

The diagram on the right shows the content of the chapter, starting from the pairs, followed by an overview of structure for each ecosystem chapter.

PAIRS



ECOSYSTEMS



1 RIVERS AND LAKES
Description of the ecosystem
River basin section
Most occuring natural hazards
Description of the drawing
Legend of the NBS illustrated
Synthesis drawing of the specific landscape
Functions of the specific NBS within this ecosystem
Functions diagram
Socio-ecological benefits
Benefits diagram
Illustration of a specific NBS
Description of the NBS, its functions and benefits
Multiple pages
4 related case studies of implemented NBS
Guidelines for implementation regarding the scale and impact, economic cost, and technical and environmental conditions
Specific challenges
Sources used in the chapter

Waterscapes

The first two ecosystems share water as a common feature and as the basis for their unique landscapes. Both being elements of a larger territorial watershed, they are inextricably linked to each other and face similar challenges as well as opportunities. In addition, they both have a major impact on the wider environment and are a great source for nature development and biodiversity.

1. RIVERS AND LAKES

Rivers have an immense spatial impact on the landscapes through which they flow. They are a backbone that structures the territory from the river sources at higher grounds to the wider valleys or delta networks of the lower flatlands. They are visible drainage systems or territorial veins. Depending on the soil conditions and strength of the water flow, the river dynamics can transform the morphology of the landscape over time through erosion creating the meandering identity of a mature river. Rivers also can be affected in the short-term by seasonal variations as well as by natural hazards such as flash floods or debris flows.

2. WETLANDS

Wetlands are created where water meets land. These areas often alternate between being flooded, dry, or become boggy such as swamps, bogs, and peatlands. Wetlands are rich ecosystems and are fundamental as resources and services for the landscape. They act as water resources and purifiers, have a very large natural carbon storage capacity, and are home to an enormous wealth of fauna and flora.

From left to right, top to bottom:
> Wootton Wetland restoration (New Forest HLS - Forestry England)
> Peatlands in Patvinsuo national park, Finland (Davide Zanchettin, CC-BY-2.0)
> Erosion following flooding, Øyeren Norway (NGI, Ingar Haug Steinholt)
> Spercheios River, OAL Greece (OPERANDUM)
> Parc du Peuple de l'Herbe, Carrières-sous-Poissy (© Nicolas DUPREY / CD 78)
> Re-meandering process of the Aire River, Geneva (Superpositions, photo Fabio Chironi)




C1. Rivers and lakes

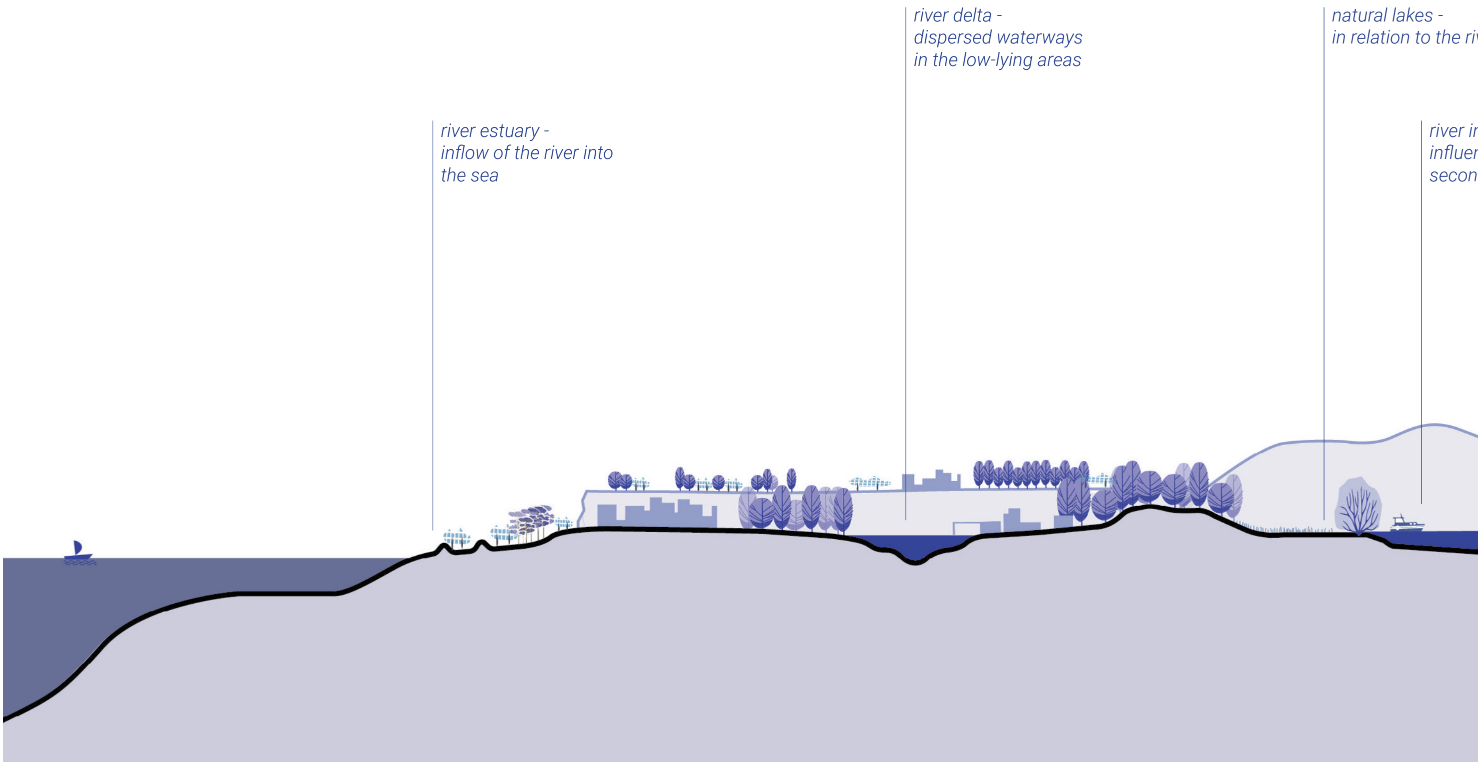
Making room for the floodable river

Rivers and lakes (including streams and ponds) are part of the freshwater habitats' family. Rivers are natural watercourses flowing gravimetrically from high elevations (mountain springs) towards another waterbody at a lower elevation. A river system comprises both the main course of the river and all the tributaries that flow into it. The area that the river system drains is known as the catchment. In addition to the river channels, riverine ecosystems include riparian zones, floodplains, and wetlands, contributing significantly to the overall riverine biodiversity, renewable resources, and ecosystem services.

Rivers are dynamic and may change form several times throughout their course. For example, a fast-flowing mountain stream may develop into a wide, deep and slow-flowing lowland river, or flow into a lake. Lakes are naturally occurring bodies of water connected to the rivers, characterized by slower-moving water compared to the inflow or outflow streams that feed or drain them.

Rivers and lakes, including riparian areas, cover about 7.5% of the EU land area. River systems are areas of great biological diversity; however, they area also areas with the most intense human activity. Consequently, freshwater biodiversity is endangered in many areas due to decades of human activities, including the construction of large dams, water diversions and pollution. They are extremely sensitive to environmental impacts as they integrate disturbances from their entire catchments. The European Joint Research Centre (JRC, 2020) reports that large parts of rivers and lakes are in a state of crisis due to pressures on land use, and in addition, climate changes are causing a significant and increasing pressure on the river and lake ecosystems.

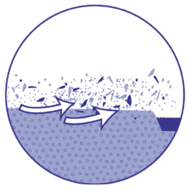
The main European legal instruments that share the objective to maintain or enhance the ecosystems or promote sustainable use include the Water Framework Directive (EC, 2000, EC, 2008b), Nitrates Directive (EC, 1991a), Bathing Water Directive (EC, 2006a), Urban Waste Water Treatment Directive (EC, 1991b), Birds Directive (EC, 2009), Groundwater Directive (EC, 2006b), Floods Directive (EC, 2007), Directive on Environmental Quality (EC, 2008a), EU Biodiversity Strategies to 2020 and to 2030 (EC, 2011 and EC, 2022), and the Invasive Alien Species Regulation (EC, 2014).



Hazards

Most hazards for rivers and lakes are related to extreme weather events, most often linked to precipitation. Extreme weather events in rivers and lakes not only affect people and properties directly exposed, but impact also the ecological health of our freshwater systems. Many of our rivers and lakes have been dramatically modified in the past by human activities, for example by "narrowing" or paving channels with concrete, thus reducing the natural ability of freshwater ecosystems to withstand or recover from these events. Land use changes have also compromised the river system's natural ability to manage floods. Impacting flood plains and wetlands. Vegetation clearcutting and changes to the natural river shape can induce riverbed incision, which consequently reshapes river channels and compromises the stability of riverbanks. Erosion due to water runoff leads to shallow riverbank instabilities that obstruct the natural water flow. Major floods can increase the transport of domestic, agricultural, and industrial pollution to rivers and lakes and subsequently reduce water quality. Drought events increase concentrations of pollution, hinder fish movement, expose water plants to damage, heat stress,, and increase the risk of eutrophication. In tropical coastal areas, storm surges caused by strong winds, tsunamis or hurricanes can impact river systems by altering flooding regimes and freshwater inputs over the short and medium term.

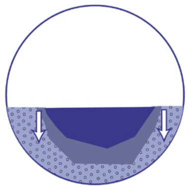
Riverine flood



Soil erosion

Drought

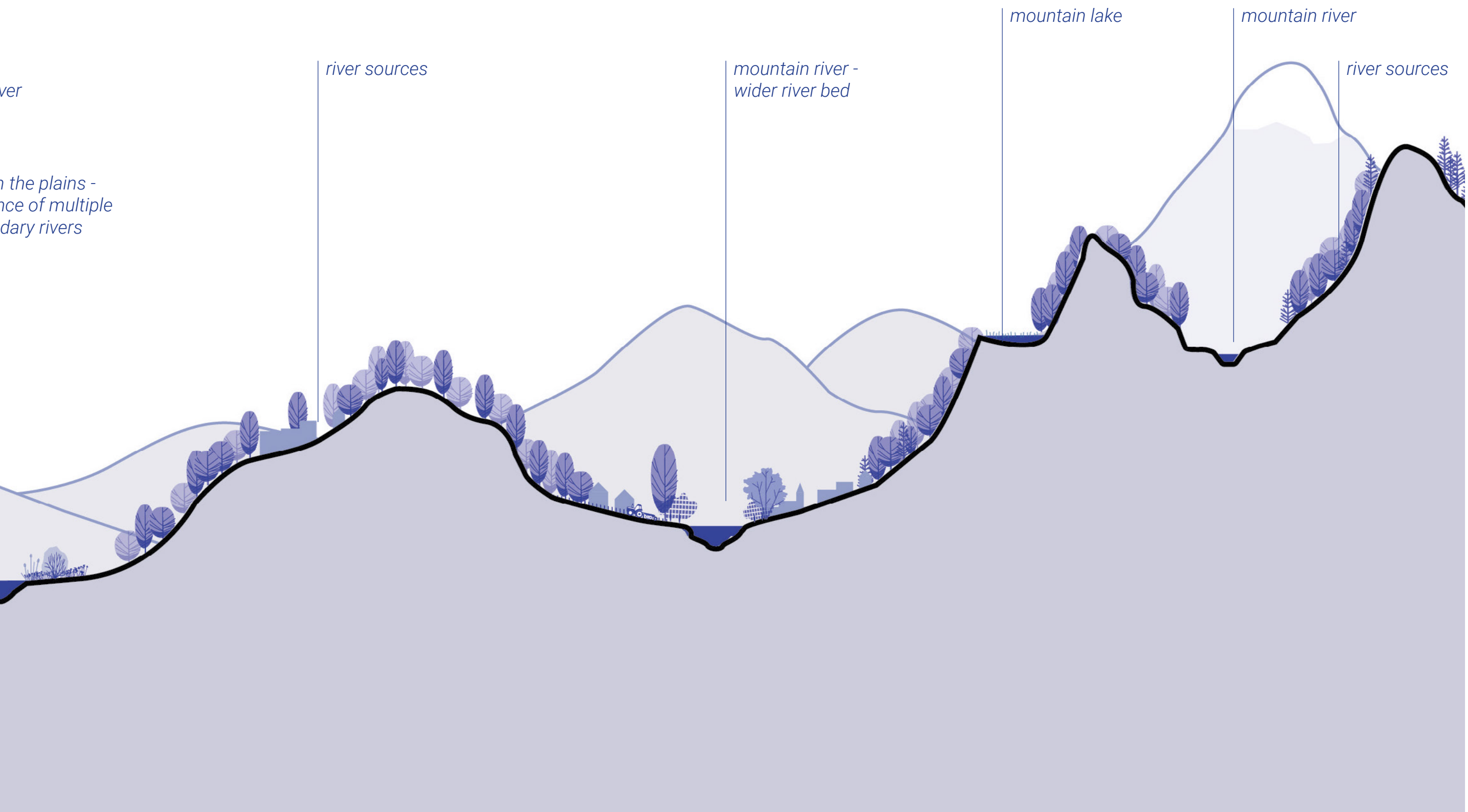
Storm surge



Riverbed incision

Eutrophication

Heat stress



A landscape synthesis

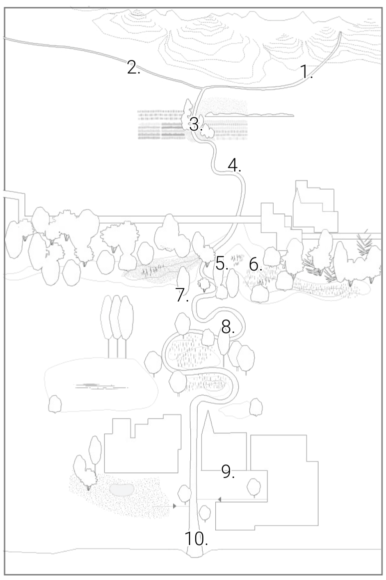
When observing a landscape shaped and determined by a river system, lakes and floodable lands, several characteristics and spatial relationships become apparent. The landscape synthesis on the opposite page illustrates aspects of river landscapes and the interaction between the natural environments, neighboring settlements and infrastructure. These range from mountainous landscapes with small, rapid streams to lower lying landscapes in agricultural and urban areas where slower flow rates and wide flood-prone riverbeds are typical. The drawing illustrates how different NBS can be implemented and how these may interact and reinforce each other. Four general approaches can be defined, and NBS can be sorted into the most applicable category.

RESTORATION
Spatial developments, infrastructure construction and/or flood protection measures (e.g. levees) can disrupt the hydrological connection between the natural flood-plain, wetlands and the watercourse itself. NBS can be implemented to restore or improve this lateral connection, which is considered crucial for mitigating flooding. The umbrella concept is 'making room for the river', which expresses the importance of providing space to influence river dynamics. The entire riverbed becomes a structuring and identifiable feature in the landscape. Further development of the flood-plain needs to be prevented, and vulnerable structures or infrastructure ideally should be relocated to maintain capacity of the flood-plain. Strategic vegetation can help alleviate the effects of flooding and drought. Riparian vegetation retains water, encourages infiltration and evaporation, while also stimulating biodiversity. The vegetation can also stabilize riverbanks and act as a buffer to prevent sediments and nutrients from entering the water. Throughout history, watercourses have been straightened with the intention to improve navigability, increase discharge and to support urban development. Restoring a more natural course to the river by restoring meanders can help to slow down flow rates and to re-establish more natural riverbanks. Re-connecting isolated arms of the river or re-opening of covered creeks are also important NBS that can help restore river landscapes.

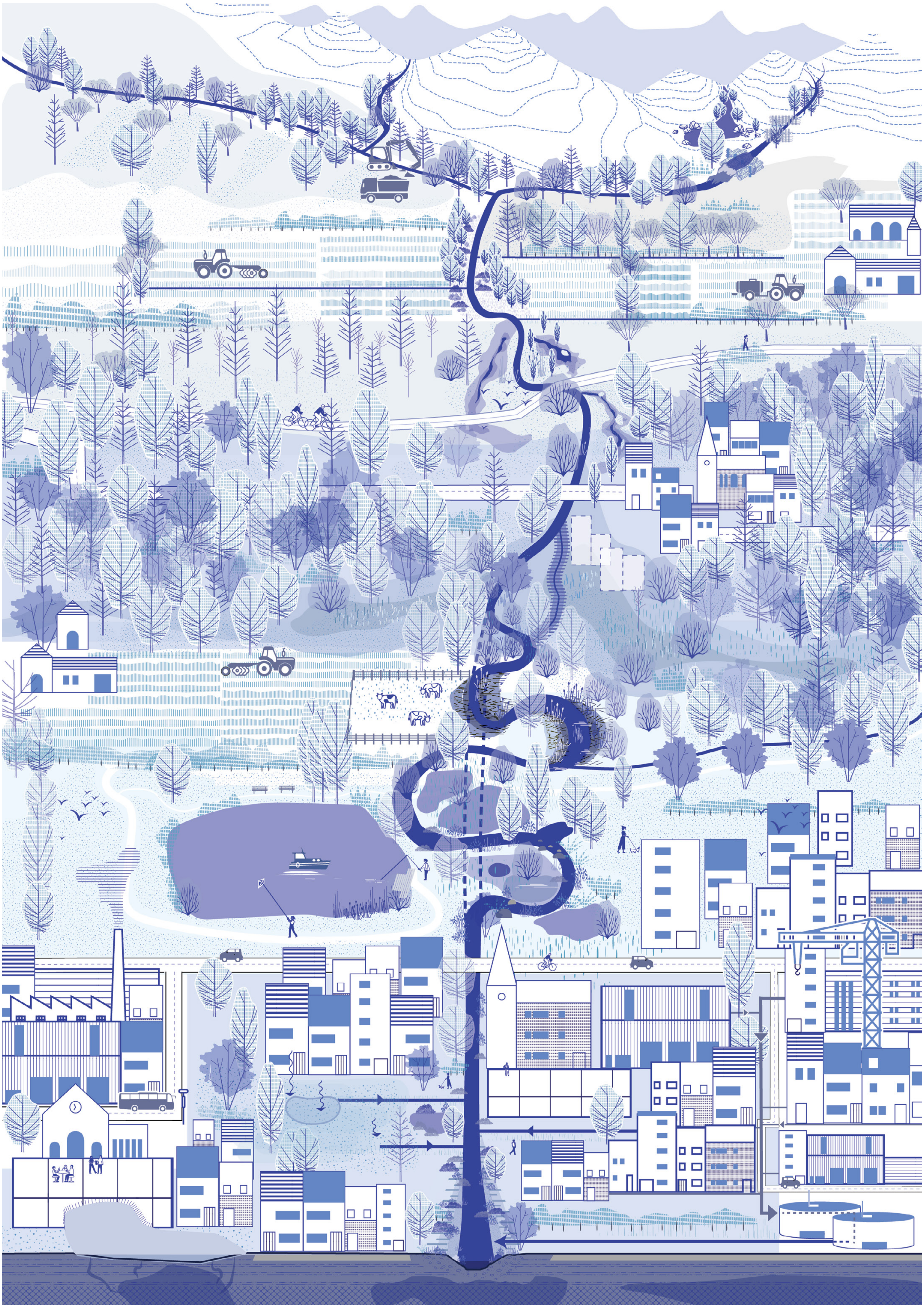
PROTECTION
The widening of a river can increase the drainage capacity of the watercourse and reduce the effects of flooding. Setting back levees introduces more space for the river, allowing lower water levels during flooding events and helping to promote the diversity of natural habitats.

CREATION
Bioengineering techniques such as the use of plants, rocks and other natural elements can help to create a more natural course of the river. Through the creation of such natural conditions with obstacles and planted areas, the flow of the water is altered and diversified, while the riparian corridor can enhance the stabilization of the banks against erosion. Installing underwater dams or weirs reduces the flow velocity and water discharge, allowing debris to deposit behind the weir and reducing erosion downstream.

MANAGEMENT
From the territorial perspective, it is fundamental to initiate multi-scalar and multi-disciplinary river management to ensure a functioning landscape. The different stakeholders, property owners and decision makers should collaborate to develop mutually agreeable solutions. The consequences of decisions taken in a certain part of the river basin will necessarily have an impact on the upstream and/or downstream areas. Management decisions include elements like water flow and discharge, vegetation management, water quality and biodiversity, and the clearing and conserving of floodplains.



1. Natural levees and sustainable dams
2. Clearing the riverbed
3. Vegetation management and buffer strips
4. Reconnecting dead-arms
5. Re-opening a covered creek
6. Making room for the natural flooding area (removing any obstructing buildings)
7. Restoring riparian vegetation
8. Re-meandering of the river
9. River (basin) management
10. Adapting the river bank



Functions

Relevant NBS for rivers and lakes include a variety of measures, with different complexity and with the aim of reducing various types of hazards such as floods, soil erosion, drought, embankment slope stability, storm surge, riverbed incision and eutrophication. The NBS represent all groups defined in this guide; restoration, protection, creation, and management. Thus, NBS for rivers and lakes are highly diversified, and bring a multitude of functions.

Climate change poses the need for NBS to mitigate (i.e. reduce emissions or improve the uptake of CO2) and adapt (i.e. reduce the impacts of climate related hazards such as floods and droughts). However, changes in land use may weaken the possibilities to install robust NBS for these purposes as less and less area is available for implementation of relevant NBS.

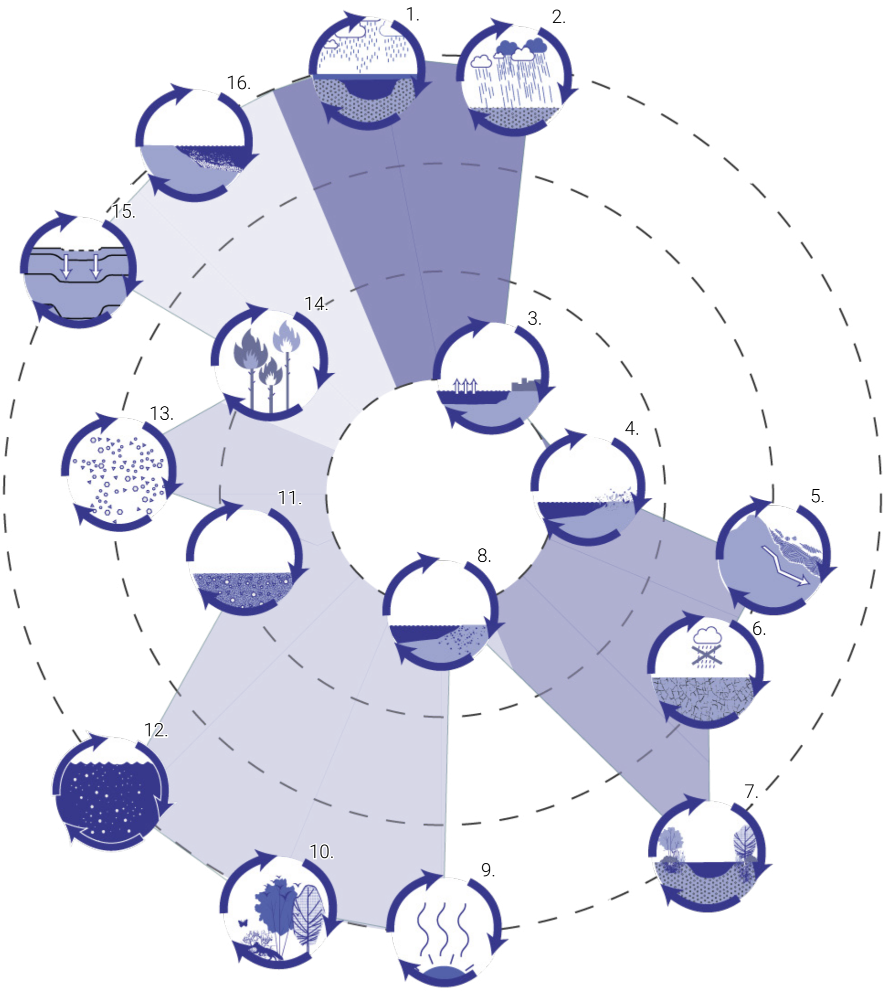
Rivers and lakes are dynamic systems and a healthy management strategy allow these to change over time . Space is needed for these changes, for example to allow rivers to re-meander or to make room for areas to flood such as floodplains and wetlands. Other NBS methods include (re)vegetation to improve the riparian zones, to stabilize the banks and to reduce soil erosion. All these methods have substantial effects on various parameters, such as water temperature, water quality and quantity, pollution, and thereby improve the ecosystem's biodiversity. In some cases, especially where standard NBS for river and lake protection are limited, nature-based engineering solutions may be used, such as soil and water bio-engineering techniques (SWB) and the use of ecological types of barriers.

water
1. Riverine flood regulation
2. Pluvial flood regulation
3. Coastal flood regulation

soil
4. Coastal erosion mitigation
5. Landslide mitigation
6. Drought mitigation
7. Riverbank erosion mitigation

habitat
8. Salt intrusion regulation
9. Heat stress regulation
10. Biodiversity stimulation
11. Soil pollution regulation
12. Water pollution regulation
13. Air pollution regulation

other
14. Wildfire regulation
15. Subsidence regulation
16. Sedimentation mitigation



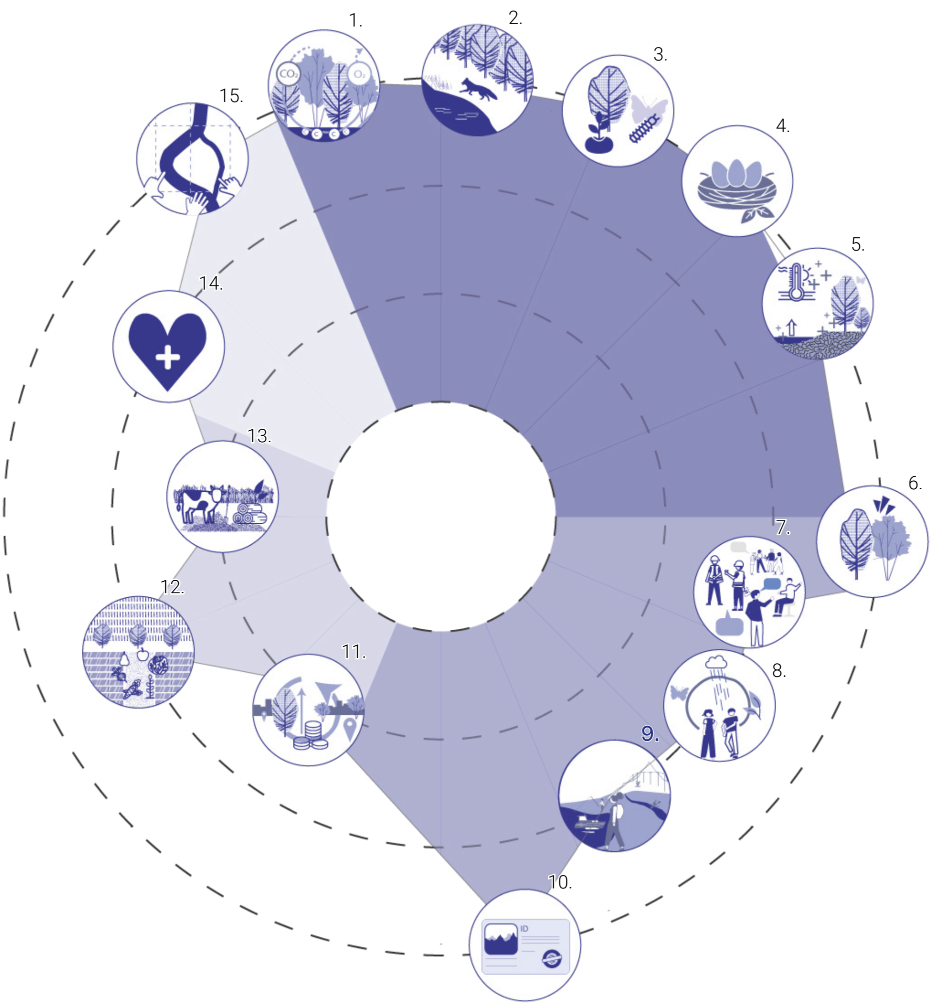
Benefits

NBS in river systems provide a range of ecological benefits. As these systems are inherently rich in biodiversity, the careful implementation of high quality NBS can greatly enhance biodiversity, improve water quality and contribute to overall ecosystem health. Additionally, NBS can significantly support climate change adaptation by reducing heat and retaining water, while offering substantial potential for carbon sequestration and carbon storage. In the case of disaster risk reduction (DRR), NBS should ensure both hazard reduction and improve biodiversity.

NBS also bring social and cultural benefits. They foster leisure and outdoor activities such as fishing, birdwatching, hiking, and cycling. These activities not only improve the quality of life but also strengthen social cohesion and provide educational opportunities, especially for young people. Involving local and regional stakeholders in the implementation of NBS promotes local democracy, cooperation, and a sense of ownership, enhancing community engagement and the sustainability of the solutions.

Economically, NBS can support livelihoods by providing resources for fishers and farmers and encouraging activities aligned with a green economy. However, fragmentation and loss of river ecosystems, along with pollution from nutrients and pesticides, pose significant threats. Implementing NBS can mitigate these issues, reversing negative trends and bolstering local economies and social sustainability.

Finally, NBS have positive impacts on human health by improving environmental conditions, reducing pollution, and creating spaces for recreational activities. These benefits contribute to overall well-being, making NBS a comprehensive approach to addressing environmental, social, economic, and health challenges.



ecology

1. Carbon storage
2. Natural corridors
3. Nature development
4. Habitat protection
5. Climate resilient landscape

cultural

6. Social interaction
7. Cultural landscapes
8. Education
9. Tourism, sport and recreation
10. Landscape identity

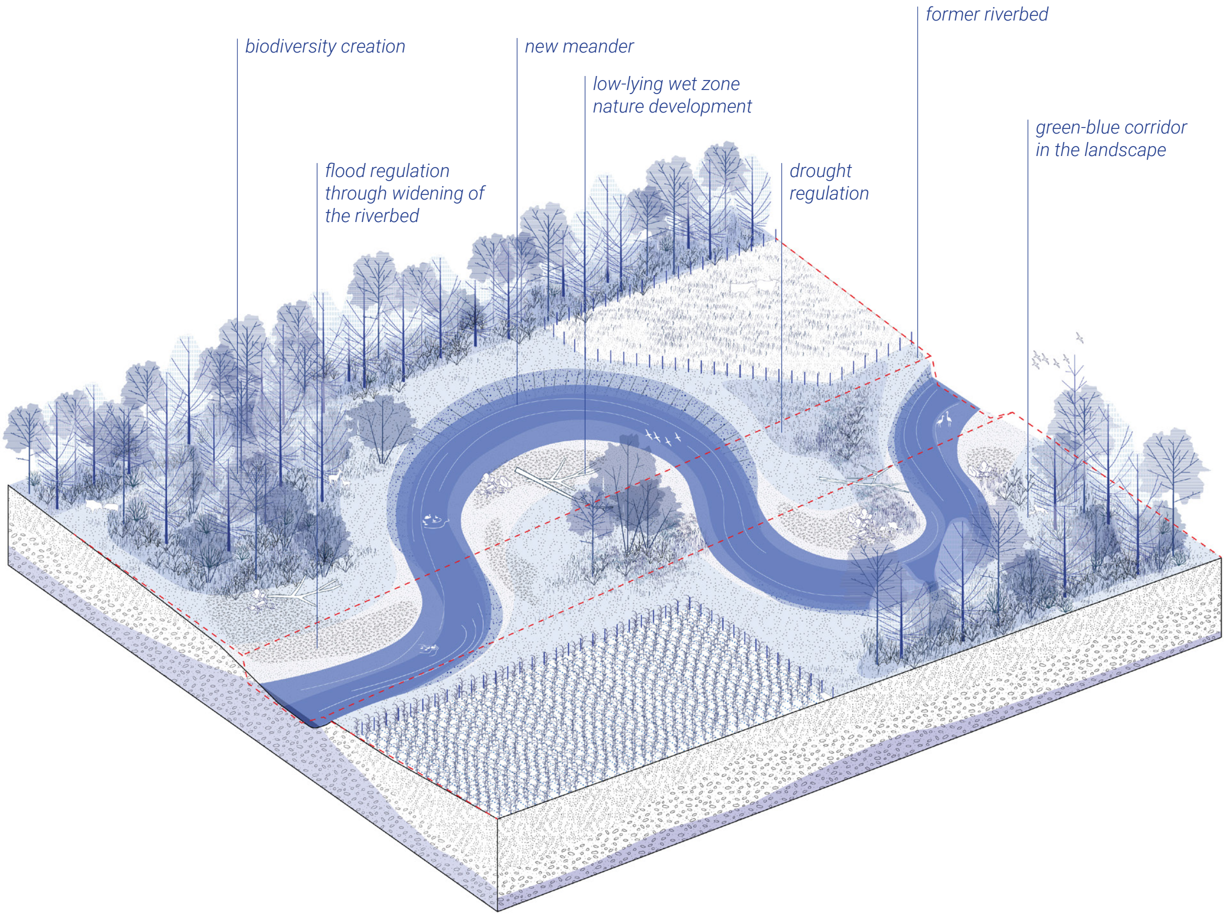
economy

11. Local jobs and green economy
12. Productive landscapes
13. Resources production

other

14. Human health
15. Integrated water management

Specific nature-based solutions



RIVER RE-MEANDERING

TYPE OF INTERVENTION

C Creation

R Restoration

HAZARDS


(Riverine) flood


Flash flood


Drought


Soil erosion

DESCRIPTION

Transforming a straightened river back into a more natural, meandering offers numerous benefits. Firstly, it restores the natural water flow in the valley. Additionally, the meanders slow down the water as it flows around the curves. In this process, the water on the outer edge of each bend moves faster than on the inner edge. Reconnecting historical meanders can restore the identity of the landscape, while providing a possible overflow in the case of riverine floods or heavy rainfalls.

The lower lying grounds along the inner edges of the meanders have important functions in terms of flood protection, and they also increase the resilience of the river valley in dry periods and enhance the biodiversity development.

MAIN FUNCTIONS AND BENEFITS

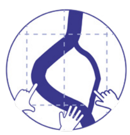

Flood regulation


Drought mitigation


Water pollution regulation

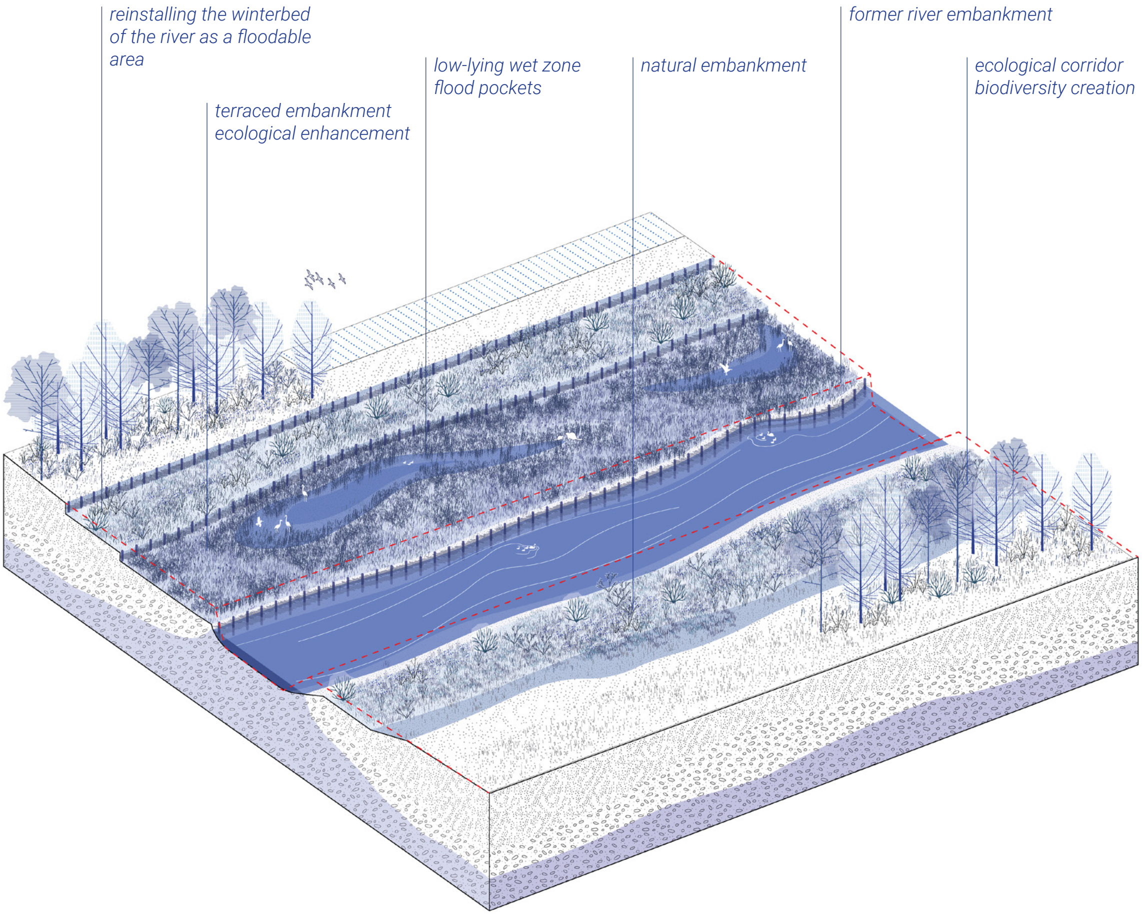

Biodiversity stimulation


Nature development


Integrated water management


Natural corridors


Landscape identity



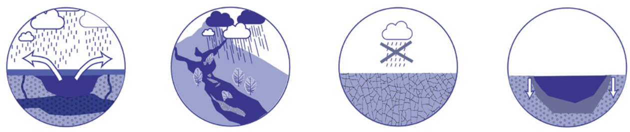
RIVERBANK ADAPTATION & SETTING BACK LEVEES

TYPE OF INTERVENTION

P Protection

R Restoration

HAZARDS



(Riverine) flood | Flash flood | Drought | Riverbed incision

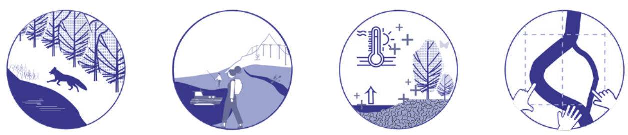
DESCRIPTION

When levees are built too close to the river, they prevent water from flowing across the natural floodplains during riverine floods, which increases the water velocity and thereby the erosion. Moreover, levees can complicate the ecological and biological dynamics of the river basin by interrupting lateral connections between streams.

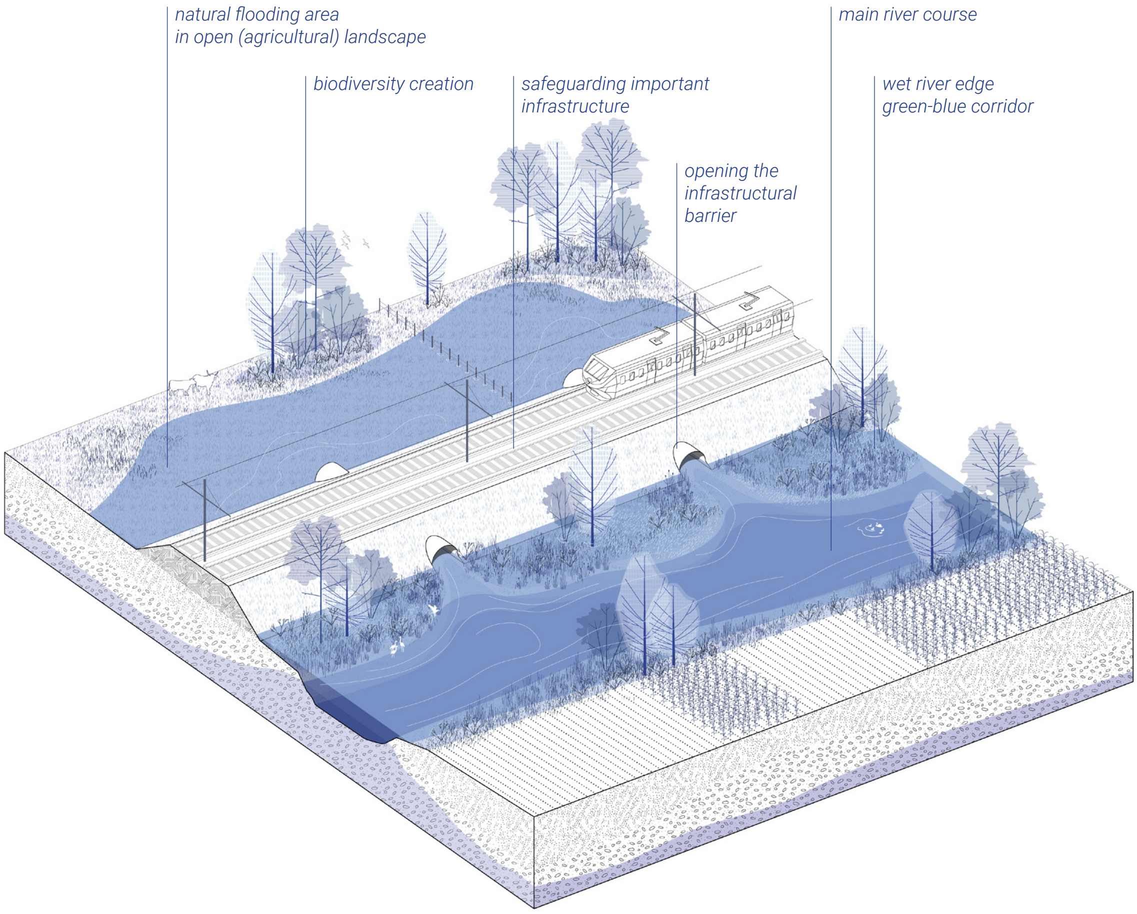
Widening the riverbed creates more room for the water in case of a riverine flood or heavy rainfall. By setting levees back, a natural flooding regime is reinstated which results in lower flood levels and more diverse habitats in the floodplain. At the same time, an adapted riverbank also decreases the risk of erosion.

MAIN FUNCTIONS AND BENEFITS

Flood regulation | Drought mitigation | Biodiversity stimulation | Riverbank erosion mitigation



Natural corridors | Tourism and recreation | Climate resilient landscape | Integrated water management



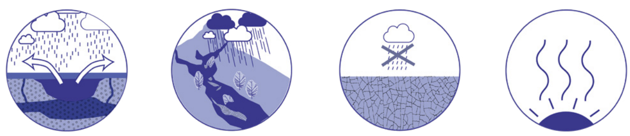
RE-ENABLING NATURAL FLOODING AREAS

TYPE OF INTERVENTION

(C) Creation

(M) Management

HAZARDS

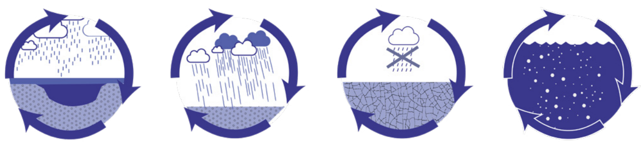


(Riverine) flood | Flash flood | Drought | Heat stress

DESCRIPTION

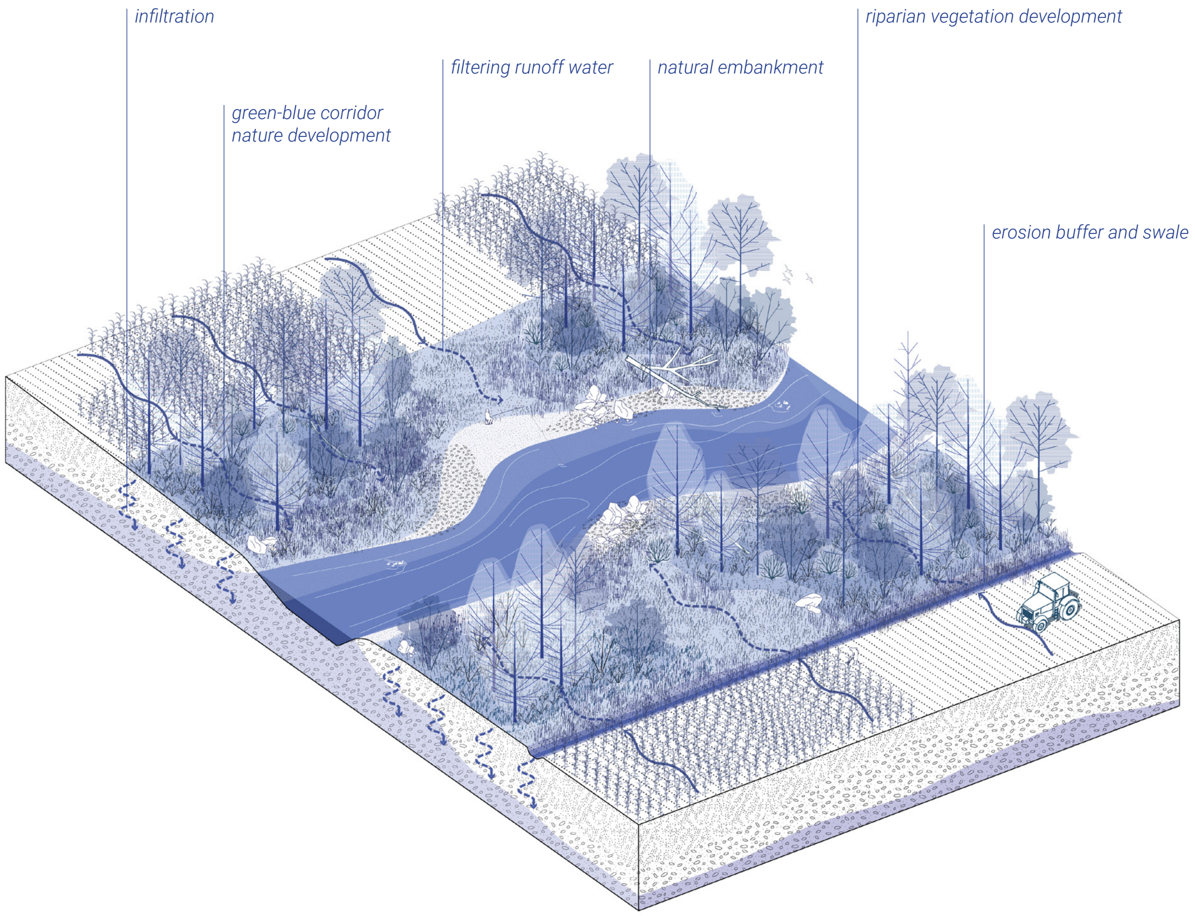
Floodplain areas along rivers serve as natural retention spaces for water during riverine floods caused by heavy rainfall and/or snowmelt. As such they play an important role in flood risk reduction. However, many former natural floodplains have been cut off from the river by extensive urban and infrastructural development over time. The re-enabling of these natural flooding areas is fundamental to recovering natural processes and ensuring future flood protection. Furthermore, these landscapes bring many opportunities for specific nature and habitat improvement while also helping to reduce drought.

MAIN FUNCTIONS AND BENEFITS



Riverine flood regulation | Pluvial flood regulation | Drought mitigation | Water pollution regulation

Education | Climate resilient landscape | Biodiversity creation | Integrated water management



RIPARIAN VEGETATION RESTORATION

TYPE OF INTERVENTION

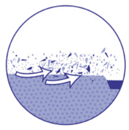
R Restoration

HAZARDS


(Riverine) flood


Eutrophication


Drought


Soil erosion

DESCRIPTION

Revegetating the floodplain and the riverbanks is a multifunctional natural measure that can reduce flooding by storing and infiltrating water and by increasing evapotranspiration. Riparian vegetation will stabilize the riverbanks and thus protect them from erosion. When located in proximity to agricultural plots, the riparian vegetation will act as a buffer, ensuring the filtering of nutrients, pesticides, and sediments before they enter the water. Once the riparian ecosystem is restored, it will bring a myriad of benefits ranging from habitat stimulation and water quality regulation to carbon storage, education and the development of nature tourism.

