HORIZON Europe Research and Innovation actions in support of the Implementation of the Adaptation to Climate Change Mission (HORIZON-MISS-2022-CLIMA-01)

Biodiversity and Ecosystem Service Characterisation and Modelling

Deliverable D5.3

Version n° 3

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About NBRACER

The impacts of climate change on people, planet and prosperity are intensifying. Many regions and communities are struggling to avoid losses and need to step up the effort to increase their climate resilience. Ongoing natural capital degradation leads to growing costs, increased vulnerability, and decreased stability of key systems. Whilst there has been noticeable progress and inspiring examples of adaptation solutions in Europe, the pressure to make rapid and visible progress has often led to a focus on stand-alone, easy-to-measure projects that tackle issues through either direct or existing policy levers, or sector-by-sector mainstreaming. But the dire trends of climate change challenge Europe, and its regions, needs exploration of new routes towards more ambitious and large-scale systemic adaptation. The European Mission on Adaptation to Climate Change (MACC) recognizes the need to adopt a systemic approach to enhance climate adaptation in EU regions, cities, and local authorities by 2030 by working across sectors and disciplines, experimenting, and involving local communities.

NBRACER contributes to the MACC by addressing this challenge with an innovative and practical approach to accelerating the transformation towards climate adaptation. Transformation journeys will be based on the smart, replicable, scalable, and transferable packaging of Nature-Based Solutions (NbS) rooted in the resources supplied by biogeographic landscapes while closing the NBS implementation gap. Regions are key players of this innovative action approach aiming at developing, testing, and implementing NbS at systemic level and building adaptation pathways supported by detailed and quantitative analysis of place-specific multi-risks, governance, socio-economic contexts, and (regional) specific needs.

NBRACER works with 'Demonstrating' and 'Replicating' regions across three different Landscapes (Marine & Coastal, Urban, Rural) in the European Atlantic biogeographical area to vision and co-design place based sustainable and innovative NBS that are tailor-made within the regional landscapes and aligned with their climate resilience plans and strategies. The solutions are upscaled into coherent regional packages that support the development of time and place specific adaptation pathways combining both technological and social innovations. The project is supporting, stimulating, and mainstreaming the deployment of Nature-Based Solutions beyond the NBRACER regions and across biogeographical areas.

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Document Information

Grant Agreement	n°101112836
Project Title	Nature Based Solutions for Atlantic Regional Climate Resilience
Project Acronym	NBRACER
Project Coordinator	Mindert de Vries, Deltares
Project Duration	1st October 2023 – 30th September 2027 (48 months)
Related Work Package	WP5
Related Task(s)	Task 5.3: Biodiversity and ecosystem service characterisation and modelling
Lead Organisation	FIHAC
Contributing Partner(s)	Deltares
Due Date	30/09/2025
Submission Date	30/09/2025
Dissemination level	PU - Public

History

Date	Version	Submitted by	Reviewed by	Comments
01/08/2025	V1	J. Barquín Ortiz	PMO	Comments on content and format
03/09/2025	V2	I. Pérez-Silos	WP5 and PMO	Comments on content and format
30/09/2025	V3	I. Pérez-Silos	Stefano Gamberoni	Approved

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Table of Contents

List of Figures

List of Tables

Summary

Deliverable 5.3 (D5.3) forms a central component of the NBRACER conceptual and operational pathway by providing the methodological basis to characterise biodiversity and ecosystem services (ES) as key ecological pillars for Nature-based Solutions (NbS). Building on the conceptual framework introduced in Deliverable 5.1 (D5.1), where climate hazards, Key Community Systems (KCS), and ecosystem functions were linked conceptually, D5.3 operationalises this framework by translating it into practical workflows, tools, and data resources that regions can adapt according to their technical capacities and initial conditions.

The deliverable has three overarching objectives: (1) to define methodological pathways for mapping and assessing biodiversity and ES relevant to risk reduction; (2) to provide data sources, tools, indicators, and modelling approaches that regions can use according to their capacities; and (3) to link these characterisation processes conceptually with the identification of functional hotspots where NbS could be implemented to mitigate climate-related impacts. Rather than providing a rigid, step-by-step methodology, the document outlines two adaptable roadmaps, a fine-scale and a coarse-scale approach, each of which can be applied in either a quantitative or qualitative way. These roadmaps cover the full bio-physical characterisation chain: biodiversity mapping, the development of biodiversity-ES relational tables, and ES assessment.

The deliverable compiles practical resources across all steps, including classification systems, geospatial datasets, EU-scale products (e.g. CORINE, Copernicus layers), indicators, functional trait databases, biophysical models, modelling platforms, and empirical proxies. It also establishes relational tables that connect hazards, ES, biodiversity features, geomorphological units, and NbS types, which act as a foundation for the later identification of functional hotspots. These components support regions in selecting appropriate approaches depending on their data availability, modelling capacities, and desired level of precision.

To illustrate the practical application of both roadmaps, Section 7 presents a comparative case study in Cantabria (Northern Spain), focusing on flood risk. The exercise contrasts fine- and coarse-scale approaches for hazard mapping, biodiversity characterisation, ES modelling (quantitative and qualitative), and the spatial identification of functional hotspots for NbS. This demonstration highlights differences in spatial resolution, thematic precision, data requirements, and decision-making potential.

Overall, D5.3 bridges the conceptual articulation of ecosystem-based resilience in D5.1 and D5.2 with the applied implementation stages to be developed in WP2, WP3, WP4, and the Mapping & Modelling Task Force. It provides a flexible but structured framework that regions can use to meet the requirements of D2.2, D3.2, D4.2 and D5.5, while ensuring scientific robustness and adaptability. The annexed resources and guidelines (Appendix 5: Guidelines) further support practitioners in identifying and applying relevant tools across the different workflows.

Keywords

Biodiversity; Ecosystem Services; Functional hotspots; Functional traits; Nature-based Solutions.

Abbreviations and acronyms

Acronym	Description
CHC	Cantabrian River Basin Authority
CICES	Common International Classification of Ecosystem Services
CLC	CORINE Land Cover
CORINE	Coordination of Information on the Environment
CRICs	Climate Risk Impact Chains
EFAS	European Flood Awareness System
ES	Ecosystem Services
FAO	Food and Agriculture Organization of the United Nations
HRL	High-Resolution Layer
KCS	Key Community System
LU	Land Use
LULC	Land Use Land Cover
MMTF	Mapping and Modelling Task Force
NbS	Nature-based Solutions
SBA	Service-Benefitting Area
SCA	Service-Connecting Area
SDM	Species Distribution Modelling
SoS	System of Systems
SPA	Service-Providing Area
WP	Work Package

1 Introduction

1.1 Setting the Scene: the NBRACER Approach

The NBRACER Operational Climate Resilience Approach provides a flexible, co-designed framework to support regional climate adaptation using Nature-based Solutions (NbS). It responds to the growing need for transformative, system-oriented strategies that move beyond fragmented, project-level interventions. The approach views regions as complex Systems of Systems (SoS), integrating biophysical, socio-cultural, and governance domains to guide resilience-building in a way that is context-sensitive and community-driven. NbS serve as the core intervention, designed not in isolation but as part of multi-dimensional portfolios that align with local values, risks, and institutional landscapes.

The NBRACER operational framework equips decision-makers with adaptable tools and processes tailored to diverse regional contexts and scales. By employing an iterative, participatory approach and advanced spatial analysis, the framework helps regions build and sustain resilience that is adaptable to evolving risks. Emphasising NbS and incorporating socio-ecological systems and ecosystem services (ES) dynamics, the framework supports comprehensive resilience planning, providing regions with a cohesive pathway to operationalise resilience strategies and prepare for climate uncertainties. This approach is applied across diverse regional landscapes - including Marine & Coastal, Urban, and Rural areas - within the Atlantic Biogeographical Region. NBRACER works directly with Demonstrating regions, serving as living laboratories for innovation, and Replicating regions, which test and adapt solutions for transferability. Regional pathways are rooted in participatory processes, while technical assessments - such as Climate Risk Impact Chains (CRICs), ecosystem service mapping, and multi-hazard risk profiling - help shape tailored NbS packages that respond to specific risks and local assets.

Structured around an eight-step operational process aligned with the Horizon Europe project Pathways2Resilience (P2R) framework (Figure 1) NBRACER guides regions from system analysis and risk assessment to solution development, pathway design and implementation. A strong focus is placed on learning, monitoring, and iterative feedback, ensuring continuous adaptation and long-term transformation. The approach supports regions not only in deploying NbS but also in mainstreaming and scaling solutions beyond the project scope, contributing to policy transformation and enhanced resilience across Europe.