MAIN FUNCTIONS AND BENEFITS


Flood regulation


Drought mitigation


Water pollution regulation

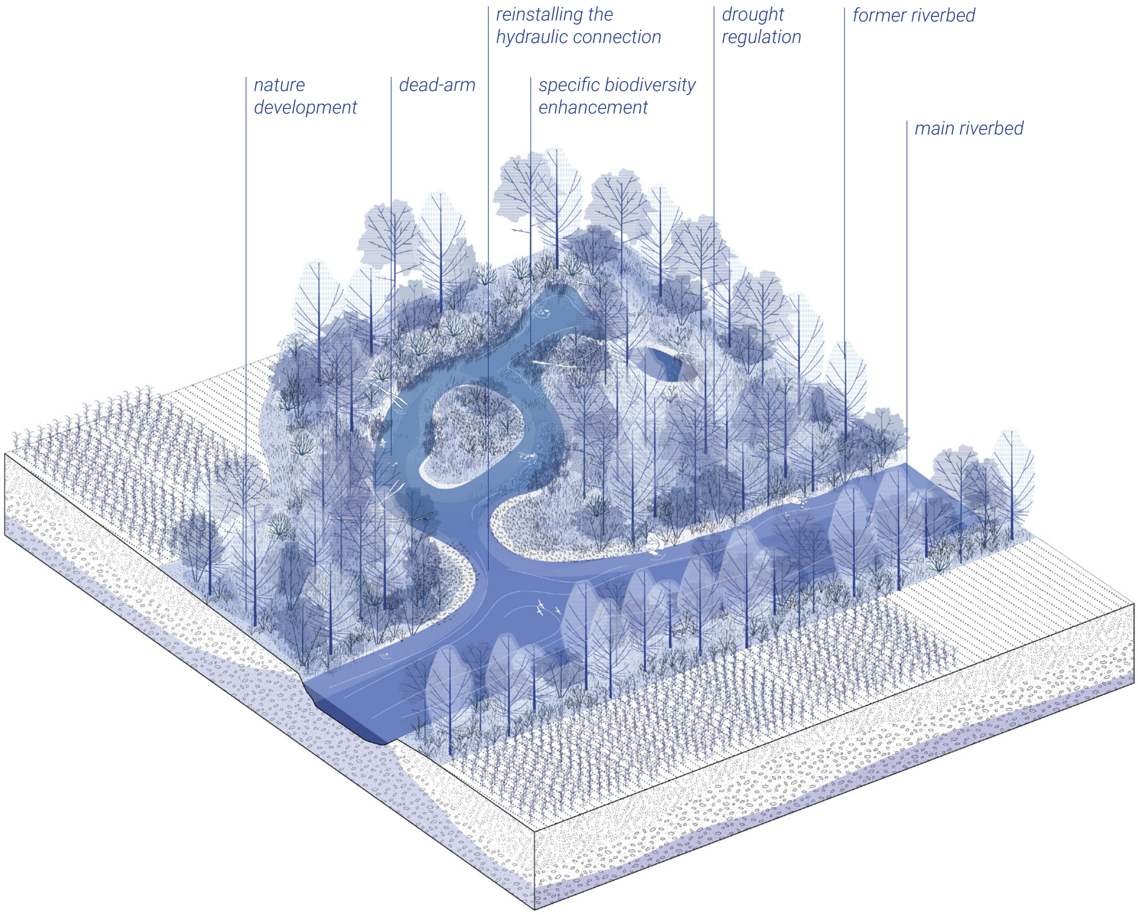

Riverbank erosion mitigation


Natural corridors


Carbon storage


Education


Tourism and recreation



DEAD-ARM RECONNECTION

TYPE OF INTERVENTION

R Restoration

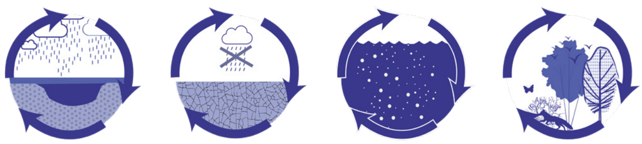
HAZARDS

(Riverine) flood | Eutrophication | Drought | Riverbed incision

DESCRIPTION

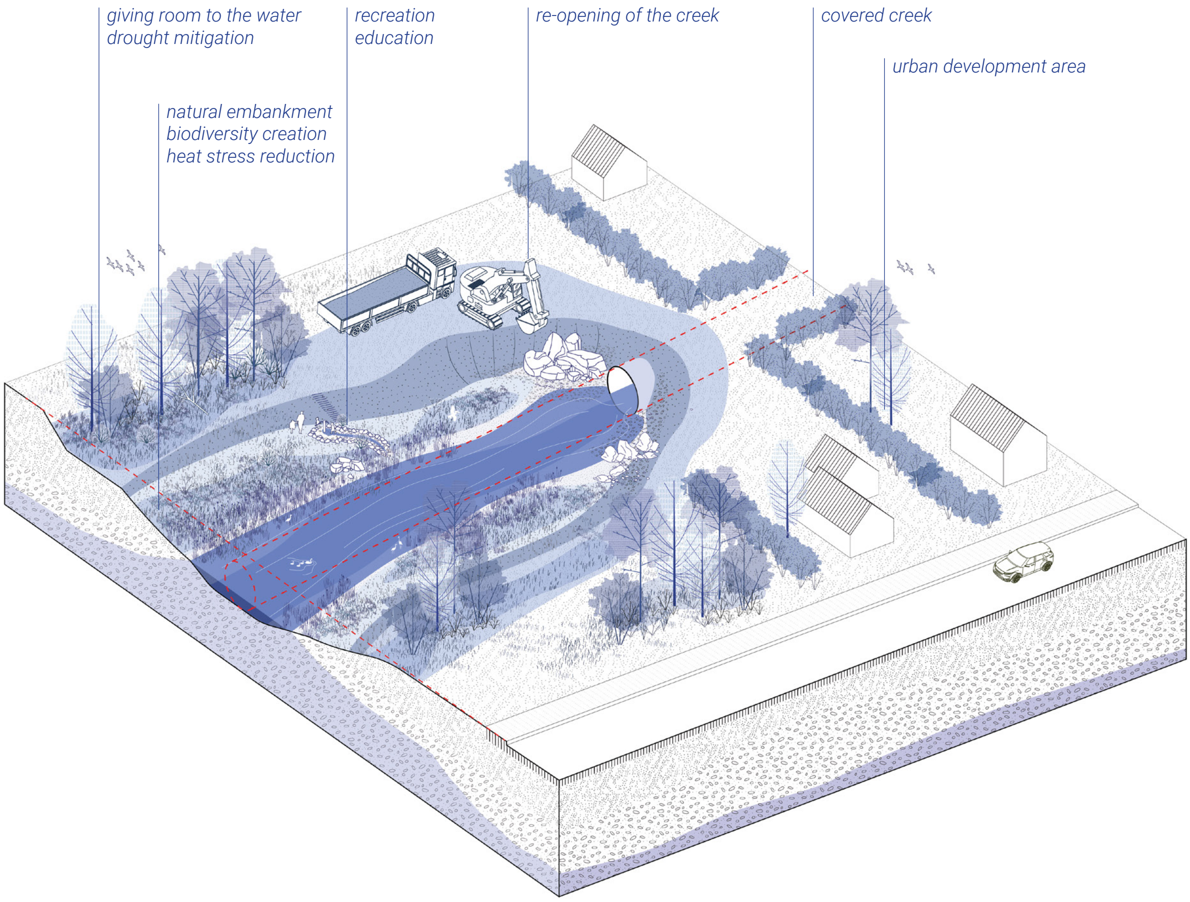
Over time, some natural river arms, meanders or inlets have been cut off, either by human intervention or by natural processes. These river bifurcations or distributaries are also known as dead-arms and result in very specific and rich ecosystems due to their lower water levels and reduced flow. Extra capacity during flooding can be generated by reconnecting these to the main water body. They also provide aquatic zones that regulate drought and heat stress. These environments are therefore highly valuable within or near urban and agricultural areas. The reconnection allows for more diverse habitats to be fostered and enhances wildlife exchange throughout the entire river valley.

MAIN FUNCTIONS AND BENEFITS



Flood regulation | Drought mitigation | Water pollution regulation | Biodiversity stimulation

Nature development | Habitat protection | Carbon storage | Landscape identity

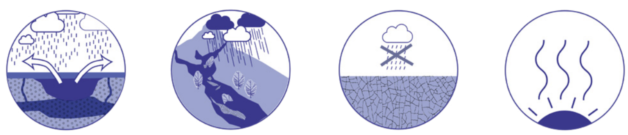


CREEK RE-OPENENING

TYPE OF INTERVENTION

R Restoration

HAZARDS

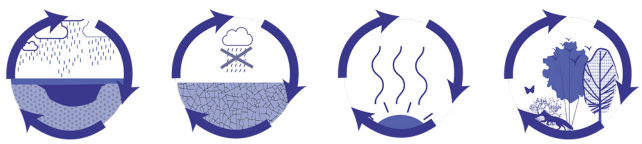


(Riverine) flood | Flash flood | Drought | Heat stress

DESCRIPTION

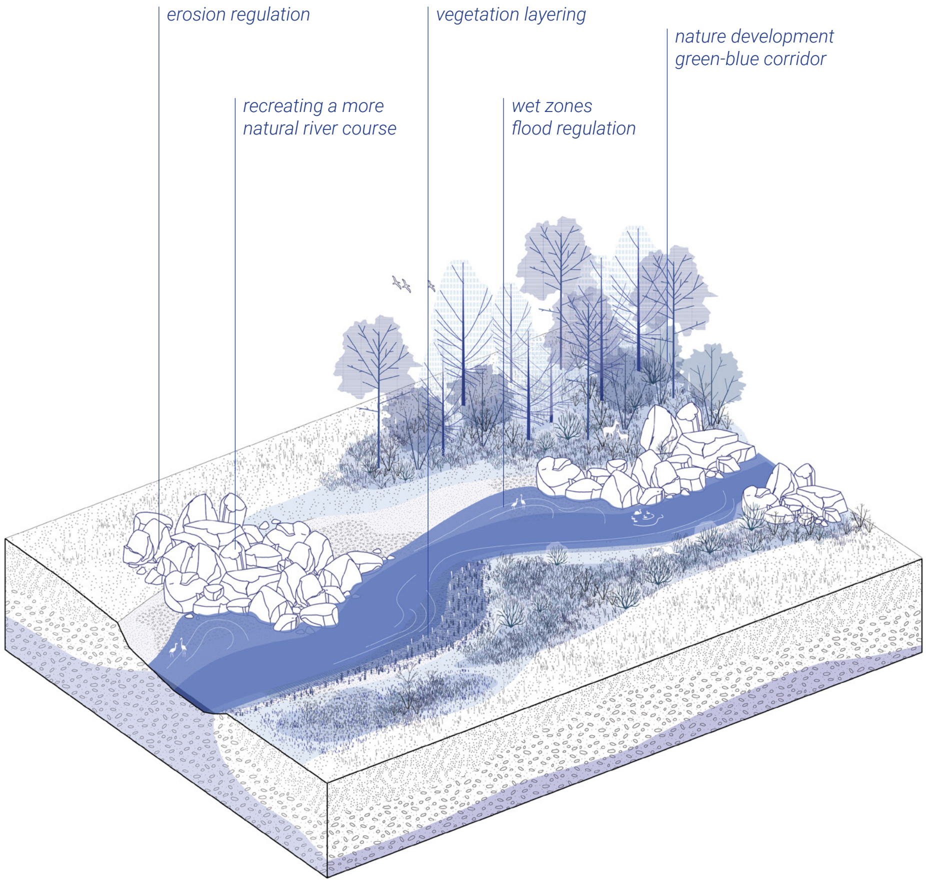
Burying or culverting a smaller stream or creek by human intervention can severely interrupt a river ecosystem. When a natural course of water is discontinued or diverted underground, it will lead to the loss of riparian vegetation, the disappearance of natural floodplains along the river and the interruption of the broader fluvial network. Re-opening the creek will restore the water flow and reduce the risk of flooding by reintroducing natural riverbanks and floodplains. Revegetating the riverbed improves the water quality and overall biodiversity and helps to stabilize the riverbanks as protection against erosion. Since many stream re-openings are located in populated urban areas, they provide opportunities for nature recreation and education. This is particularly beneficial for urban areas that often lack green infrastructure, enhancing both the ecological and recreational value of the city.

MAIN FUNCTIONS AND BENEFITS



Flood regulation | Drought mitigation | Heat stress regulation | Biodiversity stimulation

Education | Tourism and recreation | Integrated water management | Cultural landscapes



SOIL & WATER BIO-ENGINEERING TECHNIQUES

TYPE OF INTERVENTION

C Creation

R Restoration

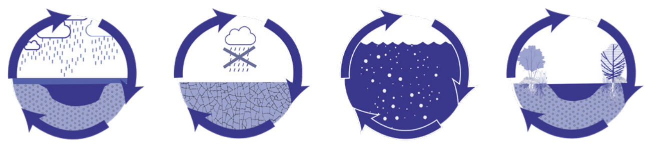
HAZARDS

(Riverine) flood | Flash flood | Drought | Riverbed incision

DESCRIPTION

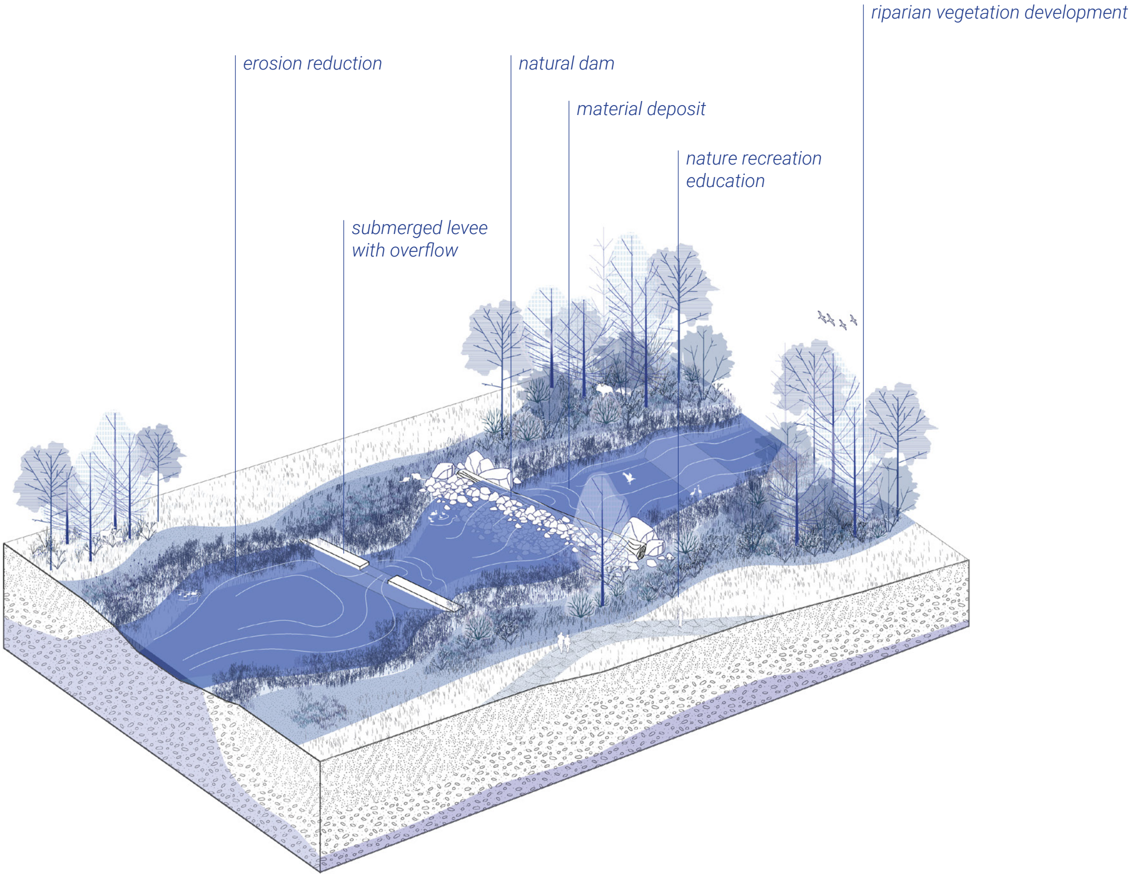
Bio-engineering techniques involve the use of plants, rocks, and other natural elements to help recreate the natural course of a river. These features divert water flow and create varied velocities. These techniques, together with specific vegetation layering can, enhance the riverbank's ecological diversity. Combining a variety of techniques is key to a more developed, biodiverse and subsequently climate resilient environment.

MAIN FUNCTIONS AND BENEFITS



Flood regulation | Drought mitigation | Water pollution regulation | Riverbank stabilization

Habitat protection | Natural corridors | Landscape identity | Climate resilient environment

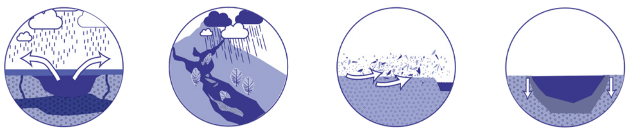


NATURAL LEVEES & SUSTAINABLE DAMS

TYPE OF INTERVENTION

C Creation

HAZARDS

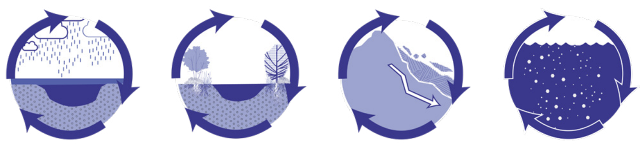


(Riverine) flood | Flash flood | Soil erosion | Riverbed incision

DESCRIPTION

Submerged dams or weirs are structures made of stone, wood or live fascines that are built across the riverbed to reduce flow velocity. They foster sediment deposition through swirling at the back of the weir and reduce erosion downstream. These natural levees can be used in very different contexts and configurations, ranging from steeper rivers to wider flat river valleys.

MAIN FUNCTIONS AND BENEFITS



Flood regulation | Riverbank stabilization | Erosion regulation | Water pollution regulation

Tourism and recreation | Natural corridors | Landscape identity | Education

NBS case studies

1.1

Natural redesign of the water profile of the Iller and its banks at Aitrach / Memmingen

Aitrach/Memmingen, Tübingen, Germany; 2016-2021

The aim is to achieve good ecological status by relocating individual sections of the bank and installing structural elements. After river widening, structures such as groynes or dead wood are installed. These measures and the design of bays and steep banks create different habitats for the biocoenosis of plants and animals. An alternation of slow-flowing sections as resting areas and fast-flowing sections is of great importance for the habitat.

Adapted riverbanks (PHUSICOS)

Applied nature-based solutions:

- Adapting the river embankment by removing the existing bank (and path) and widening the riverbed
- Applying bio-engineering techniques by adding natural elements like groynes or dead wood
- Make room for natural flooding areas by flattening the bank slope and reconnect the floodplain with the river

Hazard: erosion

Main stakeholders:

- Free State of Bavaria
- State of Baden-Württemberg
- Power plant operator

Links: Project website Agile Illers (German)

1.2

Recovery of flood plains and wetlands in La Pique basin

La Pique Basin, Haute-Garonne, France; 2017-2020

The objectives of the restoration were to reclaim flood-prone areas that have been subjected to emergency work after the June 2013 flood events. The restoration objectives are to prevent flooding and to raise awareness of good practices among stakeholders and residents. The challenges of the territory being: the flood risk and sediment management, quantitative management of water resources, preservation of wetlands and ecological continuities.

Erosion following flooding (PHUSICOS)

Applied nature-based solutions:

- River management by creating a discharge channel and elevating the riverbed (island and/or groynes) to increase sinuosity and vary the flows
- Vegetation management by composing a guide and creating refuge areas for fauna
- Crop management by promoting grazing on thet shore and the creation of watering places for the cattle
- Increase lateral mobility by clearing the riprap from the riverbed

Hazard: floods

Main stakeholders:

- "Nature en occitanie" Association
- Occitanie Region, Water agency of Adour-Garonne
- Haute-Garonne Department

Links: Presentation symposium “restoring the floodzones of our territory” (French)

1.3

On-line flood storage reservoirs at Zilefto and Komma

Zilefto and Komma, Greece; 2019-2020

Floods and droughts pose serious hydro-meteorological risks in East-Central Greece, where the Spercheios River is located. Rainfalls and riverbank overflows cause flood events regularly. Meanwhile, during the summer months, the area also faces water scarcity due to irrigation demands. The solution carried out by the OPERANDUM project is the construction of flood-storage reservoirs at Komma and Zilefto. The construction includes riverbanks stabilization, re-meandering of the river course, and cleaning and widening the riverbed.

Applied nature-based solutions:

- Construct emergency flood water storage
- Re-meandering streams
- Clear the riverbed by removing structural elements (daylighting) and sediment removal
- Adapting the river embankment
- Construction of wetlands by flattening the river slope

Spercheios River, OAL Greece (OPERANDUM)

Hazard: Agricultural drought, flash flood, riverine (fluvial) flood

Main stakeholders:

- Kentro Kainotomon Technologion AE (KKT-ITC)
- Perifereia Stereas Elladas (PSTE)
- Local citizens, agricultural associations, and NGOs
- European Commission

Links: OPERANDUM OAL Greece, OPERANDUM Komma, OPERANDUM Zilefto

1.4

Lower Danube green corridor: floodplain restoration for reducing flood and eutrophication events

Bulgaria, Romania, Ukraine, and Moldova ; 2000-ongoing

During the second half of the 20th century, three-quarters of the Lower Danube's floodplains were cut off from the main river by dikes and were transformed into agricultural areas leading to eutrophication and more extreme flood events.
The solution undertaken by the governments of Bulgaria, Romania, Ukraine, and Moldova is the establishment of a green corridor along the entire length of the Lower Danube River (~1,000 km) to preserve and restore natural floodplains.

Applied nature-based solutions:

- Make room for natural flooding areas by reconnecting the floodplain and river
- Restoring riparian vegetation by planting floodplain or riverside
- Restore surface wetlands by integrating a landscape park
- Clear the riverbed by removing structural elements (daylighting)

Succession of habitats after the restoration of agriculture polder in Mahmudia (World Wide Fund For Nature, C. Mititelu)

Hazard: Eutrophication, Riverine (fluvial) Flood, Soil Erosion

Main stakeholders:

- Governments of Bulgaria, Romania, Ukraine, and Moldova
- World Wildlife Fund (WWF)
- Local citizen and environmental NGOs
- European Commission

Links: OPERANDUM, Climate ADAPT

Guidelines

SCALE AND IMPACT

NBS for rivers and lakes can be implemented as individual approaches, but ideally, they should form part of a strategy for the whole catchment with respect to disaster risk management and nature conservation. As such, NBS for rivers and lakes are large scale measures with significant impacts. However, individual measures exhibit considerable variety, leading to notable differences in the scale and impacts of various types of NBS. For example, large scale NBS relevant for flood protection may need large areas, such as re-meandering and the use of floodplains and wetlands to increase the floodable areas. Other NBS are applicable at small/riverbank scale, for example related to use of (re)vegetation for embankment stabilization.

In general, all these measures will have a positive effect over a larger area with respect to increased biodiversity, less transport of sediments due to soil erosion, improved water quality and water quantity, carbon storage, reduced temperature, and other more socially oriented benefits.

ECONOMIC COST

Local NBS interventions , such as (re)vegetation of riverbanks, are low-cost measures, requiring (local) material for vegetation and rather simple implementation measures with little machinery. On the other hand, large scale measures aimed at improving the whole river system may be rather costly. Detailed planning and design are needed, and land acquisition may also be required. Furthermore, heavy machinery and high labor resources may be needed. In addition, costs for implementing ancillary facilities to enhance the usability of the area may be needed (e.g. picnic areas, cycling routes, and bird-watching stations). Future maintenance costs must also be considered.

ENVIRONMENTAL CONDITIONS

The NBS proposed for rivers and lakes mainly consists of measures to "restore nature" or "build back nature". The intention of these measures is to allow nature mange the hazards as it would without human intervention. From this perspective, NBS for rivers and lakes are environmentally friendly. However, there may be environmental challenges during the construction period and associated with the long-term maintenance. For example, access roads may need to be constructed for the installation phase, and the actual work of planting vegetation for embankment stabilization may have a temporarily negative effect on the environment.

The environmental impact of more innovative measures, such as soil and water bio-engineering techniques (SWB) are more uncertain. More studies are needed for establishing their environmental consequences.

TECHNICAL CONDITIONS

The NBS proposed for rivers and lakes are relevant for hazards such as floods, droughts, bank stability, and soil erosion. However, in most cases the NBS for rivers and lakes are linked to water management, whether it is to reduce the water quantity and intensity or to ensure that there is sufficient water in dry periods. Local geological conditions, for example local soil types, can also influence the effectiveness of the NBS especially for wetlands and for riverbank protection.

The local landscape and ecosystems are also important, as most NBS relevant for rivers and lakes are area intensive. The necessary area must be available and usable. Specific geological, topographical, geographical (land use) come into play, and the overall ecosystem conditions are also essential.

SPECIFIC CHALLENGES

Land availability is one of the main barriers for implementing NBS, and this is especially the case for rivers and lakes where the land is often private and not available for public use. Areas around lakes or rivers are often fertile and may be used for agricultural purposes, or they are attractive areas for leisure or commercial activities. Privately owned land may be very expensive to acquire , and for publicly owned land the formal processes for planning approval may take a long time.

Other potential challenges may be related to actual implementation. While the aim of the NBS implementation is to reduce risk and to increase biodiversity, in some cases, NBS implementation may temporarily impact Biodiversity negatively. It is important to have in mind also potential temporal damage to the ecosystem, and plan for post NBS implementation strategies that ensure a full recovery of the area.

C2. Wetlands

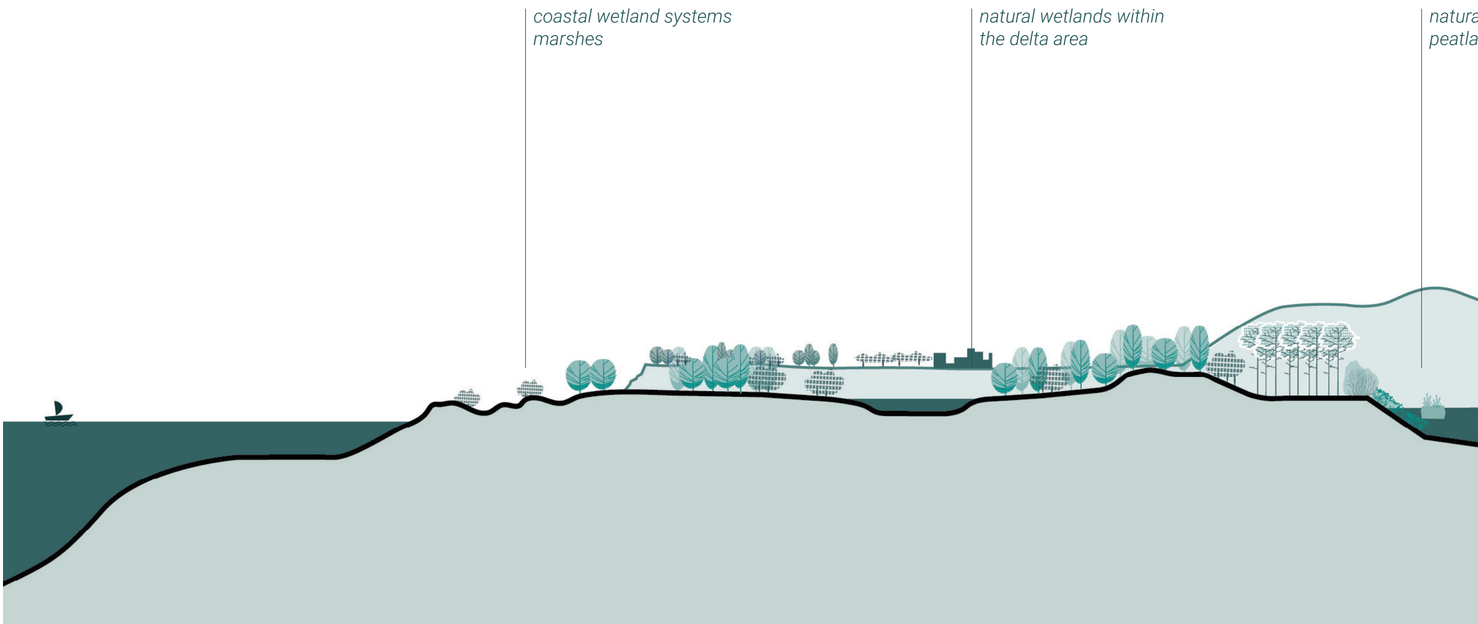
Restoring a robust waterscape

Wetlands are transitional lands that occur between aquatic and terrestrial ecosystems where the water table is often near the surface of the land or when the land is covered with shallow water. Wetlands are characterized by areas permanently or seasonally flooded or waterlogged by surface or groundwater. They have sufficient humidity levels to support an abundance of hydrophytic vegetation (e.g., duckweed, water lily, pickerel weed, cattails, woolly sedge, bulrush and royal fern) or vegetation typically adapted in saturated soils. The vegetation type mostly depends on the level of soil saturation. Seasonally dry wetlands often support trees and more sturdy vegetation while frequently flooded wetlands tend to support grasses and mosses. Wetlands are present on all continents except Antarctica (Bal¬wan & Kour, 2021)They exist in mountain, riverine and coastal landscapes. Wetlands have various qualities and include marshes, peat bogs, swamps, sloughs, wet meadows, lagoons and mangroves. There are many categories of wetlands, but they are generally classified into two main types: coastal or tidal wetlands and inland wetlands.

Coastal or tidal wetlands connect marine, freshwater and terrestrial ecosystems. Because of the mix of saltwater and freshwater associated with the fluctuation of the water levels, they succeed in supporting very few plants. Two types of such plants that can adapt to coastal wetlands are: a) grasses and grasslike plants that acclimatize to the saline conditions and form much of the tidal salt marshes that are found along the Atlantic, Gulf, and Pacific coasts, and b) salt-loving shrubs or trees like the mangroves found in tropical climates and salt hedges in the mediterranean basin. Both are essential components of the world ecological corridors and host crucial habitats for species, acting as breeding grounds for fish, stopover sites for millions of migratory birds, grazing grounds for megafauna and hunting sites for endangered predators such as tigers and sharks. They also provide crucial biota for saltwater intrusion and protecting against coastal floods.

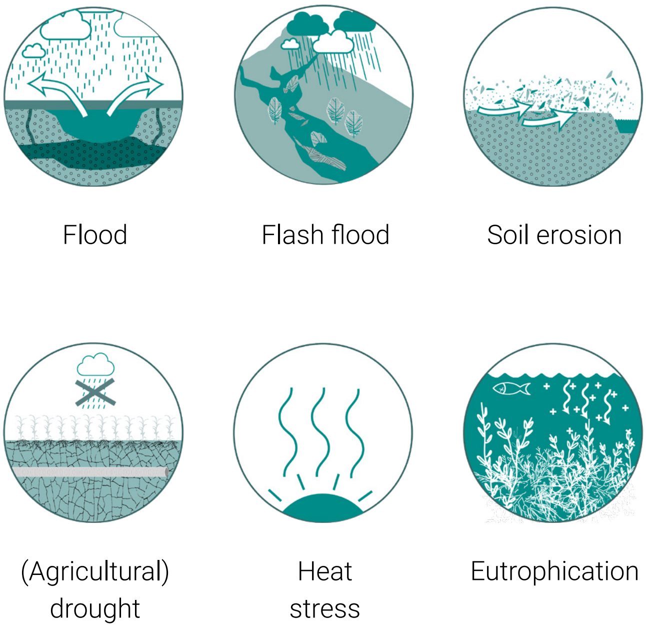
Inland wetlands are characterized by saturated soils, either due to the accumulation of precipitation or where groundwater or surface water inundate the soil surface. Peatlands are the most frequent type of inland wetland and often occur where dead vegetation fails to rot because of high humidity levels. It includes moors, bogs, mires, peat swamp forests and permafrost tundra. Peatlands represent half of the earth's wetlands and cover 3% of the global total land area. The larger peatlands are in the Arctic, the Congo basin and the Nile basin in Africa and the La Plata Basin in Patagonia in South America. However, some also exist in Europe, northern Siberia and Indonesia. Peatlands are also found in high mountains as in the Andes, Himalayas and the Alps.

Wetlands are known as a “biological super system” because they are one of the most productive ecosystems on earth due to their species richness and the multiplicity of functions they perform. While wetlands cover only 6% of the world's land surface, they are vital for the survival of 40% of the plant and animal species (Zedler and Kercher, 2005). They are crucial ecosystems for biodiversity conservation as well as for climate, water supply and human economy.



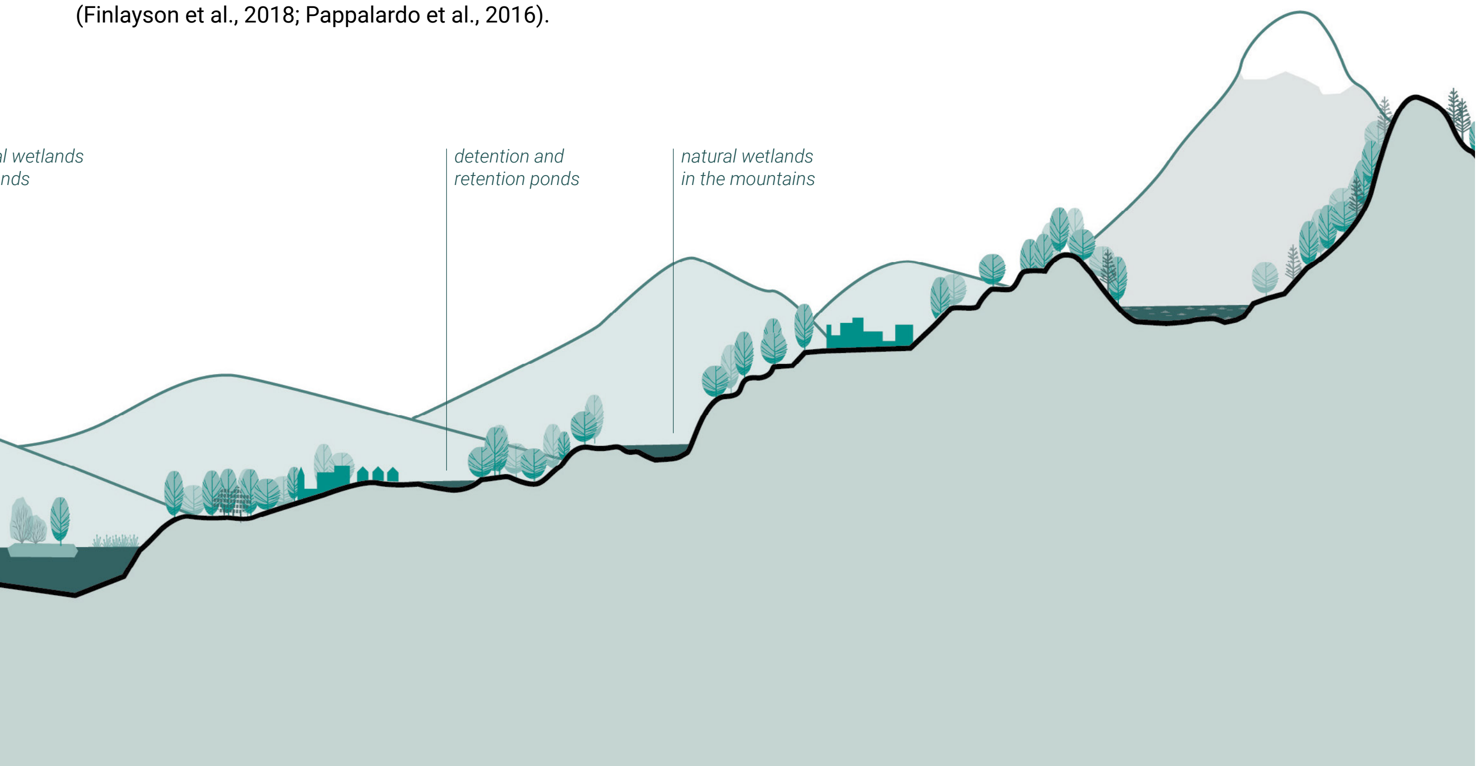
Hazards

Wetlands are among the ecosystems in which are most threatened by human activities largely due to their high productivity. They provide livelihoods for over 1 billion people worldwide. Drainage is the greatest hazard to wetlands, followed by direct extraction of natural resources for commercial uses and intense agricultural practices. As a result of developments in the draining techniques, wetlands have been massively drained to make way for agriculture and cities, leading to the disappearance of more than a third of them since 1970 (Finlayson et al., 2018).



Industrialization has become a real threat for our wetlands. For hundreds of years, wetlands were productively used for agriculture without putting their balance at risk. However, the industrial boom from the late 18th century has resulted in increasingly more intensive use of this resource, resulting in destruction or degradation of the wetlands. In agricultural areas, draining of wetlands has been initiated to create workable land. In mountainous areas, peatlands are vulnerable to degradation through overgrazing. The urbanization process drives wetland loss, with cities sprawling into rural wetlands and existing urban wetlands being filled in for industrial or residential purposes. Yet, urban wetlands are crucial for water supply, flooding risk mitigation, carbon emission storage and climate regulation.

Wetlands are also threatened by pollution with 80-90% of global untreated wastewater directly released into them (UN Water, 2020). However, they have an efficient filtering potential and can remove up to 60% of metals, 90% of sediment runoff and 90% of nitrogen but suffer under industrial and agricultural pollution (Finlayson et al., 2018; Pappalardo et al., 2016).



A landscape synthesis

Wetlands are essential natural systems and create very recognizable landscapes in between water and land, and are home to an enormous wealth of fauna and flora. Their high groundwater table is a very typical characteristic. While often being related to river systems, wetlands can also appear as independent landscapes. The various physical forms the wet ground creates are illustrated in the synthesis drawing on the opposite page, where NBS and their interactions related to these specific ecosystems are shown in more urban as well as rural contexts. Following the four different approaches, the NBS in are categorized below according to the approach to which they are most applicable.

RESTORATION
Intact surface wetlands have substantial buffering capacity to store water (like a sponge), and the restoration of surface wetlands significantly increase the resilience to floods and/or heavy rainfalls in the landscape., This buffering capacity is valuable to the surrounding territory, and act as water reservoirs in times of drought. The consequences of wetland restoration vary and are dependent on the overall context. For example, the restoration of a wetland in the lower plains will trigger a different type of biodiversity development than a wetland restoration on the edge of a city center.

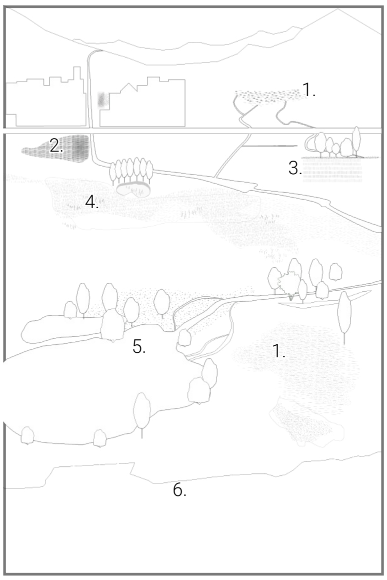
The latter can become a floodable landscape park and will bring significant added value to the urban areas.

Peatlands are a landscape form that provides excellent storage capacity for rainfall, but also for the natural storage of carbon. However, peatlands are quite vulnerable to climate change in particular due to erosion by heavy rains. Revegetation can be used to help stabilize the peatland mass, which enhances its resistance to erosion but also supports biodiversity.

PROTECTION
Wetlands can also play a significant role in terms of protection of the territory particularly in built areas, during a storm or flood event. Constructing reservoirs, basins, ponds, and/or ditches as emergency flood water storage can increase the storage capacity of the wetland system and subsequently help reduce negative consequences. These interventions can retain large amounts of water at peak times and then slowly discharge the water to infiltrate into the soil.

CREATION
Creating new lakes and wetlands to increase storage capacity can be beneficial under certain conditions. For example, riverbanks can be lowered at a specific location to link the adjacent area in the watercourse to the wetland. Furthermore, sediment ponds can also be created to capture sediment and nutrients before they enter the water system. Such constructed wetland systems should exhibit spatial continuity with the existing natural wetlands.

MANAGEMENT
Wetlands management is a challenge, requiring the optimization of storage capacity while preserving their exceptional biodiversity. They are a valuable resource, and in many parts of the world are also used for agriculture and fishing. Specific management can restore the groundwater level fluctuation and wet anaerobic soils. Improving lateral connectivity between water systems can also contribute to a healthier water system and a climate adaptive landscape.



1. Revegetation of peatlands
2. Construction of lakes and wetlands
3. Stormwater management
4. Emergency flood water storage
5. Restoring surface wetlands
6. Restoring the groundwater levels

Functions

Wetlands function as a sponge in the landscape and collect water during rain events and gradually infiltrate the water into the soil or release it into nearby water bodies. Wetlands are consequently considered as good allies against floods and drought risk. Peatlands are vital for natural flood management, significantly reducing flood risk. Peatland conservation and restoration seeks to reduce flood risk by restoring or enhancing landscape and hydrological processes. Wetlands also function as natural filters and the very low velocity of wetland water and its association with the complex interaction of plant and animals enable highly effective physical, chemical and biological processes that efficiently remove nutrients, pesticides , metals, as well as suspended sediments from the water.

For supporting habitat, wetlands stimulate biodiversity supporting both aquatic and terrestrial species. According to the IUCN (2022), 40% of all species live or breed in wetlands and 50% of bird species depend on them. Additionally, they are crucial for most amphibians and many fish species. Wetlands are also important places for scientific study and are considered as natural archives. Because of their unique condition, wetlands store seeds and pollen of extinct species, may offer insights about previous biodiversity and climates, and can also store precious fossils.

water

1. Riverine flood regulation
2. Pluvial flood regulation
3. Coastal flood regulation

soil

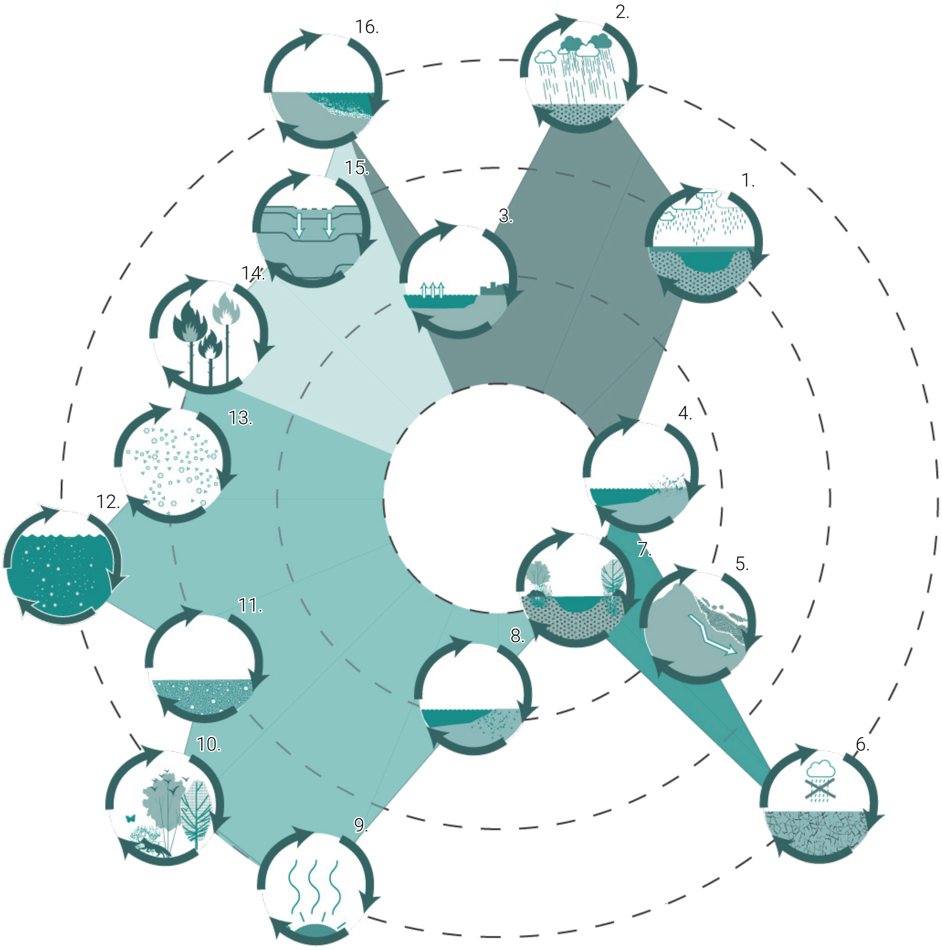
4. Coastal erosion mitigation
5. Landslide mitigation
6. Drought mitigation
7. Riverbank erosion mitigation

habitat

8. Salt intrusion regulation
9. Heat stress regulation
10. Biodiversity stimulation
11. Soil pollution regulation
12. Water pollution regulation
13. Air pollution regulation

other

14. Wildfire regulation
15. Subsidence regulation
16. Sedimentation mitigation



Benefits

Wetland conservation, restoration or creation have numerous benefits for humans and nature. Not only are wetlands biodiversity hotspots that protect habitat and provide natural corridors, but they also enhance climate resilient landscapes to reduce the impacts of climate change. In addition to these ecological benefits, wetlands are also among our best allies in climate protection. They are durable and self-sustaining carbon "sinks". Wetlands play an important and highly effective role in carbon sequestration which supports global climate change mitigation. For example, peatlands store an impressive amount of carbon. Many recreational activities take place in and around wetlands, with hunting and fishing being the most popular. Additionally, there are numerous other nature-based recreational opportunities. On a smaller scale, urban wetlands serve as vital remnants of nature, offering residents a rare sense of wildness and open space as some of the last remaining natural habitats.

Due to their multiple functions and contributions to human well-being, wetlands are vital for economies. They support national and local economies by producing valuable resources. Without functioning wetlands, governments would incur significant costs to replicate their natural services, such as providing clean water for human use. Additionally, as essential habitats and breeding grounds for fish, wetlands sustain hundreds of millions of livelihoods.

Historically, wetland has been converted to agricultural land to increase gross value. However, over time, this approach has been counterproductive, leading to a loss in the gross value of agricultural production, a decline in the value of local territories, and endangering climate and biodiversity on a global scale. More recently, the process of restoring former agricultural land to wetlands has documented that the economic cost-benefit of wetland restoration is highly positive. For example, the United States (Mississippi) calculation showed that wetland restoration enabled an add value of US$1,827 per hectare of wetland restored (Prato and Hey, 2006). Wetlands have worldwide economic importance of up to US$15 trillion dollars (MA, 2005).

ecology

1. Carbon storage
2. Natural corridors
3. Nature development
4. Habitat protection
5. Climate resilient landscape

cultural

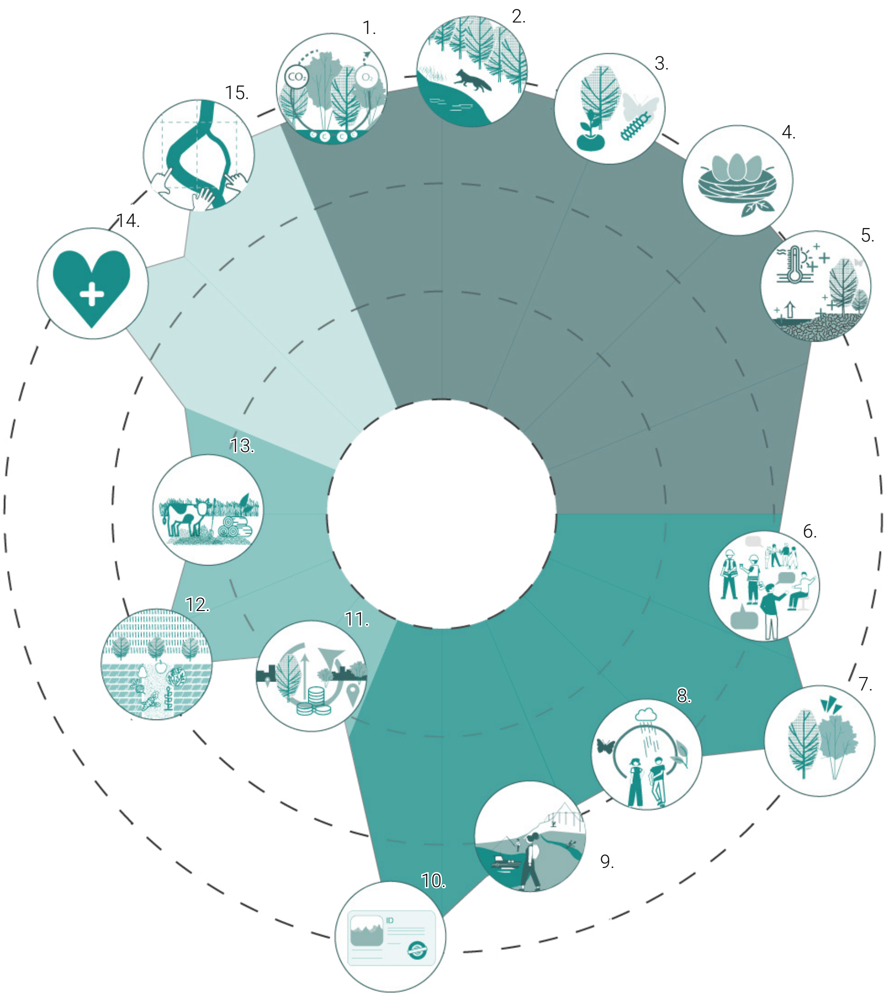
6. Social interaction
7. Cultural landscapes
8. Education
9. Tourism, sport and recreation
10. Landscape identity

economy

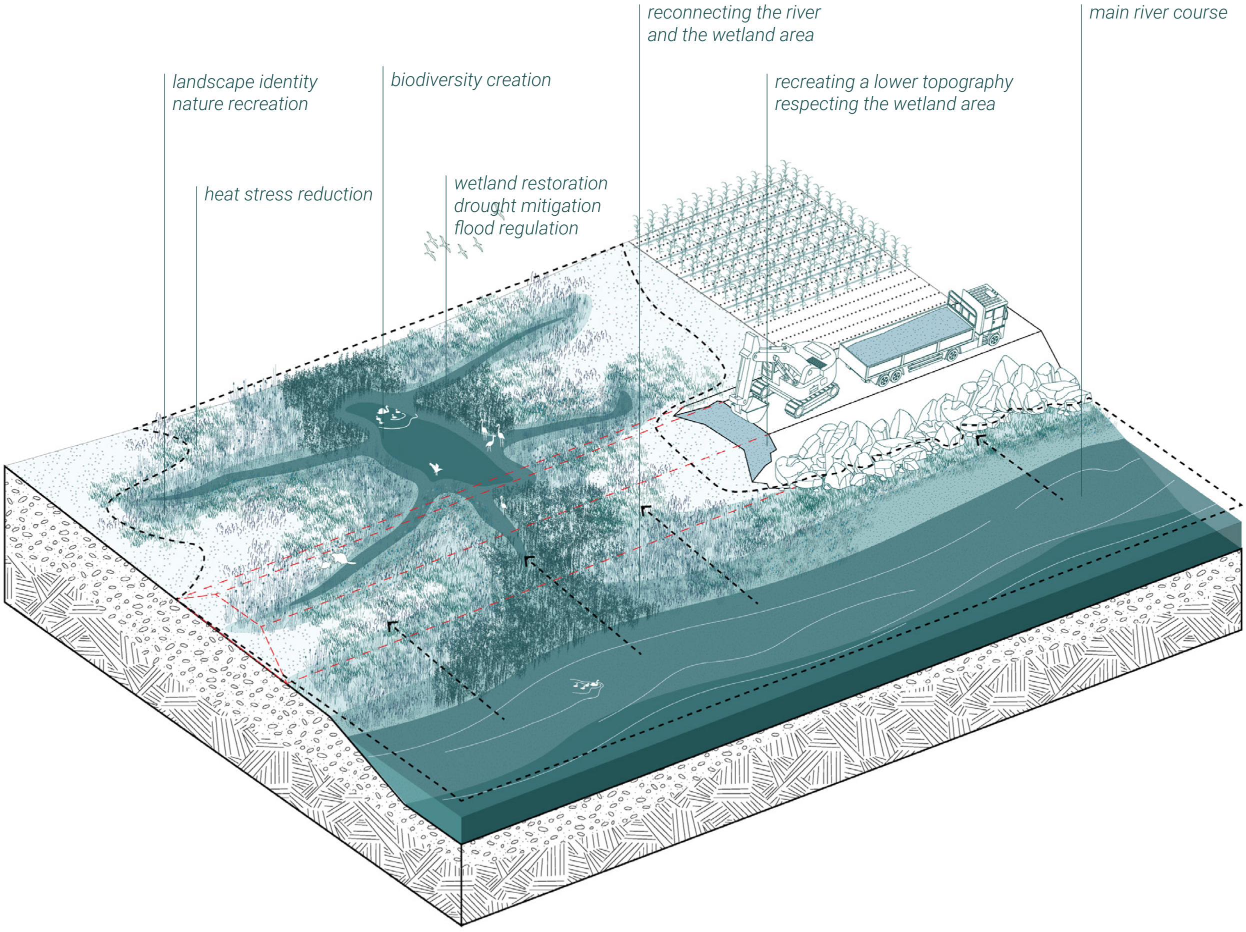
11. Local jobs and green economy
12. Productive landscapes
13. Resources production

other

14. Human health
15. Integrated water management



Specific nature-based solutions

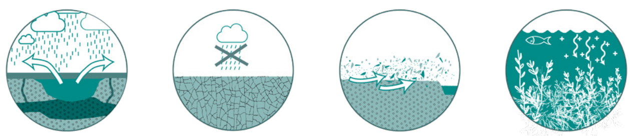


SURFACE WETLANDS RESTORATION

TYPE OF INTERVENTION

R Restoration

HAZARDS

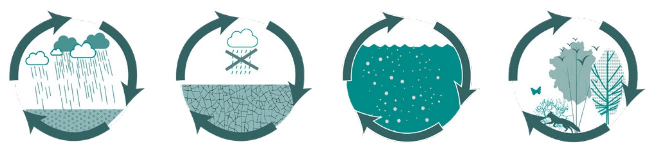


Flood | Drought | Soil erosion | Eutrophication

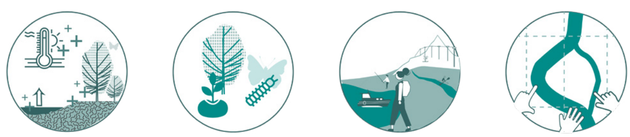
DESCRIPTION

Marshes or surface wetlands are often compared to sponges or tubs due to their ability to store water. From these marshes, the water can infiltrate slowly into the soil and recharge the ground-water table or flow towards the surrounding water systems. The surface wetlands also acti as buffers for surface water runoff and can therefore attenuate peak floods. Surface wetlands represent valuable ecosystems and strategic components in hydrological systems. Their restoration and maintenance are therefore crucial.

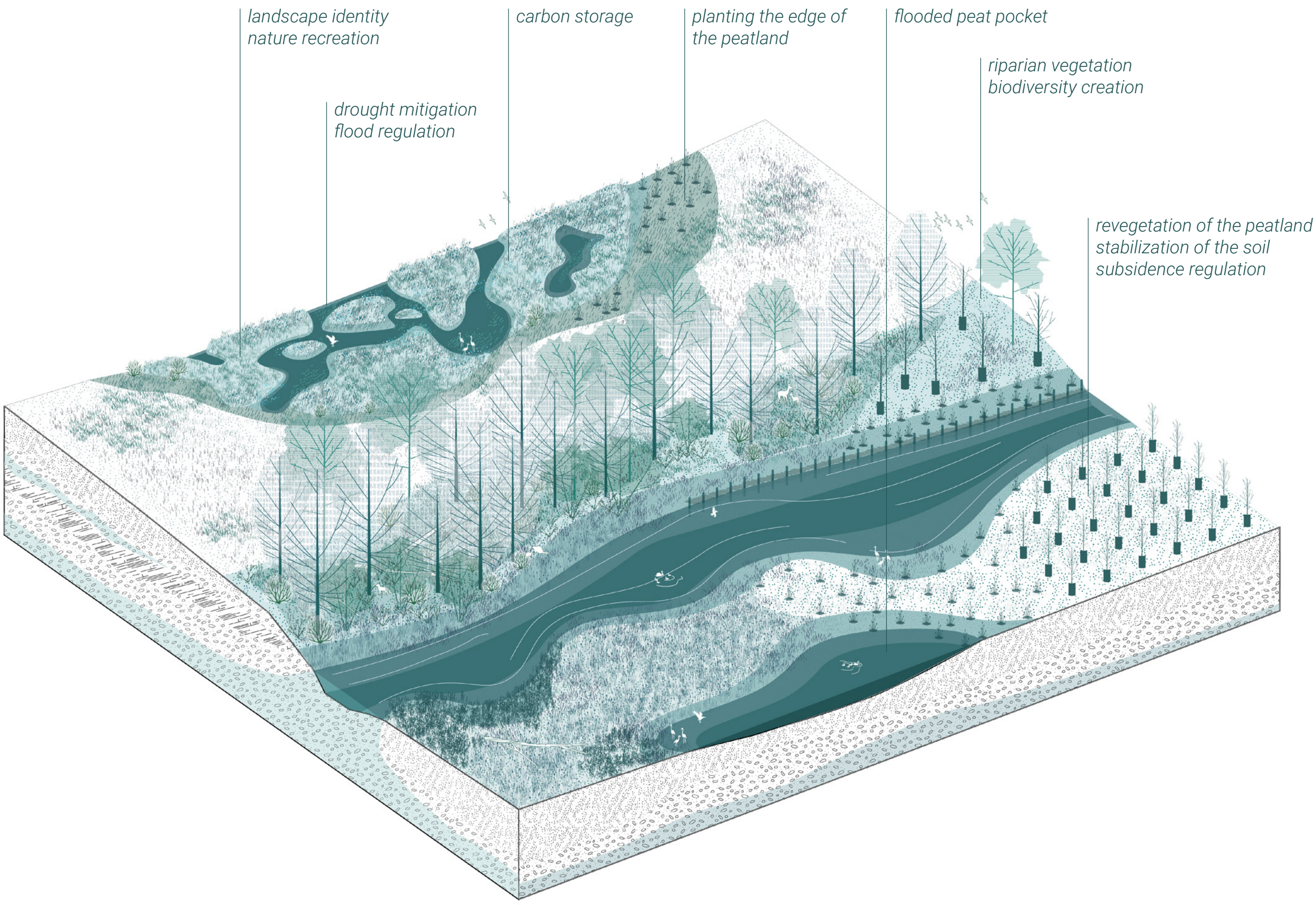
MAIN FUNCTIONS AND BENEFITS



Pluvial flood regulation | Drought mitigation | Water pollution regulation | Biodiversity stimulation



Climate resilient landscape | Nature development | Tourism and recreation | Integrated water management

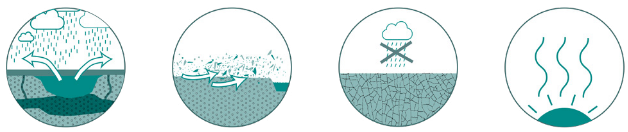


PEATLANDS REVEGETATION

TYPE OF INTERVENTION

R Restoration

HAZARDS

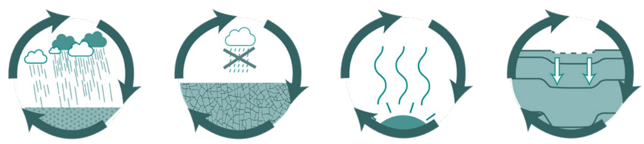


Flood | Soil erosion | Drought | Heat stress

DESCRIPTION

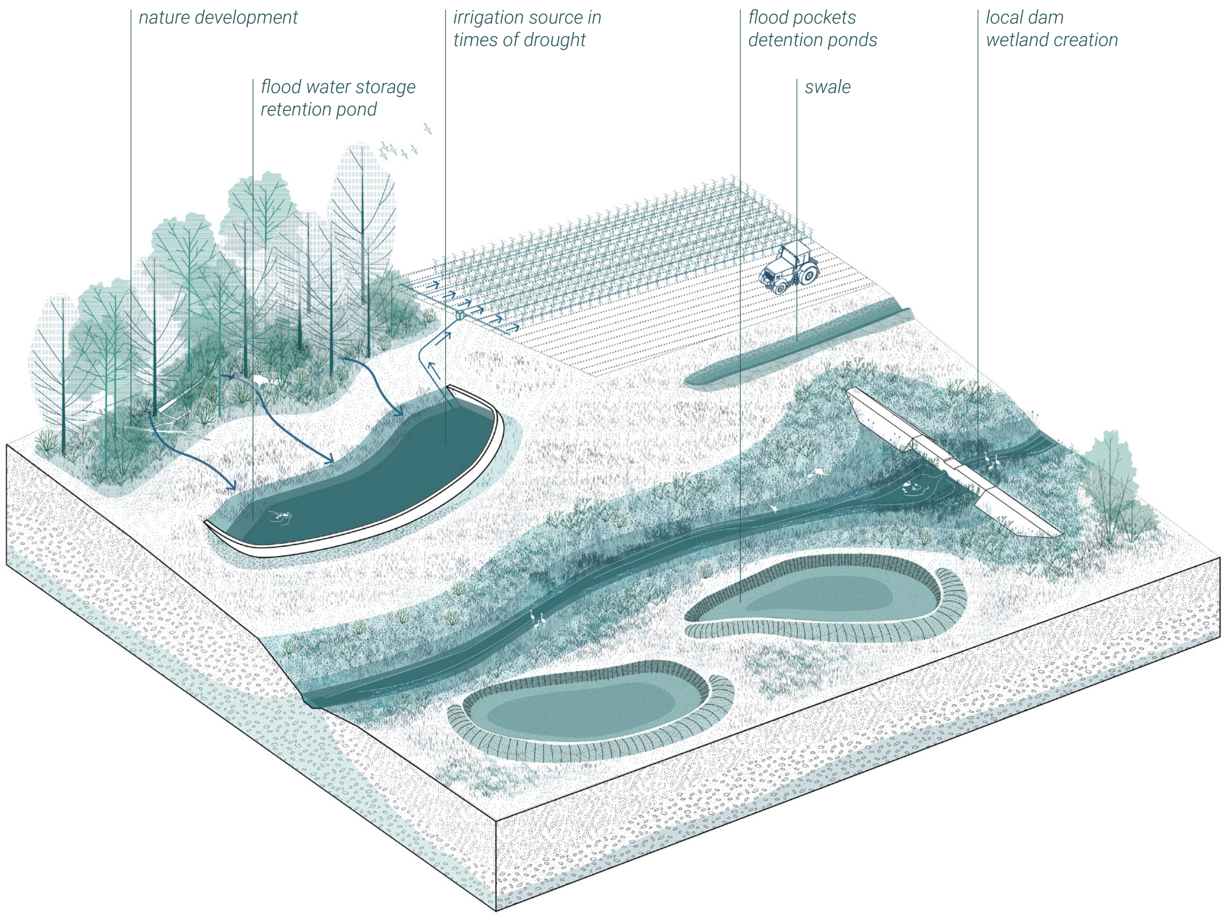
Peatlands respond rapidly to heavy rainfall and can slow the flow of surface water during storms. However, extreme climate conditions leave large areas of peatland vulnerable to erosion. Peatlands are also known to be a very efficient ecosystem for carbon storage. Moreover, the specific landscape conditions stimulate the development of rare habitats. Restoring peatlands by revegetating them can stabilize the peat mass and hence its entire ecosystem functions and cultural landscape.

MAIN FUNCTIONS AND BENEFITS



Pluvial flood regulation | Drought mitigation | Heat stress regulation | Subsidence regulation

Landscape identity | Tourism and recreation | Natural corridors | Carbon storage



EMERGENCY FLOOD WATER STORAGE

TYPE OF INTERVENTION

P Protection

M Management

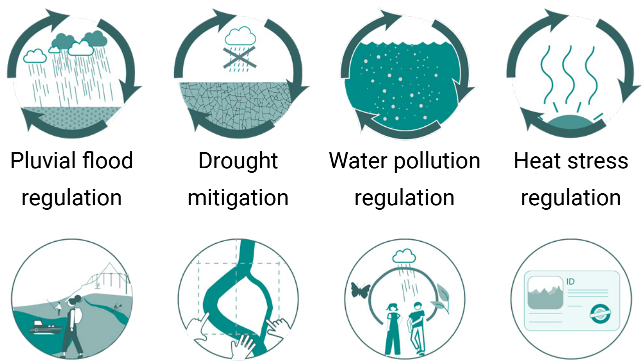
HAZARDS

Flood | Flash flood | Drought | Heat stress

DESCRIPTION

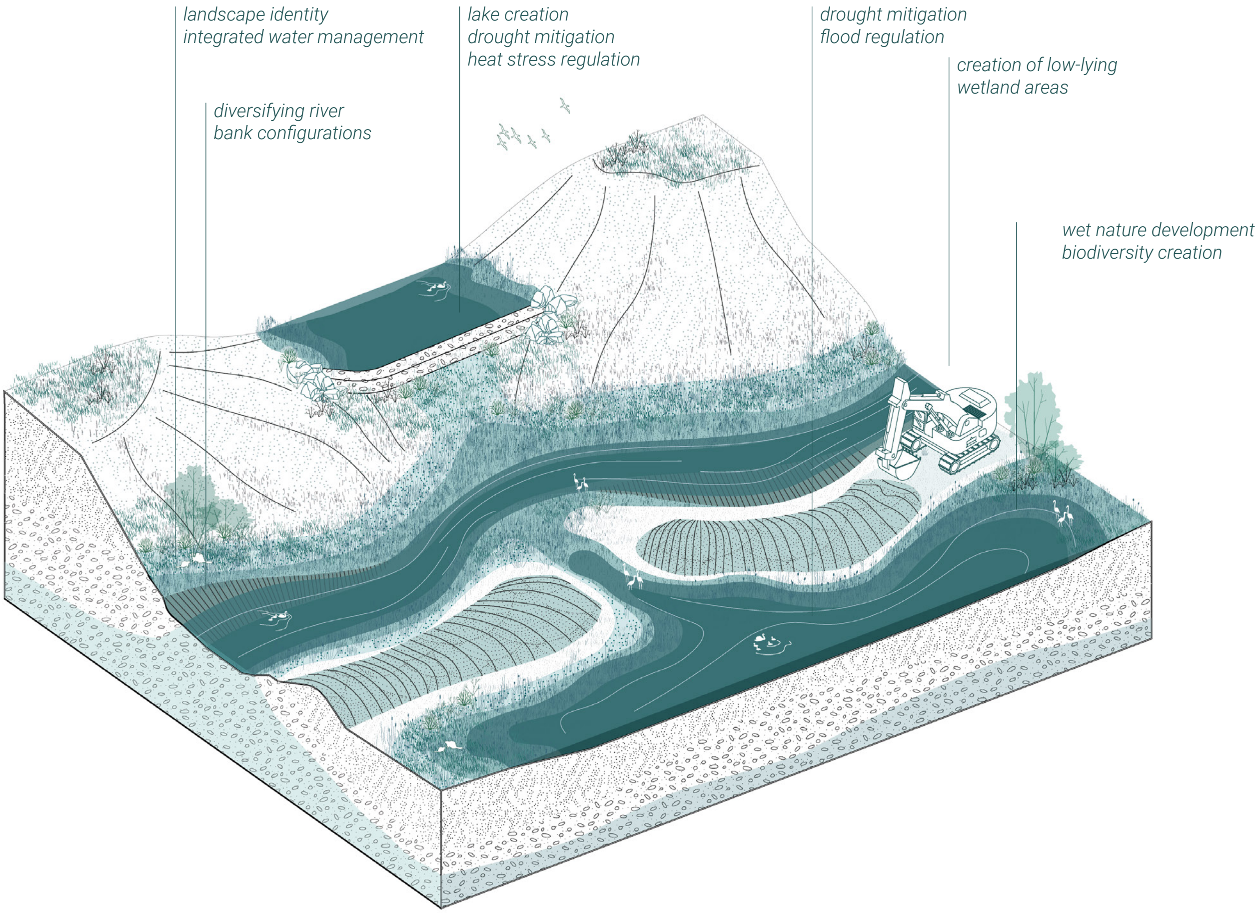
Wetlands have a significant function for flood protection. Various types of wetlands can be implemented, regarding the specific needs and the situation of the wetlands in the valley. Ponds and basins can be implemented to collect and store water from heavy rainfall on the higher grounds before it runs off to the river. In the lower areas, retention ponds are permanently filled with water for further reuse during periods of drought. Detention ponds are deeper and only temporarily store stormwater, until after the flood peak. Then they slowly discharge into the river. Strategic water management must determine the most relevant locations for these different types of flood water storage.

MAIN FUNCTIONS AND BENEFITS



Pluvial flood regulation | Drought mitigation | Water pollution regulation | Heat stress regulation

Tourism and recreation | Integrated water management | Education | Landscape identity



CONSTRUCTION OF WETLANDS

TYPE OF INTERVENTION

C Creation

HAZARDS


Flood


Flash flood


Drought

DESCRIPTION

The creation of new water bodies for wetlands can have multiple functions and benefits. Apart from water storage, they can reduce heat stress, introduce new habitats and strengthen biodiversity. Constructed wetlands are artificial wetland structures that can also clean water through a series of planted marshes and engineered soils that remove contaminants. Finally, these new wetlands can strengthen the identity of the landscape.

MAIN FUNCTIONS AND BENEFITS


Pluvial flood regulation


Drought mitigation


Biodiversity stimulation


Water pollution regulation


Education


Tourism and recreation


Integrated water management


Landscape identity

NBS case studies

2.1

Restoration of the Schellenbergmoor

Bavaria, Germany; 2010 - ...

The objective of this project was to protect the Spirken moor forest from the effects of drought and dehydration. To achieve this, the 3.3-hectare Kesselmoor was restored to increase storage capacity in this landscape. The Kesselmoor was crossed diagonally by an overgrown drainage ditch, this was remediated by installing 10 peat dams in January 2011. This influenced the groundwater level, and consequently affected the competing spruce growth causing it to be pushed back. The acrotelm formation in the inner bog was expanded leading to the stimulation of new peat formation.

Applied nature-based solutions:

- Reduce drainage by construction of peat dams

Oligotrophes in Schellenbergmoor (Friedrich Haag / Wikimedia Commons / “Münsing Schellenbergmoor 008 2023 04 27” / CC BY-SA 4.0)

Hazard: drought

Main stakeholders:

- Bayerische Staatsforsten

Links: Info brochure Quellmoore zwischen Salzach und Traun

2.2

Renaturalization of degraded peatlands to prevent wildfires

Belarus; 2009 - 2030

Belarus experienced massive draining of peatlands in the 20th century for agriculture and forestry. However, such dry lands were generally abandoned becoming vulnerable to fires and causing drastic consequences for the environment and the national economy. By July 2016, about 50,000 ha of drained peatlands were restored by re-establishing the hydrological regimes. The government of Belarus aims to restore 500,000 ha by 2030 to promote ecological tourism and decrease carbon dioxide emissions into the atmosphere.

Applied nature-based solutions:

- Restorate degraded water bodies
- Revegetate peatlands by revegetating bare peat

Hazard: wildfire

Main stakeholders:

- Ministry of Natural Resources and Environmental Protection of the Republic of Belarus

Intact peatlands (Davide Zanchettin, CC-BY-2.0)

- Royal Society for the Protection of Birds (RSPB)
- United Nations Development Programme (UNDP), European Commission, Global Environment Facility (GEF)
- Michael Succow Foundation, Coca-Cola Foundation
- Domestic peat-mining enterprises

Links: OPERANDUM, The Global Environment Facility (GEF), PANORAMA

2.3
Wootton Wetland restoration to enhance biodiversity and reduce flood risk

New Forest National Park, England, UK; 2017 - 2019

Several Sites of Special Scientific Interest (SSSI) in the New Forest National Park were in an ‘unfavorable’ condition. Forestry England restored a 4 km stretch of the stream Avon Water which had been artificially straightened and embanked in Victorian times.. The re-meandering of Avon Water resulted in the restoration of the Wootton Wetland area bringing significant benefits to wildlife and plant life. In addition, this restoration work slows down the flow reducing the impact of flood risk downstream.

Applied nature-based solutions:

- Maintain and enhance natural wetlands
- Make room for natural flooding areas by reconnection floodplains and rivers
- Re-meandering of streams,
- Clear the riverbed by removing structural elements and sediment removal (daylighting)

Wootton Wetland restoration (New Forest HLS - Forestry England)

Hazard: riverine (fluvial) flood

Main stakeholders:

- New Forest National Park Authority, Forestry England, Environment Agency, Natural England, Local parish council
- Mott MacDonald
- Visitors of the park

Links: OPERANDUM, HLS Wootton Riverine Restoration

2.4
Floating island gardens

Liverpool; UK - 2020

Two ecosystem islands have been launched at Liverpool's historic waterfront at Wapping Dock and Sefton Park. The one at Wapping Dock is a saltwater/estuarine ecosystem with a surface of 63 m². It has a submerged shingle shelf for small fish and a submerged ‘reef’ made of empty oyster shells in cages, and it is planted with saltwater tolerant reeds, grasses and flowering plants. The goal of the installation is to boost biodiversity in the dock waters, to signpost the new green route and to raise awareness of the role of nature-based solutions. The 25 m² freshwater floating ecosystem island in Sefton Park will also improve local biodiversity by providing a home for pollinators. Moreover, the roots of the planted reeds will help clean the water and improve water quality.

Applied nature-based solutions:

- Introduce and restore ecosystems
- Integrated water management
- Phytoremediation

Floating gardens, Liverpool (URBAN GreenUP, Juliet Staples, Liverpool City Council)

Hazard: euthriphication, air pollution, biodiversity loss

Main stakeholders:

- Liverpool City council
- Local dock authorities
- NGOs
- Inhabitants

Links: URBAN GreenUp Liverpool

Guidelines

SCALE AND IMPACT

Over the last 300 years, 87% of the world's wetlands have been lost. Considering their immense value for humans, biodiversity and the climate, the restoration of these precious ecosystems should be advanced prioritized within the shortest time scale and at but on the largest geographical scale (Kingsford et al., 2016). However, in the context of the practice of strategic landscape planning, this is a challenge to achieve and practically, wetland restoration projects range from different scales depending on the goals of the restoration, the degree of degradation and the site potential to host a wetland in its full functionalities. Temporally, restoration targets a mid- and long-term improvement of the landscape capacity. However, in In the short-term, active restoration induces short-term disruptive activities that should only be employed if sensitive fauna and flora are safeguarded in the process. Further to potential impacts, passive restoration with the removal of where the pressures of degradation are removed are often cheaper, less disruptive smoother for the ecosystems and achieve high acceptance or even willingness to act from a broader range of stakeholders. When degradation has been more extreme, active restoration can be more is particularly appropriate when degradation is more extreme, such as when hydrologic processes are altered or wetlands are filled in.

ECONOMIC COST

Wetland restoration can contribute significantly to meeting many global, national and local goals and initiatives. The principle of payment for ecosystem services shows the high economical value of wetland and advocates economically for their restoration. However, financing schemes for wetlands restoration around the globe differ substantially and they also face economic pushbacks. Worldwide, the average cost of restoration is about US$80,000/ha (Bayraktarov et al., 2016). However, wetland restoration costs vary based on the difficulty of the restoration exercise, the geographical context of the restoration and the particular country. Total restoration costs for projects in the Global South are almost 2 to 30 times less expensive than in the Global North. Beyond its cost, the challenge of restoration relies more on providing benefits to local economies' financial viability, establishing credibility, and ensuring social acceptability Interestingly, according to the RAMSAR convention, restored wetlands do not have to be excluded from all economic activities; users can continue to make "wise use" of the area. However, it is recommended that wetlands are considered common property.

ENVIRONMENTAL CONDITIONS

The restoration of wetlands usually does not encounter environmental conditions impacting project feasibility, as these projects are naturally in locations where wetlands previously existed. Technical and scientific knowledge are available to guide the restoration measures. One key component is the re-establishment of the water balance and the removal of the pressures of degradation.

The man-made creation of new wetlands as a nature-based solution in an environment previously without a natural wetland requires a more in-depth assessment of the landscape's capacity to hold a functional wetland. Their natural setting depends on hydro-morphological conditions that need to be carefully reproduced for the creation of a wetland. Beside the project's feasibility, the choice of the site for a restoration or creation largely depends on the potential impact of the measure, specifically its potential functionality in regulating floods and droughts and supporting biodiversity.

TECHNICAL CONDITIONS

According to Finlayson et al. (2018), there are three major categories of wetlands restoration projects: Construction of wetlands. This is a highly artificial measure requiring important hydro-morphological studies to confirm its feasibility and potential functionality. The measure uses high inputs of energy and mostly focuses only on optimizing the retention capacity of the landscape.

1. Creation of wetlands. This is the creation of wetlands using bioengineering techniques in a location where there were previously no wetlands. They induce spontaneous ecological functions and are usually multifunctional and can reach the same functionality level as natural wetlands.
2. Restoration of wetlands. This enables the recovery of natural but degraded wetlands from negative impacts. It is mostly induced by minimal intervention and maintenance.
3. Improving practice and understanding of wetland restoration is an ongoing need that depends not only on technical skills and ability, but also the consideration of socio-economic perspectives and knowledge about the probabilistic scenarios to consider the future needs in face of climate and societal changes.

SPECIFIC CHALLENGES

Wetlands continue to dwindle in a worrying trend despite world-wide support for wetlands restoration, including many local, national and international incentives supporting these efforts.

One of the major conflicts to wetlands restoration is land use rights. The RAMSAR Convention was established decades ago to protect wetlands, however they are still being degraded worldwide. The EU Green Deal recently targeted an increase in land conversion from agricultural land to natural ecosystem for biodiversity conservation. While the effect of the incentive was robust in a number of areas, it did not contribute to wetland restoration efforts as anticipated. The new EU Biodiversity Strategy targets 30% of lands for protection; however, without identification of the ecological, hydrological and climate value of the ecosystem. In this view, one of the major challenges for the implementation is in formulating a policy context that acknowledges the value of wetlands and directly incentivizes stakeholders to undertake restoration.

Learning from PHUSICOS case studies: Waterscapes

Trodalen residential development area

Øyer municipality, Gudbrandsdalen, Norway

The detailed plan for the measures at Trodalen

The lower part of the opened creek, with a plant test field

Realization: June 2022 – January 2023

Hazards: flooding

Applied NBS:

- Opening up a creek (restoration)
- Re-meandering of rivers and streams (restoration)
- Riparian vegetation restoration (restoration)
- Vegetation management (management)
- Adapting the river embankment by creating a buffer zone around the re-opened creek with retention capacity during flooding (protection)

Main stakeholders:

- Øyer municipality
- Residents in Trodalen and the whole municipality
- Norconsult (detailed design)
- County Governor
- NVE: Norwegian Directorate for Energy and Water Resources
- Innlandet County Authority

Description

Øyer municipality, just north of the town of Lillehammer, Norway, started a development project to establish 220 units of family housing for roughly 500 people. The housing development area is in an abandoned gravel pit. After the first houses were built; the project was put on hold due to flooding problems and lack of adequate flood protection.

The development area is surrounded by the steep river Søre Brynsåa on the northwest side, and the buried Trobekken creek on the southeast side. During heavy precipitation, the river and the buried creek resulted in flood problems. These challenges are expected to increase in the future due to climate change. The potential problems in the larger Søre Brynsåa will mainly be handled by traditional measures, whereas NBS are implemented to deal with problems in the Trobekken Creek.

The Trobekken Creek was opened to increase its capacity during a flood situation. About 120 meters of the lower part the creek remains buried under the access road. The water is led through a pipe with its outlet to the Søre Brynsåa, west of the new housing. Open watercourses are more robust and therefore more inclined to handle floods and will also form a new habitat for species associated with water.

The entire NBS measure at Trodalen, after construction, but before planting is completed

A small retention dam was also established to retain sediments that are transported in the creek during flood situations and to reduce water velocity. This implementation keeps the creek as natural and untouched as possible and limits the future maintenance to this specific area. It will also decrease the need for extensive measures upstream and limit sediment transport to the blue-green park area further down. Vegetation measures were implemented along the creek for erosion protection. A blue-green park was created as buffer zone in the lower part of the housing development area. This zone serves as a retention measure during a flood and as a blue-green nature park for inhabitants.

There was also a plan to test out a slightly different plant species in the blue/green park area by evaluating if plants that typically grow further south can thrive here, given the expected temperature rise due to climate change. However, the County Governor's office did not approve the introduction of non-local species, so this suggestion was not fully implemented.

Motivation for nature-based solutions

In the Gudbrandsdalen Valley, NBS are not a widely used concept. When this residential area was being regulated, it became clear that more flood protection was needed and a window of opportunity to suggest the use of NBS presented itself. The municipality was ready to adopt new ideas and was willing to put them to the test.

Much of the motivation to test NBS were the opportunity to realize additional benefits beyond just flood protection. The measures in Trodalen are expected to have a positive impact on the biodiversity in the area, while also contributing to the well-being of the residents. The use of NBS in the area limits the need for more invasive grey measures and thus enhances the natural aesthetics of the area.

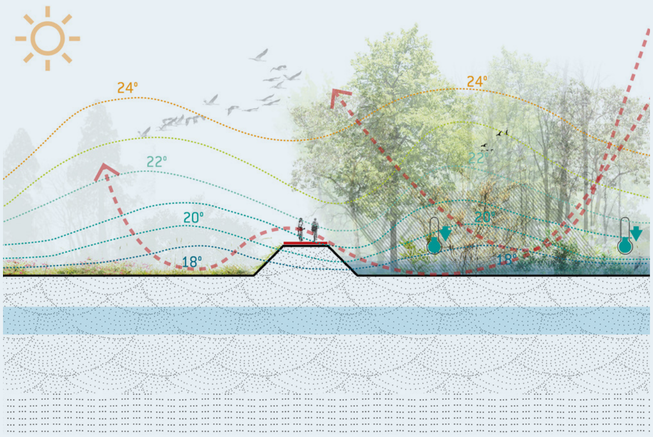
Conclusions and lessons learned

The project and the implementation of the measures went rather smoothly. No major issues arose with regard to cost, technical difficulties, or delays due to the weather, and the measures were finished in about 8 months. This serves as a good example of an NBS measure that has the potential for both replication and/or upscaling.

The regulation processes take time in a democratic society and timing is of the essence in these processes. In the case of Trodalen, PHUSICOS was able to intercept this process at an opportune time, so that the municipality was able to change course without having to launch a new full regulation process. Another lesson is the financial aspect. The NBS in Trodalen was more costly than a purely grey solution. Therefore, funding from external sources (such as the EU), was crucial for this project to be fulfilled. Finally, the collaborative climate is also essential. The Innlandet County and Øyer municipality had a good dialogue from the very beginning.

Receded green flood barrier in Jorekstad

Jorekstad, Lillehammer municipality, Norway



The dike as a landscape figure (Agence Ter)

Flooded sport facilities (Faaberg Idrettslag/Facebook)

Realization: not realized

Hazards: flooding

Applied nature-based solutions (not realized):

- Adapting the river embankment (protection)
- Natural levees and sustainable dams (creation)
- Make room for natural flooding areas (restoration)
- Riparian vegetation restoration (restoration)
- Vegetation management (management)
- Restoring surface wetlands (restoration)
- Storm water management (management)

Main stakeholders:

- Lillehammer municipality
- Residents at Jorekstad and in Lillehammer
- Users of the sports arena
- Farmers/landowners
- Innlandet County Authority as a planning and road authority
- County Governor
- Norwegian Directorate for Energy and Water Resources

Description

The Jorekstad area consists of housing, infrastructure, agricultural land, and a relatively large sports facility with football fields and a swimming hall. The area is already flood protected, with elevated riverbanks in selected locations along the straightened river. Nonetheless, the area experiences frequent flooding, with smaller floods also resulting in damage. The wetlands between the river Gausa and the agricultural land/ sports arena is designated as the nature type "forested floodplain, with very high natural value". The area consists of a grey alder and bird cherry forest, with several red listed species of trees and vascular plants. The area is also an important nesting area for passerine birds.

The proposed measure was to open the existing flood protection along the riverbank and build a new green flood barrier further away from the river. The suggested flood barrier was planned to be approximately 2300 meters long and was to be located between the agricultural land and the forested floodplain. The position of the flood barrier would protect the houses, agricultural land and the sports facilities from flooding, while at the same time allowing the riparian forest and wetland areas closer to the river to flood when needed. The barrier increases security for the local society, while at the same time providing positive effects for the local ecosystem along the river. It would also allow the river to expand during flood situations, creating both a river course with high water capacity, and room for natural processes in the watercourse.

Aerial photo of the Jorekstad area. The planned receded barrier is marked by the red line. (Statens kartverk/Geovekt/Lillehammer Municipality)

Motivation for nature-based solutions

The existing flood preventing measures implemented along the river have somewhat reduced flooding of the area, but they have also resulted in less variation in terms of species and nature types, and a general reduction in natural value. Removing the existing measures along the riverbank and implementing a receded green barrier would allow the riparian forest area to periodically flood and return to its former state. The wider flood area would also reduce the flow rate of the water, limiting erosion and sediment transport. This alleviates the problem of soil accumulation at the confluence area between the two local rivers, which further amplifies the flooding problem.

The measure will also have a positive effect on the ecological state in the area. Two football fields in the sports arena have synthetic turf resulting in large amounts of plastic fragments and microplastics being transported into the rivers during flooding events. Flooding of agricultural areas also results in nutrients such as phosphorous and nitrogen being transported into the river, which reduces water quality in the river but can also reduce the nutrients in the soil making it worse for agriculture.

Conclusions and lessons learned

Even though the measure was not realized in PHUSICOS, there is still a focus on the flooding issues at Jorekstad and the area is part of other Norwegian research projects in which other NBS are being evaluated. Thus, there are reasons to believe that a good NBS measure may be implemented here in the future. The following lessons are learned:

- The intervention was significantly delayed for reasons related to the procurement process for the detailed design of the measure, and also because the municipality would have had to revise the area plan for the region.
- During the process with the detailed design of the measure, it became clear that the cost of constructing the barrier was at least twice as high as what was estimated in the proposal.
- Furthermore, the process also demonstrated important barriers to NBS implementation such as complexities with property ownership, the time needed for public procurement, a lack of knowledge of NBS in general, and the skepticism to NBS by some of the stakeholders.

The Isar restoration
Munich, Germany

The Isar's natural embankments (TUM, A. Zingraff-Hamed)

Shallower parts of the riverbed as recreation areas (TUM, A. Zingraff-Hamed)

Realization: 2000-2011. A pilot restoration was started to test the feasibility of the measure for the site in 1999. However, the collaborative planning process of this prestigious project started already in the early 1990s.

Hazards: Flooding, erosion. The Isar River is an alpine river and drains a part of the Karwendel Mountains. It generates violent but short floods (less than a week) in spring during snowmelts and in summer after heavy rain events in the Alps. The discharge usually rises from 6 m³/s to over 1200 m³/s within a few hours. The river was channelized and regulated in the early 1900s, forcing the originally hundreds meter-wide river into a narrow channel to feed 30 hydro-electric power plants. This hydro-morphological changes led to increased intensity of the deep erosion of the river, jeopardizing bridges and draining the landscape more severely.

Applied nature-based solutions:

- River restoration

Main stakeholders:

- City of Munich, Bavarian Water Management Agency in Munich, Isar Allianz, Munchner Forum, Burkhard Landschaftsarchtiek, SKI gmbh, non-profit organizations and numerous experts in ecology, limnology, landscape architecture, forestry, hydraulics and biology that supported the authorities in the design of the river.

Description

Under the slogan "New Life for the River Isar" the 8 km long river restoration was implemented between 2000 and 2011. The restored river stretches from the southern city border at the Großhesseloher Bridge to the Deutsche Museum in the middle of the city center. The project cost of 35 million Euros was co-funded by the State of Bavaria and the City of Munich. The river restoration had three equal goals: i) reduction of the flood risk, ii) increase of the ecological quality, and iii) enhancement of its recreational potential.

To achieve these objectives, a team of planners, governmental institutions, NGOs and representatives of advocacy groups worked together on the new design of the river. In the middle of the project, the 80-year-old channelization was removed. Its concrete "corset" with levees was completely detached and the river quickly recovered its natural shape within the levee system. The riverbed was also widened by about 45 m to a total of 90 m and the riverbanks were flattened. These efforts were one of the first resemblances of 'nature' in the previously heavily artificialized area. To ensure an optimal flood risk reduction, the old embankment that was filled in after the Second World War was excavated, increasing the discharge capacity within the levee system from 800 to 1250 m³/s. In terms of improving biodiversity, new riparian gravel structures were introduced to replace the linear concrete embankments to foster dynamic habitats. The flat, species-poor grassland in the floodplain was replaced by a natural pioneer grass. To promote fish reproduction and mi-

The transformed Isar from a concrete waterway into a more biodiverse environment with accessible park areas (TUM, A. Zingraff-Hamed)

gration, the concrete weirs were replaced with fish passes. The water-based recreational potential benefits from the recovered natural features of the river and attract thousands of recreationists every sunny weekend. The riverbanks were reshaped with lowered and modelled sides to improve accessibility for bathing. Additionally, sewage treatment plants along the Isar River were upgraded to meet instream water quality requirements. The river restoration has become a great success and its effectiveness against extreme floods, potential for improving the quality of life of citizens, enabling sensitive species recovery, and becoming a local pride are already visible.

Motivation for nature-based solutions

Momentum for the restoration of the Isar built up from the civil society and became more justifiable due to the degradation of the riverine hydro-morphology because of industrial use of the water resources. Despite resistance from some groups, various non-profit organizations joined efforts in Munich within the Isar Allianz Lobby group that demanded the restoration of the Isar in 1987 in Munich and submitted restoration plans to the city council. While the motivation for adopting the restoration of the Isar, as an NBS, was driven by civil society advocacy, authorities found it plausible because, Munich needed to rethink it flood protection strategy. Initially, the flood protective grey infrastructure was able to protect the city only against an 800 m^3/s flood. However, based on calculations of the estimated 100-year flood, around 1,150 m^3/s discharge was expected, without even considering the predicted 25% increase of the summer precipitation due to climate change. These realities and uncertainties for the future flood risk suggested that it would be wiser to give “more room” to the Isar.

Conclusions and lessons learned

- Civil society can drive major socio-ecological changes in the riverscape.
- A broad, inclusive and transdisciplinary stakeholder collaboration can succeed in finding the right balance between the different societal needs.
- Establishing trust and understanding through openness, inclusiveness and transparency among stakeholders is a key to successful collaborative planning.
- 'Windows of opportunities’, no matter how small, ought to be leveraged for implementation of NBS.
- 'Flood protection does not lead to ecological degradation if advanced with the nature-based approach.
- 'Although access to nature, including rivers, has been adopted by the World Health Organization as a right, careful management is required to balance recreation with conservation.
- 'Socio-cultural and ecological needs should be balanced to achieve resilience.
- 'Awareness-raising about the importance of nature (e.g., river conservation) is needed among citizens

(Vegetated) slopes

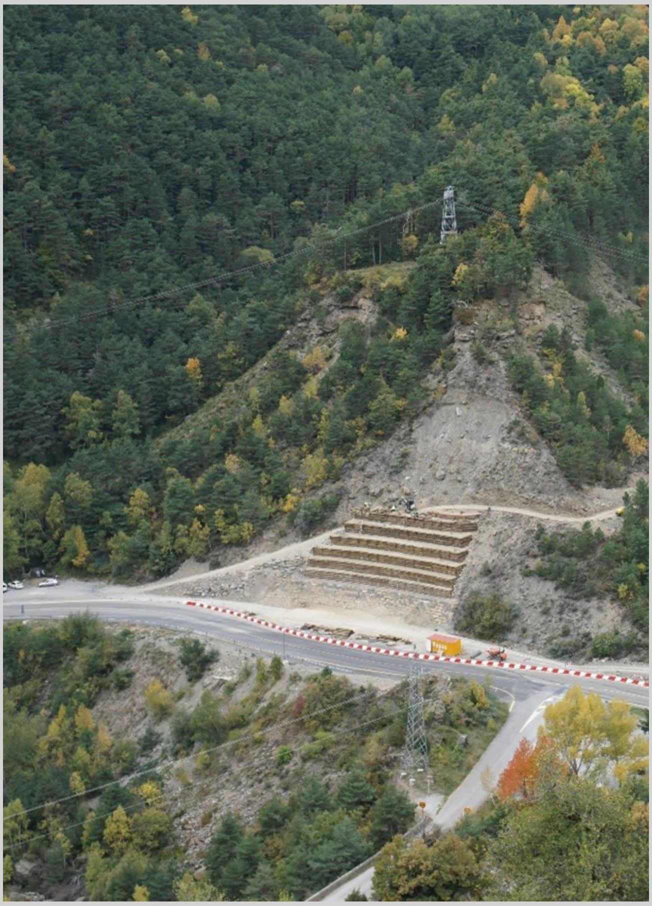
For the third and fourth ecosystem, the focus lies primarily on hills and mountain landscapes where topography is a common challenge and there are specific hazards to deal with. Interventions are needed on the slope areas itself, as a means to limit damage to downhill infrastructures, built environments, nature and cultivated lands.

3. WOODLANDS AND FORESTS

The ecosystem of woodlands and forests is characterized by the dense growth of tree landscapes, whether it is in a more natural area, a more urban forest or a canopy in a more open landscape. Depending on the climate, many types of forests can be identified. As an ecosystem it contributes with many ecosystem services to a healthy environment, such as for example the purification of the air or a specific biodiversity stimulation. On steep hills, forests can reduce the risk of landslides, rockfall and snow avalanches. This is due to the root system's soil anchoring effect and because evapotranspiration and the canopy affects the local hydrological regime. Furthermore, the forest acts as an obstacle to rockfall and can prevent the release of snow avalanches.

4. SPARSELY VEGETATED LANDS

Sparsely vegetated lands represent areas where there is very little to no vegetation, mostly situated on steep slopes. These conditions are often related to the altitude and specific climatic circumstances. Slopes and hillsides are prone to erosion, falling rocks, debris flows, avalanches and landslides. Rapidly flowing water from heavy rainfall or melting snow can also create extreme conditions and quickly gain strength as it moves downhill.



From left to right, top to bottom:
> Continuous cover forestry, OAL Finland (OPERANDUM)
> Brush layers, French Southern Alps, France (Stokes et al. 2014)
> Pristine forests on Berlin's outskirts (Kowarik, I. 2013)
> Overview of terracing works in Santa Elena, Spain (NGI, Anders Solheim)
> Current system to protect Barèges, France (OPCC-CTP)
> View of wooden gabion terraces, Erill-la-Vall, Spain (NGI, Anders Solheim)




C3. Woodlands and forests

Strategic afforestation of plains and hillsides

Woodlands and forests are an important part of the European landscape, covering a significant portion of the continent. In mountain areas, forests are often the dominant ecosystem and play a critical role in regulating water resources, preventing soil erosion, and providing habitat for wildlife among other goods and services (Egan and Price, 2017). There are many distinct types of forests, each with their own unique characteristics and ecological roles:

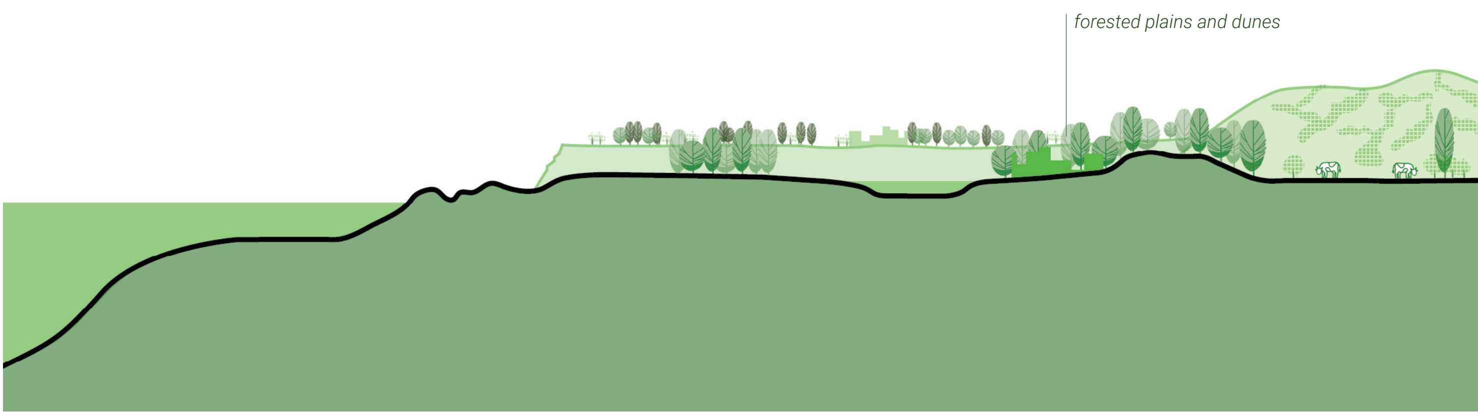
- Riparian forest: they are found along the banks of rivers and streams. They are important for maintaining water quality, as they help filter pollutants and sediment from runoff before it enters the water.
- Mid-mountain forest: they are found at intermediate elevations on mountains, typically between 1,000 and 2,500 meters above sea level. They are characterized by a mix of deciduous and evergreen trees, and can include species like oak, maple, beech, and fir.
- Mountain forest: they are found at higher elevations, typically above 2,500 meters above sea level. They are often characterized by cold temperatures, low humidity, and rocky soils, and they may be dominated by coniferous trees like spruce, pine, and fir.

Forest types can be also classified according to their slope into the following categories (EEA, 2020):

1. Lowland forest, found in areas with slopes of less than 5°.
2. Hill forest, found in areas with slopes 5 - 25°. The plant and animal diversity are slightly lower than in lowland forests.
3. Montane forest, found on the slopes of mountains in areas with slopes 25 - 45°. It is characterized by shorter trees and a sparse understory, with a lower diversity of plant and animal species than lowland and hill forests.
4. Sub-alpine forest, found in areas with slopes 45 - 60°. It is characterized by stunted trees and a minimal understory, with a very low diversity of plant and animal species.
5. Alpine tundra, found in areas with slopes above 60°. It is characterized by a complete absence of trees and a low diversity of plant and animal species, adapted to extreme cold and harsh conditions.

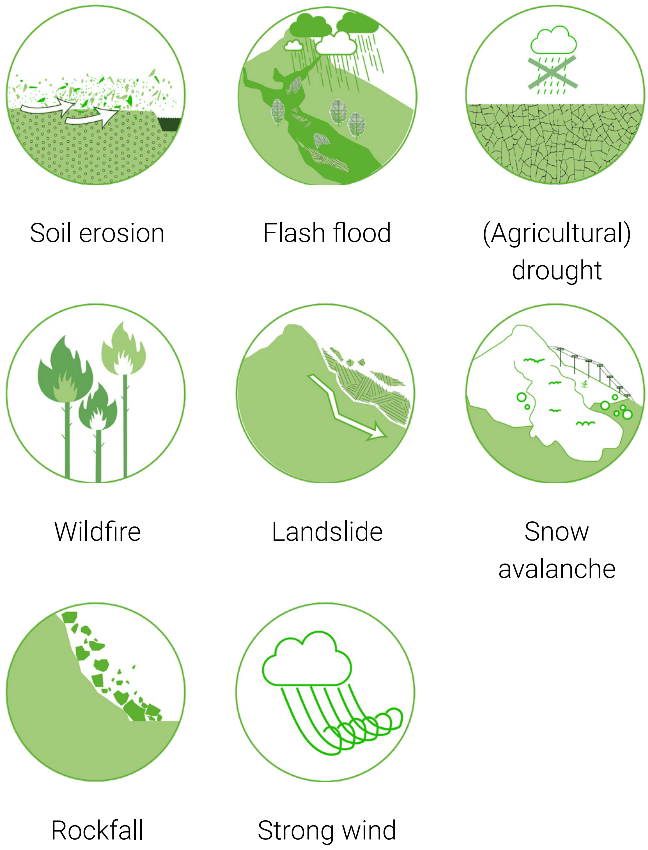
The diversity of trees in European mountain areas depends mainly on the elevation, but also on climate, and soil type of the region (Dieler 2017; EEA, 2020). The evolution of forests has been influenced by a variety of factors and drivers, including changes in land use patterns and human population dynamics, pollution and climate change (EEA, 2016). One significant factor in the evolution of forests has been the loss of traditional forest use practices and the depopulation of rural areas, especially in mountain areas. Traditional forest use practices, such as selective logging, hunting, and gathering of non-timber forest products, have shaped the structure and composition of forests for centuries. These practices create a mosaic landscape of different forest types and successional stages, which provide a range of habitats for diverse wildlife and support a variety of ecosystem services (Guadilla-Sáez et al, 2019; Chytrý et al, 2022). In addition, mosaic landscapes are more resilient to natural and climatic hazards such as fires, droughts, and heat waves (Hylander et al., 2022). However, the loss of traditional forest use practices due to changes in economic, social, and political systems has led to changes in forest structure, composition and dynamics (Orsi et al, 2020). In some cases, forests have become more homogeneous and simplified, with a lower diversity of tree species and less habitat diversity and mosaic landscape (Kulakowski et al, 2017; Thom et al, 2021) with widespread expansion of forests in much of Europe's mountainous rural areas (Amestegui et al, 2021).