The NBRACER project offers a holistic approach to enhancing climate resilience, particularly for regions facing multiple, overlapping hazards. By examining the physical, social, and governance landscapes as an interconnected system, the NBRACER approach aims to foster adaptive, scalable, and sustainable solutions that strengthen the capacity of regions to anticipate, respond to, and recover from various climate-related hazards.

The NBRACER approach leverages NbS as foundational elements that integrate with regional landscapes and enhance resilience. By considering the interplay of NbS with climate hazards, Key Community Systems (KCS), and the socio-economic environment, the framework seeks to produce cascading benefits (e.g., reducing stress on emergency services, stabilising water resources, and supporting public health) across different community dimensions. This approach enables operational resilience, requiring stakeholders to rethink their roles in maintaining and restoring resilience amidst dynamic threats.

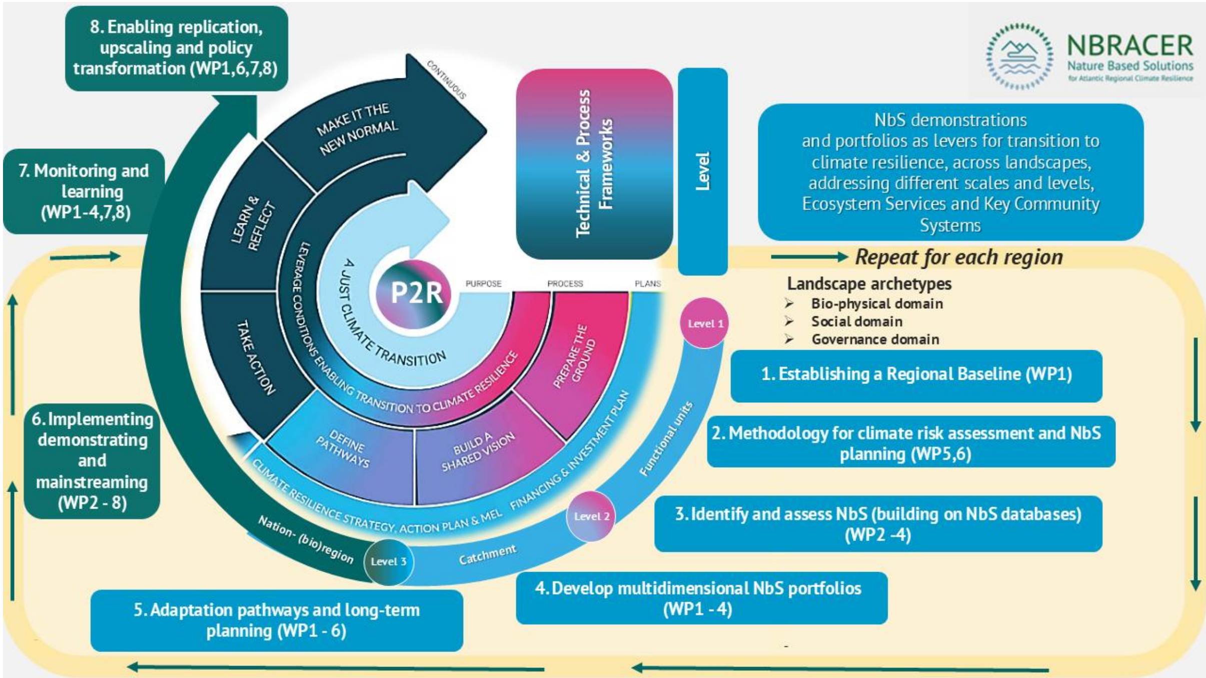

Figure 1: Overview of the NBRACER Approach with eight steps, elaborating an iterative process for achieving a just climate transition through multi-level, multi-scale and multi-domain planning.

In this context, within WP5, Deliverable 5.3 (D5.3) lays the foundation for translating the conceptual elements introduced in D5.1 into actionable tools and methods to support the identification, design, and deployment of effective NbS. While D5.1 introduced the conceptual framework linking climate hazards, KCS, and ecosystem-based regulatory functions, D5.3 focuses on operationalising this framework by providing guidance on the characterisation of biodiversity and ES, the two fundamental ecological components underpinning NbS effectiveness. In doing so, D5.3 sets out the approaches and pathways that regions can follow to conduct these characterisations, but deliberately avoids prescribing highly specific or overly technical methods that are context-dependent. Instead, such ad hoc methodologies, tailored to each region's needs and capacities, will be developed in the complementary Mapping and Modelling Guidance Document.

This deliverable presents an approach and resources to identify where and how biodiversity and ecosystem functions contribute to the regulation of specific hazards and their impacts, and therefore, to risk reduction. It introduces strategies for mapping, modelling, and analysing the provision and spatial dynamics of ES, as well as assessing biodiversity through both structural and functional attributes. By doing so, it supports regions in understanding which ecosystems—and which ecological functions—they can rely on to build resilience, and under what conditions. D5.3 thus acts as a bridge between the conceptual articulation of climate risk and ecosystem regulation (D5.1 and D5.2) and the applied risk mitigation and resilience-building activities developed across WP2, WP3, and WP4. D5.3 is key here, as it provides an approach to characterising biodiversity and ES with the aim of supporting the identification of potential hotspots for NbS implementation.

This document is structured as follows:

- **Section 1** introduces the NBRACER operational approach and situates D5.3 within the broader logic of WP5 and the project.
- **Section 2** outlines how the conceptual framework from D5.1 is operationalised into practical assessment components.
- **Section 3** explores biodiversity as a cornerstone of resilient and self-sustaining NbS, focusing on functional traits, ecological potential, and connectivity.
- **Section 4** addresses ES as key to designing functional NbS, detailing spatial-temporal dynamics and service interdependencies.
- **Section 5** presents two roadmaps (fine and coarse) tailored to regional needs, offering tools, indicators, and data sources for the characterisation of biodiversity and ES. Each step of the roadmaps is described in detail, accompanied by reference tables that list data sources and resources that regions can mobilise depending on their technical capacity. Section 5 is closely linked with Appendix 5: Guidelines, which compiles all resources and includes links to methodological exemplifications in the form of guidance notes for each roadmap option.
- **Section 6** develops relational tables linking hazards, ES, biodiversity, and NbS. These tables serve as a key resource for connecting the characterisation process with the identification of functional hotspots for NbS implementation. While hotspot identification per se is not the primary objective of D5.3—and will be addressed more specifically in the Mapping and Modelling Task Force (MMTF) and its Guidance Document—this deliverable lays the groundwork by clarifying how specific ES and ecosystems align with NbS types relevant for regulating climate risks, and that could be potentially implemented in the identified hotspots.
- **Section 7** presents a case example in the Cantabria region, showcasing a comparative application of the fine and coarse roadmaps. Although simplified, the case study integrates hazard assessment, biodiversity and ES characterisation, and a preliminary selection of functional hotspots, thereby demonstrating how differences in characterisation approaches can affect the overall process of completing Level 1 (biophysical) of the conceptual framework—from hazard identification to hotspot mapping for NbS.
- **Section 8** connects the outcomes of D5.3 to forthcoming steps in WP5 and the broader NBRACER pathway.

1.2 Objectives

The objective of this deliverable is to provide the foundations and methodological approaches needed to map and characterise the key elements required for the selection, design, and implementation of NbS as identified in the conceptual framework developed in Deliverable 5.1. Specifically, this deliverable focuses on biodiversity and ES, enabling regions and other users to identify potential NbS options to regulate different climate hazards effectively.

The specific objectives of Deliverable 5.3 are:

1. To establish and describe the connections between biodiversity and ES that need to be modelled and characterised to inform NbS planning.
2. To provide a methodological guideline to characterise and model biodiversity and the provision of multiple ES, applicable across different spatial scales, landscapes, sociocultural contexts, and varying levels of data availability.
3. To build relational tables that link climate hazards with potential NbS, by identifying ecosystems that, through the provision of regulatory ES, can mitigate the processes and impacts triggered by those hazards.
4. To demonstrate practical workflows that enable regions to characterise biodiversity and ES in their territories, showcasing examples to illustrate the application of the proposed approaches.

1.3 Target Groups: How to use this deliverable?

This deliverable is primarily intended for regional partners and practitioners, serving as a methodological reference to frame their biophysical characterisation process for identifying potential areas where NbS can be implemented. In this sense, it is important to stress that D5.3 has not been conceived as a strict step-by-step methodological manual applicable equally to all regions. The diversity of available methods and resources, combined with the heterogeneity of regional contexts in terms of technical capacity and data availability, makes such an approach unfeasible and impractical. Instead, D5.3 establishes clear workflow roadmaps and compiles methodological and data resources that regions can adapt to their specific starting conditions. These workflows will be further detailed and operationalised in the MMTF, which provides targeted support to regions for the delivery of D2.3, D3.3, and D4.3.

Presented roadmaps should therefore be seen as modular and combinable, not as rigid blocks, allowing regions to select and adapt steps according to their interests, capacities, and project needs (e.g., hazard and risk mapping, biodiversity mapping, ES characterisation, identification of functional hotspots). At the same time, the simplest workflow (the coarse qualitative roadmap) can be replicated by any region regardless of data availability, requiring only minimal technical capacity.

Although this deliverable places a strong emphasis on practical applicability, translating and operationalising concepts introduced in D5.1, it also retains a substantial theoretical component. This is intentional, as theoretical grounding underpins the scientific robustness and innovative character of a project like NBRACER. Consequently, D5.3, similar to D5.1, combines conceptual content with practical tools. We acknowledge, however, that the theoretical content may be less relevant for some target groups with limited ecological background, or for those more focused on direct methodological application. Furthermore, this deliverable is intended for both technical stakeholders (e.g., GIS analysts, ecological modellers) and non-technical stakeholders (e.g., local decision makers, adaptation planners). These groups may approach the document differently and may be interested in distinct elements. To facilitate navigation and ensure its usefulness for all audiences, we have incorporated guiding elements into the document:

- Colour-coded section headers – sections with a stronger theoretical focus are marked in yellow ( ), while those with a stronger practical orientation are marked in blue ( ).
- Highlighted resources in red ( ) – specific datasets, methods, or tools that can be directly employed by regions in their biophysical characterisation of biodiversity and ES. All these resources are also compiled in Appendix 5: Guidelines.

2 From Concept to Practice: Operationalising the Conceptual Framework

The NBRACER conceptual framework established in Deliverable 5.1 laid the theoretical foundations to understand how climate hazards in each region can be mitigated through the strategic implementation of NbS. At its core, the framework identifies and links key biophysical components (climate hazards, biodiversity, ES, and NbS) within a risk assessment approach that integrates both ecological and social dimensions. This deliverable (D5.3) aims to take these concepts further by providing practical guidance to operationalise the framework across NBRACER regions. The goal is to equip regional partners and other users with tools and approaches to map and characterise biodiversity and ES, two of the fundamental components required to design, propose, and implement effective NbS interventions.

The framework proposed in D5.1 (Figure 2) conceptualises how specific climate hazards generate abiotic flows (such as water, sediment, heat) that can threaten KCS. It also identifies which ecosystems generate the regulating ES capable of modifying these flows, and how NbS can enhance or restore the capacity of ecosystems to deliver these services, ultimately increasing socio-ecological resilience.

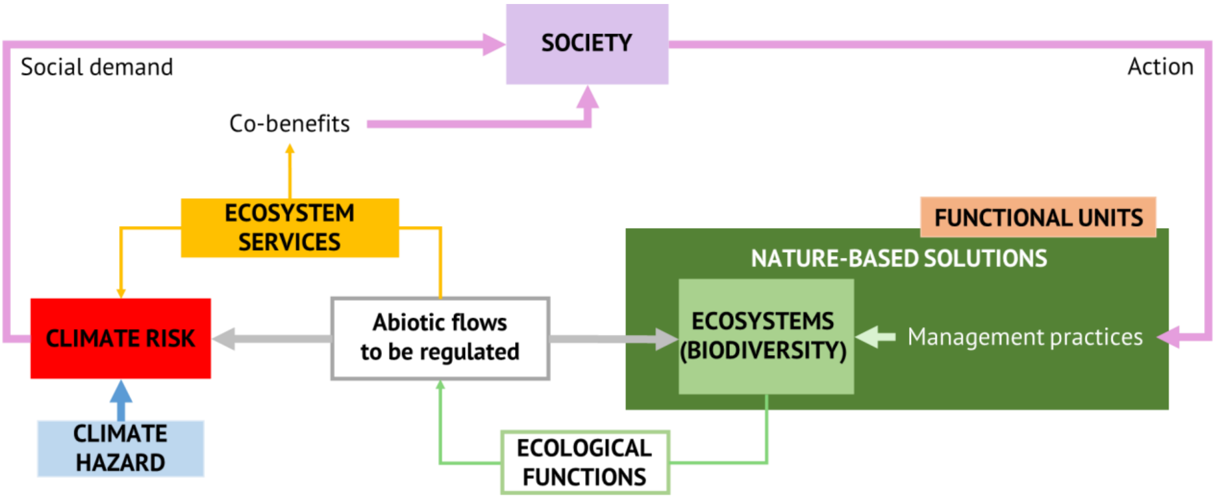

Figure 2: Summary of the conceptual framework proposed in D5.1.

In practice, this meant:

- Identifying the biodiversity components involved in providing key ES for risk regulation. Not all ecosystems provide the same ES, and even within the same ecosystem type, ES provision varies based on structural and functional characteristics, ecological condition, maturity, and location within the landscape.
- Mapping the distribution of biodiversity and ecosystems to understand what is present in the territory, where it is located, and its ecological attributes.
- Quantifying and mapping ES provision to determine their potential to regulate specific climate hazards and deliver co-benefits for society.

To organise these relationships conceptually and link hazards to NbS within a risk evaluation framework, the D5.1. has proposed developing CRICs. CRICs are models that articulate the pathways by which climate hazards propagate impacts across socio-ecological systems, identifying the points at which NbS can enhance adaptive capacity and reduce vulnerability. However, to move from conceptual understanding to territorial planning and implementation, robust characterisation and mapping of biodiversity and ES are essential. In this sense, Figure 3 illustrates the overarching process of operationalising the conceptual framework from conceptual modelling (i.e., CRICs) to on-the-ground NbS implementation. As exposed, biodiversity and ES mapping are key steps for informing the biophysical domain (Level 1) of the process. By overlaying spatial information on ecosystem distribution and the ES they provide with risk and impact analyses on KCS, it becomes possible to identify functional hotspots for NbS implementation—areas where nature-based interventions could most effectively reduce climate-related risks.

Functional hotspot: Territorial units that, from a biophysical perspective, emerge as priority candidates for NbS implementation because of their capacity to regulate hazards and mitigate associated impacts

However, these areas should be understood as potential areas, suitable for regulating risk from a strictly biophysical perspective. The final selection of these candidates should be based on a more in-depth analysis that incorporates socio-economic and governance criteria into the decision-making and prioritisation process (Levels 2 and 3).

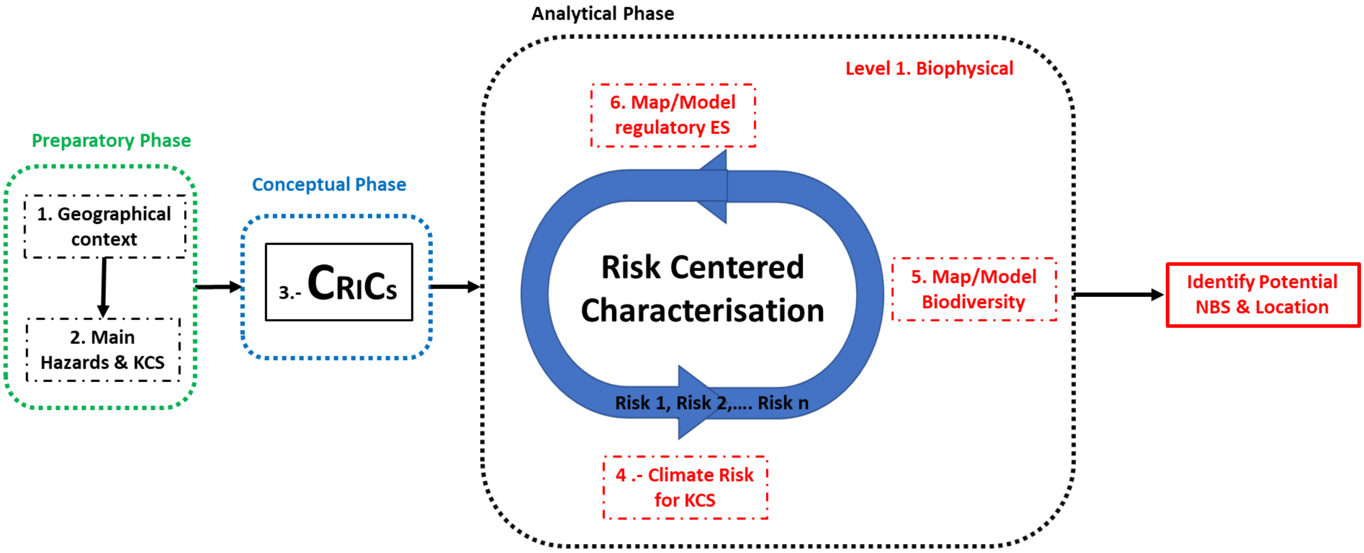

Figure 3: Operative framework for the biophysical level (Level 1) of the conceptual framework.