Overall, the evolution of forests due to loss of traditional forest use and depopulation in rural areas has important implications for biodiversity conservation and ecosystem services.



Hazards

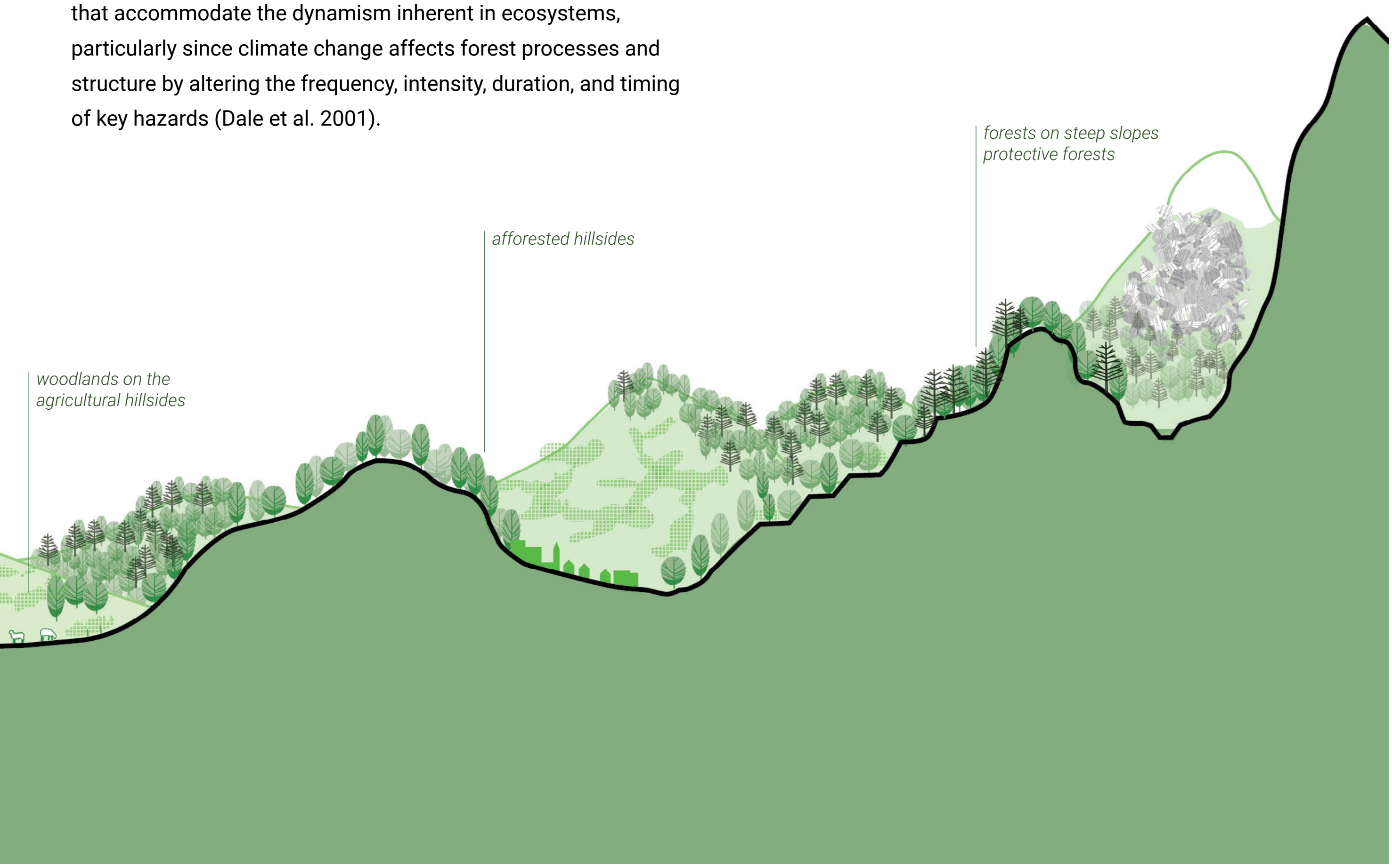
Woodlands and forests provide a wide variety of ecosystem services (ES) that benefit human society (MA 2005). Forests absorb large volumes of water, limiting soil erosion and capturing some of the heavy rain that can cause flooding and landslides. Forests also constitute a defense against natural hazards. They protect us from landslides, floods, and avalanches. The forest cover also attenuates the effects of wind.



However, forest systems worldwide are increasingly under pressure from climate change, resulting in changes to disturbance and stress regimes, including forest fires, drought, insect outbreaks, and windstorms (Allen et al. 2010; Kurz et al. 2008; Seidl et al. 2014). The impacts of climate change on European mountain forests can be summarized as follows (OPCC, 2018):

- Diversity and distribution changes of many plant communities and forest species.
- Change in forest productivity and their ability to sequester atmospheric carbon by photosynthesis.
- Changes in forests health and the possible imbalance with pathogenic agents.
- Forest fires risk and forest fire intensity increase.
- Reduction of mountain forest protective role against natural hazard.

Integrating risk management into forestry will require methods that accommodate the dynamism inherent in ecosystems, particularly since climate change affects forest processes and structure by altering the frequency, intensity, duration, and timing of key hazards (Dale et al. 2001).



A landscape synthesis

Woodlands and forests create very visible and often dense landscape structures with specific biodiversity characteristics, uses and benefits. Forested landscapes occur mostly on the hillsides as well as in the lower lying lands and can take quite different shapes, as shown in the landscape synthesis drawing on the opposite page. The different NBS that are related to afforestation and forested landscapes are illustrated and described following the four NBS approaches.

RESTORATION

Forest restoration represents an important NBS to cope with a variety of hazards, for example erosion, landslides, drought or soil erosion. By restoring forests that were formerly present, this role can again be taken up and the surrounding (built as well as unbuilt) environments can benefit from the protection that the forests offer.

PROTECTION

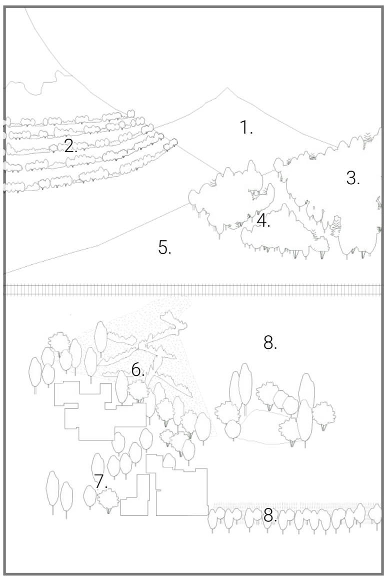
Afforestation and other natural barriers in general provide very effective protective measures. They can protect lower-lying areas from different hazards, like landslides, debris flows, snow avalanches and rockfall. Terraces and planted terraces, often reinforced with gabion walls or timber structures, can have a significant impact on the protection of downhill areas. In specific cases wooden tripods can also help to further support the slope and newly planted trees or they can specifically prevent rocks from falling further down. Apart from their technical function, these natural barriers are also adding a specific identity to the landscape and the forest structures.

CREATION

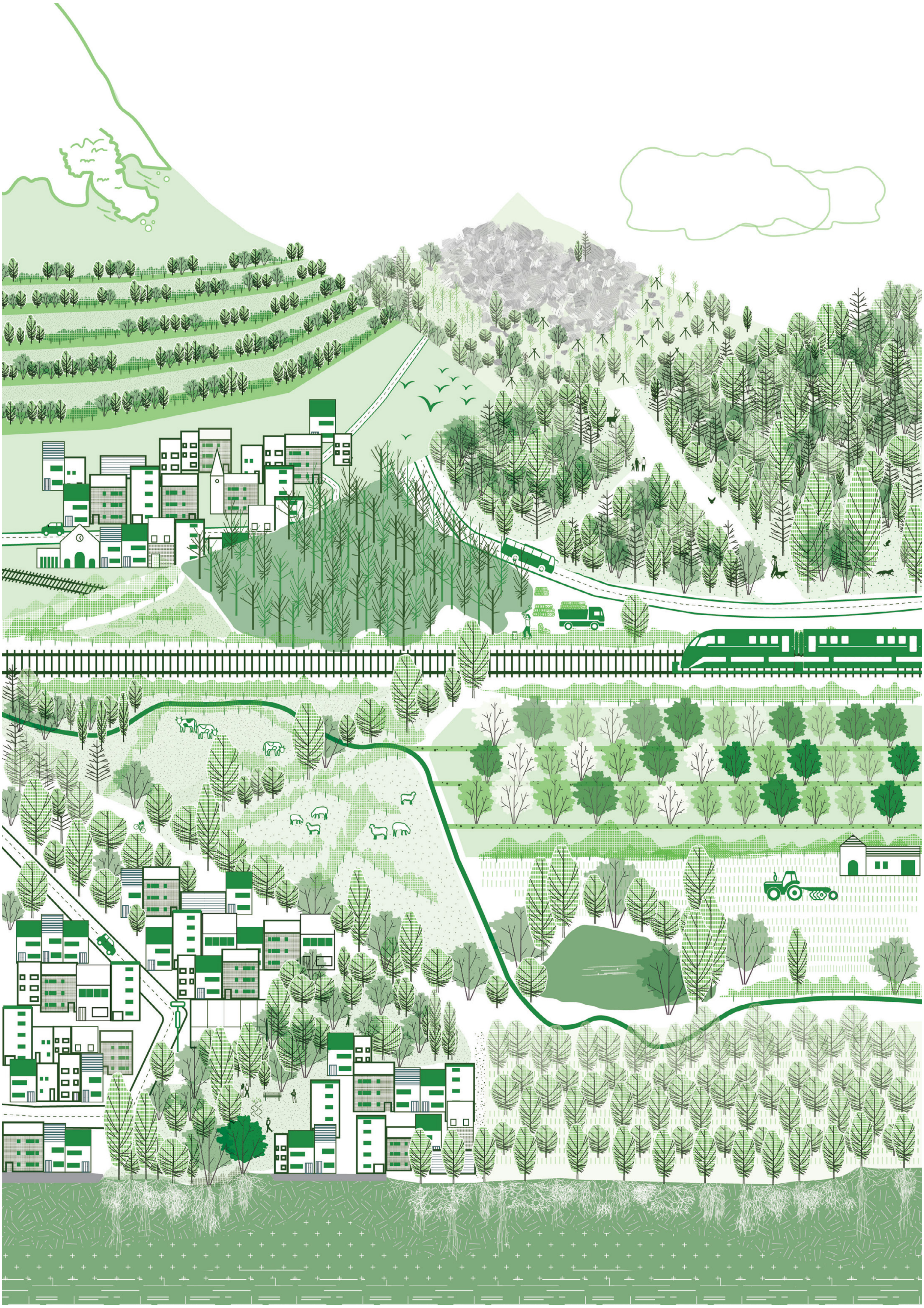
The creation of new forests and woodlands, in various forms, can diversify the landscape while adding extra functions in terms of hazard mitigation and risk reduction. The forest structures will have different configurations depending on the location and the specific conditions, On (steep) slopes, afforestation is often combined with terracing and creates a specific landscape of linear figures. The planted terraces are structures that reinforce the stability of the soil, which help to reduce the risks of landslides and snow avalanches, but also enhance biodiversity. In the plains the creation of new forests or the extension of existing forests can take various forms, ranging from urban forest parks over planted forest areas for timber production to natural forests to reinforce biodiversity corridors. One very specific type of afforestation is related to the productive landscape and can exist as a bocage structure, with rows of trees and hedges that enclose the agricultural plots and ensure additional ecosystem services like water infiltration, shadow, and habitat locations. In the more integrated concept of agroforestry, the forested landscape and the agricultural production are mixed and benefit from each other. This allows more drought-resistance, better irrigation, shadow, as well as biodiversity stimulation. Different types of agroforestry exist and each has their specificity, ranging from drought-resistant orchards over cattle - fruit production to food forests.

MANAGEMENT

Forest management is crucial in terms of longevity of these natural ecosystems. By optimizing this, ecological corridors can be encouraged throughout the territory, wildlife can flourish, and a specific management of species can be established. A well-maintained forest will offer multiple benefits for its environment on various scales. Their spatial and ecological impact is not to be underestimated.



1. Afforestation on steep slopes
2. Natural barriers and vegetated terraces
3. Forest restoration
4. Optimized forest management
5. Productive forest
6. Restoring a bocage landscape
7. Urban forest
8. Agroforestery



Functions

Woodlands and forests provide valuable ecosystem services, protecting the environment. The forest preserves water - Trees act as sponges, capable of absorbing up to six times more water than grass of equal surface area. Rain is captured by the leaves and is partially absorbed, and the rest drips to the ground where the water is filtered and purified. Forests also contribute to surface water regulation, and consequently contribute to reducing erosion, landslides and avalanches.

During the process of photosynthesis, trees absorb carbon dioxide and release oxygen improving the breathable air quality. The forests are also gigantic carbon sink, and in France alone it is estimated that trees capture as much as 70 million tons of carbon dioxide each year contributing to reducing global warming. The forest also participates in the purification of the air by filtering dust and microbial pollution from industrial activity.

Forests also contain a large proportion of the Earth's terrestrial biodiversity (Andren, 1994, Borie and Hulme, 2015, Kok et al., 2017). They provide habitats for birds, vertebrates, invertebrates, and microbes, which are impacted in different ways by current and past forest management practices. Forest management type and intensity are major drivers of structural diversity and impact biodiversity in forest ecosystems. Conservation and restoration of forest ecosystems is one of the major critical tasks for the protection of global ecosystems (Oettel et al. 2020).

Forest ecosystems, including natural forests, managed forests, agroforestry systems, and urban and peri-urban forests, can be considered as multifunctional nature-based solutions (NBS) since they contribute to the regulation of a variety of factors: such as climate regulation, carbon sequestration, air, soil, and water quality improvement, and for mitigating natural hazards, providing also recreation, spiritual enrichment and aesthetic experience, that contribute to human wellbeing (Salvatori & Pallante, 2021).

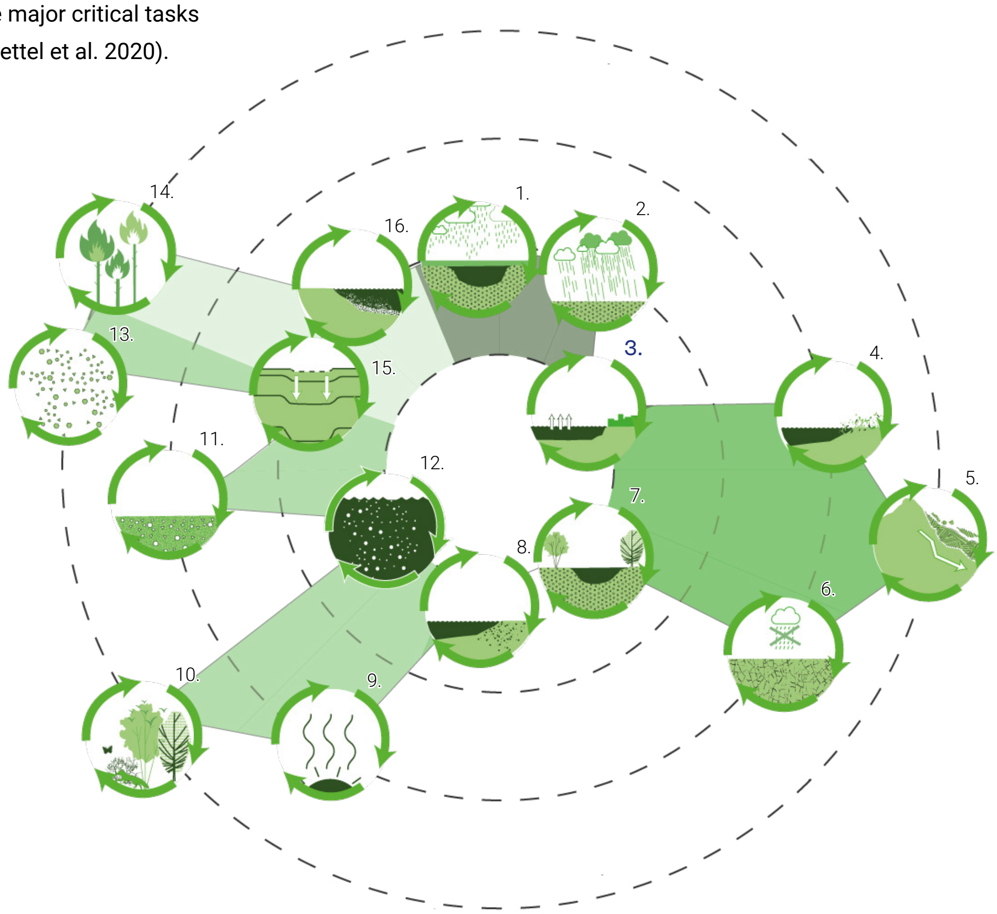
It is essential to consider the link between forest management and biodiversity in different forest ecosystems, as well as forest dynamics under the impact of climate change. Implementing NBS in woodlands and forests needs to consider these interactions and dynamics to improve the protective role the forests can play and to achieve greater impact on biodiversity.

water
1. Riverine flood regulation
2. Pluvial flood regulation
3. Coastal flood regulation

soil
4. Coastal erosion mitigation
5. Landslide mitigation
6. Drought mitigation
7. Riverbank erosion mitigation

habitat
8. Salt intrusion regulation
9. Heat stress regulation
10. Biodiversity stimulation
11. Soil pollution regulation
12. Water pollution regulation
13. Air pollution regulation

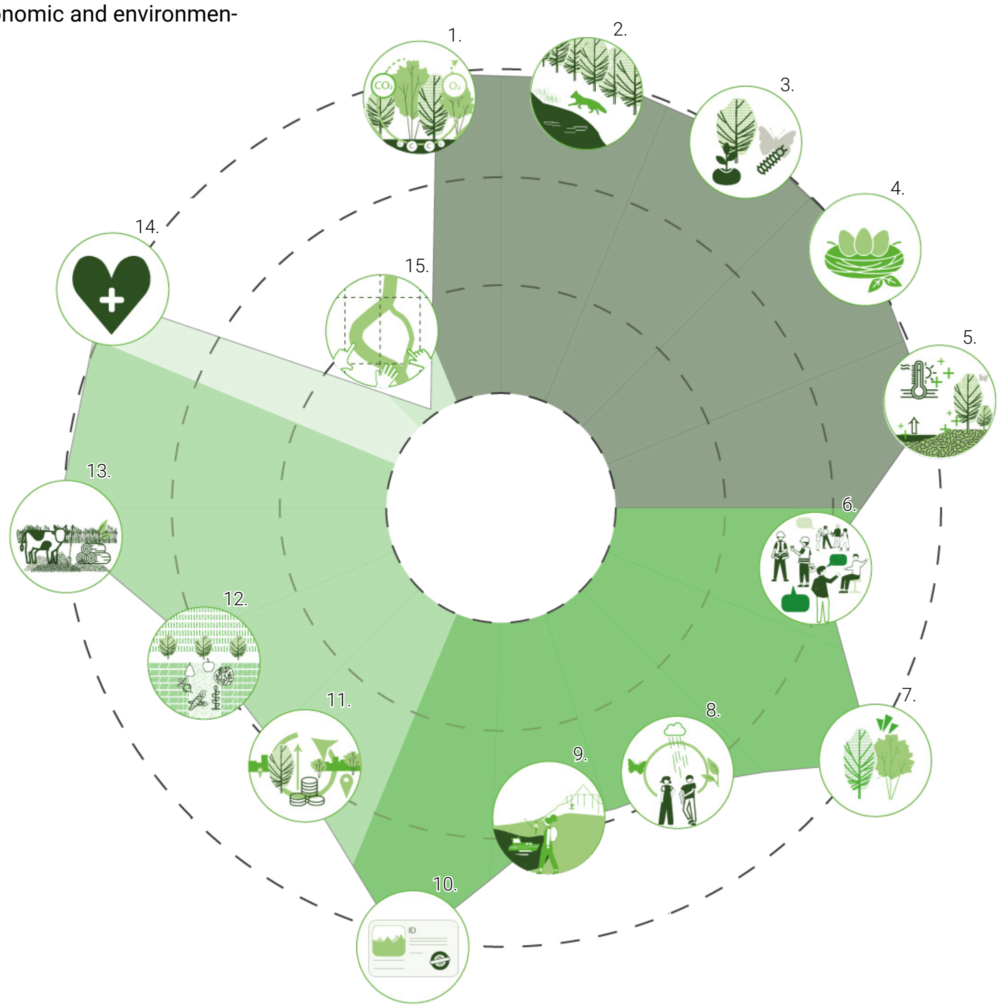
other
14. Wildfire regulation
15. Subsidence regulation
16. Sedimentation mitigation



Benefits

European mountain forests play important roles in providing various ecological, economic, and social benefits. Here are some of their key benefits (Kräuchi et al, 2000; Maroschek et al, 2015):

- Biodiversity and soil conservation: Mountain forests are home to a diverse range of plant and animal species, including many that are rare or endangered. They provide habitat, food, and shelter for a variety of wildlife and play a vital role in maintaining biodiversity.
- Watershed and natural hazards protection: Mountain forests play a crucial role in regulating water flow and quality in rivers and streams. They help to prevent soil erosion and enhance slopes stabilization, reducing the risk of landslides and floods, and filtering pollutants from runoff.
- Climate regulation and carbon sequestration: Mountain forests are important carbon sinks, helping to remove carbon dioxide from the atmosphere and store it in biomass and soil. They play a critical role in addressing climate change.
- Timber and non-timber forest products: European mountain forests provide a range of forest products, including timber, fuelwood, and non-timber products such as berries, mushrooms, and medicinal plants. Sustainable forest management practices can ensure that timber and non-timber production is balanced with ecological conservation, which is vital for maintaining a socio-economic and environmental balance in mountain areas.
- Recreation and tourism: Mountain forests are popular destinations for hiking, camping, skiing, and other outdoor activities. They offer opportunities for recreation and tourism, which can support local economies and contribute to cultural heritage.
- Cultural and spiritual values: Mountain forests are often associated with cultural and spiritual values, including traditional knowledge, beliefs, and practices. They may also have symbolic or aesthetic significance in local or national cultures.
- Human health: Forests can have a positive impact on human health by providing clean air, reducing the risk of respiratory illnesses, and promoting physical activity.



ecology

1. Carbon storage
2. Natural corridors
3. Nature development
4. Habitat protection
5. Climate resilient landscape

cultural

6. Social interaction
7. Cultural landscapes
8. Education
9. Tourism, sport and recreation
10. Landscape identity

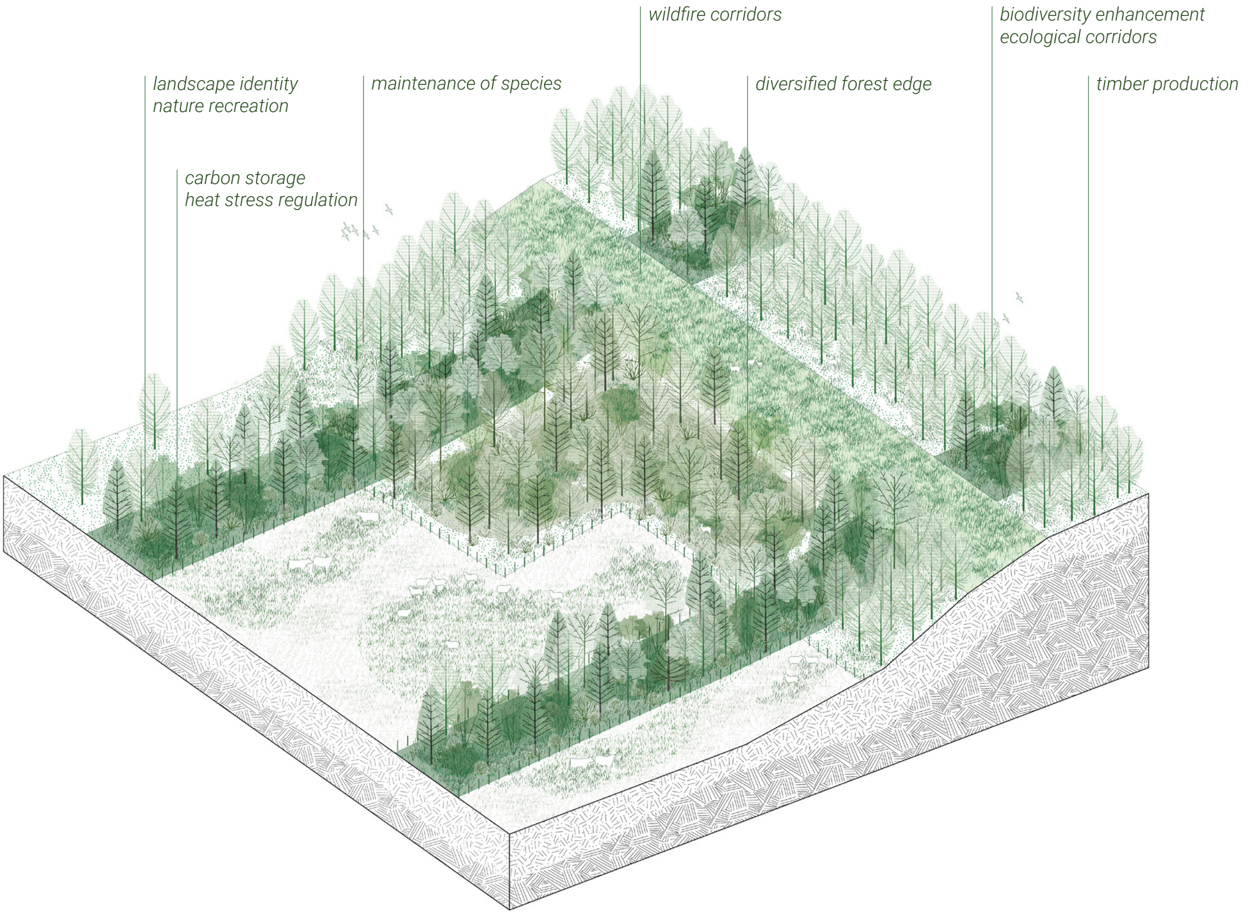
economy

11. Local jobs and green economy
12. Productive landscapes
13. Resources production

other

14. Human health
15. Integrated water management

Specific nature-based solutions



OPTIMIZED FOREST MANAGEMENT

TYPE OF INTERVENTION

M Management

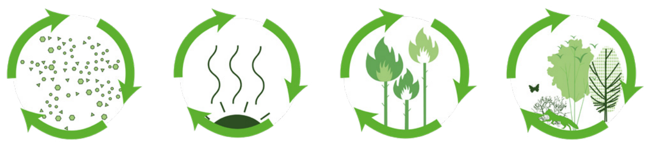
HAZARDS

Soil erosion | Drought | Strong wind | Wildfire

DESCRIPTION

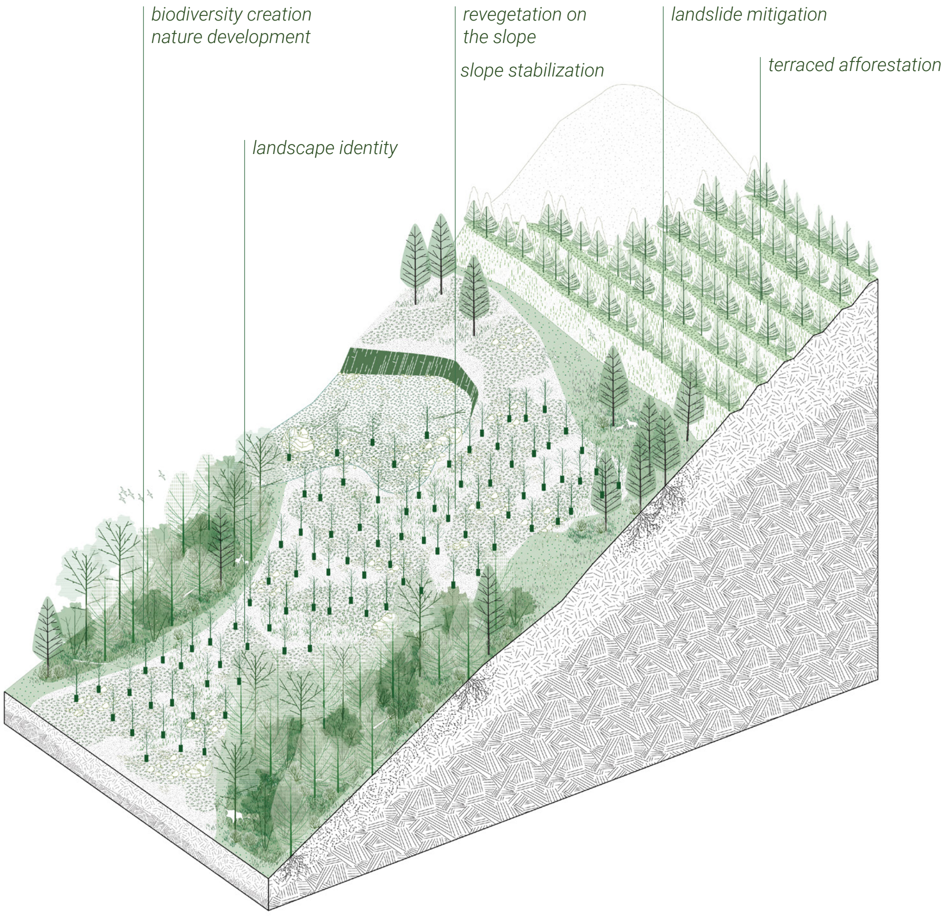
Forest management is the process of planning and implementing practices for the stewardship and use of forests to meet specific environmental, economic, social and cultural objectives. It deals with the administrative, economic, legal, social, technical and scientific aspects of managing natural and planted forests. Sustainable forest management is always aiming for a multidimensional and multipurpose approach. This will result in interdependent functions and a range of benefits. Finally, the sustainable management of a forest is always a dynamic process, evolving with the development of the ecosystem itself.

MAIN FUNCTIONS AND BENEFITS



Air pollution regulation | Heat stress regulation | Wildfire regulation | Biodiversity stimulation

Carbon storage | Human health | Tourism and recreation | Resources production



AFFORESTATION ON (STEEP) SLOPES

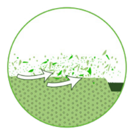
TYPE OF INTERVENTION

C Creation

HAZARDS


Avalanches


Landslides


Soil erosion


Flash flood

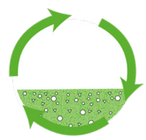
DESCRIPTION

Afforestation indicates establishing a stand of trees in an area where there was no forest before. Forests on slopes (or mountains) provide a protection function by stabilizing the slope itself and by protecting objects and infrastructure located further down the slope from natural hazards such as landslides, avalanches and rockfall. Afforestation can be implemented in various configurations (terraces, large corridors, wet forests, etc.) and should use native species with a sufficient mix to create a diverse natural environment.

MAIN FUNCTIONS AND BENEFITS


Landslide regulation


Subsidence regulation


Soil pollution regulation

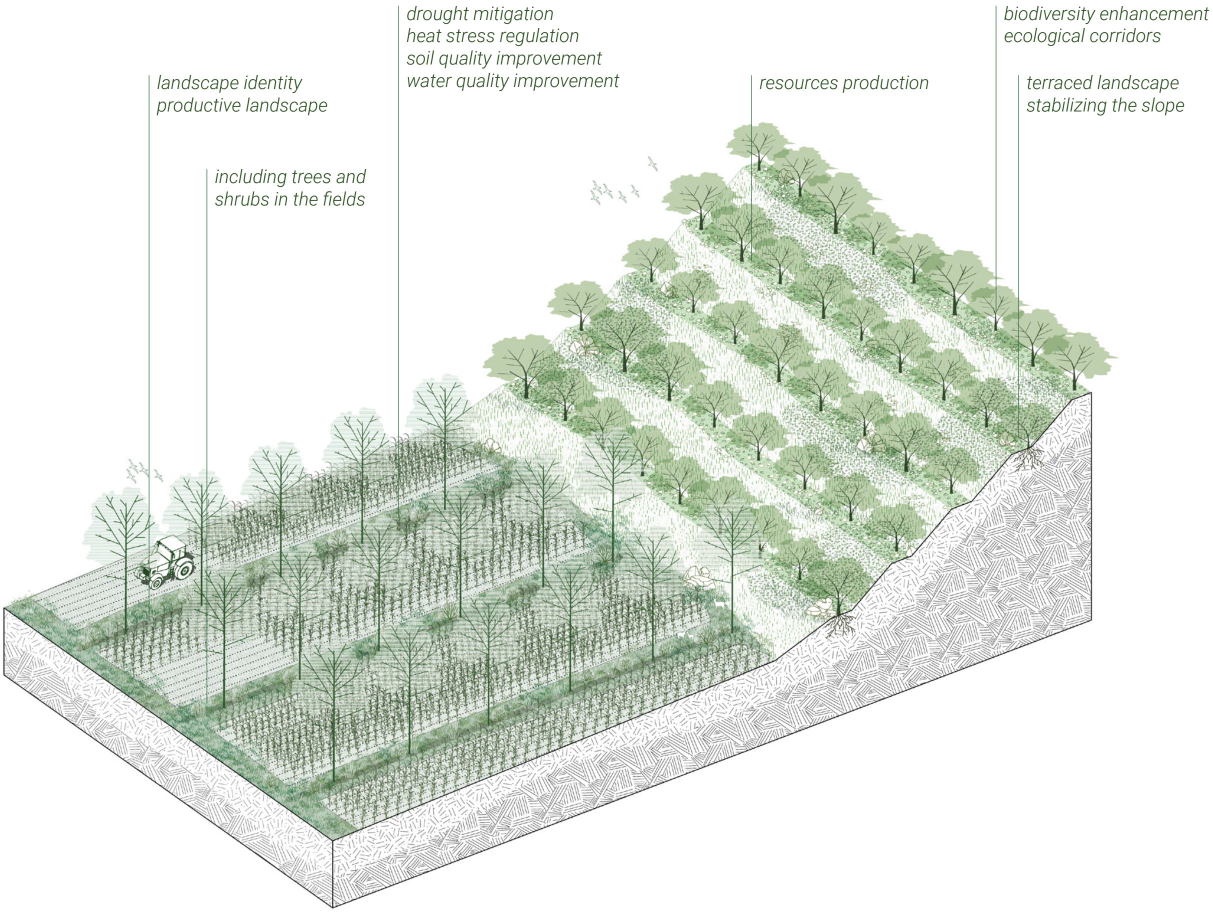

Biodiversity stimulation


Carbon storage


Education


Local jobs and economy


Landscape identity



AGROFORESTRY

TYPE OF INTERVENTION

C Creation

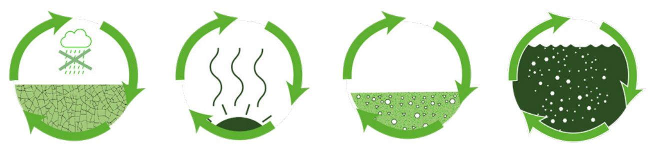
HAZARDS

Soil erosion | Agricultural drought | Flash flood | Heat stress

DESCRIPTION

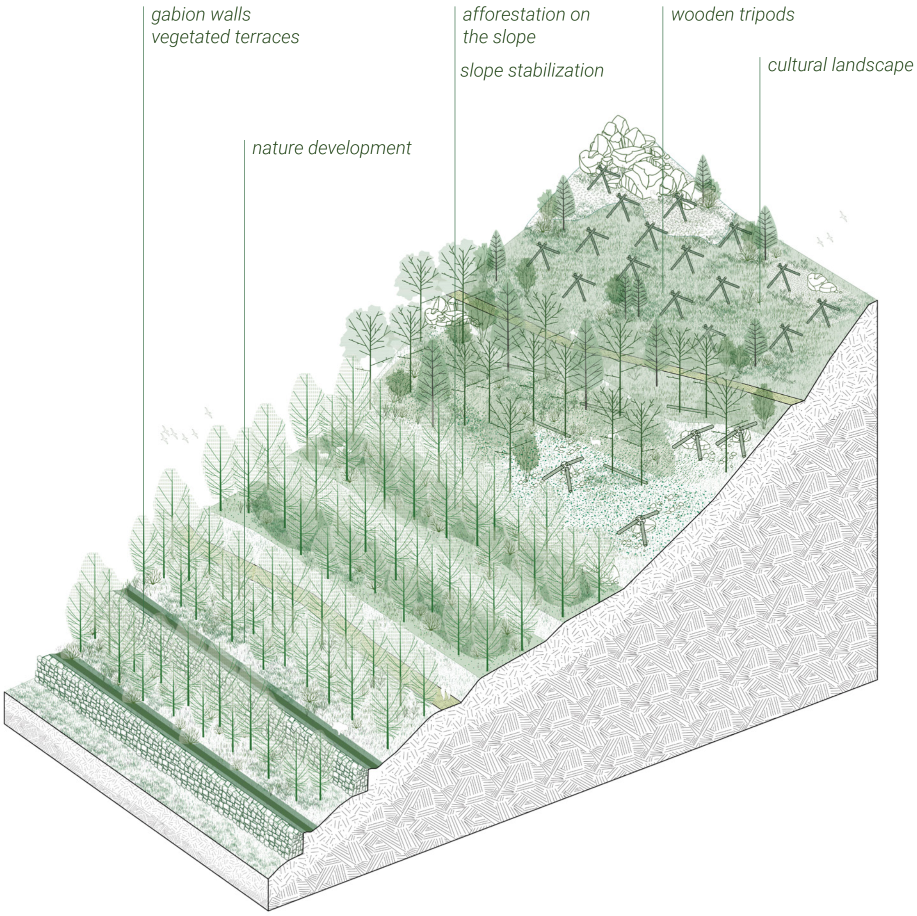
Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components. Agroforestry diversifies and enhances agricultural production and is less vulnerable to climate change because trees provide shelter to crops and reduce damage due to high spring temperature. Soil and water quality are also improved, while preventing the plots from erosion. Agroforestry systems can thus provide a wide range of economic, sociocultural, and environmental benefits.

MAIN FUNCTIONS AND BENEFITS



Drought mitigation | Heat stress regulation | Soil pollution regulation | Water pollution regulation

Local jobs and economy | Climate resilient landscape | Nature development | Resources production



NATURAL BARRIERS

TYPE OF INTERVENTION

P Protection

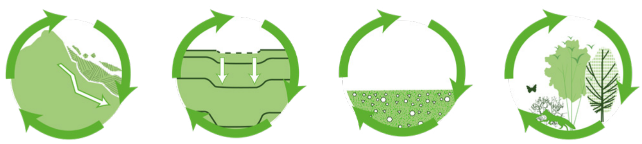
HAZARDS

Rockfall | Landslide | Snow avalanche | Debris flow

DESCRIPTION

Natural barriers represent a collection of interventions that reduce the impact of different hazards that occur mostly on sloped areas. Terracing the slope can for example reduce the flow velocity of rocks, debris, snow or soil. This effect can be reinforced by vegetating the terraces. Afforestation in general will also have a stabilizing effect on the slope and will contribute to an overall mitigation of the hazards. Specific natural structures, like wooden tripods, gabion walls or live crib walls, can be implemented to remediate against rockfall, and avalanches. The natural barriers will contribute to the cultural and educational dimensions of the landscape, while enhancing biodiversity and nature development.

MAIN FUNCTIONS AND BENEFITS



Landslide and erosion mitigation | Subsidence regulation | Soil pollution regulation | Biodiversity stimulation

Cultural landscape | Education | Nature development | Landscape identity

NBS case studies

3.1

Tree planting counters landslides and erosion in Kazbegi

Kazbegi, Georgia; 2017 - 2018

“SEMA” has carried out geo-ecological and hydro-meteorological assessment of the affected territories and has reinforced the most vulnerable slopes against erosion and landslides with rock-filled gabions and trees. Over 1000 trees were planted on the mountain slopes near the village Karkucha in Kazbegi municipality to restore degraded land and reduce the risks associated with recurrent landslides. In addition to its immediate benefits, this initiative will contribute to restoring the natural forest in the selected areas and raising environmental awareness among the municipality residents.

Tree planting (Norsk Landbruks- og matdepartementet)

Applied nature-based solutions:

- Restore the forest
- Afforestation on steep slopes

Hazard: erosion, landslides

Main stakeholders:

- The Surface Engineering and Molecular Assemblies lab (SEMA)

Links: SEMA

3.2

Continuous cover forest to reduce eutrophication near Lake Puruvesi

Vehka-Kuonanjärvi subcatchment, Finland; 2020 - ongoing

Increased loads of suspended solids derived from forestry activities in the Lake Puruvesi catchment have caused eutrophication, especially in the Lake Vehka-Kuonanjärvi subcatchment whose ecological status has changed from excellent to moderate during past decades threatening recreation, fishing, and biodiversity of the area. The OPERANDUM project has implemented continuous cover forestry, which is a forest management regime/strategy without clear-cutting. Under this regime, less nutrient and sediment leaching occurs because the ground is continuously covered with vegetation.

Landscape of the OAL Finland (OPERANDUM)

Applied nature-based solutions:

- Planting a continuous cover forest
- Restore riparian vegetation buffer zones
- Restore natural flooding areas and construct wetlands
- Apply natural levees and sustainable dams

Hazard: eutrophication, soil erosion

Main stakeholders:

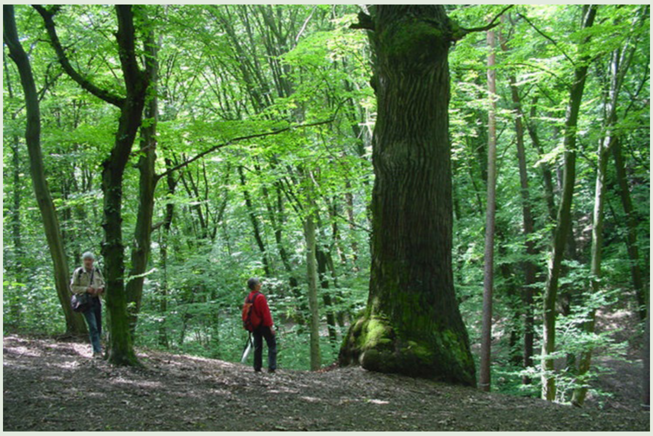
- Natural Resources Institute (Luke), Finnish Meteorological Insitute (FMI), Pro Puruvesi, European Commission, Finnish Forest Centre, South Savonia-ELYcentre
- Freshabit
- Forest owner's association

Links: OPERANDUM OAL Finland, OPERANDUM Lake Puruvesi

3.3
Reforestation using a pristine mix of tree species for flood and drought management

Berlin, Germany; 2012 - 2020

More than two million native deciduous trees were planted in the Berlin forests between 2012 and 2020 creating 1,000 hectares of new mixed forest. Oaks, lindens, elms, beeches, and other species are planted between old pine stands resulting in a pristine mix of tree species that enhances the forest's capacity to store water, replenishes groundwater reserves, and decreases levels of flood peaks. By the end of this century, all of Berlin's forests will have been converted into stable mixed forests.



Pristine forests on Berlin's outskirts (Kowarik, I. 2013)

Applied nature-based solutions:

- Restore the forest
- Apply extensive afforestation
- Optimize the forest management

Hazard: Flash Flood, Meteorological Drought

Main stakeholders:

- City of Berlin
- Berliner Forsten
- Tourists and local citizens

Links: OPERANDUM, Oppla, Berlin

3.4
Urban carbon sink as urban forest

Valladolid, Spain; 2022

The Urban Carbon Sink (UCS) is conceived as an urban forest in which species have been selected mainly for their ability to fix carbon. It is integrated into VAc11- Floodable Park and will consist in the installation of an urban woodland (initially planned planting 1,500 trees in 40,000 m² with appropriate species adapted to temporary flood conditions and with high capacity of carbon sequestration (e.g. Fraxinus spp., Betula spp., Salix spp., Populus spp.). The trees of this forest will be allocated in specific arboreal series. This area will be a new urban carbon sink and will form a new urban ecosystem. At the same time, this woodland will provide biomass for energy use with social and economic purposes.

Urban Carbon Sink, Valladolid (URBAN GreenUP, Valladolid City Council)

Hazard: air pollution, floods

Main stakeholders:

- Valladolid Municipality
- Universities
- NGOs
- Local citizens

Applied nature-based solutions:

- Carbon storage through forestry
- Water management with a floodable park
- Biomass production
- Forest management

Links: URBAN GreenUp Solutions Valladolid

Guidelines

SCALE AND IMPACT

NBS in woodlands and forests can be implemented at both small and large scale. The scale of work must be assessed and adapted to cope with a range of ecological, institutional and socio-cultural challenges.

- Large-scale reforestation process can represent a challenge in terms of forest management and planning. Afforestation needs to ensure the need for diversifying the stands not only by increasing species richness (Carreras, 2006; Prévosto et al., 2011), but also in terms of stand age to facilitate a gradual and properly planned regeneration process.
- Agroforestry can be applied at a range of scales to focus on trees in agricultural landscapes, or on a set of agricultural practices comprising tree species, their management and interaction with other components of the farm or forest systems within which they are embedded.
- Natural barriers are effective when implemented at a larger scale, for example live check dams implemented along the entire length of gullies, or living snow fences can cover infrastructure over long distances.

The impact scale can be larger than the NBS scale, as they interact with the surrounding environment, bringing additional benefits to both the area of intervention and nearby areas.

ECONOMIC COST

According to the Nature-Based Infrastructure Global Resource Centre, Nature-based infrastructure (NBI) costs around 50% less than equivalent built infrastructure while delivering the same—or better—outcomes. NBI also tends to be cheaper to maintain and more resilient to climate change. NBI in forests also brings environmental benefits: reducing air pollution and storing carbon dioxide. A major risk in the Alps are gravitational hazards (such as rockfalls) and they constitute a major risk for critical infrastructures. Existing protective structures can be augmented by protective forests as an NBS, providing a likely cost savings and reducing environmental impacts. Recent research applied a Replacement Cost approach that allows measuring the effectiveness of the protection, the need for protection and defining a harmonized method for the design of the defensive structures. The application of this model to a case study in the Italian Alps shows the forest has a relevant protective effect able to fulfil the stakeholders' needs, with a value of 30.440 €/ha, equal to 950 €/ha per year, within the 25-year timespan considered (Accastello et al, 2019). Moreover, recent monetary evaluations confirm that active management of protection forests can represent a sound investment to be integrated in local risk management strategies.

ENVIRONMENTAL CONDITIONS

A number of NBS can help protect and restore forests under different environmental conditions:

- Agroforestry is a land use system that involves growing trees together with crops or livestock. It can be used to restore degraded lands and improve soil fertility, while providing food and income.
- Forest restoration involves planting trees on degraded or deforested lands to create new forest ecosystems. This can help to reduce soil erosion, increase biodiversity and sequester carbon.
- Silvopasture involves integrating trees with pasturelands to provide shade for livestock and improve soil fertility. This can help to reduce the environmental impact of livestock farming while providing a source of income.
- Payment for ecosystem services (PES) is a mechanism for incentivizing landowners to conserve and restore forests by paying them for the ecosystem services they provide carbon sequestration, water purification, as well as biodiversity conservation.
- Sustainable forest management involves managing forests in a way that balances economic, social and environmental objectives. This can include measures such as selective logging, forest certification, and community-based forest management.

The feasibility of these solutions will depend on various factors, including the local environmental conditions, the availability of resources and expertise, and the social and economic context.

TECHNICAL CONDITIONS

Geomorphological and climatological factors are key elements to be taken care of when implementing NBS in woodlands and forests (e.g. soil type, climate conditions, altitude, and water availability). Selecting adapted trees species is also essential for succeeding in the NBS implementation. Natural local resources and local companies should also be prioritized for the implementation process.

Several factors will help ensure good NBS design and implementation, including: obtaining relevant documentation of the area (historical register of adverse events), having free access to key data (geological, land use, meteorological) and conducting risk modelling. It is also important that all this information is available and well known among the main stakeholders.

These NBS also require proper and adequate management during implementation but also after the work is completed. Responsibility may need to be shared between organizations. A previous planning and coordination process is required to ensure a satisfactory distribution and understanding of the involved entities' roles and responsibilities. This governance aspect must be considered, ensuring that stakeholders' individual and collective interests are discussed and met. Additionally, specific policy, legal and liability aspects should be addressed.

SPECIFIC CHALLENGES

Implementing NBS in woodlands and forests is contingent on good forest health, however this is threatened by land use, climate change and other weather events. Urban expansion and agriculture intensification is imposing an extensive degradation in several ecosystems, increasing human vulnerability to climate change-related events (Kalantari et al. 2023).