This deliverable addresses these needs by:

- Supporting the operationalisation of Level 1 of the conceptual framework, which focuses on identifying biophysical relationships between hazards, ecosystems, and NbS options.
- Providing methods and tools to characterise biodiversity and ES across different spatial scales and data availability contexts (section 5).

- Laying the groundwork for identifying and prioritising NbS types and their spatial deployment to achieve effective risk reduction and resilience-building strategies in each region (section 6).

3 Biodiversity: Key Aspects to Design and Implement Resilient and Self-Sustaining NbS

NbS rely fundamentally on biodiversity to deliver benefits for society and ecosystems. On one hand, biodiversity underpins the functional capacity of ecosystems to regulate risks and provide essential ES. On the other hand, it is in itself an objective of NbS, as maintaining healthy and diverse ecosystems ensures long-term resilience and sustainability (Figure 4).

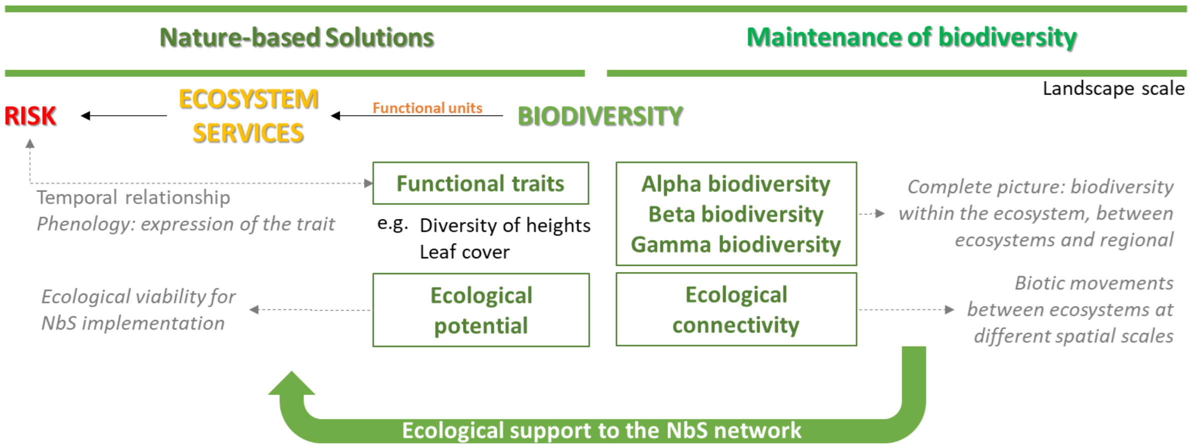

Figure 4: Core biodiversity factors implied in NbS design, implementation and maintenance.

Functional trait: Observable characteristics of an organism, such as morphological, physiological, biochemical, phenological, or behavioural traits, that influence its survival and reproduction (fitness) or its impact on the ecosystem (e.g., tree height, size and root structure).

In recent decades, ecological research has made significant advances in understanding how the morphological, physiological, biochemical, and structural characteristics of organisms—commonly referred to as functional traits—respond to environmental conditions and influence ecosystem processes (Díaz et al., 2013). This growing body of evidence also demonstrates a strong relationship between functional traits and the provision of ES. However, functional traits remain underutilised in NbS design despite their potential to tailor interventions to specific risks and contexts. Likewise, beyond the selection of species and traits, the maintenance of biodiversity patterns across spatial scales and the ecological connectivity of habitats are fundamental to ensure that NbS remain functional and self-sustaining under current and future environmental conditions (Seddon et al., 2021).

Viewed from the inverse perspective, NbS should also be designed to ensure the protection of biodiversity. Biodiversity patterns operate across multiple spatial scales—from local species pools to ecosystem-level diversity and regional or landscape-level. Importantly, ecological processes at one scale influence others, driving changes in species distributions and, consequently, ecosystem functioning. This cross-scale interplay must be carefully considered when implementing NbS at both local and larger scales, as ecological changes can cascade in either direction—top-down or bottom-up—affecting biodiversity dynamics. Moreover, ecologically similar habitats may be spatially fragmented within a landscape mosaic yet remain functionally connected through ecological fluxes and dispersal pathways that sustain population viability. While some NbS explicitly aim to address habitat fragmentation, all actions should be designed to maintain or enhance ecological connectivity as a core principle.

This dual role of biodiversity—as both a provider of regulatory functions and an essential condition for sustainable NbS—forms the basis of the following two subsections. The first examines how functional traits and ecological potential influence the selection and design of NbS, while the second focuses on the biodiversity patterns and connectivity needed to sustain NbS effectiveness over time and across scales.

3.1 NbS, Functional Traits and Ecological Potential

Organisms and ecosystems are involved in numerous physicochemical cycles and biological interactions that occur within and across ecosystem boundaries, simultaneously providing multiple ecological processes and functions—a phenomenon known as multifunctionality (Manning et al., 2018). At the landscape level, humans benefit from these functions in the form of ES, ranging from carbon sequestration to clean water provision or recreation opportunities (Fisher et al., 2009).

The ability of ecosystems to provide these functions and services depends on a combination of abiotic and biotic factors. As enunciated by Pérez-Silos et al. (2025), ES depend fundamentally on three key ecosystem components: the intensity of abiotic flows (e.g., water, sediment, or solar energy), the biodiversity patterns in space and time, and the ecosystem functioning rates. ES provision would have a stronger or lighter dependence on each of these three components, depending on the biophysical interactions that determine their generation. For example, while dilution capacity or erosion protection are governed by the occurrence of certain abiotic flows (i.e., water inputs and their properties such as soil erodibility; Terrado et al. 2014), biomass provision or bioremediation are more related to biodiversity because they depend strongly on organisms' biological activities (i.e., growth or physiological rates; Zieritz et al. 2022). Water quality and carbon sequestration arise from the interaction via food webs between biological communities and circulating abiotic flows, often involving other ecosystem components such as soils or sediments (Keeler et al. 2012). In this case, both ES are closely dependent on ecosystem functioning properties like nutrient recycling rates, organic matter dynamics or river metabolism.

Functional units: Geomorphological entities -such as beaches, hillslopes, river reaches, etc- that capture the scale at which ecosystems interact with physical processes to generate ES

As developed in D5.1, one of the key abiotic determinants is the functional unit where a given ecosystem is located. Functional units are geomorphological entities—such as hillslopes, riparian zones, estuaries, floodplains, or beaches—that integrate specific abiotic processes (e.g., runoff generation, sediment transport, water infiltration) and thus define the physical flows to be regulated. The effectiveness of an ecosystem in providing a service is therefore conditioned not only by its intrinsic ecological characteristics, but also by its spatial position within the landscape and the dominant processes occurring there. For instance, forests located on steep slopes with high rainfall play a critical role in regulating soil erosion and runoff generation, while forests in lowland plains contribute differently, for example, to microclimate regulation and carbon storage

(Lamb, 2018). Hence, the geomorphological setting establishes the potential of an ecosystem to provide specific ES. This potential is then modulated by the biotic attributes of the ecosystem, particularly the functional traits of its constituent organisms. Functional traits are measurable morphological, physiological, biochemical, or phenological characteristics of organisms that influence their fitness and shape ecosystem processes (Violle et al., 2007). Over the last decade, trait-based ecology has emerged as a powerful framework to link community composition to ecosystem functioning, demonstrating, for example, that nitrogen-fixing species enhance soil fertility (de Bello et al., 2007) or that high specific leaf area correlates with productivity and rapid nutrient cycling (Ruiz Diaz Britez et al., 2014).

In the context of NbS, functional trait-based approaches have been proposed as valuable tools in its design. By targeting the preservation or enhancement of specific traits—or ecosystems characterised by key functional attributes—NbS can address particular environmental risks more effectively and promote adaptive capacity (e.g., Wellmann et al., 2023). For example, selecting tree species with high wood density and deep roots improves slope stability and erosion control, while also enhancing carbon sequestration (Yang et al., 2024). In urban NbS, traits related to drought tolerance, shading capacity, and pollutant capture are prioritised to maximise co-benefits (Ramachandran et al., 2024). Moreover, the use of functional traits in NbS projects should be objective-oriented to ensure effectiveness. For instance, when the primary objective of an NbS is to preserve or enhance ES provision and/or landscape connectivity in relatively well-preserved ecosystems, functional traits may serve as indicators of NbS effectiveness rather than as attributes to be actively manipulated. In contrast, when NbS are implemented in highly disturbed contexts (e.g., post-flood restoration), functional traits become central to intervention design—not only in terms of ecological functioning, but also in relation to social and cultural values. For example, selecting tree species with traits that confer drought tolerance while simultaneously maximising shade and providing aesthetic value in urban environments (Ramachandran et al., 2024).

Integrating functional traits into the design of NbS is a reciprocal and dynamic process. Environmental conditions at the local scale act as filters, selecting species whose functional characteristics enable them to persist under specific biotic and abiotic constraints (de Bello et al., 2013). This environmental filtering process shapes communities with trait compositions that, in turn, influence ecosystem functioning and feedback to local environmental conditions (Lartey et al., 2025). For example, in Atlantic regions, moderate to high precipitation, mild temperatures, higher elevations, north-facing slopes, and organic-rich soils promote the establishment of broadleaf forests over other vegetation types such as coniferous forests or shrublands. Broadleaf forests, in turn, exhibit distinctive functional traits such as higher specific leaf area, which supports elevated productivity and growth rates, while higher wood density enhances structural resistance to drought and wind disturbance (Ruiz Diaz Britez et al., 2014; Yang et al., 2024). Accordingly, the conservation and restoration of broadleaf forests may offer an effective NbS strategy to buffer against climate warming and intensifying weather extremes, given their functional capacity to regulate microclimate, hydrology, and disturbance regimes.

When NbS are designed for climate change adaptation or risk mitigation, priority should be given to habitats or ecosystems that are most effective in reducing the impact of the targeted risk or in enhancing the resilience of the landscape. However, not all habitats can be restored "anywhere we need them", as environmental conditions may no longer support their ecological viability. In

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some cases, site-specific factors inherently limit the establishment of certain ecosystem types; in others, historical environmental conditions might have been irreversibly altered—either through natural processes or human-induced disturbances, including climate change. Returning to the example of broadleaf forests, these ecosystems exhibit an altitudinal threshold beyond which their growth is no longer sustainable. Above this limit, only more stress-tolerant communities, such as grasslands, ferns, lichens, or mosses, can persist. Accordingly, broad ecological principles must be integrated into the spatial planning of NbS to ensure their ecological feasibility and long-term cost-effectiveness. Moreover, climate–functional trait relationships should be carefully considered, as they are dynamic and interactive (Andrew et al., 2019).

3.2 Maintenance of Biodiversity Patterns and Ecological Connectivity

NbS can be implemented at relatively small spatial scales—such as the restoration of an urban wetland—or across multiple sites to address risks operating at broader scales, for example, reforestation of hillslopes at the catchment level to mitigate flood hazards. Regardless of scale, both localised and landscape-level interventions influence biodiversity patterns at local and regional levels.

At the local scale, preserving species richness (alpha diversity; see Figure 5) and associated functional traits within a community supports the maintenance of ecosystem functions and ES. Diverse communities often exhibit functional redundancy, where multiple species perform similar ecological roles. Under disturbance, some species may decline, but others with overlapping functions can maintain ecosystem processes, enhancing functional stability and resilience (Oliver et al., 2015; Wang & Loreau, 2016). Additionally, at landscape and regional scales, maintaining diversity across sites (beta diversity) enhances the capacity of ecosystems to resist regime shifts and sustain multifunctionality across spatial scales. For example, forests with different species assemblages across an altitudinal gradient provide complementary ES and maintain landscape-level resilience against climate extremes.

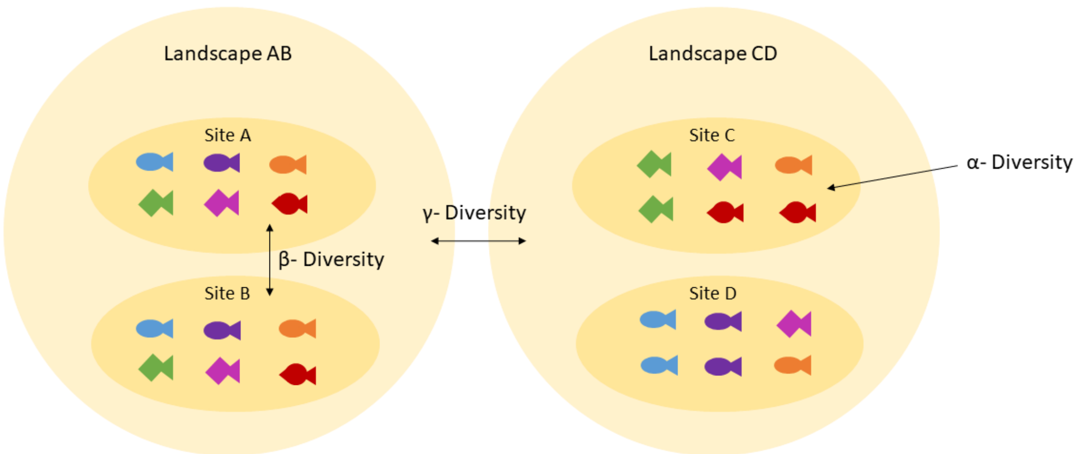

Figure 5: Difference between alpha, beta and gamma diversity (Anja Knaebel; Wikimedia Commons).

A critical dimension in this context is ecological connectivity. Meta-ecosystem theory emphasises that the flows of organisms (e.g., dispersal, migration), materials (e.g., nutrients, sediments), and processes (e.g., productivity, decomposition) across ecosystems shape biodiversity patterns, ecosystem functioning, and resilience (Angeler et al., 2023; Loreau et al., 2003). Connectivity ensures that species can disperse to track shifting habitats under climate change (Nuñez et al., 2013), maintain viable populations, and facilitate gene flow, which underpins evolutionary potential. But connectivity is also critical for ecological processes. For example, the flow of organic matter and nutrients from riparian zones to streams influences aquatic food webs, while hydrological connectivity between floodplains and rivers regulates nutrient dynamics and sediment deposition (Sponseller et al., 2013). However, landscape planning often focuses on structural connectivity for species movement, overlooking these cross-ecosystem flows (Bolliger & Silbernagel, 2020).

The *spatial insurance hypothesis* predicts that moderate connectivity between habitat patches maintains high biodiversity, increasing both the stability and average levels of ecosystem functions across landscapes (Gonzalez et al., 2009; Loreau et al., 2003). In other words, well-connected habitats can buffer disturbances by allowing species and functions to persist across space, thereby enhancing ecosystem resilience. This idea is further supported by *metacommunity theory*, which emphasises that biological connections within and between habitat patches—ranging from just a few metres to hundreds of kilometres, depending on species' dispersal capacities (Hanski, 1999; Leibold et al., 2004) are critical for sustaining populations, species interactions, and functional diversity. Regional-scale processes regulate the movement of organisms, energy, and materials, while local dynamics involve interactions with abiotic conditions and other species. Together, these cross-scale feedback shapes community structure, functional composition, and the overall resilience of ecosystems (Loreau et al., 2003).

Green and blue infrastructure networks: Strategically planned systems of natural and semi-natural areas designed to maintain biodiversity, sustain ecological processes, and provide multiple ES across landscapes. Green infrastructure - Environment - European Commission

Therefore, ensuring the ecological functioning of NbS requires scaling from individual interventions to integrated ecological networks. NbS should not be conceived as isolated solutions but as part of green and blue infrastructure networks (Pérez-Silos, 2021). Critically, fragmentation or loss of connectivity may push ecosystems beyond tipping points where their capacity to deliver ES collapses, underscoring the need to prioritise NbS in areas where maintaining or restoring connectivity is essential (Scheffer et al., 2001).

4 Ecosystem Services: Key Aspects to Design and Implement Functional NbS

NbS harness the capacity of ecosystems to regulate environmental processes and mitigate risks while simultaneously delivering multiple co-benefits. As detailed in the previous section, biodiversity—through its functional traits and ecological potential—underpins the provision of ES. However, effective planning, design, and implementation of NbS also requires considering two key aspects of ES: their spatial-temporal dynamics and their functional relationships with other ES.

Firstly, ES are spatially and temporally dynamic. The benefits provided by ecosystems often emerge at locations distant from where the biophysical interactions that generate them occur, and their delivery can fluctuate over time due to environmental variability and human demand. Secondly, ES are functionally interconnected, with synergies, trade-offs, and dependencies among them determining the net outcomes of NbS interventions. Recognising and managing these aspects is fundamental to maximising co-benefits, minimising unintended consequences, and achieving resilient and self-sustaining NbS.