Other challenges have to do with the ownership and management of the forests themselves, depending on whether they are state-owned or private, and how responsibility for their administration and maintenance is shared.

NBS in woodlands and forests may require customization to adapt the design and the implementation to the topography, type of soil, biodiversity gain, hazard, or other factors. The design should also consider limited maintenance needs and ideally optimize natural evolution without external supporting activity. For example, the construction process of an NBS might be adapted to allow a high degree of technicality (vertical works) or to incorporate manual work to avoiding construction activities causing loss of soil or impacting biodiversity.

C4. Sparsely vegetated lands

Modifying the slope with natural barriers

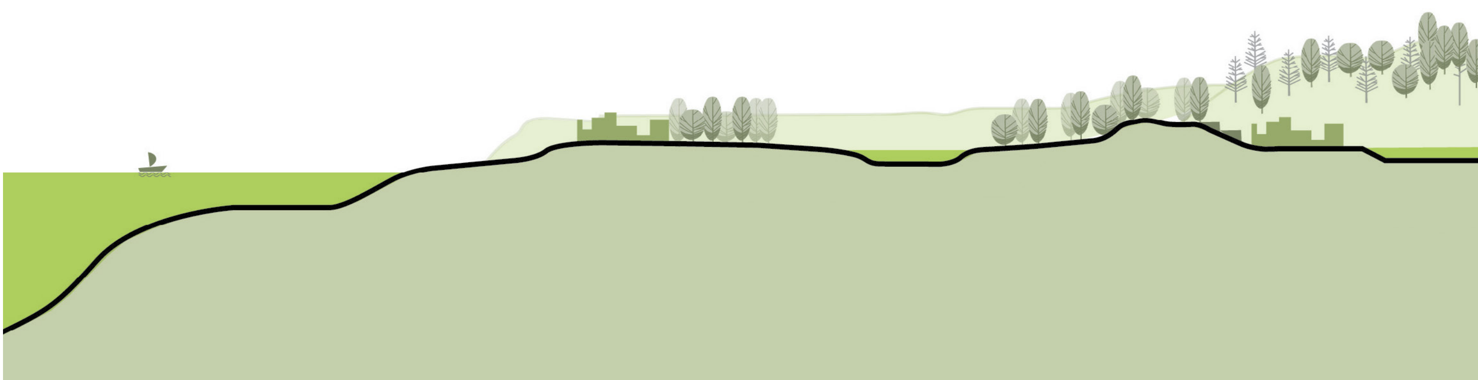
Sparsely vegetated lands are characterized by treeless terrestrial ecosystems, where the absence of trees most often is typically not a result of human influence (e.g. steppes, tundra, lichen heath, rocky outcrops, and scattered high-altitude vegetation). These lands encompass a diverse array of ecosystem types and are found in locations ranging from alpine regions to coastal dunes. They occur throughout Europe, and they are shaped by geological or climatological processes. About 1.5% of the total EU land area is covered by sparsely vegetated land. These landscapes and habitats are important for biodiversity and provide many services, also appreciated for leisure and tourism.

However, sparsely vegetated lands are threatened by habitat conversion. According to JRC (2020) land take, due to the urban development and other land use changes, shows a significant long-term negative trend with a change rate of -45.6% per decade. In the period 2000-2012, sprawl of mines and quarries and construction sites are the most impacting factors.

Although many of the ecosystem typologies that fall within sparsely vegetated lands are widespread, this chapter focuses on those mountain areas where there is little to no vegetation on steep slopes. Ecosystem types above the climatic tree line often encompass large, interconnected areas. However, distinct ecosystems can also be found in smaller areas distributed in a mosaic pattern.

Sparsely vegetated lands in mountain ecosystems are characterized by harsh environmental conditions. These include often long-lasting snow cover, short growing seasons and topographically related disturbances such as avalanches, rockfall or landslides. A common characteristic is that they do not include established forests, either due to shallow soil cover, to climatic factors (primarily temperature), or to disturbance (land use). Mountain ecosystems and inhabiting animal and plant species are generally well adapted to these conditions. However, they may react sensitively to changes of climate, land-use and other stressors. In particular, climate change is causing the tree line to shift to higher elevations, which will likely have a significant impact on these ecosystems.

Main legal instruments that share the objective to maintain or enhance the sustainable use of ecosystems in these areas include the Birds and Habitats Directives, EU Biodiversity Strategies to 2020 and to 2030, and the Invasive Alien Species Regulation.



Hazards

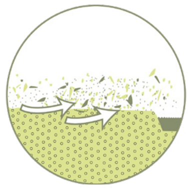
Sparsely vegetated lands in mountainous areas with little or no vegetation are prone to specific hazards including landslides and avalanches, debris flows, rockfall and erosion.

Climate change, in combination with land use changes, deforestation, and overgrazing, may affect the occurrence of landslides, as well as snow avalanches.

Heavy rainfall can generate rapid extreme floods, with or without sediments (flash floods/debris flows), within a short period, causing devastating damages. Under such events, debris flows are channelized into gullies and may have large run-out distances. Conversely, when water volumes are low and the topography is such that no preferential water drainage is available, debris flows can be unchannelized, resulting in a more widespread distribution of material In both cases, bed entrainment during propagation can increase the final volume of debris reaching the valley.

The likelihood of rockfalls is increased by weathering, erosion, and human activities. Rockfalls may be more localized to the single rock/cliff scale and may have shorter run-out distances.

At high altitudes rising temperatures are causing glaciers to melt, leading to increased water flow, which in turn accelerates the erosion of sediments and rocks accumulating in downstream ecosystems and thus affecting water quality and disrupting aquatic habitats.



Soil erosion

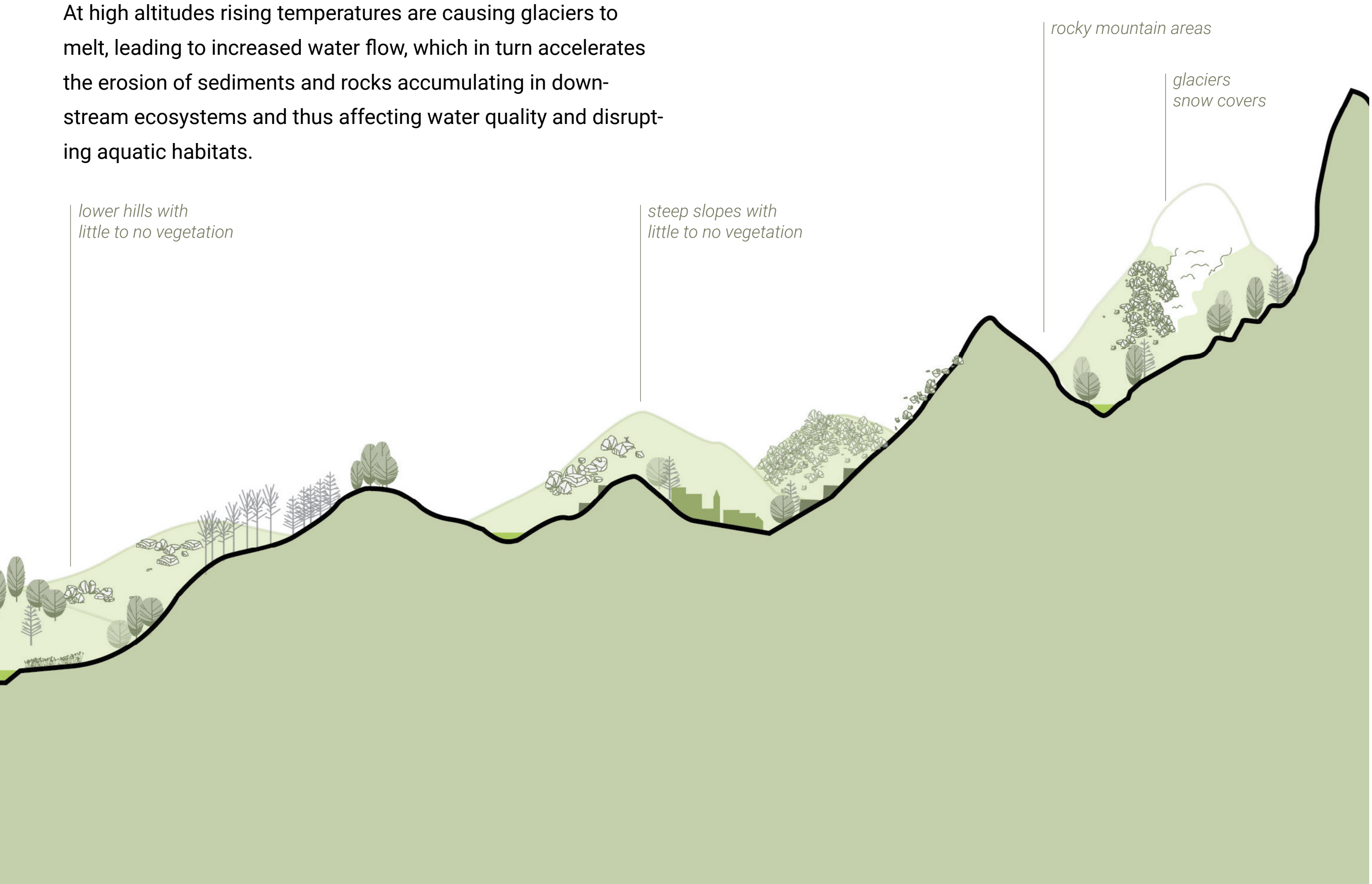
Flash flood

Landslide

Snow avalanche

Rockfall

Debris flow



A landscape synthesis

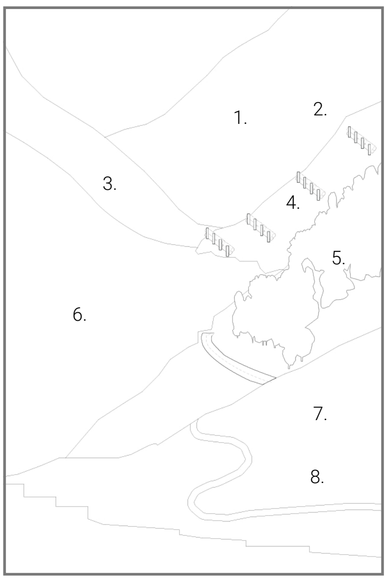
Sparsely vegetated lands in alpine regions can to a large degree be defined by the hazards which are present and impact the landscape. Therefore, NBS that are implemented to reduce the risk of these hazards often reform the topography and restructure the slopes. Numerous NBS can be applied, each specifically focusing on certain hazards and typical slope conditions. The landscape synthesis on the opposite page illustrates how these NBS can be integrated in the mountain areas. They are described following the four NBS approaches below.

RESTORATION
In some high-mountain areas the lack of vegetation can be due to the influence of human activities or extreme conditions such as drought or forest fires, which severely affect the natural biodiversity and the landscape. Restoration of the vegetation is a strategic NBS in these areas, as it can improve soil strength and permeability, and therefore reduces erosion over time. In locations that are difficult to reach or ecologically vulnerable, the (re)planting requires a specific approach such as the use of fungi or microbe-assisted revegetation or hydro-seeding. In the more accessible and less steep areas, different types of vegetation such as hedges, bushes and appropriate tree species can restructure the landscape.

PROTECTION
Slopes can also be reinforced using a variety of wooden structures such as gravity walls built from tree trunks to prevent erosion, or vegetated wooden gabions whose porous structures can trap debris flows and sediment during intense runoff. Vegetation is often planted within and between the different wooden structures, promoting biodiversity and assuring a stronger anchoring for the structures themselves. Additionally, the wooden structures can also be used to protect the plants until they have a stabilizing effect. Other types of local protective measures include the installation of natural barriers like walls constructed out of natural materials which can provide protection from rockfall. Other examples include living snow fences that can offer a shelter from avalanches and vegetated live gully breaks that can reduce flow velocities of rainwater and prevent torrential flooding. When well-integrated, these NBS can become an intrinsic part of the mountainous landscape structure and reinforce natural protection against hazards.

CREATION
Larger-scale interventions in the landscape can also be a strategy to stabilize the soil. For example, terraces can be used to transform a (steep) slope into a series of stepped structures and therefore drastically change the landscape. These methods have been used historically for agricultural purposes, creating flat spaces for cultivation in areas of higher elevation and abundant rainfall. Today, the technique is also used for various other purposes such as leveling of building land or infrastructure projects. In the case of risk management, terraces are mainly used for reducing soil erosion, improved management of runoff surfaces across the slope and slope (re)vegetation. A variation of terraces includes drainage trenches where excavated ditches are filled with natural materials such as willow twigs. Drainage contributes to slope stability by draining surface and groundwater and retaining eroded material and debris. Vegetation can also be planted in stages by excavating layers and filling them with living materials such as cut branches, rooted plants, and soil material. Usually these are linear structures, which will further strengthen the soil through the vegetation. Interventions like live smiles can hold loose soil on the slope and protect plant roots during heavy storms. These NBS all have a significant visual impact on the landscape and reinforce the coherence of a natural, yet resilient mountainous environment.

MANAGEMENT
Continued human intervention may be necessary to manage these ecosystems and to sustain conservation activities, as these continue to face pressures from habitat conversion, fires, eutrophication, agriculture and tourism. Governmental policy such as the Habitats Directive, Natura 2000 network and nationally designated conservation areas contribute to long-term management and protection.



1. Natural barriers
2. Microbe-assisted revegetation
3. Terracing
4. Wooden constructions
5. Afforestation
6. Restoring landslide scars through vegetation
7. Vegetation layering
8. Stabilizing the slope

Functions

NBS in sparsely vegetated mountainous areas provide many functions, with the two key functions being the reduction of risks from hazards typical for steep slopes (e.g., landslides, avalanches, rockfall and debris flow) and the enhancement of biodiversity.

Terracing can influence large areas or even an entire catchment. This technique has been used for centuries in the agricultural sector and has also proven to be a viable NBS, functioning to stabilize slopes, control erosion and conserve soil and water. Since terracing reduces the risk of landslides, this technique also functions to protect biodiversity. When a landslide occurs, the ecological status of the affected areas (source, run out and deposition) is severely damaged. It is therefore good practice to intervene in landslide prone areas, both to stabilize potential remaining unstable zones and to reduce the probability of sediment runoff due to precipitation. The long-term effect of terracing with planted vegetations is an almost invisible mountain slope, where local vegetation thrives and provides provisioning, regulating, and supporting ecosystem services.

Living snow fences consisting of lines of trees to protect railways or roads can function as habitat corridors for birds or wild animals, as well as natural infrastructure that links fragmented habitats, especially when implemented over long distances.

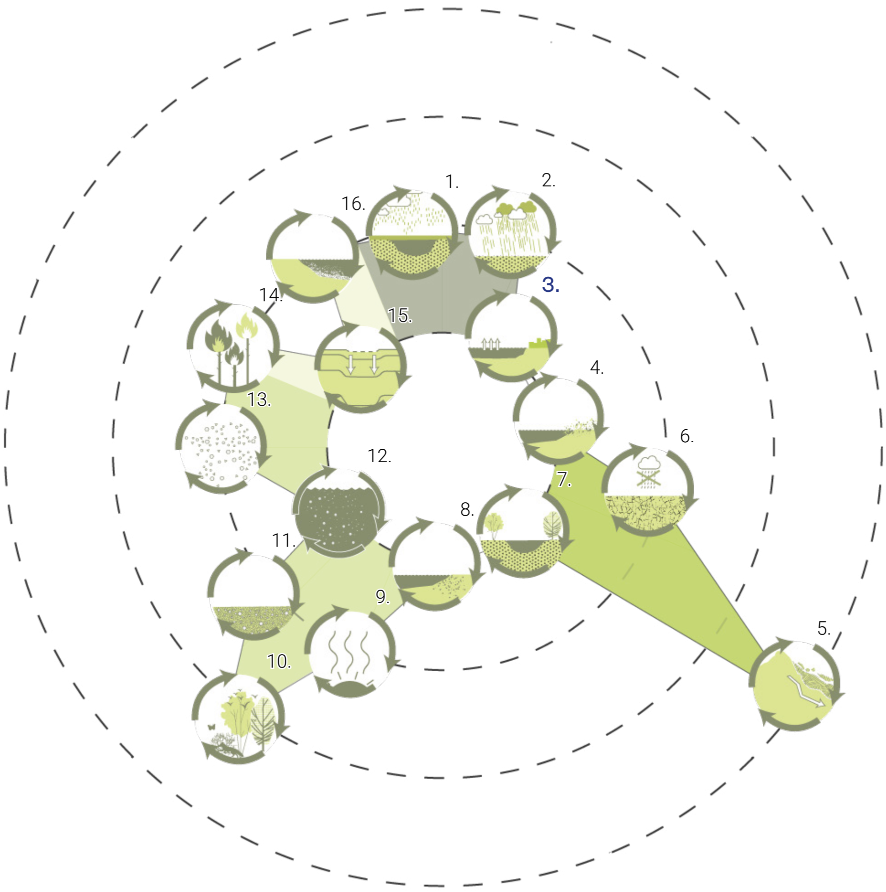
Further to these NBS interventions, microbe assisted revegetation in sparsely vegetated steep slopes can function to boost the vegetation growth and modify soil behavior. For example, microbially induced calcite precipitation and biological exudates (such as vegetation mucilage or biopolymers) can change both soil strength and permeability. Fungal activity can also improve erosion resistance and alter the rheology of the soil, as shown by preliminary results from pioneering research. Microbiota can also have beneficial effects on plant traits that can minimize erosion.

water
1. Riverine flood regulation
2. Pluvial flood regulation
3. Coastal flood regulation

soil
4. Coastal erosion mitigation
5. Landslide mitigation
6. Drought mitigation
7. Riverbank erosion mitigation

habitat
8. Salt intrusion regulation
9. Heat stress regulation
10. Biodiversity stimulation
11. Soil pollution regulation
12. Water pollution regulation
13. Air pollution regulation

other
14. Wildfire regulation
15. Subsidence regulation
16. Sedimentation mitigation



Benefits

The greatest benefit of NBS in sparsely vegetated lands in mountain areas is to build a climate resilient landscape, which has been described in detail in the previous section as a main function of NBS in these areas. Further to this, NBS in these ecosystems are crucial for preserving and protecting important habitats for species that have adapted or survived in these conditions. In particular, the use of local natural materials (e.g., local rocks, timber) to create structures can both improve soil quality and create environments suitable for hosting micro-ecosystems of wild animals and insects. NBS that employ plant-based or bio-based soil improvement methods can also improve microbiological biodiversity and nutrient availability in the rhizosphere, which in turn enhances and protects flora and fauna biodiversity. This creates nests for wild species and attracts pollinators, contributing to a healthier and more balanced ecosystem. In addition to enhancing biodiversity, NBS in these ecosystems may also contribute to carbon sequestration and thus potentially mitigate climate change.

Integrating NBS in these areas also provides cultural benefits and fosters landscape identity. Reshaping slopes with terracing can contribute to effective land management in culturally significant areas, supporting activities like grazing and hunting. Additionally, many NBS can improve services appreciated for leisure and tourism, especially for sports such as skiing, climbing, and via ferrata. Skiing facilities, resorts, and trekking areas are examples of tourism infrastructure in these ecosystems. By exploring NBS that integrate with these infrastructures, we can ensure a balance between societal needs and ecosystem protection.

Social benefits are substantial, including job creation and economic enhancement. Integrating NBS into the existing ecosystem, particularly through hybrid solutions, can provide a wide range of benefits and added value to society and the economy by utilizing natural materials and resources. This integration supports tourism and sports, fosters community engagement further benefiting human well-being.

ecology

1. Carbon storage
2. Natural corridors
3. Nature development
4. Habitat protection
5. Climate resilient landscape

cultural

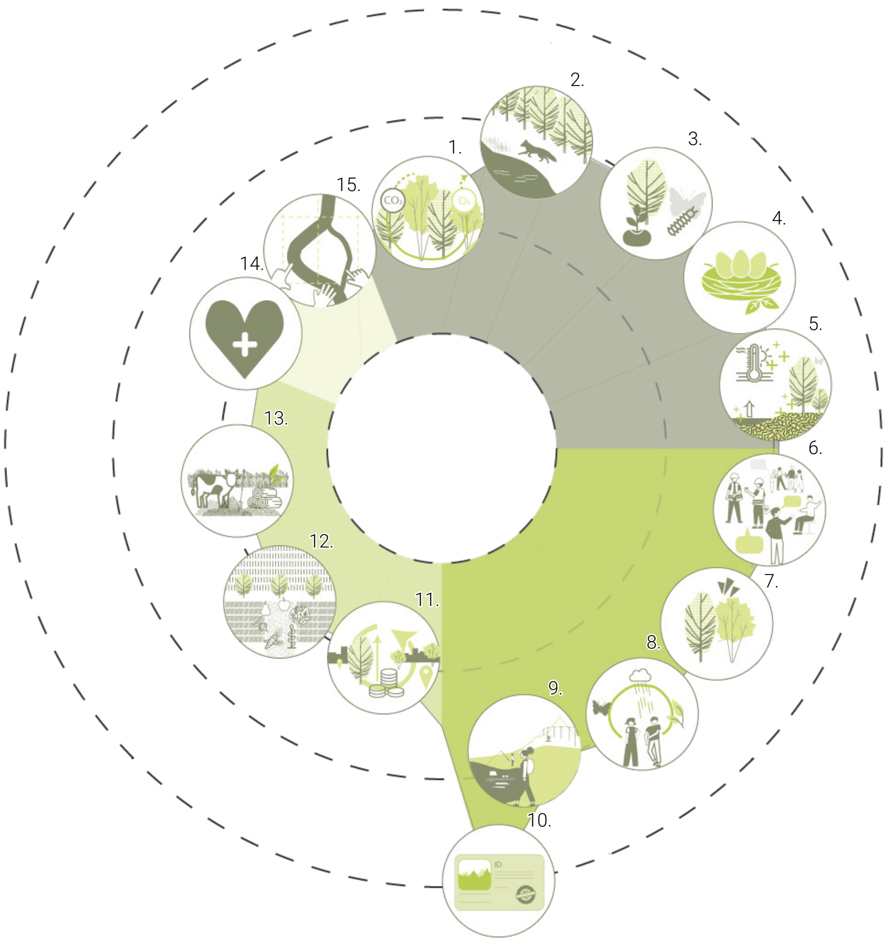
6. Social interaction
7. Cultural landscapes
8. Education
9. Tourism, sport and recreation
10. Landscape identity

economy

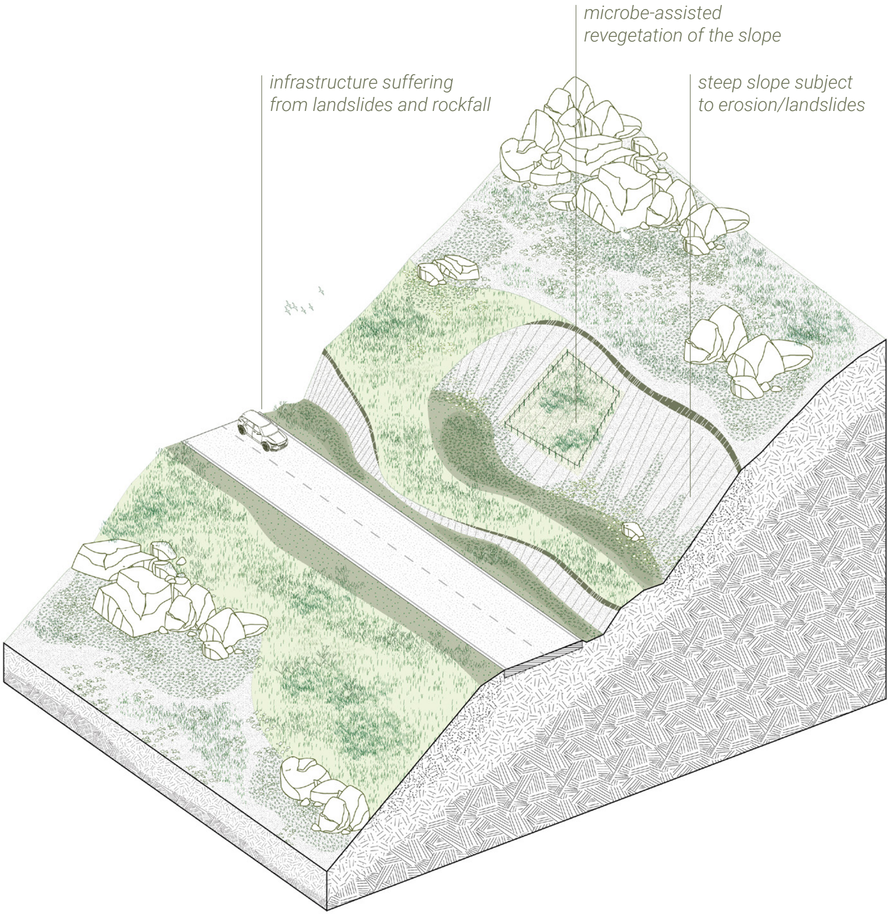
11. Local jobs and green economy
12. Productive landscapes
13. Resources production

other

14. Human health
15. Integrated water management



Specific nature-based solutions

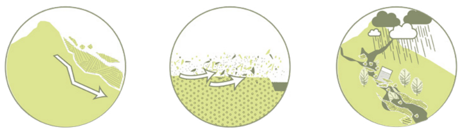


MICROBE-ASSISTED REVEGETATION

TYPE OF INTERVENTION

R Restoration

HAZARDS

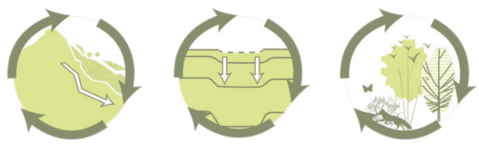


Landslide | Soil erosion | Debris flow

DESCRIPTION

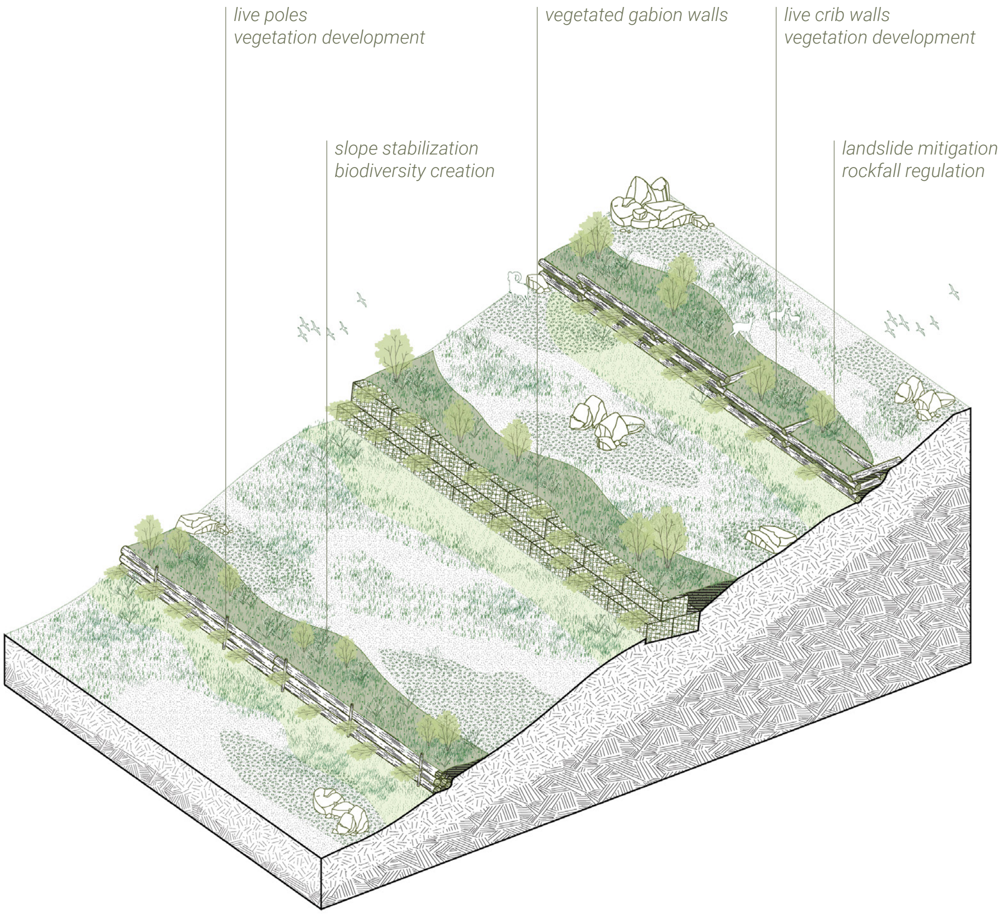
In landscapes affected by landslides and erosion, the soil can be further stabilized through microbe-assisted revegetation in spaces where little to no vegetation is remaining. The process of isolating and inoculating of site-specific grains can help restore the ecosystem in a rapid and cost-effective way. The growth-promoting effects of bacteria to enhance plant traits that most strongly contribute to slope stability, are the foundation of this NBS. Revegetation can be easily executed through hydro-seeding or spray-cover grasses.

MAIN FUNCTIONS AND BENEFITS



Landslide and erosion mitigation | Subsidence regulation | Biodiversity stimulation

Education | Climate resilient landscape | Nature development



WOODEN CONSTRUCTIONS

TYPE OF INTERVENTION

P Protection

C Creation

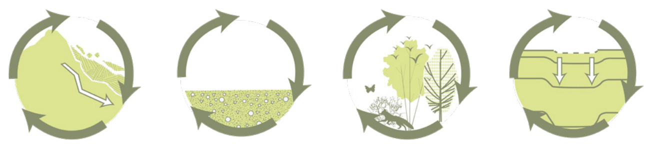
HAZARDS

Rockfall | Landslide | Snow avalanche | Debris flow

DESCRIPTION

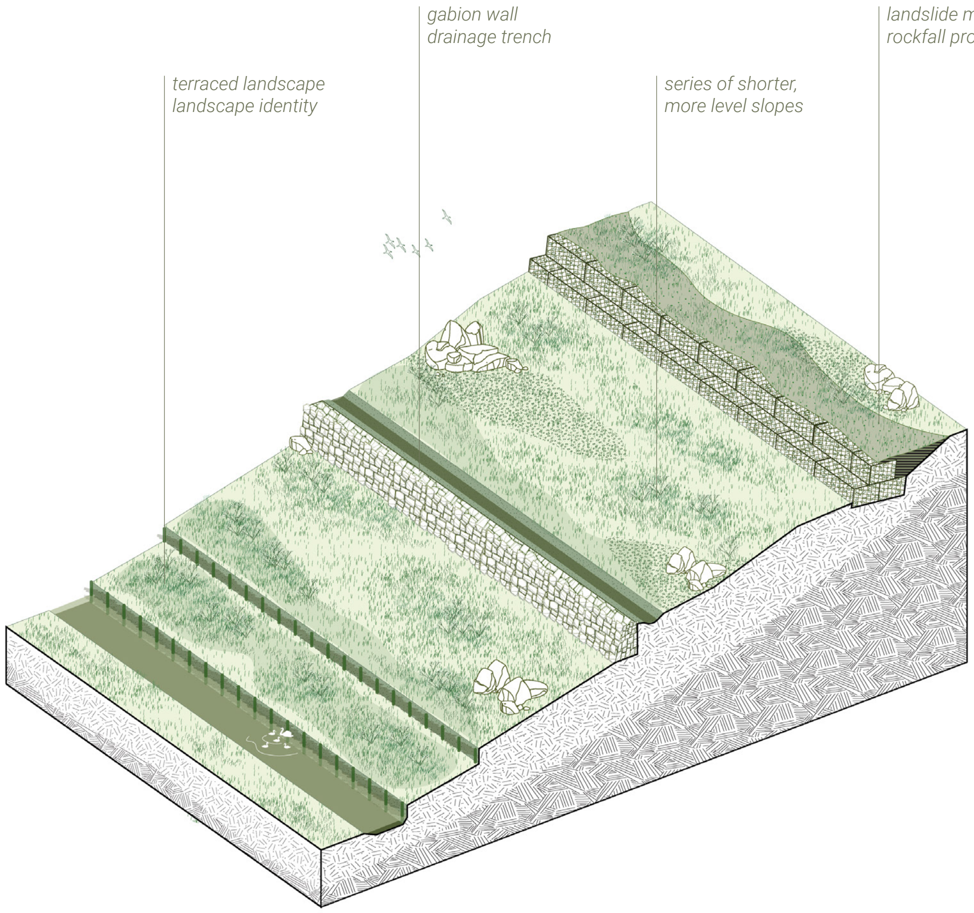
To stabilize slopes impacted by landslides and erosion, various types of wooden constructions can be employed to stabilize the slope and to protect the planted vegetation until the plants are fully grown and have a stabilizing effect. For example, vegetated wooden gabions are used to reinforce and protect the slopes from fast-moving stormwater, while live smiles aim to hold slumping soils on slopes and therefore protect plant roots from being exposed. Live poles are composed of tree branches or trunks and protect the slope from erosion, while they create terraces for vegetation to grow. Live crib walls are retention walls in the form of a timber crib backfilled with local earth and plant materials, aiming to reduce erosion and shallow landslides.

MAIN FUNCTIONS AND BENEFITS



Landslide and erosion mitigation | Soil pollution regulation | Biodiversity stimulation | Subsidence regulation

Cultural landscape | Climate resilient landscape | Nature development | Education

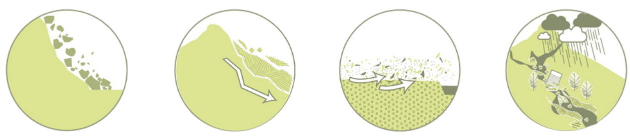


TERRACING

TYPE OF INTERVENTION

C Creation

HAZARDS

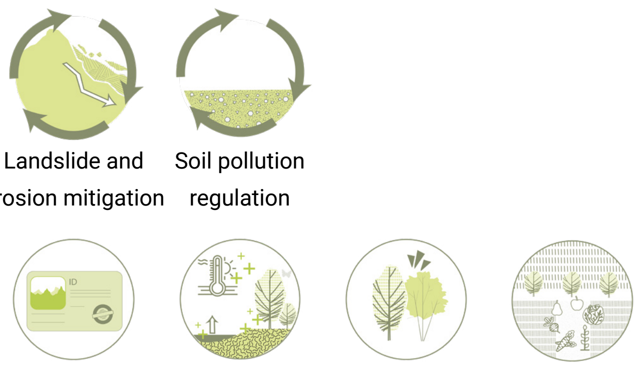


Rockfall | Landslide | Soil erosion | Debris flow

DESCRIPTION

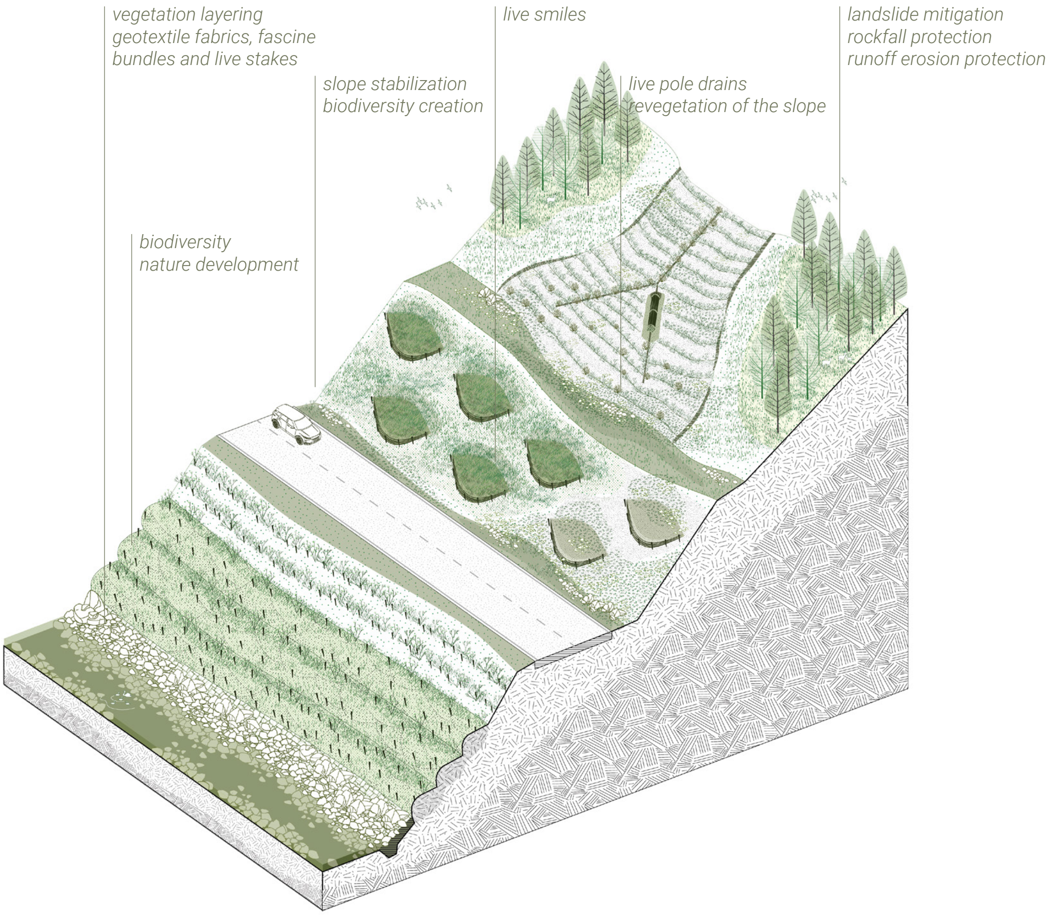
Terracing consists of converting a steep slope into a series of step-like structures. The main functions are controlling and guiding slope debris, reducing soil erosion and creating more flat and suitable lands for cultivation. Terracing also increases the slope rugosity, which slows down gravity driven movements, such as landslides and avalanches. Water will flow at a relatively slower pace and infiltrate more locally instead of flowing directly down the slope.

MAIN FUNCTIONS AND BENEFITS



Landslide and erosion mitigation | Soil pollution regulation

Landscape identity | Climate resilient landscape | Cultural landscape | Productive landscape



VEGETATION LAYERING OR SOIL BIO-ENGINEERING

TYPE OF INTERVENTION

C Creation

HAZARDS

Rockfall | Landslide | Snow avalanche | Debris flow

DESCRIPTION

Vegetation layering usually involves the modification of the slope gradient by layering brush consisting of live cut branches and rooted plants which are placed into excavated terraces and filled with compacted soil material. The vegetation can be planted in several ways, related to the main action needed on the slope. Live pole drains use roots as drain collectors on the landslide scar, while the revegetation of the slope helps to stabilize the soil further. Live smiles also aim to hold loose soils on the slope and therefore protect the vegetation layers introduced on the slope. In a similar way, vegetation can be introduced and protected through live stakes, live fascine bundles and geotextile fabrics. They all aim to stabilize the slope through hydrological and mechanical reinforcement provided by roots and aboveground vegetation.

MAIN FUNCTIONS AND BENEFITS

Landslide and erosion mitigation | Subsidence regulation | Biodiversity stimulation | Soil pollution regulation

Landscape identity | Climate resilient landscape | Cultural landscape | Education

NBS case studies

4.1
Ecosystem-based erosion control
Ehen, Ismailli, Azerbaijan; 2015 - 2018

As a result of unsustainable human activity over time and climate changes, pastures in the high mountain areas of the South Caucasus face problems of erosion, degradation, desertification, and loss of biodiversity. Together with the local community and stakeholders of the village Ehen, a participative approach was employed to implement and test affordable solutions to manage erosion, flooding, and to (re)vegetate mountain slopes.

Applied nature-based solutions:
- Stabilize slopes and riverbeds by tree planting and afforestation
- Implement a pasture management
- Modify and stabilize the soil by terracing
- Implement wooden fences as protection measure
- Implement a management for drought resistant orchard

Tree planting (Stock photo/USDA NRCS Montana, CC PDM 1.0)

Hazard: erosion rockfall, floods

Main stakeholders:
- The Ministry of Ecology and Natural Resources of Azerbaijan
- The Deutsche Gesellschaft fuer Zusammenarbeit (GIZ)
- local community

Links: Wocat SLM Approaches

4.2
Reduce surface erosion and shallow landslides at Catterline Bay
Catterline Bay, Aberdeenshire, Scotland, UK; 2019 - 2022

Catterline Bay is subject to soil liquefaction, shallow landslides, and erosion due to its sloped topography. The soil is a cohesive mixture of silty sands with clay and low vegetational cover. NBS implemented within the OPERANDUM project include the implementation of a live pole drain (, i.e. a sustainable drainage system at the toe of a slope where surface and groundwater accumulation are common), and the implementation of two live ground anchors (i.e. temporary iron structures that support the vegetation growth at the crest of slopes).

Applied nature-based solutions:
- Stabilize and revegetate the slope by implementing live pole drains, live ground anchors, live crib walls, brush layering and live stakes, and live slope lattice
- Construct stakes fences and palisades
- Revegetation by high density planting

Hazard: landslide, soil erosion

Live pole drain at Catterline Bay, OAL UK (Operandum)

Main stakeholders:
- Glasgow Caledonian University
- Catterline Braes Action Group (CBAG), Naturalea
- University of Glasgow, Delft University of Technology, University of Bologna
- European Commission
- Local citizens

Links: OPERANDUM OAL UK, OPERANDUM live pole drain, OPERANDUM live ground anchors

4.3

Brush layers and mats to stabilize marly gullies

French Southern Alps, France; 2002 - 2008

Heavy rainfall events in the French Southern Alps resulted in high sediment yields at the exit of marly catchments causing significant socio-economic and ecological problems downstream. The solution was the installation of more than 2000 brush layers and brush mats in 160 gullies. Results confirmed the natural succession of native plants and significant quantities of trapped sediments. These bioengineering structures can withstand high hydrological forces with return periods of 100 years.

Applied nature-based solutions:

- Stabilize and revegetate the slope by brush layering
- Use bio-engineering techniques like brush mattresses

Water erosion in marly gullies in the French Southern Alps (Stokes et al. 2014)

Hazard: flood, landslide, soil erosion

Main stakeholders:

- Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (INRAE)
- Local citizens

Links: OPERANDUM, article Plant and Soil, article Ecological Engineering

4.4

Bio-engineering measures to repair extensive landslide scars on natural terrain

Lantau Island, Hong Kong, China; 2013 - 2018

A severe rainstorm in June 2008 resulted in significant land sliding throughout the natural hillsides of Lantau Island, with some areas experiencing over 20 landslides within individual catchments. Emergency repair works requiring 4,500 m² of shotcrete were carried out shortly after the failures. Soil bioengineering measures were adopted as a means of providing low-cost, low-carbon footprint and more natural hillside restoration. These measures provided a largely maintenance free, sustainable, and more environmentally acceptable alternative to conventional slope works. The NBS adopted are intended to reduce the rate of deterioration of the landslide scars, enhance the resilience against intense rainstorms, and promote climate change adaptation while providing biodiversity enhancement benefits.

Applied nature-based solutions:

- Revegetate the natural terrain with bioengineering techniques Vegetation coverage to protect the soil from future surface erosion

Soil bio-engineering measures to restore the natural hillside (Courtesy of the Geotechnical Engineering Office of the Hong Kong SAR Government)

Hazard: landslide, debris flows, soil erosion

Main stakeholders:

- Geotechnical Engineering Office of Civil Engineering and Development Department, Hong Kong SAR Government
- Local villagers and citizens
- District Council members

Links: CEDD Hong Kong GEO Report

Guidelines

SCALE AND IMPACT

NBS for sparsely vegetated lands in mountain areas are strongly linked to the heterogeneity of landscapes in this ecosystem. Implementations may be made as single interventions at small scale (e.g., a slope), or upscaled to solutions covering large areas. The single intervention NBS have high replicability potential and their extent may increase by upscaling or replicating them in slopes with similar features.

Natural barriers are effective when implemented at larger scale, for example live check dams implemented along the entire length of gullies or living snow fences that protect infrastructure over long distances.

The impact scale can be larger than the NBS scale, as they interact with the surrounding environment, bringing additional benefits to both the area of intervention and areas nearby.

ECONOMIC COST

Estimating the economic costs of NBS requires taking into account their life cycles, which are interconnected with the life cycles of the raw materials used. For example, vegetated walls or gabions have life cycles that range from a few decades (e.g., wood or timber) to hundreds of years (e.g., vegetation).

NBS for these ecosystems mostly involves using vegetation and natural materials, preferably found locally, to create structures and natural barriers to prevent and mitigate natural hazards. The costs are therefore largely associated with the availability of these raw materials.

Changing and re-shaping a slope or a specific topography (e.g., terracing) may require heavy machinery and high labor demand, which can significantly increase the costs for realization. In addition, maintenance or replacement of wooden structures due to timber degradation must also be considered at the beginning of the planned intervention. Challenging topography and high altitudes are also factors that strongly influence the economic costs for both implementation and maintenance of NBS implemented in these ecosystems, especially when the NBS implies afforestation of high-altitude areas, which can only be accessible via helicopters.

ENVIRONMENTAL CONDITIONS

Assessing the environmental conditions is essential for designing, planning and implementing effective NBS. An ecological baseline assessment should be conducted prior to the NBS interventions and should include information about soil type and availability, water content, as well as meteorological variables to identify potential challenges that may be faced during the implementation phase. This baseline assessment is useful to select native plants most suitable to achieve the desired goals as well as to identify invasive plants. The more suitable plant species are chosen considering both technical and engineering requirements (e.g., high root density, high erosion resistance, additional root cohesion) for ensuring a proper hazard mitigation. Furthermore, they should be adaptable to the projected climate change.

This information is subsequently used to select a combination of plants rather than a single species, thus increasing diversity, while preventing pest diffusion or colonization from only one or few species.

After the NBS intervention is completed, an additional ecological assessment should be conducted as part of the monitoring program. These results can then be compared to the ecological baseline assessment to evaluate the impacts of the NBS interventions on the local fauna.

TECHNICAL CONDITIONS

Soil type and water availability are probably the most important factors affecting the technical conditions for NBS implementation in sparsely vegetated lands. The NBS implementation strategy of planting vegetation in these ecosystems located in mountainous areas requires the availability of healthy soil or as a minimum, soil conservation techniques to ensure the soil is as productive as possible. Furthermore, since irrigation is a challenge in these areas, the conscious selection of native species best suited for low-water and low-nutrient soil can help ensure the long-term health of the ecosystem and its effectiveness to reduce erosion and slope instability.

SPECIFIC CHALLENGES

The degradation of some areas due to overuse and the increased exposure from tourism and sports can increase the risk of climate-induced geo-hazards such as erosion from surface runoff, rockfalls, and rainfall-induced debris flows. Furthermore, changes in the duration of snow cover will also have more indirect impacts on ecosystem types in that water supply to crags and rock faces will diminish earlier in the season, and streambeds will dry out for longer periods. It is expected that the tree line will migrate upwards during the next 50 years. Since areas at higher elevations cover a smaller area, this upward migration of the tree line will reduce the overall size of these ecosystem types in the mountains. Since higher elevations cover smaller areas, this upward migration will generally reduce the overall size of these ecosystem types in the mountains.

Specific challenges related to NBS implementation in these ecosystem types are related to the sometimes hostile and harsh soil and water conditions. Mapping these challenges together with local communities to capture their local knowledge can be useful to overcome these specific challenges during the NBS implementation and establishment phase.

Accessibility to the areas for the NBS interventions may be also a challenge, given the high altitudes and often difficult topography.

Learning from PHUSICOS case studies: Woodlands and forests

Snow avalanches at Capet Forest
Sers and Barèges, Hautes-Pyrénées, Occitanie, France


Coexisting grey and green solutions (OPCC-CTP)


Tripods protection at Capet (NGI, Anders Solheim)

Realization: 2019 - 2022

Hazards: snow avalanches

Applied nature-based solutions:
- Afforestation on steep slopes (creation)
- Optimized forest management (management)
- Wooden tripods (protection)

Main stakeholders:
- French Forest National Office (ONF)
- Service of Mountain Terrain Restoration (RTM) in association with the French State represented by the Departmental Direction of the Territories (Hautes-Pyrénées),
- Working Community of the Pyrenees (CTP)
- Pyrenean Climate Change Observatory (OPCC)
- Municipalities of Barèges and Sers

Links:
- PHUSICOS Case studies
- Working Community of the Pyrenees
- OPCC
- ONF-RTM des Hautes-Pyrénées et Pyrénées- Atlantiques

Description
The risk posed by snow avalanches to the village of Barèges is high due to the village's proximity to the 'Midaou' avalanche path. Avalanches have reached the village numerous times in the past, the most recent event occurring in 2013. This historical risk has been managed over time by the gradual implementation of 981 'grey' protective structures on the slope and release area covering a total length of 6km. They are designed to protect against avalanches with a return period of 100 years.

The snowpack may build up higher than the ca. 4 m high existing structures due to the effects of the prevailing winds and drifting. In the event in 2013 for example, the avalanche was initially released in the upper 0.3 m of snow exceeding 4 m snow height. The NBS developed by PHUSICOS consist of afforestation by planted trees of 9 different species all of which should be adapted to the climate and elevation (1800-2200 m asl.) of the site. A detailed study (Bordeaux Sciences Agro, 2019) on the best-adapted tree species to face natural hazards in mountainous areas (taking into account climatic, topographical, soil conditions and climate change) provided the foundation for the afforestation efforts in Capet. The plants are either protected by the 88 newly built wooden tripods, by the existing grey structures, or by existing natural groups of trees. The plants are planted in polygons downslope of the protective structure. In total there are 257 polygons, 189 big polygons with 30 plants in each and 68 small polygons with 16 plants in each, totaling about 6758 trees, which were planted over a period of 4 years,

Traditional (grey) system to protect Barèges (OPCC-CTP)

but with the same age of plants in each polygon. The wooden tripods are also meant to serve as protection structures against avalanche release as long as they are standing, and until the planted trees grow high enough and develop a stem thickness to act as effective protection against avalanche release in 20-30 years. This is particularly important in barren areas with little or no existing vegetation or existing grey structures.