4.1 Spatial and Temporal Dynamics

As presented in D5.1, ES are generated within process-related landscape units such as catchments, habitats, or geomorphological units (i.e., functional units sensu Laca, 2021). While the ES framework effectively identifies where and under what conditions nature generates benefits, a critical insight is that the locations providing ES (supply areas) often differ from those benefiting from them (demand areas: in the logic of NBRACER, those risk areas with KCS that can suffer the impacts of a climate hazard).

In this sense, Syrbe and Walz (2012) define three key spatial categories related to ES flows (Figure 6):

- Service-providing areas (SPA): Spatial units where biophysical interactions generate the ES, such as forests providing flood regulation by enhancing infiltration and reducing runoff.
- Service-connecting areas (SCA): Units that connect SPAs to benefiting areas, facilitating the flow of ES benefits across the landscape. For instance, riparian corridors transport sediment and regulate nutrients with downstream benefits.
- Service-benefiting areas (SBA): Units where society receives or consumes ES, such as downstream towns protected from flooding by upstream forested catchments.

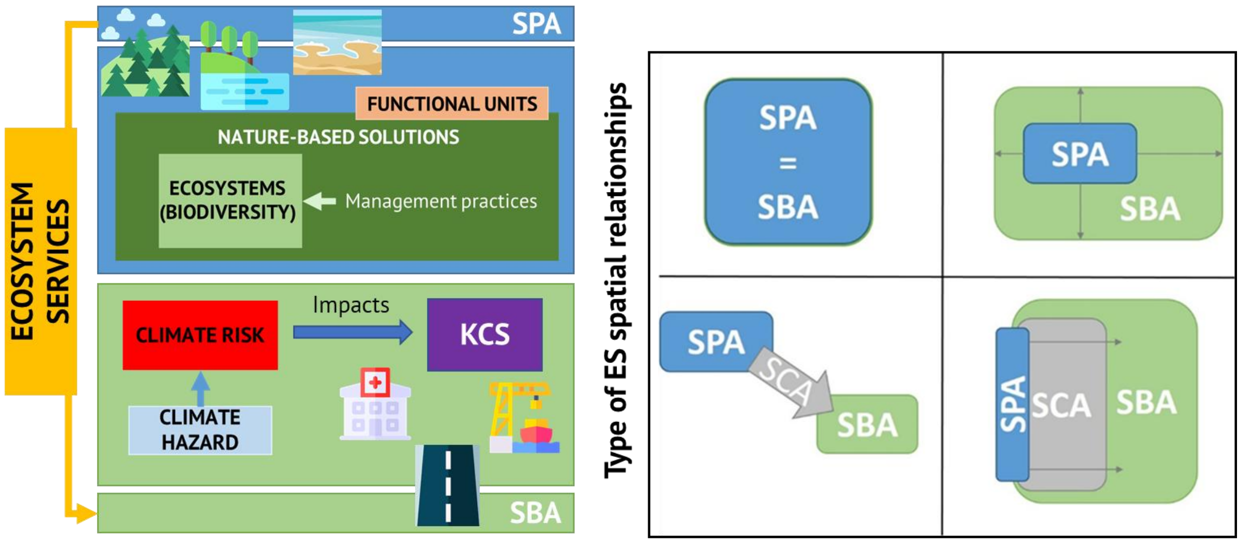

Figure 6: Spatial dynamics in ES provision. Possible spatial relationships between service providing area (SPA) and service benefiting area (SBA) (according to Fisher et al., 2009): upper left: 'in situ': SPA and SBA are identical, i.e., the ES is provided and benefits realised in the same area. Upper right: 'omnidirectional': SBA extends SPA without any directional bias. Lower left: 'directional' – slope dependent: SBA lies downslope (downstream) from SPA, i.e., the ES is realised by gravitational processes (cold air, water, avalanche, landslide). Lower right: 'directional' – without strong slope dependence: SBA lies 'behind' the SPA relating to higher-ranking directional effects. Adapted from Syrbe and Walz, 2012.

Moreover, ES provision is not static. Temporal fluctuations arise due to:

- Abiotic or biotic changes affecting the service-generating processes (e.g., seasonal variations in plant productivity altering pasture provisioning).
- Changes in demand, such as increased water needs in summer tourism peaks.
- Time lags between ES generation and benefit delivery. For example, aquifer recharge by forest infiltration in winter mitigates drought risk only during subsequent dry seasons.

The spatial and temporal decoupling between supply and demand implies that NbS planning must account for the spatial configuration of SPAs, SCAs, and SBAs, ensuring that interventions target not only the hazard location but also the areas generating and transmitting ES benefits. Furthermore, the effectiveness of NbS in risk mitigation depends on the correct alignment of these spatial dynamics within the catchment or landscape context.

4.2 Functional Relationships Between Different Ecosystem Services

ES rarely operate in isolation. Recent studies have shown that ES co-occur, interact, and influence each other in complex ways across landscapes, revealing opportunities for win-win synergies as well as risks of unintended trade-offs (Chan et al., 2006; Egoh et al., 2008; Naidoo et al., 2008). In this sense, Bennett et al. (2009) identified two main mechanisms behind these relationships:

- Shared drivers: Multiple ES respond to the same environmental driver (e.g., precipitation, land use). For example, increased fertiliser use boosts crop production but reduces clean water provision through nutrient runoff (Carpenter et al., 2009).

- Direct or indirect interactions: Changes in one ES directly alter another. For instance, afforestation enhances carbon sequestration, but increased tree evapotranspiration reduces water availability (Pérez-Silos et al., 2021).

Based on these interactions, relationships among ES can be categorised as:

- Synergies: Both ES increase or decrease together (e.g., forest roots reduce erosion while enhancing flood regulation; Pérez-Silos et al., 2021).
- Trade-offs: One ES increases while another decreases (e.g., fertiliser use increases crop yield while degrading water quality; Carpenter et al., 2009).
- Exclusions: Provision of one ES excludes another (e.g., provision of ES derived from crops prevents all forest-based ES, such as hydrological or erosion regulation; Wratten et al., 2013).
- No-effect: No significant interaction between two ES (e.g., riparian forest cooling river temperatures without affecting adjacent crop yield; Pérez-Silos, 2021; Pérez-Silos et al., 2021).

Crucially, these relationships are often non-linear and scale-dependent (Lee and Lautenbach, 2016; Lindborg et al., 2017). For example, floodplain inundation may temporarily reduce grassland pasture provision (trade-off) but enhance productivity in the medium term through nutrient deposition (synergy). Understanding these relationships is vital for NbS design. Interventions targeting a single ES without considering its broader ecological context risk creating maladaptive outcomes or missed opportunities for co-benefits. Instead, NbS should be strategically planned to maximise synergies, minimise trade-offs, and ensure equitable distribution of ES benefits across the landscape.

5 Characterising Biodiversity and Ecosystem Services: Two Roadmaps to Guide Regional Implementation

Characterising biodiversity and ES to identify where and how NbS can be most effectively implemented poses significant challenges due to the complex interplay of biotic and abiotic factors, as discussed in the previous sections. In essence, biodiversity forms the ecological substrate through which ES emerge: the spatial location of ecosystems within functional units, and their specific functional traits, are what ultimately determine the type, quantity, and effectiveness of the ES they provide (Figure 7). In this context, the presence of specific climate-related risks, as identified through the methodologies developed in D5.2 (Bishop et al., 2025), defines the spatial areas where ES are needed—i.e., the SBA. This risk-based demand determines which ES should be prioritised and guides the identification of SPA, where the relevant ecosystems already exist or could potentially be restored to regulate the processes involved in generating impacts on KCS. Thus, the connection between ES and the identification of functional hotspots for NbS implementation is direct and operational.

However, in many cases, ES provision does not currently occur in locations where it would be beneficial. In these situations, it becomes essential to assess whether the potential generation of the desired service is feasible through ecological restoration. This will depend on another key dimension of biodiversity: its ecological potential. In this sense, mapping, not only the current extent of ecosystems, but also their potential distribution, is critical to evaluate the viability of restoration-based NbS. Identifying whether a particular habitat could be re-established in a given location based on climatic, edaphic, or topographic conditions provides valuable insight into where NbS can realistically be implemented and sustained.

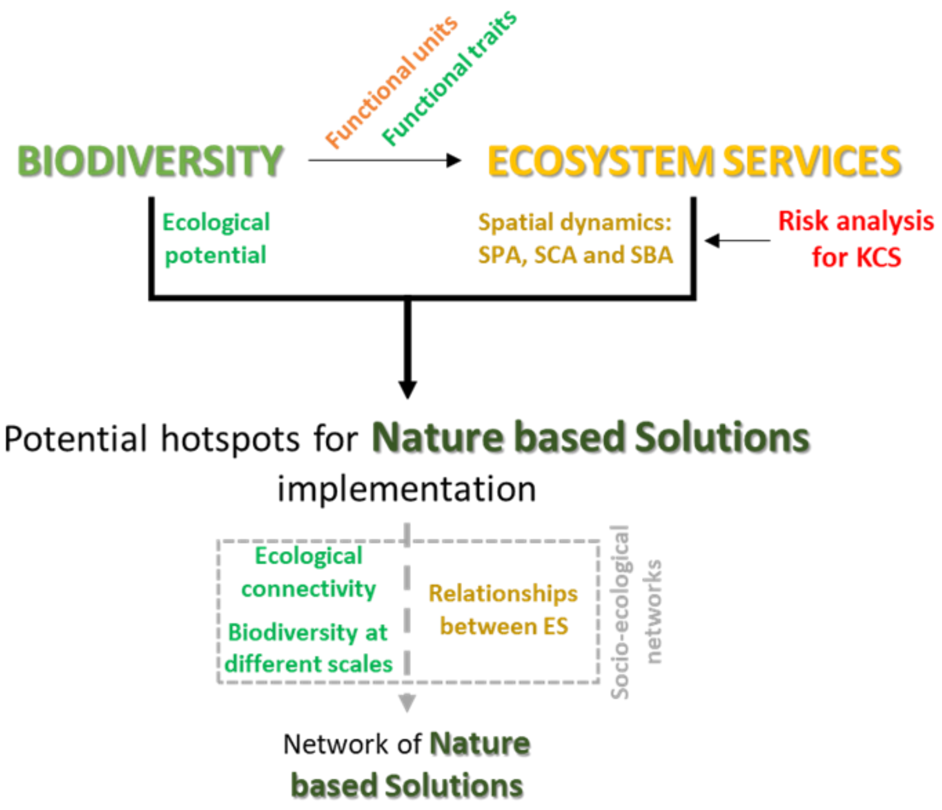

Figure 7: Key Biophysical elements implied in the identification of hotspots for NbS implementation.

The long-term sustainability and effectiveness of NbS at the landscape level, as shown in the lower portion of Figure 7, require moving beyond isolated interventions. Designing NbS as interconnected elements within broader socio-ecological networks—which preserve ecological connectivity, maintain biodiversity at multiple scales, and manage trade-offs and synergies between ES—is essential for fostering self-sustaining, adaptive strategies in the face of climate change and system-wide risks.

Two roadmaps to guide regional implementation in NBRACER

The capacity of regions to carry out the characterisation of the implied features described above depends largely on their technical capabilities, which include access to geospatial datasets, ecological modelling skills, availability of biodiversity and ES indicators, and the active involvement of both technical staff and local experts. However, NBRACER regions start from different baselines in terms of data availability, technical infrastructure, and institutional capacity. This heterogeneity must be acknowledged within WP5, which therefore proposes a flexible, multi-entry framework for characterising biodiversity and ES. As illustrated in Figure 8, three principal options for characterisation are considered:

1. Direct use of existing local or regional datasets combined with expert-based local knowledge.
2. Integration of harmonised global or European datasets and knowledge platforms.
3. Application of ecological and biophysical models to generate new layers or indicators.

Each of these options involves trade-offs between data availability, processing requirements, and the resolution and reliability of outputs. The choice of the option for each step of the characterisation process must therefore be tailored to the specific constraints and opportunities of each region.

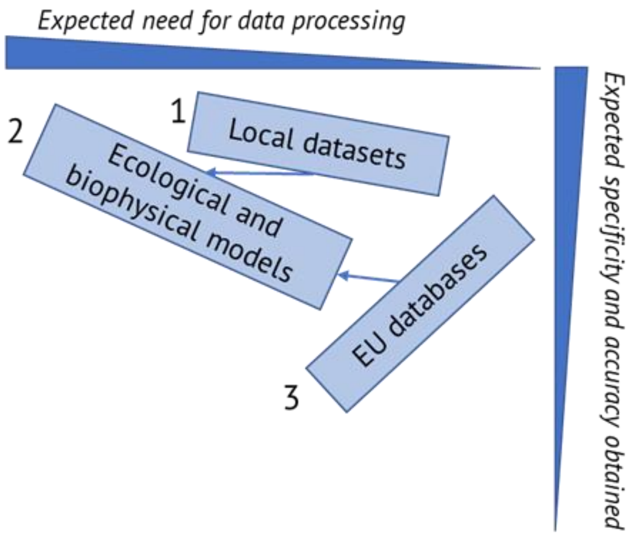

Figure 8: Possible options to map and characterise biodiversity and ES. Option 1 is generally the most accurate approach for mapping biodiversity and ES, as it relies on empirical data. However, collecting these data—particularly through fieldwork—is often costly and time-consuming. In addition, many ES, as well as certain aspects of biodiversity mapping, cannot be directly inferred from empirical observations alone and therefore require specific models (Option 2) to be produced or to extrapolate local measurements to larger areas. This increases processing demands and affects both the specificity and precision of the outputs. Option 3, on the other hand, involves the use of large datasets that are typically easy to access. These are often remote-sensing-based databases or products derived from pre-existing ecological models. They can be used directly to map or extract indicators, but they can also serve as inputs for modelling workflows of the type described under Option 2.

Building upon this premise, Figure 9 outlines a roadmap for regional characterisation efforts based on two pillars: (1) biodiversity mapping and (2) ES modelling. The proposed workflow identifies critical steps—such as identifying spatial units (e.g., habitats, ecosystems), establishing links with ES provisioning, and selecting appropriate indicators (that could be evaluated in Task 5.4) or modelling tools—that can be tackled at multiple spatial scales and with different levels of specificity. In this case, our roadmap establishes two parallel lines of development that can also be combined in their respective steps:

- A coarse-resolution pathway, suitable for regions with limited data or technical capacity, which relies on existing datasets, easily accessible variables over large areas, and a simplified consideration of the ecological characteristics determining ES provision.
- A fine-resolution pathway, suitable for regions with greater data availability and modelling capacities, based on the use and/or development of detailed spatial models and a more refined assessment of the ecological mechanisms underpinning ES provision.

In both cases, the ultimate goal is to enable regions to produce spatially explicit outputs (ES maps) that reflect the type and intensity of ES potentially delivered by ecosystems, guiding the identification of priority areas (i.e., functional hotspots) for NbS implementation.