Motivation for nature-based solutions

In 1860, the military hospital in Barèges was destroyed by an avalanche of powdery snow that came down the Theil avalanche path. Other avalanches had occurred before, but it was this event, along with the promulgation of a law on the reforestation of the mountains, which initiated the creation of a special commission with representatives of the military engineering and forestry administration, facilitated in the presence of Napoleon III. This was the starting point for applying a double strategy based on the construction of civil engineering infrastructures and reforestation, with reforestation being identified as the only way to eliminate the problem at its source.

Reforestation or the implementation of NBS in Capet is therefore not a new strategy. Today ONF-RTM continues to implement this dual strategy, ensuring the maintenance of traditional structures and continuing reforestation campaigns. This complementarity strategy between grey and green solutions is therefore considered the most relevant and adaptable to respond to snow avalanches.

Conclusions and lessons learned

The solutions in place at Capet to deal with snow avalanches are hybrid solutions, combining civil engineering works and reforestation using tree species that have demonstrated their adaptability to climatic, topographical, soil conditions as well as climate change. This strategy, in place since the beginning, continues to be implemented today. It has proven its effectiveness and has also economic advantages.

The experience with the NBS installations is that some of the tripods were damaged by snow creep and had to be repaired. Different orientations and construction details were tested. Furthermore, several plants have died. The 'survival rate' seems to vary with soil thickness, but other factors, such as local topography and exposure may also influence the growth. A certain loss is expected, and even required, since the plants in each polygon are planted too dense for all to grow properly.

Erosion and rock fall at Santa Elena

Santa Elena in Biescas, Province of Huesca, Aragon, Spain

Overview of Santa Elena before the works (OPCC-CTP)

Detail of the gabions in Santa Elena (OPCC-CTP)

Realization: 2019 - 2023

Hazards: rockfall and erosion

Applied nature-based solutions:

- Terracing formed by dry masonry walls at the base and timber gabions filled with local sediment (creation, protection)
- Vegetation layering (creation)
- Stabilizing the slopes through revegetation (restoration)

Main stakeholders:

- EGTC Pirineos – Pyrénées
- Working Community of the Pyrénées (CTP)
- Pyrenean Climate Change Observatory (OPCC)
- Government of Aragon, Huesca Provincial Council

Links:

- PHUSICOS Case studies
- EGTC Pirineos - Pyrénées
- Working Community of the Pyrenees
- OPCC

Description

The slope at Santa Elena has been identified as one of the high-risk locations along road A-136, which is an important route between Spain and France (road RD-934 in France). The slope is in a terminal moraine, formed by the confluence of two valley glaciers during the last glaciation, the 'Würm', which in the Pyrenees ended 16000 years BP. The steep slope cuts through a thick moraine deposit creating problems of erosion and instability. The main risk is caused by rocks falling on the road, because the visibility of the area from the road is low and the traffic speed often high. Attempts at mitigation with nets do not appear to work well, and do not solve the problem of boulders and smaller rocks coming loose due to erosion.

The measures implemented by PHUSICOS at Santa Elena consist of terraces formed by a 5 m high dry masonry wall at the base, followed by 10 terraces constructed by logs. The log constructions are in the form of timber gabions and filled with local sediment, with a 10 cm layer of organic soil on top for planting of bush vegetation on the terraces. In addition, about 1 m deep holes are filled with organic soil at 3 m intervals along the terraces for the planting of larger trees. The wooden gabions closest to the access road are filled first to allow access for the construction machines. They are overfilled with sediment to ensure that the wooden gabions are not damaged by the weight of the construction machines. All dug-out material is used in the construction, mainly as filling for the gabions. Additional sediments and organic soil had to be brought in to enhance

Overview of works in Santa Elena (NGI, Anders Solheim)

the revegetation process. All plants used in the NBS are local and adapted to the climate, altitude, and the local geology (glacial till). The Hippophae ramnoides is a shrub particularly recommended for stabilizing slopes; the roots distribute rapidly and extensively, providing in addition a non-leguminous nitrogen fixation role to the surrounding soils.

Motivation for nature-based solutions

Most of the Pyrenean valleys have slopes with till deposits. Many of them threaten critical infrastructure, such as roads, railroads, dams, or other types of infrastructure. Terracing and revegetating are not new measures; several examples of large old structures can be seen in other locations in the region. In Arratiecho, close to Biescas (about 5 km south of Santa Elena), similar measures were implemented in 1905, and consisted of a combination of terraces built from dry masonry walls and afforested with local tree species. In addition, a spillway for torrential floods and debris flows was constructed along the main channel which was also constructed of dry masonry with energy-breaking weirs. Today the area appears as a forested hillside from the distance, and landslides have not caused a problem during the last 115 years. These works in Arratiecho, as well as others in the Aragon Valleys, were designed and implemented by forestry engineers from Huesca, Aragon and were an outstanding and pioneering contribution to the Spanish forest hydrology during the 20th century. Their approach in combating torrential floods and snow avalanches in the Upper Gállego River has resulted in the protection of a village near the town of Canfranc. Additionally, the massive afforestation works have protected the international railway station of Los Arañones. All these are examples of early NBS or hybrid solutions which work after decades of operation.

Conclusions and lessons learned

The implemented solution in Santa Elena is inspired by the hydro-forestry remodeling works of the Pyrenean valleys at the beginning of the twentieth century. The dry-stone walls have been replaced by wooden terraces that have the same goal of facilitating the growth of forest in the till deposit. Construction work started slowly, but as experience was gained, the process accelerated as the construction company became accustomed to the work and the use of mini construction machines.

Now that the work is almost completed, there is growing interest from institutional actors and individuals. Site visits and showcasing these interventions are key to making this type of solution known, to inspire replication in other Pyrenean valleys facing the same problems or to highlight the know-how of local companies with local resources to provide such a solution.

Debris flow mitigation in Erill-la-Vall

Erill la Vall, Municipality of Vall de Boí, Catalonia, Spain

View of the terraces (NGI, Anders Solheim)

Detail of grassed terraces (NGI, Anders Solheim)

Realization: 2021 - 2022

Hazards: erosion and debris flow

Applied nature-based solutions:

- Terracing formed by dry masonry walls at the base and timber gabions filled with local sediment (creation, protection)
- Live crib walls (protection)
- Vegetated layering with local species (creating)

Main stakeholders:

- Geo-Hazard Advisors - Kuroba4,
- Working Community of the Pyrenees (CTP)
- Pyrenean Climate Change Observatory (OPCC)
- Municipality of Vall de Boí

Links:

- PHUSICOS Case studies
- GeoHazad Advisors Kuroba4
- Working Community of the Pyrenees
- OPCC
- Municipality of Vall de Boí

Description

The main hazards at the Erill-la-Vall site in Catalonia, Spain are erosion and debris flows from a thick (>50m) boulder-rich till complex. Numerous smaller gullies feed debris into the main debris flow channel, which eventually reach the Village of Erill-la-Vall, in the Vall de Boí municipality. An earlier attempt was made to mitigate the hazard by constructing a stiff barrier (a wall) below the steepest part, however this was filled up by debris only 2-3 years after construction. A flexible barrier (a debris flow net) was then established at a bit upstream of the wall, at a significantly lower cost. This intervention was also filled up. However, the result of these two mitigation attempts created steps (terraces) in the terrain. These steps reduce debris flow energy and limit erosion. Monitoring measurements installed at the site include an instrumented drill hole (with piezometers), a rain gauge, and a micro-seismic network. Some of the measurements have time series back to 2007.

The annual precipitation of the area is about 1100 mm/year, mainly in the fall and spring. However, intensive showers in July-August appear to have the worst effect on the debris flow potential. Interpretation of the monitoring data shows two different processes. Heavy rain triggers immediate response in the surface sediments, causing erosion, debris flow and rockfall. However, a piezometer at 30 m depth in the borehole shows a response to heavy rain after 10-15 days, and this may trigger larger, deep-seated events. Such an event occurred in 1907, after a long period of rain.

Overview of the Erill site: the village in the foreground and the valleys in the back (NGI, Anders Solheim)

The NBS measures consist of terraces constructed by dry stone walls and timber. These are constructed in the lower parts of the steepest part of the two main gullies. The terraces are to be covered with organic soil and planted with local vegetation, grass, bushes, and trees. Soil and turf from the area is used, and natural fertilizers from local grazing animals are applied on the terraces. In total about 2500 plants will be used, all local species (Betula pendula, Salix purpurea, Salix caprea, Rhamnus alpina, Viburnum opulus, Corylus avellana, Prunus spinosa, Fraxinus excelsior and Salix sp.). The terraces are constructed starting from below and as high up as possible with an excavator. The work was conducted by a small, local company. The effects of the measures have been modelled with RAMMS-Debris flow, in cooperation with WSL, Switzerland. There is a high resolution (2 cm) digital terrain model for the area, measured by drone-based LiDAR. A new debris flow net will be installed downslope of the terraces, between the existing net and the terraces, to create another step and prevent further lowering of the erosional base.

Motivation for nature-based solutions

Due to the older measures installed at the Erill-la-Vall site, the solutions implemented can be considered as hybrid solutions. The terraces have been built with local raw material and have a high potential for increasing biodiversity. There are several sites in these parts of the Pyrenees that have thick till deposits and similar problems with debris flow. The Erill-la-Vall case is the best known and probably the most serious in terms of risk. However, 11 gullies affect urban areas in the Vall de Boí region, and 9 of them are being evaluated for possible risk reduction measures, similar to those implemented in Erill-la- Vall. Moreover, in the province of Lleida, at least 35 gullies have similar hazards, so the potential for upscaling this NBS in the Pyrenees, and probably elsewhere, is significant.

Conclusions and lessons learned

In Erill-la-Vall, the local interest and enthusiasm of the municipal authorities and citizens of the valley were important in order to avoid obstacles and ensuring a fast initiation of the work. The Erill-la- Vall site was proposed very late in PHUSICOS project and here the attitude of the local authorities were an important incentive for the implementation of the measures. It is a pilot case with high upscaling potential, essential to provide relevant and adapted solutions for different gullies in Pyrenean valleys.

Rock fall at Artouste

Artouste, Municipality of Laruns, Pyrénées-Atlantiques, Nouvelle-Aquitaine, France

Detail of wooden tripod to fix a loose rock on the surface (OPCC-CTP)

Experimental site for testing wooden structures (OPCC-CTP)

Realization: 2019 - 2023

Hazards: rockfall

Applied nature-based solutions:
- Wooden constructions (protection)
- Afforestation on steep slopes (creation)
- Rockfall protection walls as natural barriers (protection)

Main stakeholders:
- EGTC Pirineos – Pyrénées, Working Community of the Pyrenees (CTP), Pyrenean Climate Change Observatory (OPCC)
- Municipality of Laruns
- Pyrenees National Park
- French Forest National Office (ONF),
- Mountains Land Restoration Services (ONF-RTM)
- Departmental Government (CD64)

Links:
- PHUSICOS Case studies
- EGTC Pirineos – Pyrénées
- Working Community of the Pyrenees
- OPCC
- Municipality of Laruns
- Pyrenean National Park
- ONF-RTM des Hautes-Pyrénées et Pyrénées- Atlantiques
- Departmental Government 64

Description

Hazards at Artouste are caused by rockfall initiating from the exposed rock ledges and from loose blocks resting on the ground surface in the steep slope. The site borders the Artouste hydro-power dam where the RD-934 descends in sharp curves from the height of the reservoir to the base of the dam. The slope is steep, and falling rocks often hit the road, creating dangerous situations. A fatal accident occurred in 2013 when a car was directly hit. The site is divided into 6 zones based on geotechnical characteristics. After discussions with the stakeholders (landowner and manager of the protected area and forest).

It was decided that PHUSICOS would intervene in two of the zones. The NBS interventions proposed and approved consisted of different structures made by wood and/or local stones. The solutions rely on active measures (manual stabilization and/or timber structures) to stabilize the source areas and passive measures (mixed wood and/or stone structures) to slow down and/or divert rocks in their trajectories, enhancing the protective role of the forest. Initially the slope morphology was surveyed in detail with ground-based LiDAR. In addition, a handheld LiDAR was used to map the forest in detail, comprising each individual tree. The entire slope, including the release zones is forested with mainly pine and birch trees. The forest therefore also plays an important protective role. Following the LiDAR surveys, all release zones as well as individual loose blocks have been mapped and marked indicating the type of measure to be implemented. Smaller rocks were simply moved manually to stable positions behind trees or groups of trees.

Artouste site meeting with territorial actors (OPCC-CTP)

The measures implemented in the slope are primarily different wooden structures, but also local stones are used to stabilize some of the exposed ledges. The logs used are taken from local forests; however, not in the Artouste slope. They are moisture-protected in the lower ends, anchored in the ground by long iron rods and either bolted or tied together in the top ends. Each structure is designed individually for the specific block or ledge they stabilize.

A related activity is underway in La Peña Estación (Spain), where a test facility for NBS to mitigate rockfall is being set up in the premises of the company doing the wood works at Artouste. This open-field test site has similar characteristics to that of the Artouste site.

Motivation for nature-based solutions

The solutions implemented at Artouste should be classified as a hybrid solution. They do not include a vegetation component to enhance growth or increase biodiversity. However, the solutions are selected to minimize the footprint of construction and to preserve the natural environment to the highest possible degree. All materials are lifted in by helicopter, so no new access roads for machinery have been made. After the material was in place in the slope, all the structures was built by hand, to avoid any use of heavy machinery on the ground. Care has also been taken to avoid the removal of trees, as the natural forest also serves as a protective agent for rock fall. In total, the implemented solutions are environmentally gentler than a traditional solution with concrete, nets and more extensive bolting. In addition to the PHUSICOS measures, some tree removal as part of the site management and hiking path maintenance was also carried out by the Pyrenean National Park or the French Forest Office (ONF). The cut trunks are placed between living trees to further increase the protective role of the forest.

Conclusions and lessons learned

Work on the Artouste slope was delayed partly due to bureaucratic reasons and the need to obtain permits. The area is in the center of the Pyrenees National Park, and the park authorities were initially skeptical of operations in the forests of the Artouste slope. The lesson learned from the Artouste site is the importance of establishing cooperation with all stakeholders early in the project, clarify all potential obstacles and negotiating solutions where necessary to minimize implementation delays.

The innovation of this intervention lies in using mixed techniques by implementing a rock protection technology that has been used mostly with grey materials (metal fences, nets, concrete galleries) and replace it with wooden frames, combined with forest management. It also lies in the close cooperation and agreements with the national, regional and local actors. The measures, once tested and found functional, have a large upscaling potential as similar problems and restrictions exist in many valleys of the Pyrenees as well as elsewhere.

Microbial assisted revegetation in the Kaunertal valley

Kaunertal Valley, Tyrol, Austria

The Kaunertal valley with its steep slopes (UNIVIE, Stefan Haselberger)

Implementing the seed mixes on site (UNIVIE, Stefan Haselberger)

Realization: 2018 - 2023

Hazards: Erosion

Applied nature-based solutions:

- Microbe-assisted revegetation (restoration)

Main stakeholders:

- Ski resort and glacier road company "Kaunertaler Gletscherbahnen Gesellschaft m.b.H."
- Greening company Grasberger GmbH
- Municipality Kaunertal
- Universty of Vienna
- Paris-Lodronne University Salzburg

Links:

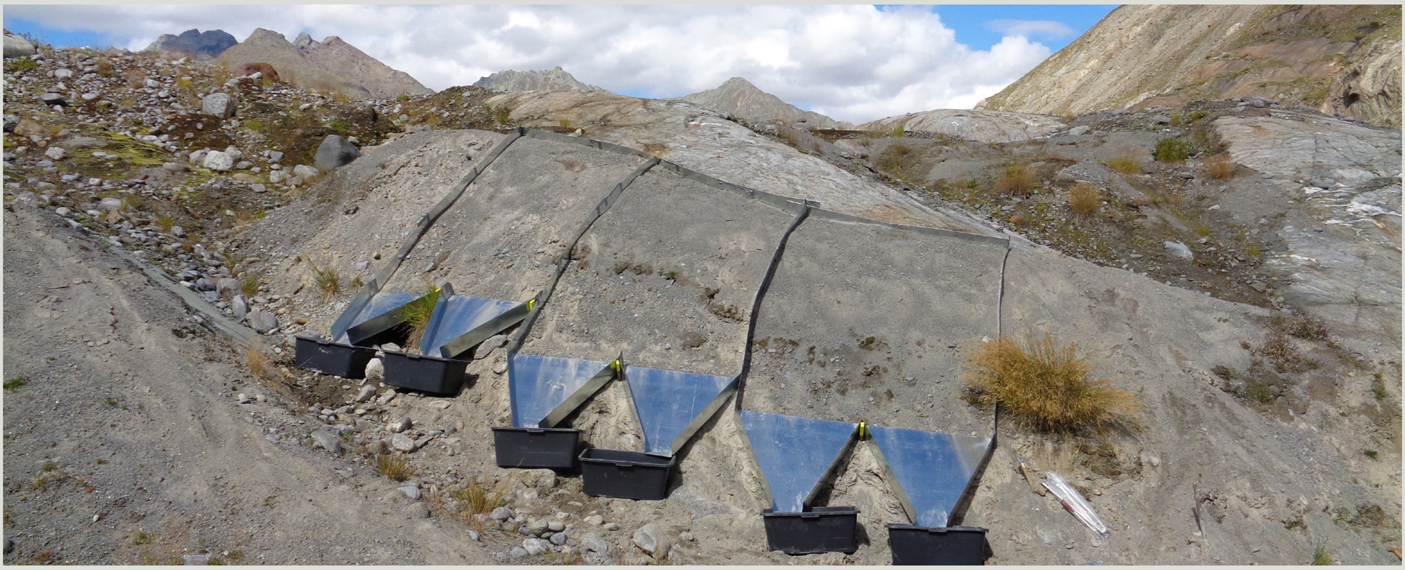
- Kaunertal (youtube)
- Podcast According to Nature (spotify)
- Sediment Dynamics in High-Mountain Environments (youtube)

Description

The Kaunertal Valley in south-western Austria represents a typical crystalline alpine valley formed by the Gaptschferner glacier, the second biggest ice mass in Austria. Climate change did not only take a toll on the Gepatschferner glacier but also negatively influences the permafrost in higher altitudes. The degradation of the cryosphere leaves areas of surface sediments prone to erosion and exposed to extreme hydrological events, resulting in a growing probability of mass movements, such as debris flows and shallow landslides. Current mitigation strategies, particularly for debris flows, included massive grey sedimentation basins in the valley floor that were developed in size based on historic sediment delivery rates.

To encounter the problem at the root, one has been looking at local and altitude adapted vegetation that could stabilize erosive areas and therefore limit sediment delivery to the valley floor. Additionally, the local microbiome was screened in the lab for its' effects on the vegetation. Single local bacteria could be identified that promote favorable plant functionalities like an early point of germination, a dense and/or long root system, and more/bigger leaves to encounter erosion.

The work in Kaunertal included establishing 60 test plots, in which the natural plant communities and their trades, as well as the microbiome were recorded and analyzed. Erosion was measured as a function of vegetation cover in these plots. A test run of a commercially available and altitude adapted seed



The different test configurations on the slope (UNIVIE, Stefan Haselberger)

mixture with microbiome was conducted in the plots in October 2020. Unfortunately, intense summer rain in June and July 2021 washed most of the seeds from the slope. Hence, only a general increase in vegetation cover could be observed in the plots with the seed mixture and seed mixture with microbiome, but no statistically significant results were derived from this test run. In October 2022, a second demonstration of the NBS was implemented using mechanical hydroseeding on newly constructed ski slopes as well as road cuts. The evaluation of these measures is pending.

Motivation for Nature-based solutions

People advanced into the pro-glacial alpine areas to conquer the untamed wilderness, expand grazing areas for their cattle, develop hydro-power dams, ski-resorts, or scenic glacier views. All these interests demanded the expansion of road systems and infrastructure into a high-altitude ecosystem. To stabilize unconsolidated road cuts or ski slopes it was common from the seventies onward to bring out allochthonous seeds that did not belong to the region or to the altitude. This led to the pestilent growths of lupines throughout Kaunertal Valley and is documented for many other mountainous areas as well.

This pest and measures against it, along with the growing probability of mass movements, such as debris flows and shallow landslides were observed. Together with the knowledge about the stabilizing effect of vegetation on surface processes this has led to the motivation of changing the existing hydroseeding methods to a more eco-sensitive and efficient version.

Conclusions and lessons learned

- The work on site would not have been possible without the goodwill and help of the public, represented as farmers and owners of the land we worked on, and the shepherds and hunters that supported us with helpful information and material. Frequent and in person communication is crucial for such a relationship. Living on site in the summer and being part of the community and engaged even outside the research helped the outcome.
- Validating laboratory findings in a high mountain environment with its weather extremes and steep slopes is a challenge in a 5-year project. A more moderate environment for this pilot study would probably have led to more stable results.
- The biodiversity of the seed mixture and the upscaling of the NBS is currently limited by the availability of certain seeds, costs of the microbiome, and hence resulting costs to upscale the production.

Dynamic lower lands

The last two ecosystems are related to the lower lying areas within the river basin or in the areas with softer topographical changes, such as coastal cliffs or productive hills. Moreover, these ecosystems are specific in their vegetation and soil conditions and show a wide range of productive landscapes.

5. CROP-, GRASS-, HEATHLANDS AND SHRUBS

Heathlands and shrubs are low and closed cover vegetation, characterized by small plants like bushes and shrubs in combination with herbs. Crop- and grasslands can also refer to more productive landscapes, in lowlands as well as on higher altitudes. They often take an intermediate position between more intensively managed grasslands and mature woodlands, which makes them accessible and interesting for cultivation. They suffer from drought during certain months which can also pose risks for their environment and habitat, especially concerning water quality.

6. COASTAL LANDS

Coastal ecosystems are situated on the threshold between land and ocean, often where river systems end up in the sea. They include mangroves, salt marshes, seagrass meadows and coral reefs and they are home to unique habitats given the specific conditions of saltwater and fluctuating tides. Coastal landscapes are under increasing climatic pressure with sea level rise and coastal erosion as the most pronounced hazards. Additionally, they can become a threat to freshwater ecosystems, with salt intrusion and drought as main examples.

From left to right, top to bottom:
> Serchio River Basin, Northern Tuscany, Italy (ADBS, Nicola Del Seppia)
> Transitional vegetation in Po di Goro, OAL Italy (OPERANDUM)
> Autochtone animal breeds (Diogo Miranda)
> Intact windbreak in Georgia (Panorama solutions, photo © E.C.O. Kirchmeir)
> Titchwell marsh (Francesco Ungaro)
> Dune construction at Volano Beach, OAL Italy (OPERANDUM)



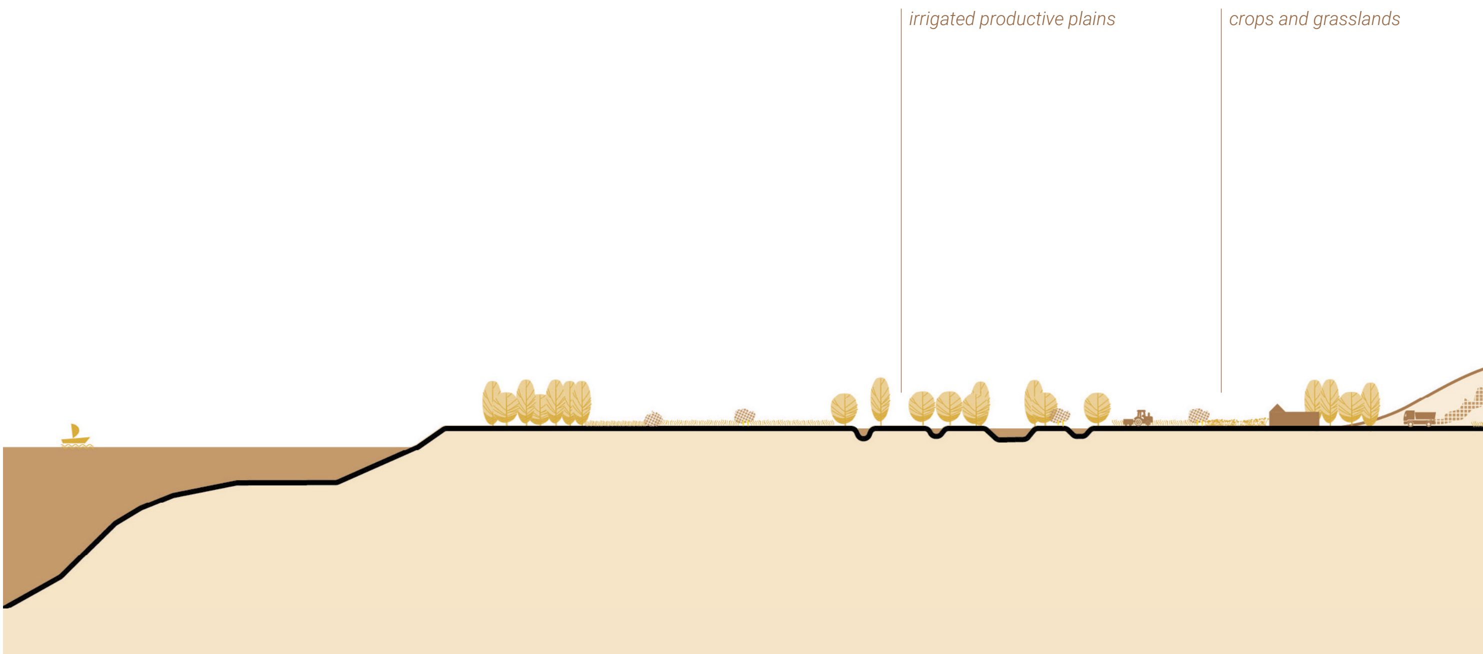

C5. Crops, grass-, heathlands & shrubs

Smart (re)vegetation and land use

This ecosystem represents an important part of open landscapes at different altitudes. It clusters crops and grasslands as cultivated areas, and heathlands and shrubs as areas with a transitional function to the surrounding landscapes. Low vegetation is characteristic for all.

Cultivated areas and pastures (including grasslands), also known as agroecosystems, cover nearly half of the European land area and are predominately managed ecosystems (JRC, 2020). Human management is necessary to maintain these ecosystems in good condition, which is crucial as agroecosystems host some of the richest habitats for species and are therefore important sources of biodiversity, as well as contributing to food security. However, the JRC's 2020 report concludes that despite ongoing efforts, the long-term degradation and biodiversity loss in agroecosystems have not improved over the last decade. Additionally, the pressures contributing to this degradation remain unchanged or are even increasing. This issue is particularly acute for grasslands, as highlighted in the most recent "State of Nature in the EU" report. The report identifies agriculture as the most reported pressure affecting habitats and species. Specifically, the abandonment of grasslands and agricultural intensification are significantly impacting pollinator species, farmland birds, and semi-natural habitats (EEA, 2020). Further to these past and present pressures, the impacts of climate change must also be considered and the JRC concludes that “there is no evidence that reversal of biodiversity trends and improvement of ecosystem condition will take place, if appropriate actions are not taken” (JRC, 2020).

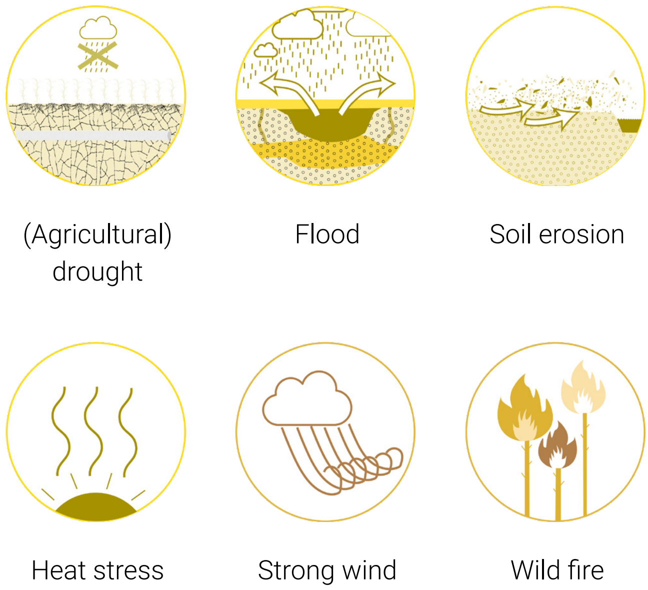
Heathlands and shrubs are specific ecosystems that are dominated by herbs, mosses, low vegetation and woody plants. They cover about 4% of the total EU land area (JRC, 2020) and can be interpreted as intermediary landscapes, lying between cultivated grasslands and woodlands. Most of these landscapes are subject to human interventions and cultivation, like grazing and mowing. Current challenges facing heathlands and shrublands include surface area conversion (i.e., ecosystems, are transformed into urban, agricultural, or other human-developed landscapes), fires, and eutrophication (JRC, 2020). Despite a decrease in the pressures on heathlands and shrubs over the last decade, their total area has still diminished by 1.2%. Although this percentage may seem relatively small, it represents the highest relative decline among all ecosystems in relation to their overall area. Fortunately, a relatively high area (40%) of the total area for heathlands and shrubs is covered by European legislation in the Natura 2000 network. This is advantageous for their . preservation to keep the ecological functions and ecosystem services guaranteed for the surrounding landscapes.

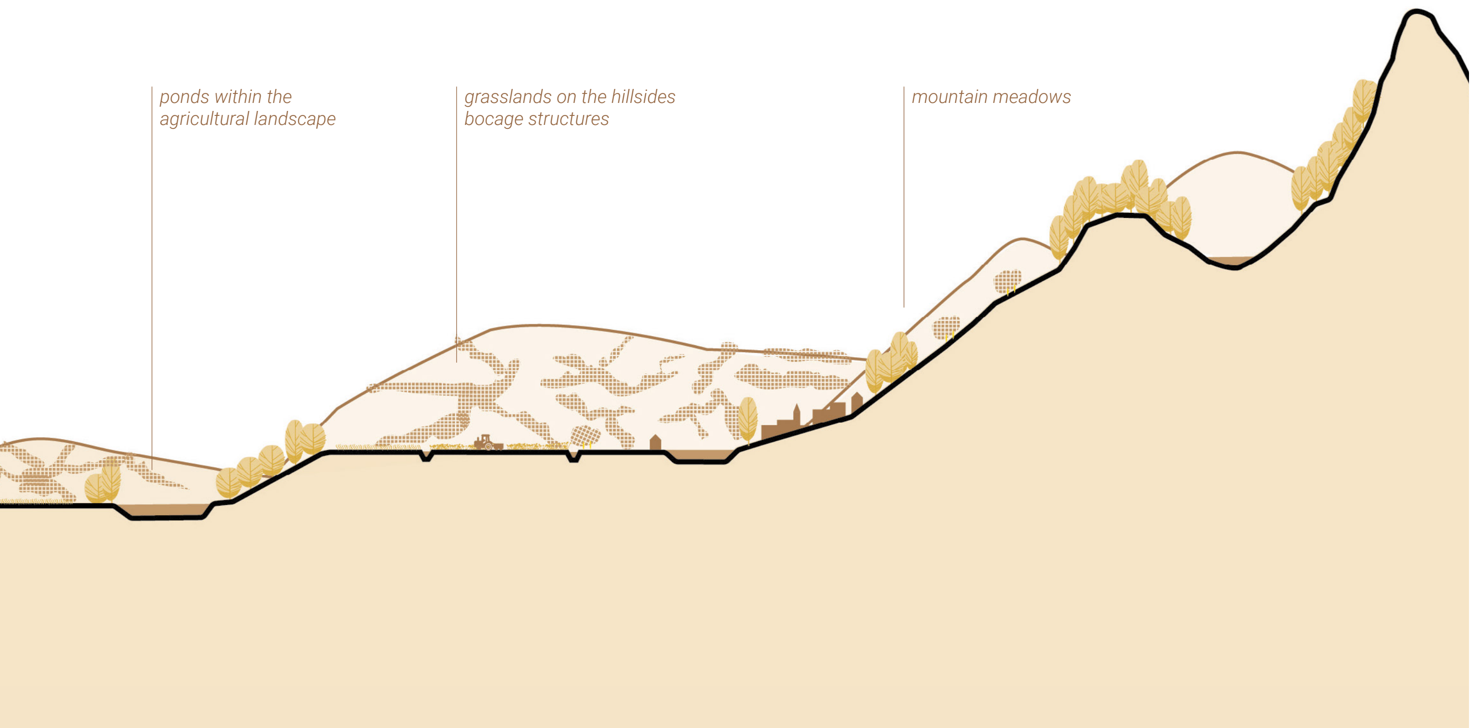


Hazards

The drivers and subsequent pressures on degradation and biodiversity loss of crop- and grasslands, heathlands and shrubs reflect the hazards in these areas. As mentioned previously, these include agricultural and livestock activities that lead to pollution, eutrophication as well as water exploitation. In the IPCC's 6th Assessment Report (IPCC, 2022), Working Group II reports for Europe that the second highest risk of climate change is heat and drought stress on crops with irrigation being limited by water availability (Bednar-Friedl et al. 2022). In addition to drought, these ecosystems are also impacted by extreme hydro-meteorological events resulting in floods and subsequently soil erosion. The loss of soil in agroecosystems further exacerbates the transport of particulate pollutants and can also accelerate the processing of silting in irrigation channels.

Furthermore, extreme water pumping from underground aquifers agricultural purposes can cause subsidence of the land which in some areas near the coast promotes saline intrusion. With regard to heathlands, it is important to note that burning practices used in several regions can lead to an increase in wildfires due to warming trends and drought (JRC, 2020).





A landscape synthesis

The different cultivated landscapes and their more natural edges represent a strong identity in the lower-lying plains and the lower hills. An integrated landscape system can be developed where production, ecology and water management are in balance and reinforce each other. This will be dependent on the elevation, the specific surrounding nature and the productive ambitions for the land, Different NBS are illustrated in the landscape synthesis drawing on the opposite page and are described below following the four NBS approaches.

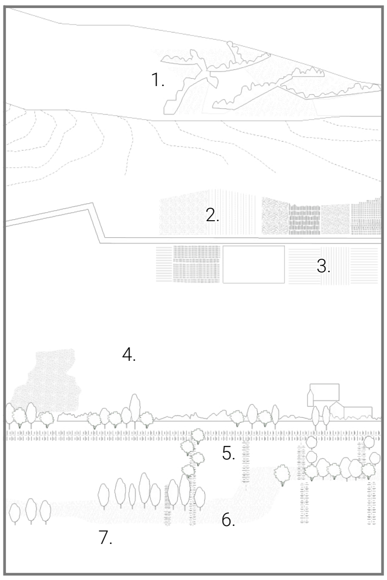
RESTORATION
The traditional bocage structures with agricultural plots surrounded by hedges, shrubs and woodsides are valuable landscapes, representing a balance between natural and productive systems. Traditionally this landscape configuration is present in the plains and lower hills. The hedge structures offer a strong added value in terms of biodiversity, habitat locations, water management, carbon storage, and shade. Therefore, restoring the hedges and shrubs as part of a traditional productive landscape composition can help to reinforce its resilience. In agroecosystems, channels often define the landscapes in a recognizable grid structure and these existing canals can be transformed, widened or reshaped. Revegetating their banks can allow for better stability and more biodiversity. Vegetated buffer strips can be implemented on the edge of the fields with the goal of optimizing the soil quality, the water quality in the canals and the biodiversity levels. They are effective measures to regulate many of the hazards within the agricultural fields. This NBS helps to transform a very mono-oriented productive landscape into a diverse landscape structure.

PROTECTION
Protection of these ecosystems requires an assessment of the loss and degradation drivers, e.g. conversion to cropland, overgrazing, fire and climate change. More sustainable land management can be achieved through collaboration with local communities, farmers and herders, e.g. by implementing incentives for less intensive, agricultural practices, and promoting variation in species, number and distribution of animals.

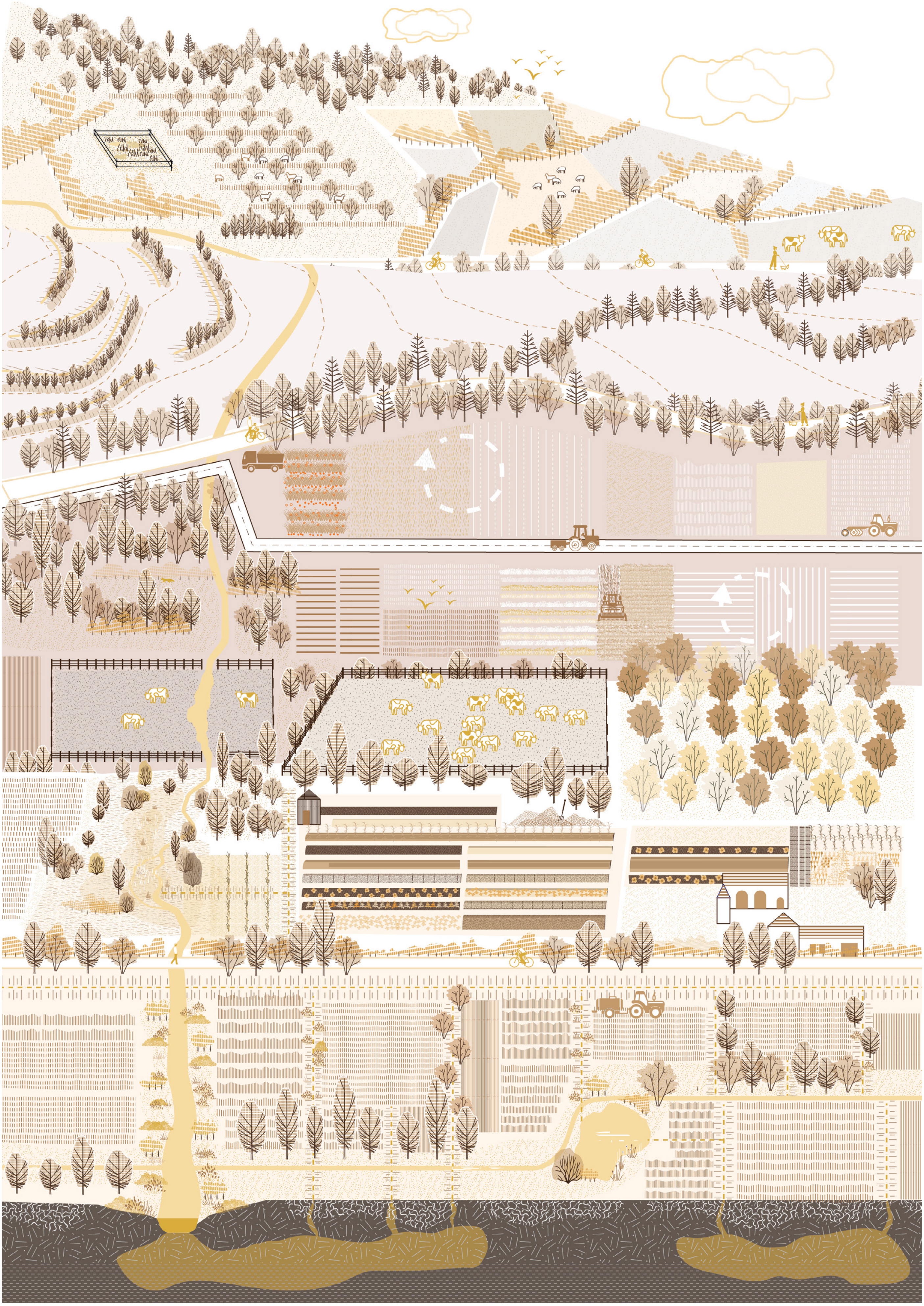
CREATION
Specific NBS can be applied to remediate agricultural drought, to regulate soil erosion and pollution from nutrients or pesticides, and to reinforce the overall biodiversity with the productive fields in this landscape. To reduce these impacts, a sustainable irrigation and drainage system with canals can also be created to allow for a coherent water management of the territory with regulation of irrigation and drainage flows, and also including sedimentation ponds and the necessary links to the rest of the water system.

As an alternative, existing canals can be transformed, widened or reshaped. Biodiversity and stability can be improved by revegetation of their banks. The vegetation can be implemented as buffer strips, promoting biodiversity, improving water quality in the canals, and reducing erosion and sediment transport. These engineered canals often result in a regular structure providing an easily recognizable landscape structures providing effective mitigation of a number of hazards in agricultural land use.

MANAGEMENT
An integrated management is crucial to preserve agroecosystems as valuable landscapes. The management should focus on various aspects and should be specifically adjusted for the climatic conditions, elevation and soil conditions. One aspect is the crop management, which deals with the different crop strategies like crop rotation or cover crops. An intelligent management related to the types of crops and timing of their respective growth cycles, can be beneficial for the entire agroecosystem. Strategic soil management is also a fundamental aspect in addition to specific crop strategies. A healthy and living soil is the base for a flourishing agricultural landscape. When working with conservation tillage for example, parts of the harvest will cover the ground and make sure that it is protected and enriched through this process. Other soil care measures, like organic matter enrichment or soil phytoremediation can also contribute to a rich and productive landscape. The key to a sustainable agricultural landscape is to diversify and manage the crops, the water system, their interactions and the scale of production in a strategic manner.



1. Hedges and shrubs
2. Crop management and rotation
3. Conservation tillage
4. Soil care
5. Sustainable irrigation and drainage system
6. Vegetated buffer strips
7. Soil care measures



Functions

The implementation of NBS in these areas aims to reduce surface erosion and the maintenance of the banks of rivers and canals, promoting the reduction of sediment transport and increasing the overall hydraulic resilience of the territory. Furthermore, NBS also contributes to the control of the surface runoff and the transfer of pollutants from agricultural and grazing soils to canals and lakes, improving the ecosystem's ecological status. These protection measures can be considered a "win-win" strategy as they improve the water quality and reduce the hydraulic risk associated with smaller hydraulic networks. These solutions are beneficial to the overall efficiency of the canal system, even in the presence of extreme meteorological events that result in flooding. For example, the decrease in soil erosion and the slowing down of the surface water runoff speed allow for greater rooting of various plants and, with them, the ecosystem recovery. NBS in agroecosystems also function to reduce agricultural drought, defined by a shortage of moisture in the soil, by for example reducing the processes of evapotranspiration in the agroecosystem. From a landscape point of view, NBS perform an important function because they seamlessly integrate into the landscape, subsequently facilitating the recovery of degraded areas.

water

1. Riverine flood regulation
2. Pluvial flood regulation
3. Coastal flood regulation

soil

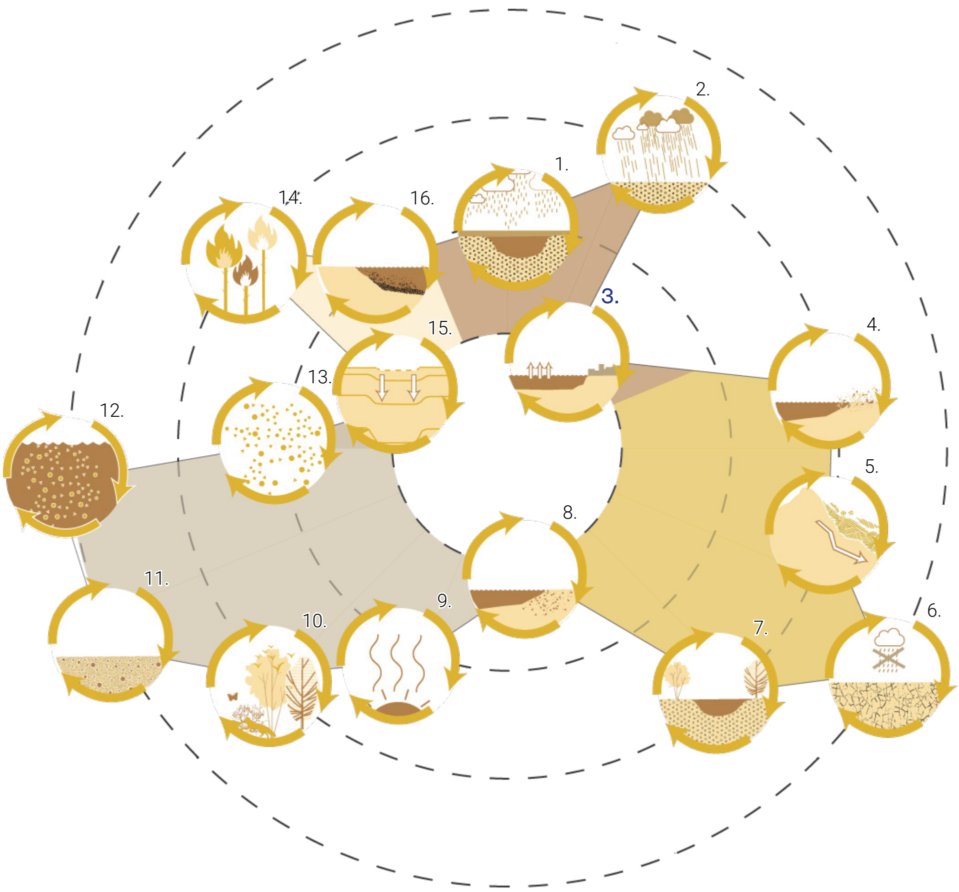
4. Coastal erosion mitigation
5. Landslide mitigation
6. Drought mitigation
7. Riverbank erosion mitigation

habitat

8. Salt intrusion regulation
9. Heat stress regulation
10. Biodiversity stimulation
11. Soil pollution regulation
12. Water pollution regulation
13. Air pollution regulation

other

14. Wildfire regulation
15. Subsidence regulation
16. Sedimentation mitigation



Benefits

NBS in these ecosystems provide significant ecological benefits. For instance, the creation of buffer strips in cultivated areas can enhance biodiversity and thus protect habitats. Heathlands and shrubs are important ecosystems for biodiversity as well as carbon storage (JRC, 2020), and NBS to support that is beneficial for climate mitigation. Culturally, NBS in selected agroecosystems help preserve and enhance the cultural landscape, fostering social interactions within communities. By improving the quality of water resources and the overall ecological state, previously abandoned or inaccessible areas can be revitalized. This revitalization allows for local tourism and recreational activities such as birdwatching and kayaking, which in turn supports local associations and businesses in the tourism industry. Additional economic benefits include NBS that creates sustainable practices of agriculture that can lead to long-term stability. NBS in these areas that improve water quality also contribute to human health benefits as access to cleaner water reduces the incidence of waterborne diseases, while natural landscapes provide spaces for exercise, relaxation, and social interaction.

ecology

1. Carbon storage
2. Natural corridors
3. Nature development
4. Habitat protection
5. Climate resilient landscape

cultural

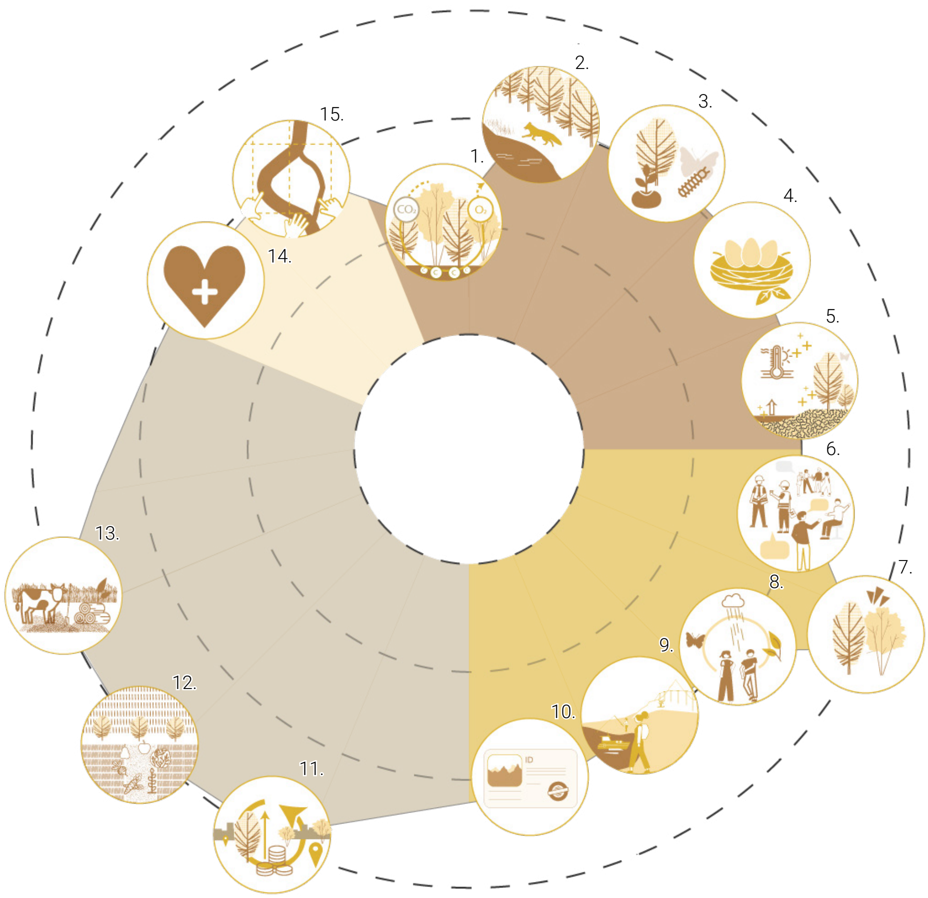
6. Social interaction
7. Cultural landscapes
8. Education
9. Tourism, sport and recreation
10. Landscape identity

economy

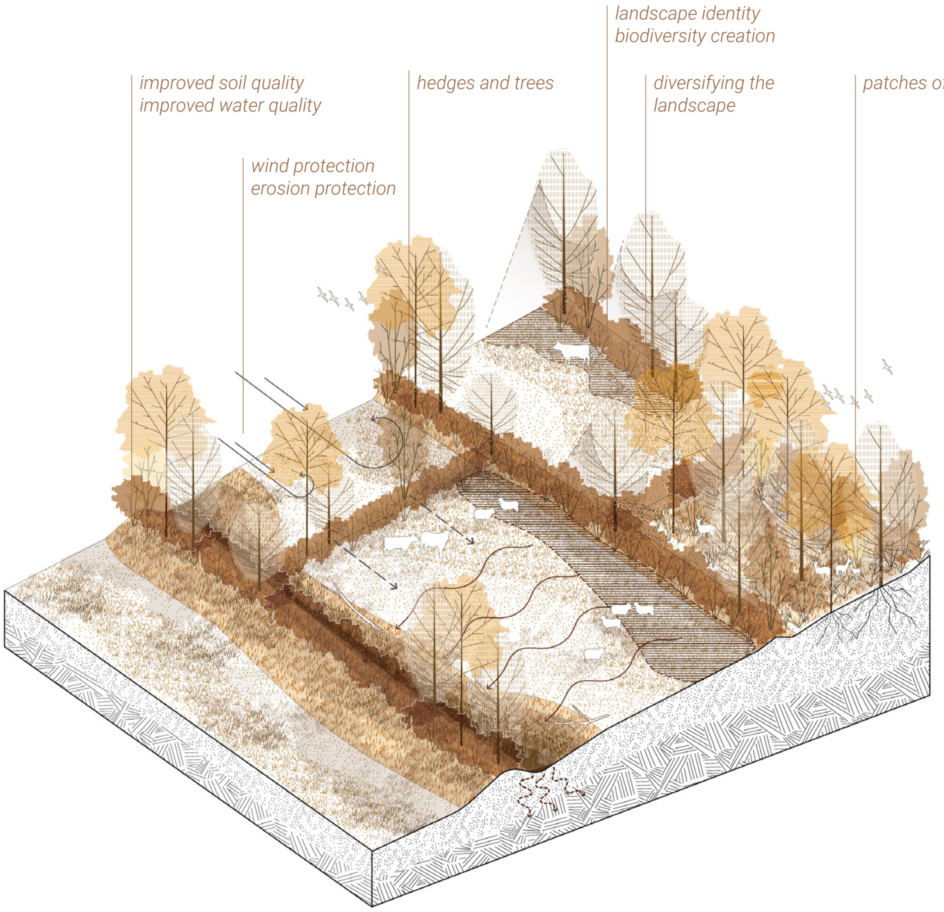
11. Local jobs and green economy
12. Productive landscapes
13. Resources production

other

14. Human health
15. Integrated water management



Specific nature-based solutions

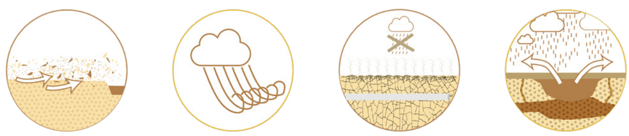


HEDGES AND BOCAGE STRUCTURE

TYPE OF INTERVENTION

R Restoration

HAZARDS



Soil erosion | Strong wind | Agricultural drought | Flood

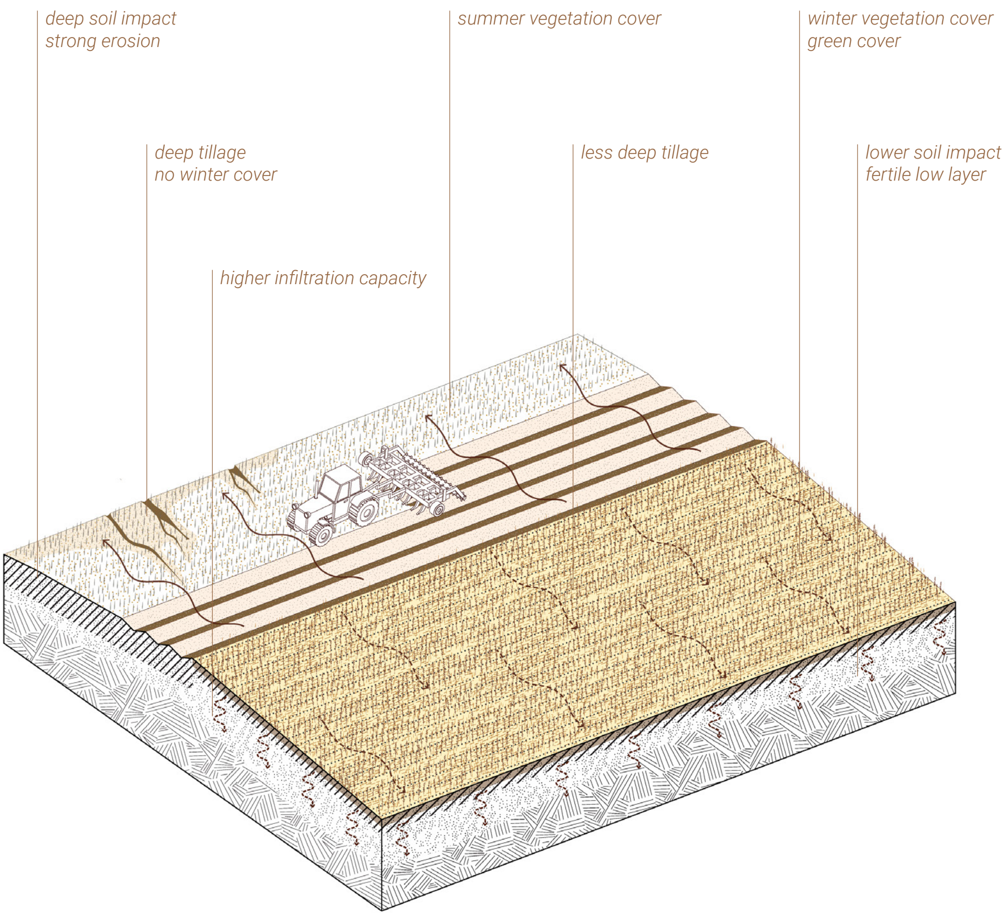
DESCRIPTION

The bocage landscape dates to the 18th century and is therefore an example of a very old NBS. This historical patchwork consists of an irregular network of small fields and meadows, enclosed by a system of hedges, wooden banks, and trees. The network also acts as a microclimate and protects the (agricultural) land against wind, water and erosion in more hilly areas. The network of hedges and wooden banks also functions as an ecological corridor between nature areas, such as forests, and is often used as a reproductive site for local fauna.

MAIN FUNCTIONS AND BENEFITS

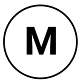
Drought mitigation | Landslide and erosion regulation | Pluvial flood regulation | Water pollution regulation

Landscape identity | Natural corridors | Productive landscape | Climate resilient landscape



CONSERVATION TILLAGE

TYPE OF INTERVENTION



Management

HAZARDS

Soil erosion

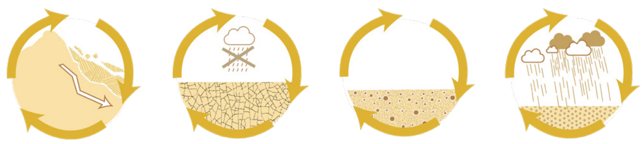
Landslide

Flood

DESCRIPTION

Conservation tillage or 'no-till farming' is an agricultural method characterized by a significant reduction in the frequency and intensity of tillage operations. This includes the practice of leaving the remains of last year's crops in the field throughout the cycle of planting next year's crops This approach is especially useful to reduce the risks of soil erosion. Additional benefits are the improvement of soil health by minimizing soil disturbance and the reduction of runoff water (e.g. stormwater). Many farmers combine no-till farming with more natural practices of herbicide and fertilizer use. Overall, this approach aims to contribute towards a sustainable agricultural system.

MAIN FUNCTIONS AND BENEFITS



Landslide and erosion regulation

Drought mitigation

Soil pollution regulation

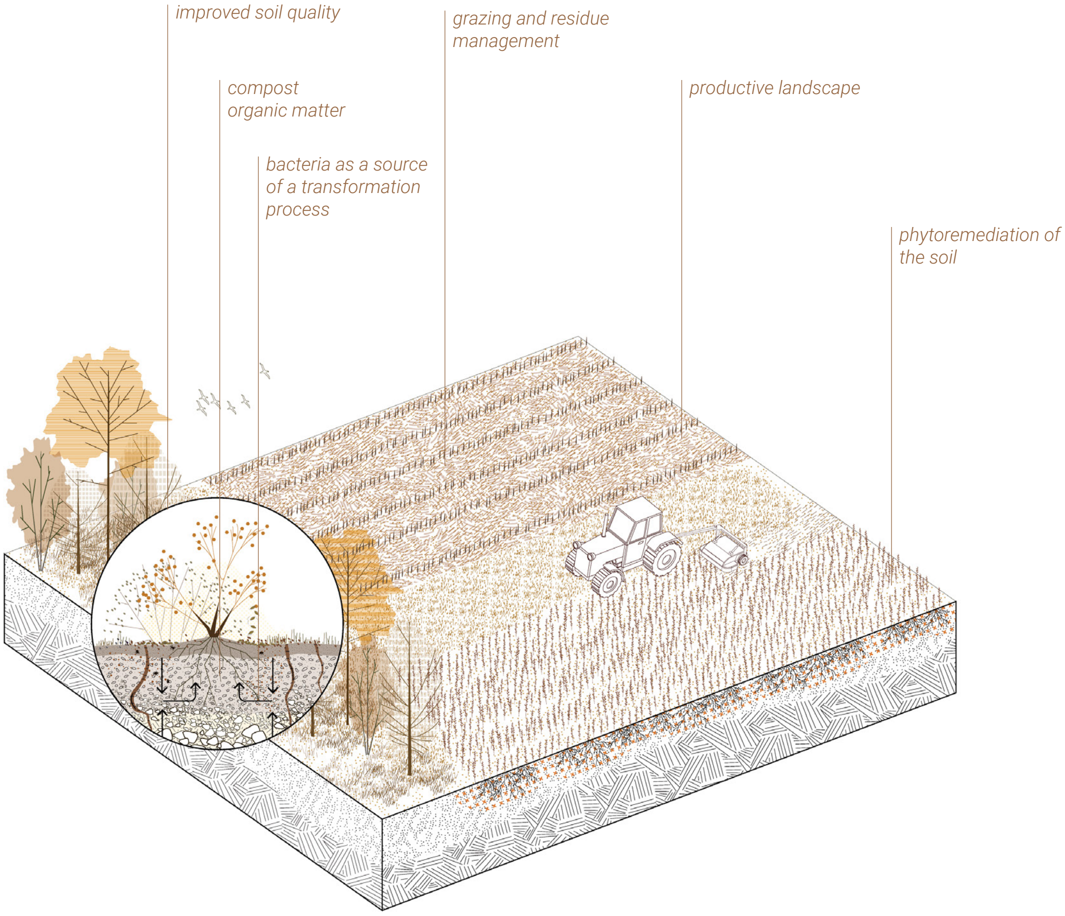
Pluvial flood regulation

Nature development

Biodiversity

Productive landscape

Education

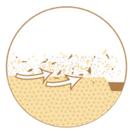


SOIL CARE

TYPE OF INTERVENTION

M Management

HAZARDS


Soil erosion


Agricultural drought

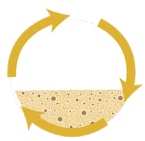

Heat stress

DESCRIPTION

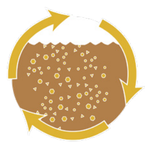
The approach of soil care refers to a wide range of planting methods that improve the physical properties of the soil, such as water retention capacity, permeability, water infiltration, drainage, aeration and structure. In general, it aims to provide a better environment for root penetration and growth. For example, the use of different soil micro-organisms can improve the drought resilience of plants, and the use of organic matter enhances soil structure and acts as a reservoir for nutrients. Soil care is the foundation of sustainable agricultural environment.

MAIN FUNCTIONS AND BENEFITS


Drought mitigation


Soil pollution regulation


Pluvial flood regulation

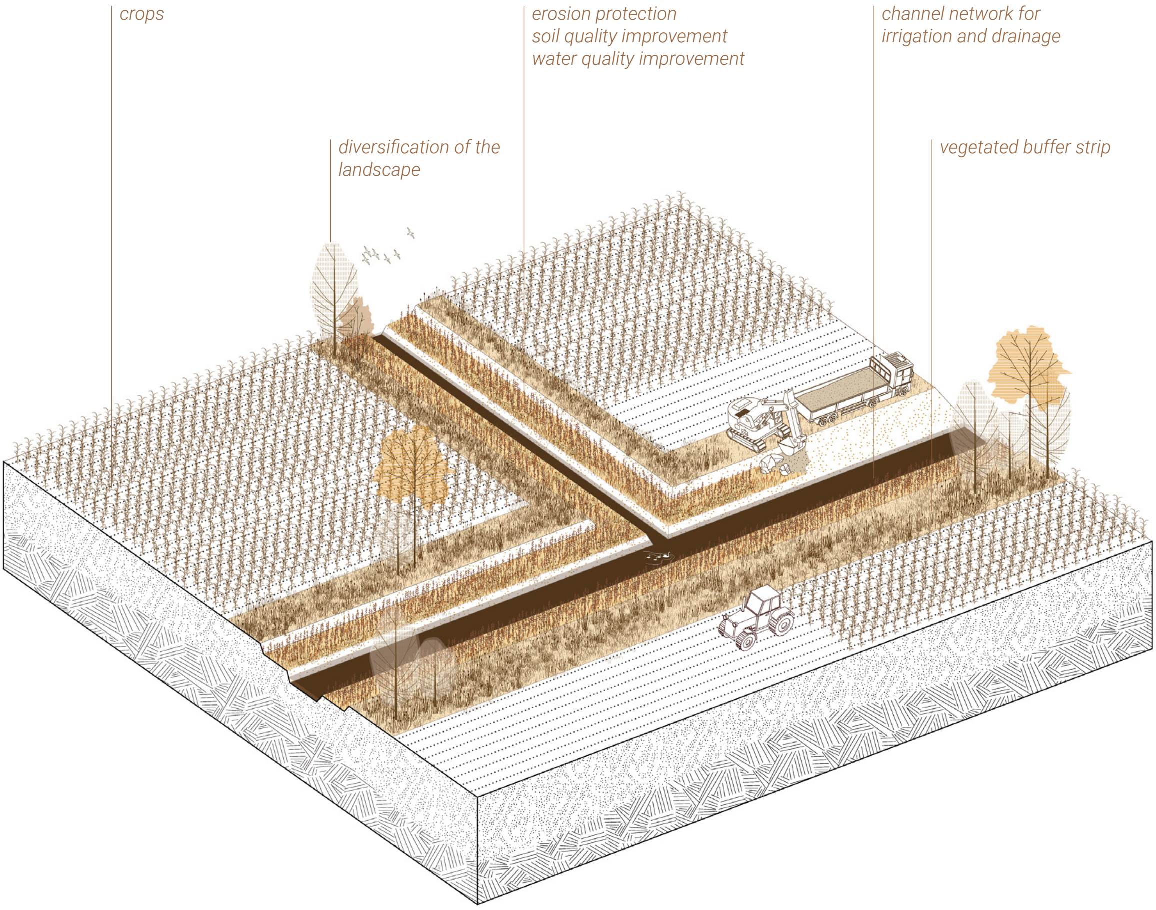

Water pollution regulation


Productive landscape


Resources production


Biodiversity


Human health



VEGETATED BUFFER STRIPS

TYPE OF INTERVENTION

C Creation

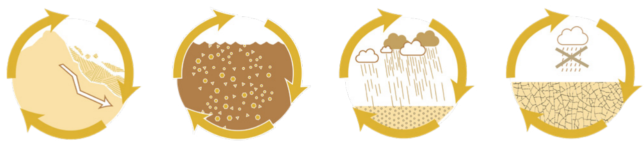
HAZARDS

Soil erosion | Agricultural drought | Eutrophication

DESCRIPTION

Buffer strips are vegetated areas consisting of bands of multi-annual herbaceous species or tree and shrub species planted at the edges of cultivated fields or along a secondary canal network. In many countries buffer strips are required between agricultural land and water bodies, such as lakes, rivers and canals. They have the advantage of being reversible, sustainable over time and synergistic with other measures. These vegetated strips limit soil erosion, trap sediments, and enhance the filtration of potential nutrients or pollutants flowing into adjacent water bodies. Therefore, they contribute to improving the water quality and the ecological status of rivers, lakes and surrounding areas.

MAIN FUNCTIONS AND BENEFITS



Erosion regulation | Water pollution regulation | Pluvial flood regulation | Drought mitigation

Natural corridors | Habitat protection | Productive landscape | Climate resilient landscape

NBS case studies

5.1

Agroecology practices on Can Genover farm

Alt Amporda, Girona, Catalonia, Spain; 2010 - 2014

The 'Can Genover farm' and its management are a prime example of how the farming and livestock sector can also be adapted to the effects of climate change via a strategy which promotes quality, resilience and organic production. Some solutions that have been developed are the use of a cattle breed that is well-adapted to the climate, an extensive grazing and residue management (Voisin-style), an overall agroecological management of the entire estate (265 ha), as well as the collection and re-using of water in small aquatic ecosystems (ponds).

Applied nature-based solutions:

- Use a cattle breed that is adapted to the climate
- Implement an extensive grazing management
- Apply a cropping management by crop rotation and minimal cultivation
- Restore and maintain hedges and flower concentrations
- Improve water management by creating ponds

Extensive grazing (OPCC-CTP, Biograssfed farm)

Hazard: water scarcity, droughts, erosion

Main stakeholders:

- Spanish Society of Organic Farming (SEAE)
- Ministry for Ecological Transition
- Biograssfed

Links: Biograssfed, OPCC, PHUSICOS

5.2

Soil and water conservation practices to prevent drought events

Alentejo, Portugal; 1990 - ongoing

Alentejo is a semi-arid region dedicated to agriculture and forestry. Herdade do Freixo do Meio is an organic certified farm of 440 hectares that carries out the montado, a multifunctional agro-silvo-pastoral system of cork and holm oak trees combined with pastures, and cereal or forage agriculture. An example of a sustainable measure is a farmer-made organic liquid fertilizer rich in bacteria introduced in drip irrigation. The farm organizes training courses on ecological management and ecological landscape design.

Applied nature-based solutions:

- Apply a grazing and residue management
- Soil care by sustainable fertilizer and organic mulch
- Create a sustainable irrigation and drainage system by contour ditches
- Apply conservation tillage practices
- Apply agroforestry and vegetated filter strips
- Create a sustainable drainage system by contour ditches

Autochtone animal breeds (Diogo Miranda)

Hazard: agricultural drought, meteorological drought, soil erosion

Main stakeholders:

- Farmers and consumers of Herdade do Freixo do Meio farm

Links: OPERANDUM, article Climate ADAPT, article Ecological Engineering

5.3

Restoration of windbreaks to prevent soil erosion and improve land productivity

Dedoplistskaro, Georgia; 2009 - 2019

As part of the “Sustainable Management of Biodiversity, South Caucasus” and the “Integrated Biodiversity Management, South Caucasus” programs, 11 km long windbreaks were rehabilitated or newly established in Georgia, with fruit trees and shrubs planted in 10 m wide bands. Restoration of windbreaks helps to protect the area by reducing moisture loss and wind velocity up to 200 meters into arable land. In addition, it increases timber production and provides refuge areas for plant species, birds, and small mammals.

Applied nature-based solutions:

- Restore hedges and shrubs
- Implement windbreaks by planting trees
- Use windbreaks to improve soil care
- Apply land management and improve resilience

Hazard: agricultural drought, soil erosion, strong wind

Intact windbreak in Georgia (Panorama solutions, photo © E.C.O. Kirchmeir)

Main stakeholders:

- Deutsche Gesellschaft für Internationale Zusammenarbeit
- State Research Center for Agriculture (under the Georgian Ministry of Agriculture)
- Friends’ Association of Vashlovani Protected Areas
- Local farmers

Links: OPERANDUM, Panorama Solutions

5.4

Smart soil production in climate-smart urban farming precinct

Ìzmir, Turkey; 2019 - 2021

Smart soil holds the key not only to improving agricultural productivity, but also making significant contributions to climate mitigation thanks to a substance called 'biochar'. In a climate-smart urban farming precinct there will be smart soil production areas targeting dense urban areas, poor with soil and leftover spaces near built residential districts. By returning carbon to the soil on a massive scale, scientists and researchers believe that an effective solution to climate change is readily available in our soils.. A field experiment has been carried out for two years in an agricultural soil in Sasali Natural Life Park.

Applied nature-based solutions:

- Soil quality improvement.
- Food quality improvement.
- Water management
- Crops production improvement
- Carbon storage

Smart Soils (İzmir)

Hazard: agricultural drought, soil pollution, water pollution

Main stakeholders:

- Ìzmir Municipality
- Local farmers
- Agrifood manufacturers
- NGOs

Links: URBAN GreenUp Solutions

Guidelines

SCALE AND IMPACT

The scale of application and the related impact ranges from the scale of the individual farmland to larger areas that encompass the river basin, and ultimately to the national and European scale when carrying out required monitoring according to the Habitat Directive. In general, NBS in these ecosystems are suitable for all areas where agricultural pressure is considered strong. The NBS are very versatile and, if properly calibrated, they can also be successfully applied in areas characterized by different problems and needs. For example, NBS interventions in the agricultural area around lake Massaciuccoli highlight how measures can be implemented individually or in combination. Implementing at the farm scale also resulted in positive impacts regarding the local farmers who were willing to take an active role in becoming part of the NBS construction and maintenance process, contributing with their own knowledge and skills in land management.

ECONOMIC COST

Estimating costs in especially agroecosystems is a challenge as it includes estimating the costs of the selected plants (e.g., trees, shrubs, local vegetation), planting the vegetation, potential costs for the land as well as revenue lost from replacing the farming or gazing area. Further to these costs is the future cost of maintenance. Earlier reported costs of buffer strips are estimated at 400-800 €/ha to establish the buffer strips and an annual cost of 125-230 €/ha (EC, 2006).

ENVIRONMENTAL CONDITIONS

Interventions to improve the surface water network level (e.g., grassing of canal banks, construction of buffer strips or sedimentation basins) can be adopted in most of the lowland areas. These interventions can be particularly significant when the geological and geomorphological setting of the areas favor high rates of subsidence due to the presence of peat and clay. The adoption of NBS can help all areas with similar conditions of vulnerability towards soil compaction, erosion and particle transport.

The conditions that should be present when adopting similar methods are:

- Depressed, flat or low-hilly areas.
- Soils with a high organic content (i.e., peat, clay, silt).
- Companies that practice an intensive agriculture oriented towards the cultivation of cereals, and industrial crops that leave the ground bare during the period between crops.
- Cultivated areas immediately upstream of densely populated areas and with limited capacity to absorb flood events.

TECHNICAL CONDITIONS

The use of NBS is becoming more accepted in farming communities and, as a result, makes it easier for farmland owners to implement such solutions. The selection of areas and canals suitable for the application of NBS must consider several factors including the type of soil , and agricultural crops as well as the characteristics and slope of the irrigation canals. The availability of terrain data is also important and information from remote sensing techniques (LiDAR, UAV, GNSS) or topographic levelling surveys are useful After the NBS are implemented, a monitoring system including the chemical-physical parameters of water and soil is needed to evaluate the effectiveness of the measures and to quantify the environmental and ecosystem improvement.

SPECIFIC CHALLENGES

The main challenge is represented by the extension of NBS and the possibility to overlap with productive agricultural areas. This aspect has a particular impact since it can lead to a decrease in land usage compromising the relationships with farmers.

Improving the cooperation and the relationship with farmers is essential for the implementation of NBS. The vegetative cycles of the herbaceous species planted in the agricultural landscape must also be considered in relation to the sowing and harvesting periods of the farm's production schedule. For this reason, it is necessary to ensure this expertise is included by someone who is very familiar with the local agricultural reality and who knows the farmers. Finally, securing the necessary permits for implementing the NBS can be another challenge. Bureaucratic processes may require time, and therefore can be perceived as a discouraging factor for implementing NBS by the interested parties.

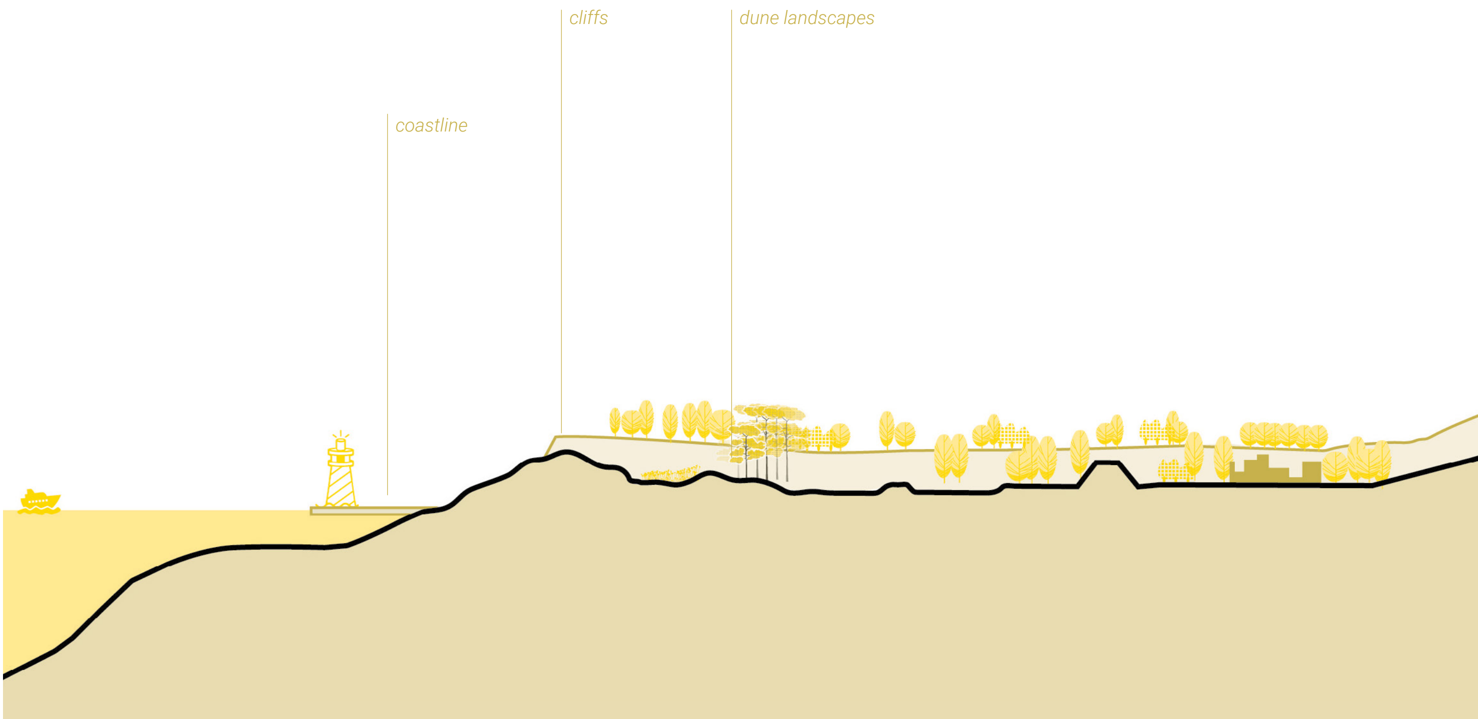
C6. Coastal lands

Reinforcing the threshold between sea and land

The coastal ecosystem is the interface between land and ocean whose boundary limits usually range between 50 meters below mean sea level and 50 meters above the high tide level (Alcamo et al., 2003) and includes different types of marine habitats such as mangroves, coral reefs, seagrass beds, and estuaries. According to JRC (2020), the definition encompasses all marine waters, including waters at the land/sea interface with salinity higher than 0,5%. Rivers that flow from the mountains to the ocean also play a significant role and can lead to fluctuations in temperature, salinity, and turbidity in coastal habitats. The mixing between freshwater from rivers and saltwater from the ocean generates transitional water areas characterized by an intermediate salinity (brackish water). These transitional waters include coastal wetlands (e.g. saltmarshes, salines, and intertidal flats), river estuaries, and lagoons (i.e. shallow water bodies with a highly restricted connection to the ocean). A marine salinity regime is typical of marine inlets such as fjords (i.e. elongated and deep inlets of glacial origin), and embayments (i.e. shallow systems with no glacial origin).

Since the coast represents the boundary between land and ocean, this ecosystem has great value both in terms of biodiversity and socio-economic activities that include recreational activities (e.g., beach tourism and birdwatching) and livelihoods (e.g., coastal aquaculture and fishing). This richness of opportunities has attracted many people to live along the coast. According to JRC (2020), approximately 40% of the EU's population live in coastal areas and for them the seas and oceans are linked with culture, identity and a sense of belonging. However, decades of overfishing, discharge of nutrients, contaminants and litter have led to a rapid decline of conditions and thereby increasing their vulnerability to the growing pressure of anthropogenic and climate disturbances. These disturbances can increase the risk of extreme hydro-meteorological events endangering the flora, fauna, and population that live in coastal habitats.

Several EU and global policies aim to establish a sustainable management of the coastal ecosystem such as the Marine Strategy Framework Directive, Integrated Maritime Policy, Water Framework Directive, Bathing Water Directive, Birds and Habitats Directives, Floods Directive, Directive on Environmental Quality, EU Biodiversity Strategies to 2020 and to 2030, Invasive Alien Species Regulation, as well as the 2030 Agenda for Sustainable Development.

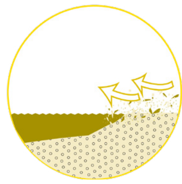


Hazards

TThe coastal ecosystem is exposed to several hazards occurring at the interface between land and ocean (IRDR, 2014; Debele et al., 2019). The most common hazards are coastal floods and storm surges that occur when tidal changes, thunderstorms, hurricanes, or rapid changes in atmospheric pressure result in higher-than-normal water levels along the coast. The high water levels affect the natural habitats as well as anthropogenic activities by temporarily submerging them. submerged. The action of waves, winds, and tides can result in coastal erosion that causes temporary or permanent loss of sediments or landmass. Cliffs are also exposed to soil erosion and landslides due to surface-water runoff. Floods and erosion can expose transitional water to a larger amount of saltwater or determine saltwater intrusion into fresh and groundwater. Salt-wedge intrusion occurs when saltwater intrudes the estuaries and can extend up the river for tens of kilometers affecting biodiversity and water resources essential for livelihood and agricultural activities. This phenomenon is exacerbated by low river flows due to hydrological drought. The ecological state of coastal habitats is also affected by eutrophication which leads to algae blooms and oxygen deficiency.

Coastal flood

Storm surge

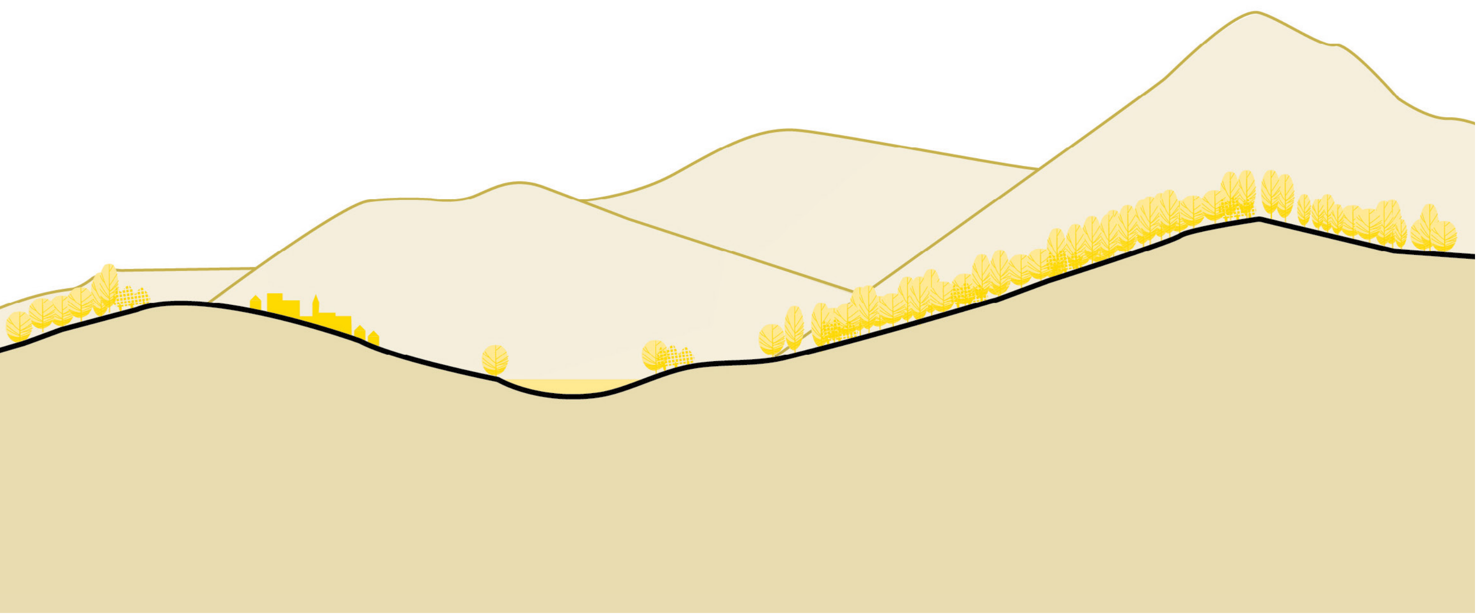


Coastal erosion

Drought

Eutrophication

Strong wind



A landscape synthesis

Coastal landscapes can have quite different spatial configurations, ranging from dune corridors over salt marshes or mangrove forests to (vegetated) cliffs. The fragile interface between sea and land is subject to various dynamics and faces different types of challenges, especially in relation to climate change and sea level rise. NBS can be strategically implemented to preserve the diverse qualities of this ecosystem. The landscape synthesis drawing on the opposite page illustrates this, while they are also described below following the four NBS approaches.

RESTORATION
The human occupation of the coastlines over time has disrupted many of the natural processes and introduced often harsh infrastructures. Several actions to restore a more natural coastline can be identified. The hydrology can be restored through the clearing and reconfiguration of the seashores, by removing structural artificial elements or by setting back estuarine defenses. The storage of the water system will be enhanced in this way.

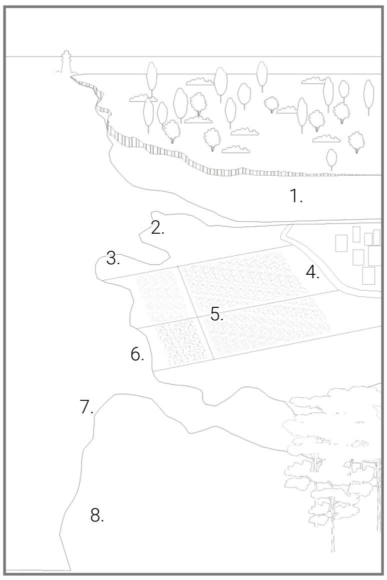
Restoration of the different natural coastal landscapes is crucial to reinforce the overall resilience. Salt marsh restoration can contribute to flood protection and biodiversity enhancement, while mangrove restoration reduces flood risk and regulates saline intrusion. Dune restoration and beach nourishment imitate the natural sediment movement and allows for natural flood protection while reinforcing the very particular landscape corridor and ecosystem of the dunes.

PROTECTION
Urban environments in proximity to the coastline are often protected by dike infrastructures. These can also be reinforced with natural transversal elements that can break the seawater flow before arriving at the dike, for example using live pole structures, overlapping crib walls, or sand reinforcement. In locations without existing dike protection, new sustainable dams can be constructed out of permeable structures and natural materials like rocks.

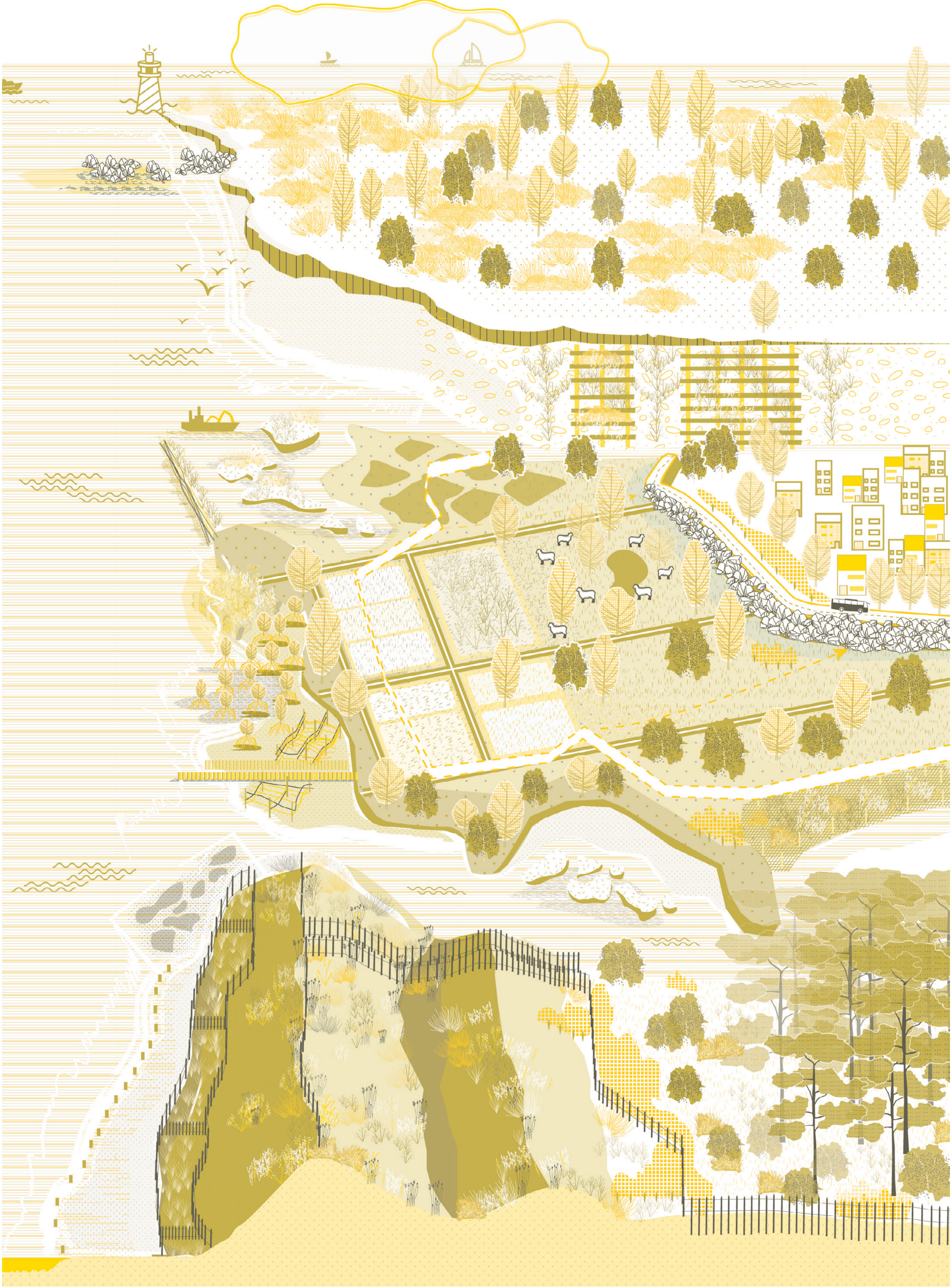
CREATION
In certain areas, the creation of new dune landscapes can help to mitigate sea level rise and coastal erosion. These dunes can be more effective than infrastructural protection and can contribute to the natural coastline. Apart from dune structures, artificial reefs and submerged structures can also help to reduce coastal erosion, while promoting marine life and biodiversity.

Finally, different slope stabilization techniques can also be implemented on the higher coastal areas like dunes and cliffs: vegetating through dense planting or planting mats, live pole drains, crib walls or palisades. They all contribute to a (planted) natural coastline.

MANAGEMENT
A strategic vision on the integral management of the coastal landscape and the solutions to mitigate the different hazards is necessary to create a territorial coherence. The balance between protection of inhabited coastlines and natural coastal ecosystems must be meticulously defined. Apart from the management of these different ecosystems, specific sedimentation management through seabed landscaping, dredging and sediment removal is necessary. This helps to anticipate coastal erosion and flooding.

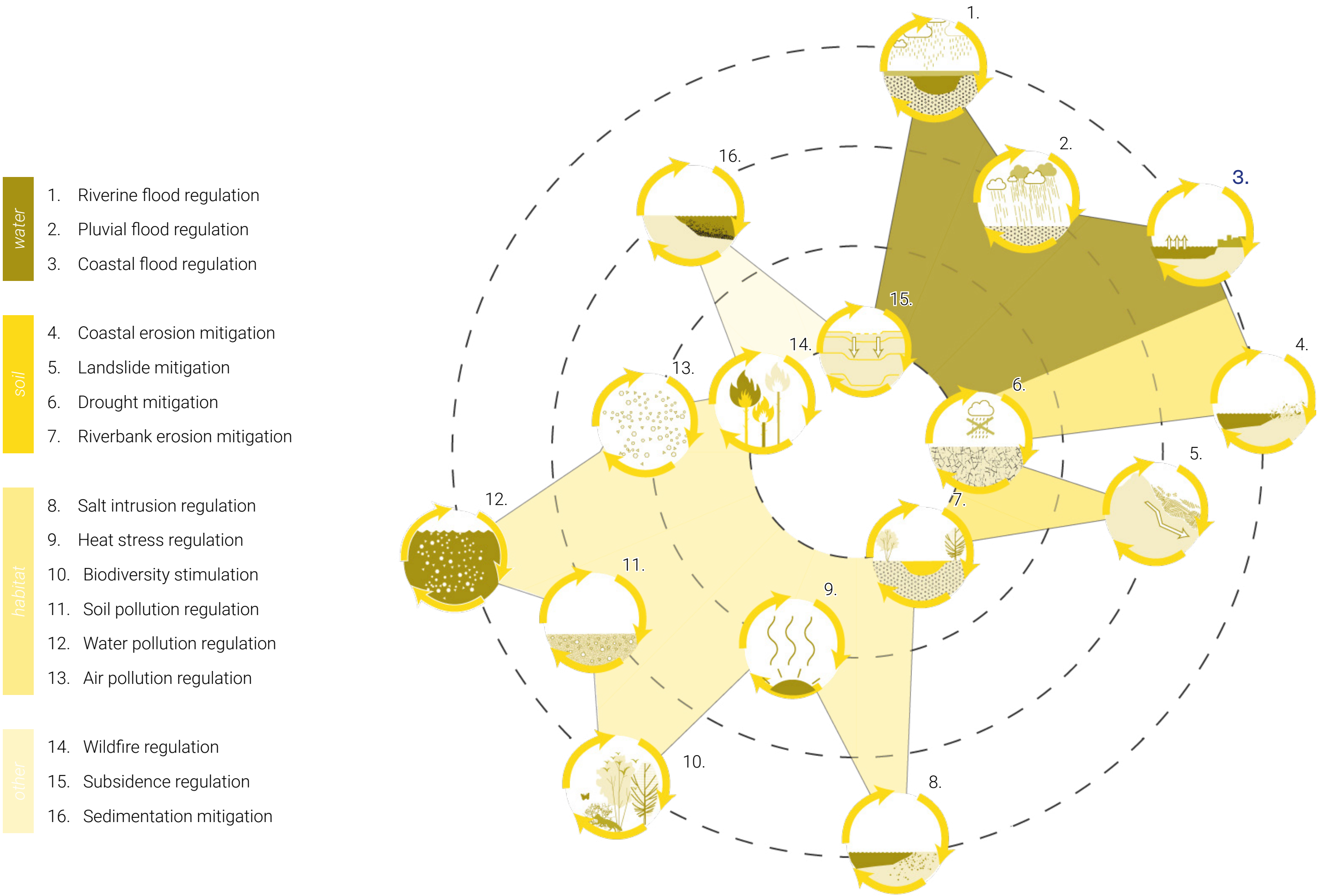


1. Vegetating the shoreline
2. Sedimentation management
3. Dike reinforcement
4. Restoring the hydrology
5. Salt marsh restoration
6. Sustainable dams
7. Artificials reefs and submerged structures
8. Beach nourishment and dune restoration



Functions

NBS interventions offer several functions that provide regulation of potential hydro-meteorological hazards in the coastal ecosystem. Coastal floods and storm surges are mitigated by the construction or restoration of natural barriers both over the land (e.g., mangroves, sand dunes, and natural sea walls), or in the ocean (e.g., coral and oyster reefs, seagrasses, and saltmarshes). These solutions reduce the wave amplitude and energy leading to a reduction of the flooded area and can be combined with already-existing grey solutions to provide further protection (e.g., dike reinforcement). By protecting the coast from wave action, these NBS reduce coastal erosion. The impacts of coastal erosion can be also lessened by replacing the lost sediment (e.g., beach nourishments). Since nourishments and dunes are made of sand, they are also exposed to erosion by waves and winds. To stabilize these sand structures, they are usually combined with the restoration of native seashore vegetation. Plant roots can reinforce the soil, preventing also erosion (e.g., high-density planting). Other techniques stabilize slopes through anchors (e.g., live ground anchors), timbers and live branch cuttings (e.g., live crib walls). Cuttings and willow fascines are used to fill ditches and create natural drainage systems like live pole drains. Erosion control is also essential in transitional habitats whose health depends on hydrology and sediment dynamics. Mangroves, salt marshes, and wetlands reduce water flow enabling sediment deposition and improving water quality. This deposition allows the vertical accretion of transitional habitats. However, an excess of sediments can choke these habitats losing their open water areas. Sediment-management techniques facilitate finding a balance in the amount of sediment by applying: 1) sediment removal to improve water circulation when the amount is too high, and 2) mechanical re-introduction from rivers or permeable structures that trap sediments when the amount is too low. The preservation of vegetation is essential to absorb nutrients from the water and the bottom sediments reducing eutrophication. The restoration of riparian vegetation in estuaries can also promote groundwater recharge contributing to the reduction of saltwater intrusion. Halophytes are planted in salt-wedge estuaries to directly absorb salt.



Benefits

NBS interventions in the coastal ecosystem can reduce damage to infrastructures, properties, and socio-economic activities due to a lower occurrence and magnitude of hydro-meteorological hazards leading to direct benefits (i.e., market benefits). Furthermore, the protection, sustainable management, restoration, or implementation of habitats and/or natural features along the coast by implementing NBS provide environmental, social, and economic indirect benefits (Ommer et al., 2022).

Benefits in the coastal ecosystem include:

- Carbon storage, as tidal wetlands are important components of the terrestrial biological carbon pool removing carbon from the atmosphere by photosynthesis of aquatic plants and the burial of organic sediments
- Biodiversity, as the construction of dunes protect freshwater from saltwater intrusion and a potential loss in biodiversity. For example, a dune in Bellocchio Beach would protect the freshwater lagoon from saltwater intrusion because of flood events, with total biodiversity benefits of 840,000 – 5,520,000 euros every year (OPERANDUM Deliverable D5.3, 2022)
- Well-being because the preservation and restoration of beaches and other habitats along the coast can foster recreational activities (e.g., water sports) with advantages on the physical and mental health of the citizens
- Public participation since stakeholder engagement can foster a sense of ownership between citizens facilitating the maintenance of the NBS interventions over time, increasing trust in decision-making, local knowledge, and social cohesion
- Finance and economy. The preservation of coastal ecosystems by using NBS interventions can result in 1) balanced management of fish and invertebrate stocks providing livelihoods through fishing activities, 2) local tax revenue through the provision of aesthetic landscapes that can attract tourism and increase property value, 3) green job and business creation through the involvement of citizens during the NBS implementation, maintenance, and monitoring phases

ecology

1. Carbon storage
2. Natural corridors
3. Nature development
4. Habitat protection
5. Climate resilient landscape

cultural

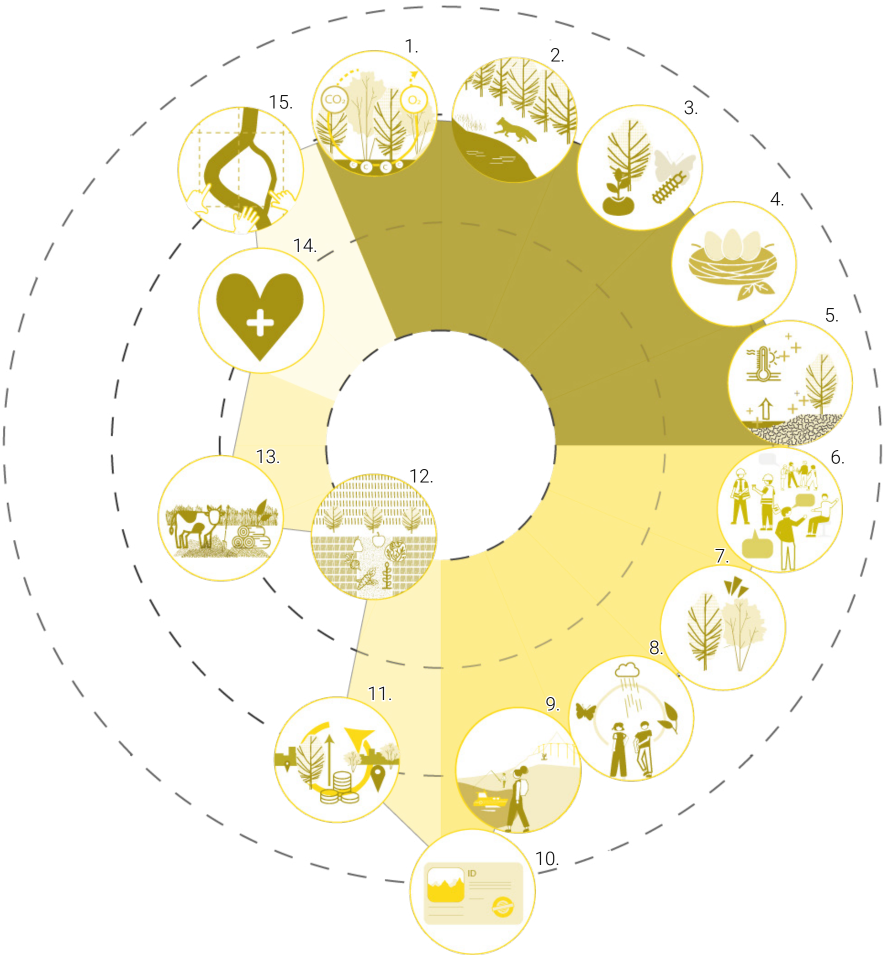
6. Social interaction
7. Cultural landscapes
8. Education
9. Tourism, sport and recreation
10. Landscape identity

economy

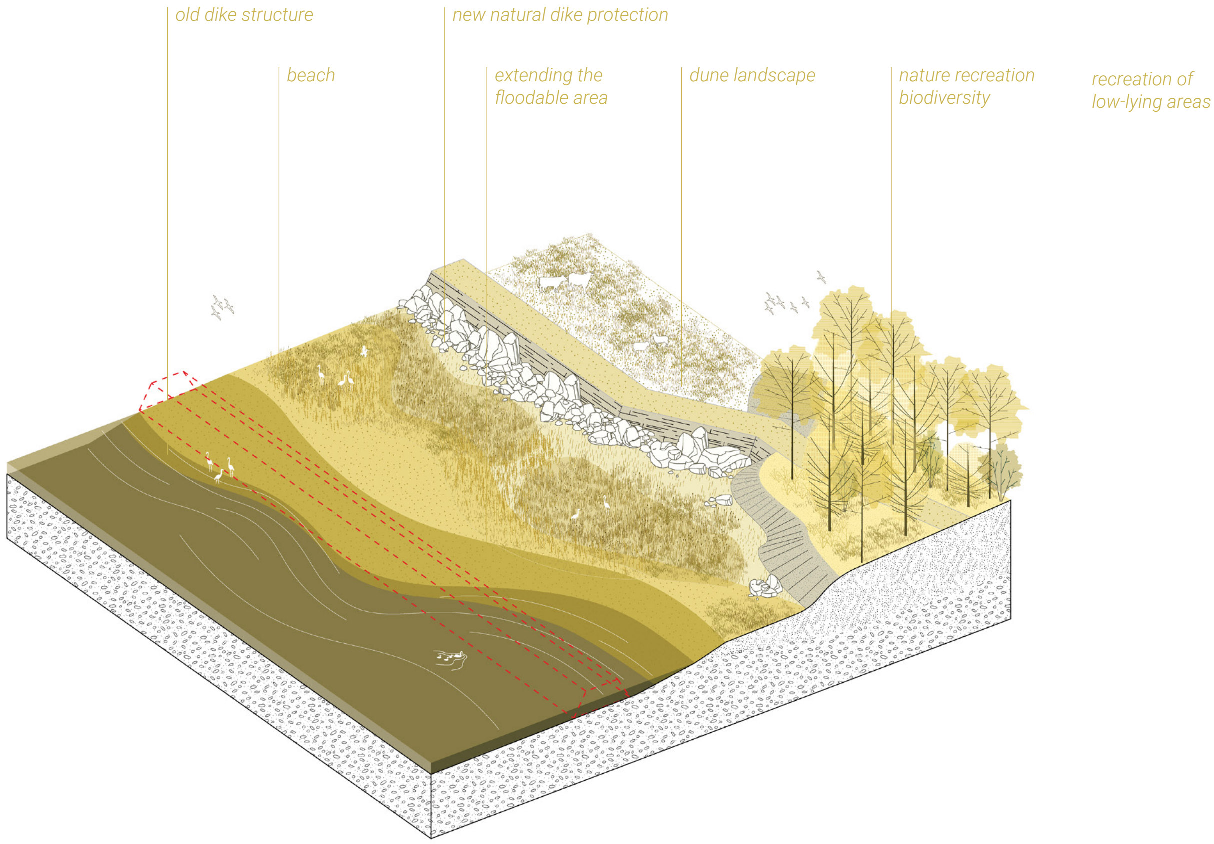
11. Local jobs and green economy
12. Productive landscapes
13. Resources production

other

14. Human health
15. Integrated water management



Specific nature-based solutions

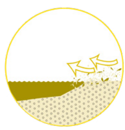


DIKE MODIFICATION

TYPE OF INTERVENTION

P Protection

HAZARDS


Coastal erosion


Coastal flood


Storm surge

DESCRIPTION

Artificial dike infrastructures in proximity to the shoreline are obstructing the ecological continuity between the sea and the shore. The ecological connections can be restored by removing these dikes and providing a more natural protection system on land. Pushing back the protective infrastructure allows for a broader floodable area and more diverse coastal ecosystems. A new dike can be built up out of natural materials like rocks, sand, and planted hills.

MAIN FUNCTIONS AND BENEFITS


Coastal erosion mitigation


Sea level rise adaptation

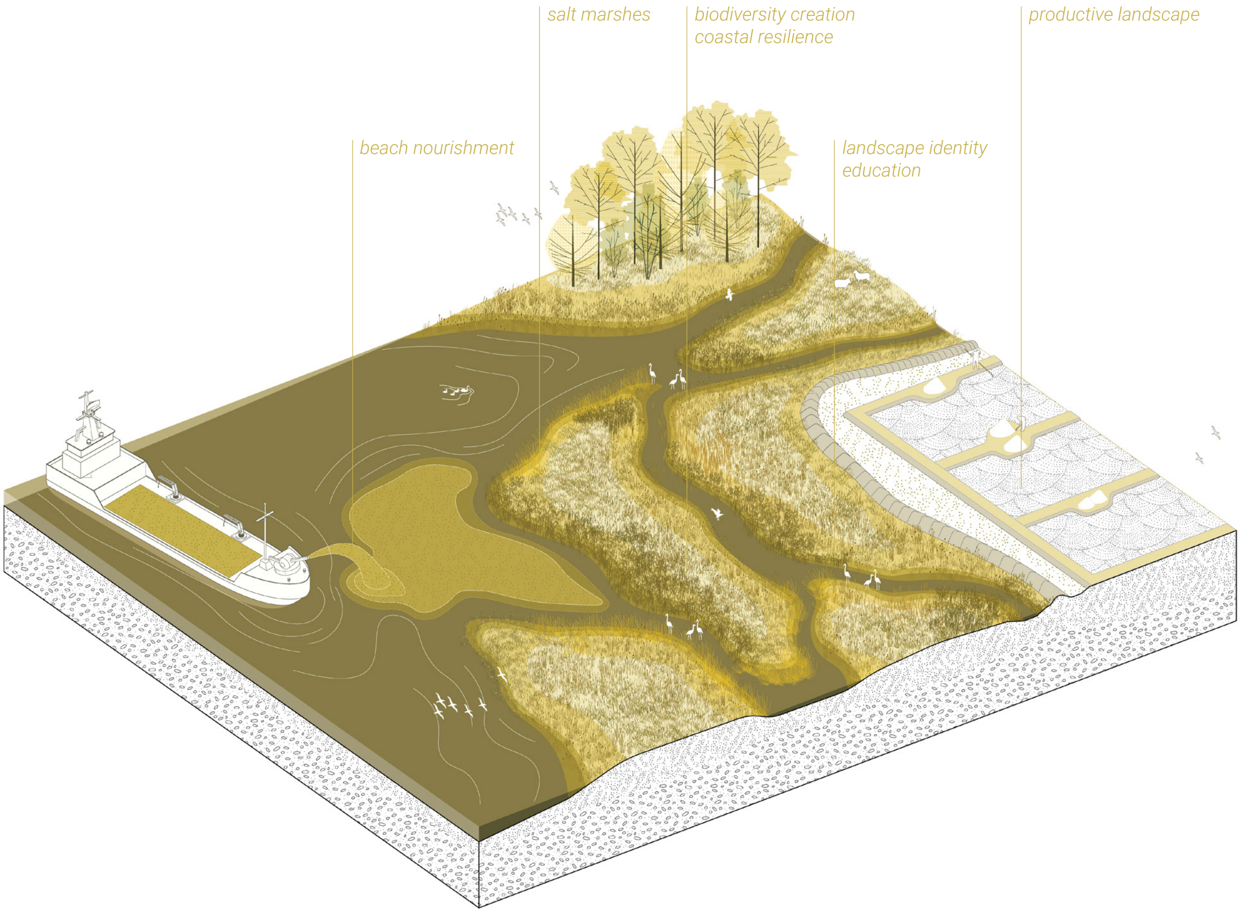

Biodiversity stimulation


Nature development


Climate resilient landscape


Habitat protection


Tourism and recreation



SALT MARSH RESTORATION

TYPE OF INTERVENTION

R Restoration

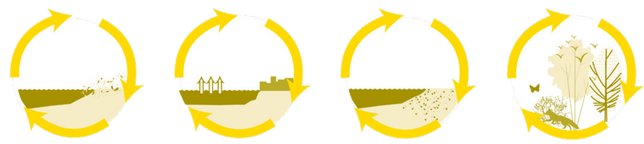
HAZARDS

Coastal erosion | Coastal flood | Storm surge

DESCRIPTION

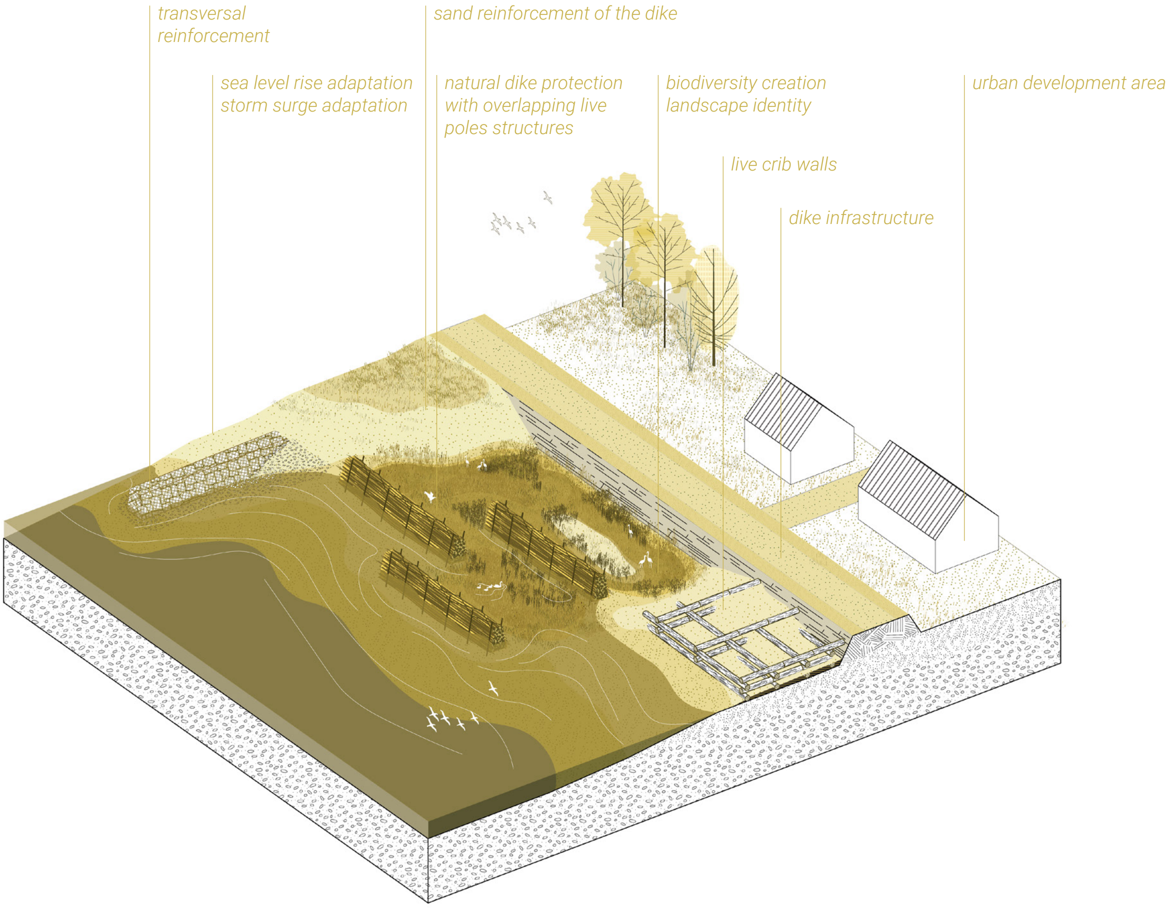
Salt marshes exist in synergy with the sea and its dynamics. Areas where human actions disrupted this natural connection in the past may be strategically recovered by removing obstacles, restoring the tidal influence, and sediment flows to enable the conditions for salt marsh development. One common approach used in sandy shores for beach erosion is to artificially widen the beach with sand. Beach nourishment relies on feeding sand along a beach and allowing wave and tidal action to distribute it along the shore. Planting mats can facilitate the re-establishment of salt marsh species. Plants are grown on relatively dense coconut mats, where the roots can grow, before being placed in the marsh. The specific salt environment is home to a very identitarian ecosystem of plants and animals.

MAIN FUNCTIONS AND BENEFITS



Coastal erosion mitigation | Sea level rise adaptation | Salt intrusion regulation | Biodiversity stimulation

Nature development | Climate resilient landscape | Landscape identity | Local jobs and economy



DIKE REINFORCEMENT

TYPE OF INTERVENTION

P Protection

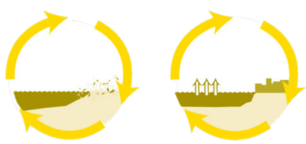
HAZARDS

Coastal erosion | Coastal flood | Storm surge

DESCRIPTION

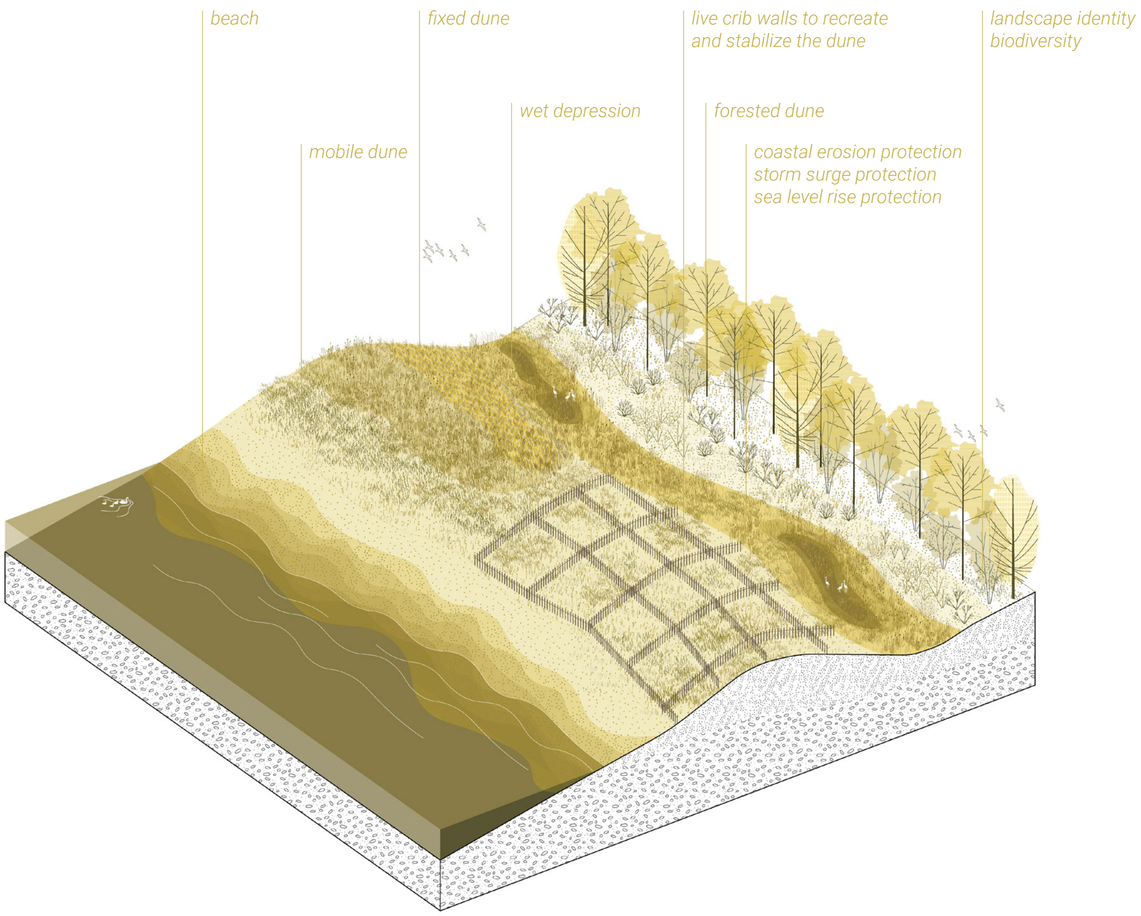
In certain areas the existing dike infrastructures must be reinforced to protect urban areas from the effects of climate change and sea level rise. This reinforcement can be built up of natural structures and materials. Transversal elements to break the strength of the seawater flow can be made of sand dunes or transversal stone breakwaters. Structures in parallel with the existing dike can be made from overlapping live poles that break the strong waves before they reach the existing dike, while introducing valuable sites for habitat development. Live crib walls can also allow coastal vegetation to grow and create a first protective layer on the outside of the dike structure.

MAIN FUNCTIONS AND BENEFITS



Coastal erosion mitigation | Sea level rise adaptation

Landscape identity | Tourism and recreation | Biodiversity | Climate resilient landscape

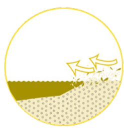


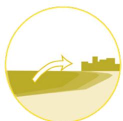
DUNE RESTORATION

TYPE OF INTERVENTION

R Restoration

HAZARDS


Coastal erosion


Coastal flood


Storm surge

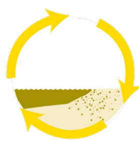
DESCRIPTION

To prevent excessive coastal retreat, a natural dune landscape can be regenerated. Such a dune landscape is built up of several specific components. A fixed and forested dune landscape is situated on the inland side. A wet depression separates this dune from the fixed and mobile dunes on the seaside. These are most vulnerable to coastal erosion and therefore need to be reinforced. After adding sand and optionally stabilizing it with fence structures, extra vegetation can help to reinforce the dune. The use of native plants and dune grasses will reinforce the landscape identity.

MAIN FUNCTIONS AND BENEFITS


Coastal erosion mitigation


Sea level rise adaptation


Salt intrusion regulation


Biodiversity stimulation


Tourism and recreation


Climate resilient landscape


Landscape identity


Education

NBS case studies

6.1

Artificial dune made of natural materials for coastal protection, Lido di Volano, Italy

Lido di Volano, Italy; 2022

Volano beach is in the Po Delta Biosphere Reserve and is strongly affected by marine erosion due to storm surges. To cope with these hazards, the researchers of the OPERANDUM project have constructed an artificial dune made of sand, wood, and coconut-fiber geotextiles with different structural solutions and coverages of the top. The dune represents a dynamic barrier that constantly undergoes small adjustments in response to changes in wind, wave, or sea level.

Applied nature-based solutions:

- Create artificial sand dunes
- Vegetate sand dunes by planting

Hazard: erosion, coastal flood, storm surge

Links: OPERANDUM OAL Italy, OPERANDUM Lido di Volano

The dune after two months from the construction, OAL Italy (OPERANDUM)

Main stakeholders:

- University of Bologna, ARPAE Emilia Romagna, RINA Consulting, IRIS SAS - Environmental engineering, NATURALEA
- Euro-Mediterranean Center on Climate Change (CMCC)
- Emilia-Romagna Region – Regional Agency for Land Security and Civil Protection - Ferrara Service,
- Carabinieri for Biodiversity - Punta Marina (Ravenna),
- Tourists and local citizens, European Commission

6.2

Habitat restoration in Titchwell Marsh reserve and protection against coastal floods and erosion

Norfolk, England, UK; 2011 - 2011

Considerable pressure from climate-induced sea-level rise leads to “coastal squeeze” where intertidal habitats are prevented from migrating landwards due to the presence of sea walls. The project in Titchwell Marsh reserve consisted in a “managed realignment” scheme in which a new wall was constructed. A breach allows the sea to enter resulting in a tidal saltmarsh that is attractive to birds and acts as sea defense. Sea defenses should be sufficient to protect the site for the next 50 years.

Applied nature-based solutions:

- Set back estuarine defences to enhance storage (sea walls, dike)
- Implement permeable structures (sea revetment)
- Restore hydrology by removing structural elements
- Restore surface wetlands (marshes)
- Maintain intertidal salt marsh beds

Titchwell marsh (Francesco Ungaro)

Hazard: coastal erosion, coastal flood

Main stakeholders:

- Titchwell Marsh Reserve Authority
- Royal Society for the Protection of Birds (RSPB)
- Visitors of the reserve
- European Commission

Links: OPERANDUM, Climate ADAPT

6.3

Saltmarsh to reduce saltwater intrusion in estuaries

Po di Goro, Italy; 2020 - ongoing

Po di Goro is in the Po Delta Biosphere Reserve. Tour- ism, agriculture, and fish farming constitutes the main economic activity. However, in case of limited river flow due to drought, salt intrusion may reach several tens of kilometers upstream damaging the ecosystem and activities. The OPERANDUM Project has conducted laboratory and modeling activities for the characterization of halophyte species (e.g., Atriplex portu-la-coides) confirming their remarkable retention capacity that allows these plants to absorb salt and store it inside their cells.

Applied nature-based solutions:

- Restore saltmarshes to decrease salt intrusion caused by drought

Hazard: hydrological drought, sea water intrusion

Links: OPERANDUM

Po di Goro, OAL Italy (OPERANDUM)

Main stakeholders:

- University of Bologna, ARPAE Emilia Romagna, RINA Con-sulting, IRIS SAS - Environmental engineering, NATURALEA
- Euro-Mediterranean Center on Climate Change (CMCC)
- Emilia-Romagna Region – Regional Agency for Land Security and Civil Protection - Ferrara Service,
- Carabinieri for Biodiversity - Punta Marina (Ravenna),
- Tourists and local citizens, European Commission

6.4

A transboundary depoldered area for flood protection and nature: Hedwige and Prosper Polders

Scheldt Estuary, Belgium and the Netherlands; 2005 - 2023

The Hedwige-Prosper polders project is part of the Belgian Sigma Plan. This integrated plan is reinforcing dikes and quay walls and opening flood areas to protect land along the Scheldt Estuary and the upstream basin against floods. In this specific project, the outer defenses of the Hedwige and the Prosper polders - low lying areas of reclaimed land - are being removed, reopening these areas to the tides. Opening these two polders provides ‘storage’ for storm surge waters, reducing the water level at Antwerp and upstream and thereby improving safety in this urban and industrial area. New estuarine intertidal areas are also created, providing space for tidal nature.

Applied nature-based solutions:

- Rehabilitation and restoration of rivers and floodplains
- Improved design of dikes and levees
- Restoration and management of coastal wetlands

Hedwige-Prosper polder (Image Landsat / Copernicus, Image ©2024 airbus, Google Earth 51o19'59N 4o14'39E Eye alt. 4.55 km , Date 6/1/2021)

Hazard: storm surges, flooding

Main stakeholders:

- Research team
- Governmental organizations (Belgian and Dutch)
- Farmers of both polders (Belgian and Dutch)
- European Commission: Interreg project Polder2C's

Links: Sigmaplan - Hedwige Prosper Polder

Guidelines

SCALE AND IMPACT

The scale of NBS interventions in the coastal ecosystem usually ranges between a few meters and a few kilometers. Single interventions that establish better coastal management, stabilize a cliff or create a barrier to reduce the impact of waves on the coast (e.g., dunes) are usually small-scale interventions (1 m - 1 km). However, the extent of these interventions can be increased by upscaling or replicating them in stretches of coastline with similar features. Since high urbanization along the coast often results in changes in land use and environmental degradation, projects that aim to restore hydrology, saltmarshes or mangroves can reach tens of kilometers.

The impact scale is usually larger than the scale of NBS interventions. As NBS are made by natural features, NBS usually interact dynamically with the surrounding areas. For instance, the sand of nourishments can be spread by waves and winds, or the restored vegetation can colonize other land plots. Furthermore, NBS can offer protection against floods and saltwater intrusion to the freshwater and urban areas located close to the coastline. An example is the plantation of halophytes into the estuaries which can absorb salt reducing the advance of salt wedges upstream.

ECONOMIC COST

The estimation of NBS economic costs is not straightforward because the quantification of costs must consider the designed lifetime of the NBS which can vary between a few years (e.g., beach nourishment) to a hundred years (e.g., live crib wall). As with grey solutions, NBS costs derive from several phases like planning, design, possible land acquisitions, baseline assessments, implementation, maintenance, and possible rehabilitation after damages from anthropogenic or hydro-meteorological events.

The total cost varies considerably with the type of NBS intervention and its scale. A single microscale intervention can cost a few thousand euros. For instance, NBS that aims to stabilize a cliff such as live ground anchors and crib walls cost about 300 and 1,000 euros per square meter, respectively (GeoIKP). On the other hand, a mesoscale hydrology restoration as for the renaturalization of the Rhône Delta (Camargue, France) reached a cost of 1.5 million euros. However, the implementation of a grey solution (e.g., a dyke system) in this area would entail a larger cost estimated at 7-13 million euros (GeoIKP). This case study provides an example of how NBS interventions are usually more cost-effective than traditional engineering solutions.

ENVIRONMENTAL CONDITIONS

One pillar of the NBS definition is to foster biodiversity and provide ecosystem services through the protection, sustainable management, restoration, or implementation of habitats and/or natural features. However, natural features need to be carefully selected because they may result in a perturbation of the involved coastal ecosystem. Before the NBS interventions, a biodiversity assessment is needed to identify invasive plants and select the most suitable native plants to achieve the project goals (e.g., deep-rooted plants against the erosion of shores and dunes). Choosing a combination of plants is more effective than using a single species, as it provides better management of pest diffusion.

The biodiversity assessment also helps to evaluate the impacts of the NBS interventions on the local fauna. For instance, sand nourishments may kill most of the benthic fauna by burial during an initial stage after the implementation. Furthermore, some species of shorebirds may be disturbed by 1) a change of salinity due to a hydrology restoration, and 2) the noise of construction activities.

TECHNICAL CONDITIONS

Several technical conditions can determine the design and implementation of NBS interventions in the coastal ecosystem:

- NBS interventions require a minimum space to be implemented. For instance, sand dune construction may not be feasible if coastal erosion has already destroyed most of the beach.
- NBS consist of more natural features that are also exposed to coastal erosion and floods. A lifetime assessment is required to understand if an NBS is feasible in a specific area.
- NBS implementation is an advanced step that occurs after a rigorous permission process that responds to local administrative authorities and citizens (i.e., local stakeholders) including their needs in a co-creation process of the NBS interventions. Since the coast is home to various recreational and socio-economic activities (e.g., beach clubs, and fisheries) that can limit the availability of space for NBS interventions, the permission process should be co-designed with stakeholders and if necessary, include land acquisitions.

SPECIFIC CHALLENGES

NBS interventions in the coastal ecosystem address to several specific challenges of our society, such as to:

- improve mitigation of climate change, and adaptation and resilience to its impacts.
- promote the conservation and sustainable use of the ocean, seas, and marine resources contributing to reach a proper management of aquatic plants, fish, and invertebrate stocks.
- offer protection against flood, eutrophication, and saltwater-intrusion events to ensure the availability of freshwater and contribute to health, livelihoods, and well-being.
- promote a sustained, inclusive, and sustainable economic growth through the preservation of marine resources and the establishment of a better balance between anthropogenic and ecosystem processes.
- promote a larger stakeholder engagement in the management of coastal habitats, and build effective, accountable, and inclusive institutions at all levels.

Learning from PHUSICOS case studies: Dynamic lower lands

Serchio River Basin

Northern Tuscany, Italy

Plantation of buffer strips (Serchio ADBS, Nicola Del Seppia)

Gentle management of the canals (Serchio ADBS, Nicola Del Seppia)

Realization: March 2019 – August 2022

Hazards: water pollution, flooding, erosion, extreme drought and water deficit, natural and anthropogenic subsidence, ecosystems and biodiversity quality impairment

Applied nature-based solutions:

- Vegetated buffer strips
- Conservation tillage (management)
- Sedimentation ponds and pits
- Applying a river management (management)

Main stakeholders:

- Land Reclamation Consortium Toscana Nord
- The Northern Apennines River Basin District Authority
- The regional natural Park of Migliarino San Rossore Massaciuccoli
- The municipalities of Vecchiano, Pisa, Viareggio, and Massarosa, farmers and citizens
- Trade associations and Environmental associations,
- Political representatives,
- Students, Researchers

Online links:

- Nature-based solutions in Europe (EEA Report 1/2021)
- The integrated system of Nature-based solutions to mitigate floods and drought risks in the Serchio River Basin (Italy)

Description

The Serchio River Basin is defined as a basin of national interest according to Italian law and is included in the Regional Natural Park of Migliarino - San Rossore – Massaciuccoli. It is designated as an area of naturalistic interest, valuable biological diversity, and of international and national importance. Furthermore, it is part of Nature 2000 network as Special Protected Area and Site of Community Importance, as well as a RAMSAR site (a wetland site designated to be of international importance). The lower part of the Serchio River includes the sub-basin of Massaciuccoli Lake. Since the beginning of the twentieth century, the territory has been characterized by a strong process of agricultural development and urbanization that has led to deep transformation.

Massaciuccoli Lake is a coastal lake surrounded by marshy areas. Since 1930, a large part of the basin has been drained for agricultural purposes by means of a complex network of artificial ditches and pumping stations forcing water from the drained areas into the lake. As the final water receptor, Massaciuccoli Lake has become a sensitive and vulnerable area, especially to nutrients (e.g., nitrates and phosphates) and sediment run-off (e.g. erosion) coming from large-scale and intensive agricultural use. Considering the ecological value of this wetland, actions have been planned to restore and preserve it. In this context, the EU Horizon 2020 PHUSICOS project (2018-2023) aimed at identifying, applying and monitoring NBS to reduce the impacts of climate change (mainly droughts and

Sedimentation basin in action (Serchio ADBS, Nicola Del Seppia)

flooding) and to increase the overall ecosystem resilience. The NBS selected for Serchio River Basin are also intended to limit soil and nutrient loss from cultivated fields and to reduce pollutant loads to the lake. NBS include: a sedimentation basin, large-scale buffer-strips combined with conservation agriculture techniques (minimum-tillage and cover-crops), and gentle management of canals. NBS are implemented through the "Living Lab" approach, a largely participative approach recognized as an efficient model for addressing environmental issues and achieving multi-functionality. The approach is based on the active involvement of stakeholders with the aim to collaborate for co-creating, validating and testing innovative solutions.

A number of chemical and physical parameters are measured in the canals and the sedimentation basin, aimed at monitoring the effects of the measures for pollution, sediment run-off and hydraulic capacity of the canals. Measurements are conducted as a continuous series from probes in the water, and by regular sampling campaigns. In addition, topographic levelling surveys, photogrammetry, and analyses of satellite data are used to monitor subsidence, conditions of the vegetation and crops, soil moisture and suspended matter in the canal waters.

Motivation for nature-based solutions

The NBS have been identified and applied for numerous reasons:

- The naturalistic value of the Serchio River Basin and the Massaciuccoli Lake
- NBS offer sustainable, reversible, multipurpose (win-win) and flexible alternatives for various objectives (synergistic)
- NBS provide improvements to natural ecosystems and biodiversity
- NBS enhance "natural capital" rather than deplete it
- NBS create possibilities for a greener, more competitive and more efficient bioeconomy

Conclusions:

The implementation of NBS in the Serchio River Basin is expected to slow down the process of discharging pollutants from the agricultural land to the lake, to contribute to the control of soil erosion, and to reduce solid transport through the canals. All together, these actions will increase the overall hydraulic resilience of the territory against flooding and water scarcity. Furthermore, socio-economic benefits are expected from the implementation such as the creation of new tourism and recreational opportunities. Finally, climate change mitigation benefits are expected. Most interventions implemented in the case study area are included in the River Basin Management Plan and the Flood Risk Management Plan of the Northern Apennines River Basin District. These plans are in accordance with the European Water Framework and Floods Directives. The solutions implemented in the case study area are expected to have a long lifetime, especially if they are properly monitored and maintained. The multidisciplinary monitoring program testing the effectiveness of the NBS implemented thus far in the Serchio River Basin supports the long-term sustainability of the interventions.

D. A way forward

D1. A transdisciplinary approach to NBS as a key to success

The approach towards nature-based solutions has much to gain from thorough cooperation between researchers and practicing landscape architects. It is necessary to bring the richness of the experiences, insights and knowledge of both around the table, aiming for a coherent and complete landscape strategy. It is usually a challenge to bring together these two approaches that can be quite different and even seemingly opposed:

- Researchers usually apply a primarily rational approach, carried out through their specific field of expertise. They often work in silos, each within their own specialization, to later present their research results and offer a panorama of all the aspects (technical, social, ecological and financial) of the proposed NBS.
- Landscape architects proceed rather by a project-oriented approach or a transversal design-research exercise at different scales. By invoking various disciplines to take into account the physical components of the territory, the landscape architects aim to produce a synthesis, where all the elements of the project are brought together in a territorial vision, where NBS are central.

These two approaches, the one more analytical and specialized and the other transversal and synthetic can in the end be very complementary. A good articulation between them can allow for remarkable progress and innovations in terms of NBS-oriented landscape interventions. If the NBS proposed are partly or entirely dealing with the natural landscape, the realization requires the intervention of a landscape architect. Apart from that, it also requires the involvement of other profiles at different levels: to define the relation between the site and society, to determine the transformations and the future functioning of the site, to establish a future maintenance strategy, however light it may be. The current challenges we are facing today, like rising water levels, heat stress, biodiversity loss, etc. require at the same time theoretical and spatial reflections and articulations. The one cannot go without the other if one aims to formulate a coherent mitigation strategy.

Often, scientific researchers tend to see practicing landscape architects as illustrators, who only enter the scene after the serious analysis and research is concluded. However, landscape architects are convinced that a design research process is the driver of transformation, being fed by various inputs and analyses. While the spatial strategy remains in the center, several peripheral considerations can influence and stimulate finetuning the proposed NBS. However, this finetuning process will not drastically change the base concept of the landscape structure.

Rather than comparing these two approaches, it is essential to imagine them working in tandem, not separately or consecutively. By interacting continuously throughout the process, a successful development and implementation of the NBS will become more feasible. The design of NBS should intrinsically be a co-design process. These new interactions between academic research and landscape architecture, based on experimentation, are the key to innovation and adaptation to climate change, and to a creative anticipation. Within the PHUSICOS project, some of the different case-study sites are examples of such transdisciplinary approaches, especially for part of the design process. Inspiration was brought to the table with a landscape vision, and at the same time, specific technical aspects were investigated. The NBS guidebook also takes this transdisciplinary thinking as a point of departure for the successful development and implementation of NBS for the various ecosystems.

D2. NBS in PHUSICOS case-studies: lessons learned

Many of the lessons learned during the project relate to implementation barriers. However, the following elements are considered important for future NBS projects:

PLANNING

In PHUSICOS, many of the planned interventions described in the original project proposal appeared well planned and ready for implementation when they were included in the project description. However, when the project started it became apparent that this was not the case for all, and the necessary detailed planning that ensued was time-consuming. Many elements needed considerations and clarifications, which were not adequately addressed prior. Examples include:

- Detailed design of the interventions: This is often sub-contracted to an external consultant, and not all have the required experience and competence to design NBS. Furthermore, the design takes time and often the design phase uncovered that the original cost estimate was too low, as was the case for Jorekstad in Norway.
- Permissions, property issues and regulations: These are all elements important to consider, and which may lead to project delays. This certainly occurred in PHUSICOS and
- included property issues in Jorekstad, Norway, permissions related to national parks at Artouste in the Pyrenees, and dam regulations for the intervention in Skurdalsåa, Norway.
- Early stakeholder involvement: Involving stakeholders of all levels at an early stage promotes enthusiasm and a sense of ownership to the intervention. There is generally extremely limited knowledge about the positive benefits that NBS can provide, and proper information and discussions around this may help overcome skepticism. The interventions in the Serchio River Basin case site (Lake Massaciuccoli) in Italy, and at the concept case site in Kaunertal, Austria are good examples of this. There is also a huge learning potential from the stakeholder involvement in the Isar concept case. Particularly important success factors include:
    - A broad participation of the civil society
    - An open-minded local and regional administration
    - Multi-scale and multidisciplinary round table discussions
    - Neutral facilitation and mediation helped to overcome conflicts
    - Trust and confidence between the stakeholders.

MONITORING

As most of the NBS interventions in PHUSICOS were delayed, and some not completed until very near the end of the project, monitoring results will first be available long after PHUSICOS. Exceptions include Erill-la-Vall in the Spanish Pyrenees, where monitoring had been going on for 15 years due to other projects, and at Lake Massaciuccoli, Italy, where some of the interventions were completed early due to good planning and early stakeholder involvement. These experiences illustrate that monitoring must be planned in detail in parallel with the planning of the NBS itself. Baseline data should be acquired before the implementation of the NBS, and for the same parameters that are to be monitored after the NBS implementation. In general, collected data should include land use, hydrology, biological environment, air and water quality. Monitoring should start immediately after the implementation is complete.

Monitoring may last for many years, and also comes with a cost that will need to be budgeted for. It is also necessary to have clearly defined responsibilities for acquiring the monitoring data and subsequently analyzing and reporting the findings. Ideally the monitoring data should be made available and easily accessible to stakeholders, such as for Erill-la-Vall in the Pyrenees and the interventions by Lake Massaciuccoli in Italy. Such success stories and well documented monitoring will improve the NBS evidence based to reduce one of the main barriers to NBS implementation which is the lack of proof of their efficiency.

MAINTENANCE

NBS are not maintenance-free. Required maintenance will vary from site to site and is intervention specific. Maintenance activities may include forest management and replanting dead plants, as seen in Capet Forest; replacing damaged logs on the slopes at Artouste; mowing buffer strips at Lake Massaciuccoli; and maintaining the threshold in the Skurdalsåa dam. As for monitoring, maintenance should take place for many years and must be planned and included in the cost estimates. Responsibility for the maintenance must also be defined. Hence, this should also be part of the NBS intervention planning process.

ACCEPTING HYBRID SOLUTIONS

Most of the PHUSICOS interventions may be classified as hybrid solutions, rather than exclusively NBS. Exceptions include the buffer strips at Lake Massaciuccoli, Italy and the afforestation in Capet, the French Pyrenees. The experience to bring forward is that some pragmatism is needed. Certain problems may be solved by NBS alone; however, when reducing the risk of hydro-meteorological impacts is the priority to protect life and property, a traditional grey solution may be the only feasible option. In such instances, we believe that a hybrid solution that also meets the requirements of enhancing biodiversity may also be considered as an NBS.

The measures implemented in PHUSICOS differ on a scale between 100% NBS and nearly 100% grey. The closest to the grey structure is probably the improved dam at the Skurdalsåa case in Gudbrandsdalen, Norway, whereas other interventions are very close to the other end of the scale. When evaluating measures, considering what the alternatives would be is important. As an example, the rockfall interventions in the slope at Artouste, the French Pyrenees, will probably not increase the biodiversity of the slope, and part of the constructions may appear 'grey'. However, the alternatives would imply the use of heavy machinery, establishment of access roads for construction, and significant cutting of trees Similarly, the alternatives to the intervention in Skurdalsåa would be traditional barriers along significant lengths along the river.

In connection to this point, it is worth mentioning that Norway has implemented national guidelines for climate adaptation, which state that nature-based solutions must be explicitly addressed as an alternative to be assessed along with any grey solution. Should the NBS solution be dismissed, the reason must be substantiated. At present, this is only a 'soft' guideline without consequences if not followed. However, guidelines like this, particularly if spread and made more regulative, will eventually lead to wider use of NBS and various forms of hybrid solutions where this is possible.

SHARING EXPERIENCE

Finally, interventions like those implemented in PHUSICOS, and in particular when monitoring data and results appear, must be used to teach and inform all types and levels of actors involved in disaster risk reduction (DRR). This is being carried out with good results at the demonstrator case site in Italy, where also other farmers than those directly involved in the measures around Lake Massaciuccoli have become interested in applying similar measures in their fields. The PHUSICOS measures have also been used as examples in the 'NBS-Lab' activities performed by ADBS in Italy, where different classes of actors, from students to professionals participated. Related activities include the webinar and spring school arranged by project partner TUM, in collaboration with CTP, using both the Isar case and the NBS implementations in the Pyrenees as cases and 'outdoor classrooms'. A final example is the two-day seminar hosted by CTP, in Laruns, France, in April 2023, with participants from private and public technical entities came together to discuss and practical and technical issues in the planning and implemented of the selected NBS.

D3. Links to EU and other programs

The European Commission (EC) is investing considerably in NBS and green growth, with the goal of positioning Europe as a leader for 'innovation with nature'. NBS are therefore dealt with in several different policy domains, including climate change adaptation and mitigation, disaster risk management, biodiversity, water management, research and innovation. For example, NBS are included in the new EU Strategy on Adaptation to Climate Change, in which they are considered essential for increasing climate resilience and sustaining healthy water, oceans, and soils. Also, the recently released EU Biodiversity Strategy for 2030 and Forest Strategy - all representing key pillars of the ambitious European Green Deal (EGD) - rely on NBS to both preserve and restore ecosystem integrity and increase climate resilience. A further milestone of the Biodiversity Strategy is the recently ratified Nature Restoration Law, which includes legally binding nature restoration targets across Europe. NBS are also increasingly featured in EU policies and strategies going beyond conservation and environmental protection. For example, the Farm to Fork Strategy promotes the use of NBS (such as agroecology practices) to transition to a sustainable food system.

As the number of legislations addressing NBS in the EU are expanding, figure D-1 provides a non-exhaustive overview of the most recent and relevant policy and financial instruments at the EU level. The NBS guidebook does not aim to be directly included in EU policies or directives. Instead, it seeks to inspire further exploration into the broad spectrum of possibilities that NBS can offer.

FINANCIAL INSTRUMENT

European Maritime, Fisheries and Aquaculture Fund (**EMFAF**) - *2021*

European Agricultural Fund for Rural Development (**EAFRD**)

European Regional Development Fund (**ERDF**)

European Social Fund Plus (**ESF+**) - *2021*

Cohesion Fund (**CF**) - *2021*

Just Transition Fund (**JTF**) - *2021*

Social Climate Fund (**SCF**) - *2022*

DIRECTIVE

Birds Directive - *1979/2009*

Habitats Directive - *1992*

Water Framework Directive (**WFD**) - *2000*

Floods Directive - *2006*

Marine Strategy Framework Directive (**MSFD**) - *2008*

Environmental Impact Assessment Directive (**EIA**) - *1985*

Strategic Environmental Assessment Directive (**SEA**) - *2001*

POLICY FRAMEWORK

8th Environment Action Programme (**EAP**) - *2018*

Reform on the Common Agricultural Policy (**CAP**) - *2021*

SET OF POLICY INITIATIVES

European Green Deal (**EGD**) - *2019*, as part of this:
- Farm to Fork Strategy - *2021*
- Biodiversity Strategy to 2030 - *2020*
- New Adaptation Strategy to Climate Change - *2021*
- European Climate Law - *2021*

FUNDING PROGRAMME

Horizon Europe Framework for Research and Innovation

REGULATION

EU taxonomy for sustainable activities - *2020*

STRATEGY

Biodiversity Strategy to 2030 (2020), as part of this:
- Proposal for a Nature Restoration Law - *2024*
- New EU Forest strategy for 2030 - *2021*

Green Infrastructure Strategy - *2013*

Strategy for a Sustainable Blue Economy (**SBE**) - *2021*

Figure D-1: Non-exhaustive overview of the most recent and relevant policiy and financial instruments at the EU level

D4. Suggested actions

Nearly 50% of the rural areas in the world are classified as mountainous regions and are exposed to risk from geological and hydrometeorological hazards. Mountains tend to amplify these risks, and even more so under extreme weather events. However, mountainous regions have not received the same attention as densely populated urban areas in national disaster risk reduction (DRR) plans. However, this focus is shifting as mountain areas are becoming 'hot spots' regarding the impacts of climate change (EEA, 2020). Furthermore, the positioning of mountain areas in a river basin perspective provides a comprehensive backdrop to capture the integrated nature of natural hazards and the implementation of NBS to reduce these hazards due to extreme hydro-meteorological events.

The overarching objective of PHUSICOS to demonstrate the implantation of NBS at five European case study sites has been achieved and a total of 15 NBS were implemented during the PHUSICOS project period. Of these, 11 are physical interventions and 4 are educational, Living Lab, and dissemination activities. The physical NBS measures are addressing a wide range of natural hazards including flooding, debris flows, erosion and shallow slope instability, rock fall, and snow avalanches. Continuing to collect monitoring data at these case study sites is a long-term objective and will further develop the evidence base on NBS performance and document their co-benefits to increase stakeholders' confidence in NBS. Further to continued monitoring, transformation of governance structures and continued learning and capacity building will help mainstream NBS for disaster risk reduction in the future. For NBS implementation to become more widespread and effective, it is essential to transform governance structures and to create appropriate legal, institutional, political and financial conditions. Recommendations to address this transformation of governance structures as well as the barriers to NBS implementation, accompanied by suggested innovations, include:

- Update EU policies and promote mandatory policy instruments, by considering the following (e.g. enforcing legally binding targets such as reservation of a proportion of land for forest cover in Member States as in the proposed EU Nature Restoration Law, streamlining simplified NBS approval procedures by introducing self-certification schemes, switching the burden of proof to grey measures by making consideration of NBS a requirement for infrastructure projects).
- Mobilize public and private finance (e.g. unlocking public and private funding for nature-positive activities with specific focus on funding for climate adaptation/disaster risk reduction, merging complementary funding streams (green and grey) into single programs that prioritize NBS, such as disaster risk reduction or water management plans, developing innovative financing mechanisms such as resilience bonds or payment for ecosystem services to address land availability problems, promoting co-financing options such as subsidies and tax rebates for NBS investments).
- Prioritize research and a robust knowledge base (e.g., increasing monitoring to track short- and long-term impacts, strengthening evidence on NBS effectiveness, developing formal standards, including building codes and insurance regulations).
- Train the workforce and build capacities (e.g. creating an NBS Project Preparation Facility (PPF) at the local and/or national level by providing support to nature-based enterprises, creating user-friendly benefit and co-benefit catalogues for the private sector, developing new educational and training programs specific to NBS design and implementation, including guidelines and standards such as the IUCN Global Standard for NBS, using innovative learning tools such as virtual-reality learning platforms).

Additional policy reforms that are recommended to be explored to tackle these challenges include extending the scope of the EU Environmental Impact Assessment (EIA) Directive and the EU Taxonomy. The EIA Directive, a far-reaching and stakeholder-inclusive policy instrument for proposed infrastructure projects. Enforcing compulsory EIAs for a significantly broader range of infrastructure projects and including extensive accounting of NBS co-benefits to biodiversity and climate change, over an appropriately lengthy time horizon, will effectively switch the burden of proof from NBS to grey infrastructure. More stringent documentation of traditional grey infrastructure's negative impacts to biodiversity and climate change will also tackle the barrier of grey path dependency. The EIA Directive is a cross-cutting instrument which integrates environmental concerns and is a corner stone of the European Green Deal and its investment pillar – the Sustainable Europe Investment Plan (EU 2021: 35 years of EU Environmental Impact Assessment). Extending the EU Taxonomy done by classifying nature-negative investment and subsequently discouraging nature-negative investing. The large gap in EU financing for NBS as well as financing at the local (municipal) scale can benefit from taking a close look at 'grey' experience, especially the upsurge of private financing for renewable energy. While this experience cannot be fully transplanted to nature-positive investment (given its public-good nature), one lesson to be learned is extending the EU taxonomy to promote divestment from nature-negative assets. The EU taxonomy for sustainable activities is a major step in this direction by clarifying those investments that are environmentally sustainable in the context of the European Green Deal. The planned extension of the EU Taxonomy is a powerful instrument which could be made more effective if mandatory and accompanied with an enforcement mechanism.

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Internet resources

UN Environmental program (www.unep.org/unep-and-nature-based-solutions)

Wetlands International (www.wetlands.org)

DIEM project - Discovery Islands Ecosystem Mapping (diemproject.org)

Artsdatabanken (Species database) (www.artsdatabanken.no), in Norwegian

OPERANDUM project (www.operandum-project.eu)

PHUSICOS project (www.phusicos.eu)

SABICAS project (www.sabicas.no), in Norwegian

GeoIKP, Platform for Nature-based solutions(geoikp.operandum-project.eu), OPERANDUM Project

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