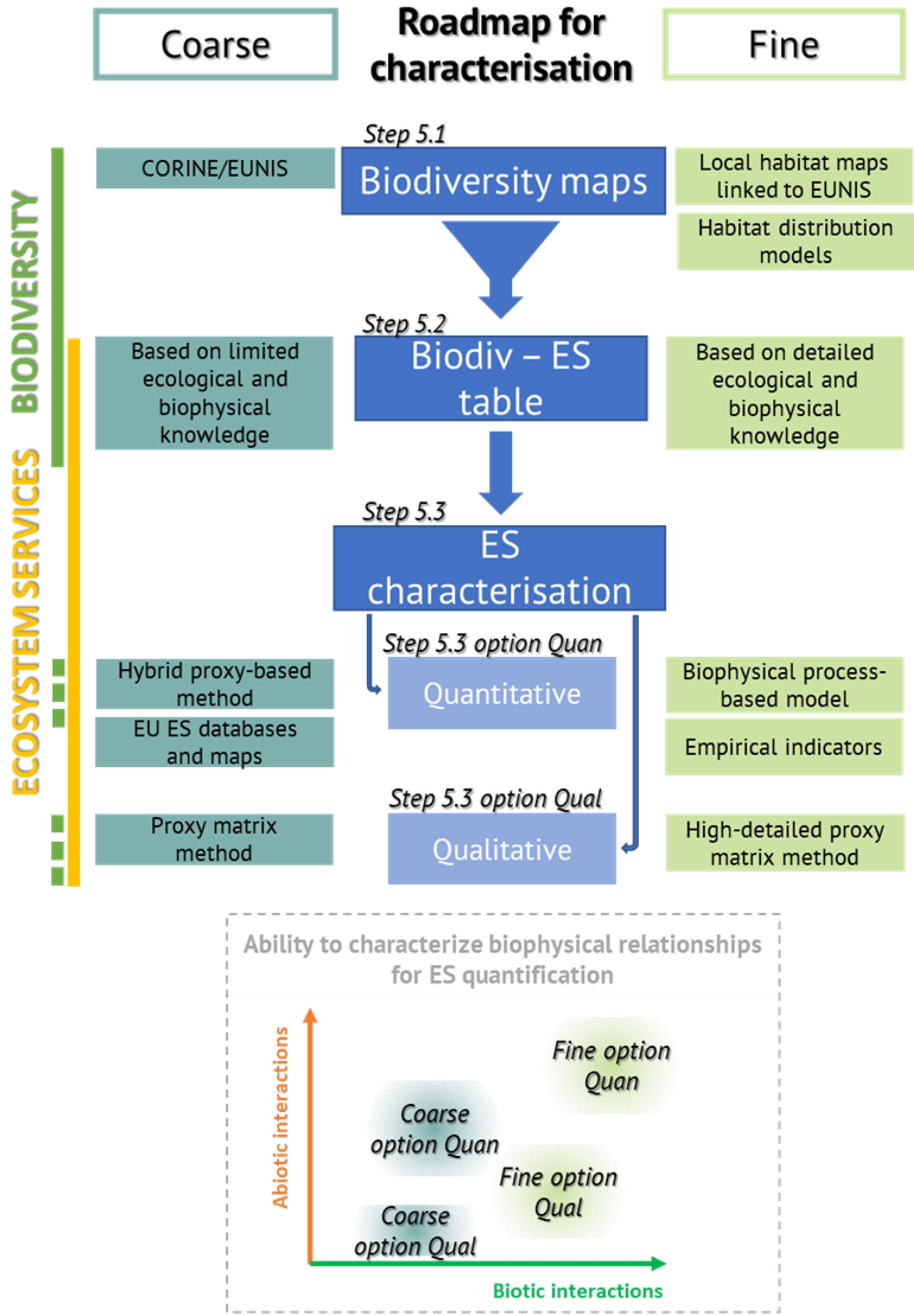

Figure 9: Coarse and fine roadmap for mapping and modelling ES (part of the MMTF roadmap: Level 1 – Step 2).

The first step of the roadmap (Step 5.1) focuses on biodiversity mapping, a relatively straightforward task that involves identifying and mapping ecosystem and habitat types using existing land cover datasets, remote sensing products (e.g., Copernicus), or expert-based classifications. However, as highlighted in Section 3, translating this biodiversity information into ES provision introduces additional complexity. The spatial position of ecosystems within geomorphological functional units and their associated functional attributes (e.g., functional traits) are critical for determining which services can be provided, to what degree, and under what environmental conditions. This also requires considering the spatial decoupling between SPA and SBA, and therefore characterising ecosystems according to the role they play in ES flows (SPA, SCA or SBA).

Step 5.2, therefore, addresses the development of relational tables that conceptually define the link between biodiversity and ES, identifying the spatial (functional unit) and functional (key traits and ecological processes) characteristics that determine the potential provision of each ES by specific ecosystem or habitat types. This step builds upon Step 5.1 and requires a detailed characterisation of the abiotic context, as well as the ecological structure and functioning of each mapped unit.

Once these relationships have been specified, Step 5.3 moves towards the spatial mapping of ES, in either a quantitative (5.3–Quan) or qualitative (5.3–Qual) way. The chosen option depends on the capacity to represent and model the most relevant biophysical interactions identified in the relational table (Step 5.2), which will ultimately condition the precision of the ES maps. In the quantitative approach, direct indicators, biophysical models, and proxies are used to characterise ES provision. These methods are able to capture both biotic and abiotic interactions, since they integrate biological variables with physical drivers. In the qualitative approach, ES provision is inferred through expert knowledge and literature review. Although this approach can achieve a good representation of biotic interactions when ecological expertise is available, its ability to capture abiotic dynamics is more limited and depends strongly on local knowledge.

The remainder of this section follows the structure of the roadmap, explaining the approaches, data sources and tools available at each step: (5.1) habitat/ecosystem mapping; (5.2) relational tables bridging biodiversity and ES; and (5.3) ES quantification—either through quantitative models/indicators or through qualitative, expert-based assessments. The two pathways (fine-resolution vs coarse-resolution) are presented in parallel, highlighting their respective strengths, limitations and data requirements. Figure 10 provides directions on which path to take.

This decision framework helps regions to choose the most appropriate pathway for ES characterisation based on their data availability, ecological knowledge, and modelling capacity. The first decision to make is whether high-resolution habitat or biodiversity maps are available; if not, coarser land cover products such as CORINE can serve as a starting point. Next, the framework asks whether local ecological expertise exists to refine biodiversity-ES relationships, guiding the user toward either generic relational tables or optimised, locally adapted ones. We further distinguish between modelling and non-modelling approaches. Thus, those with technical capacity can apply quantitative, process-based models using tools like InVEST, ARIES, SWAT, or INCA, while those without are directed toward qualitative, expert-based scoring. Finally, both coarse and fine roadmaps converge on ES characterisation, either as categorical ES maps (for

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qualitative approaches) or continuous ES probability layers (for quantitative approaches) which can then be linked to biodiversity and risk for NbS hotspot identification.

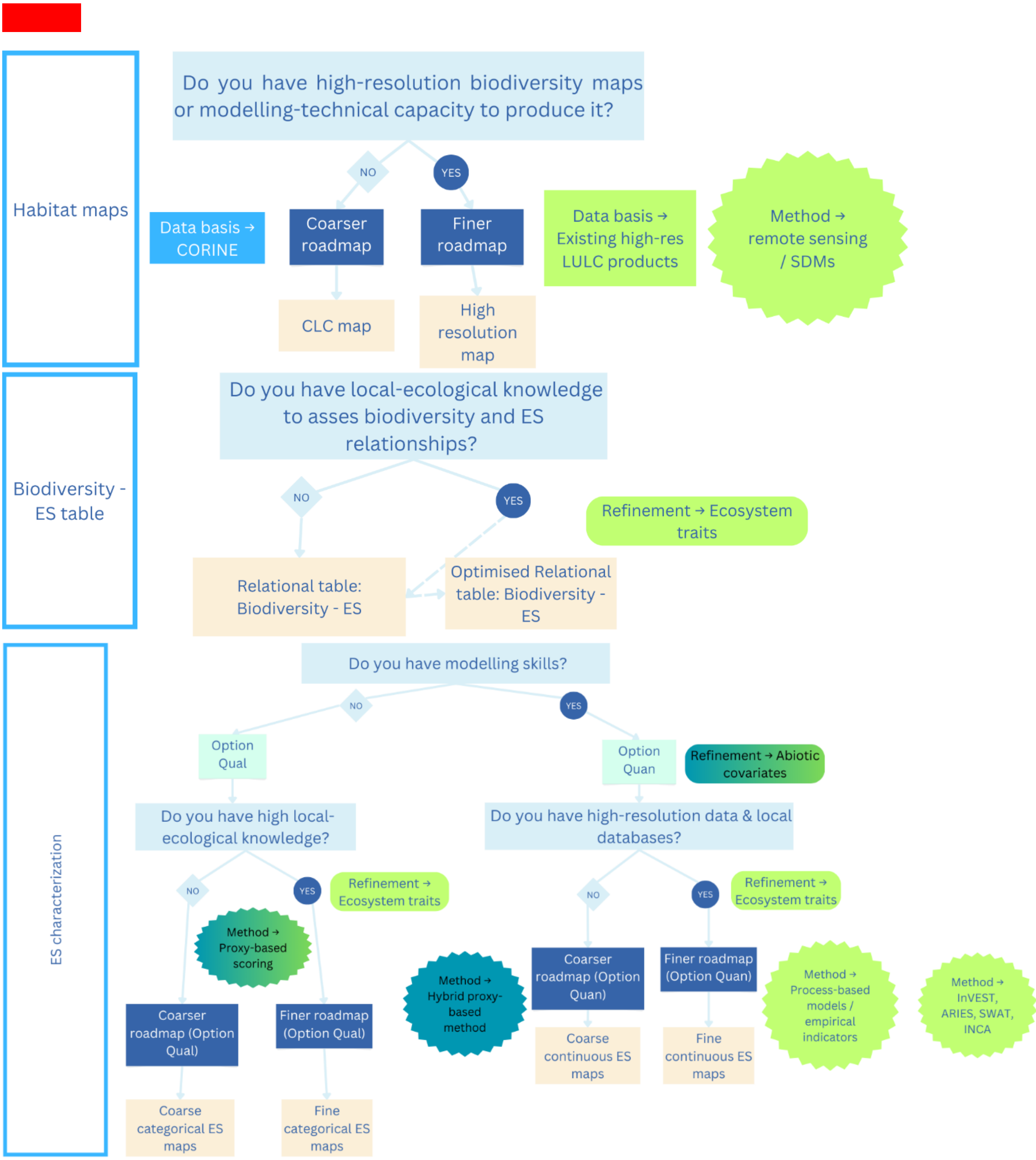

Figure 10: Decision tree for selecting either pathways for ES characterisation, based on data availability, ecological knowledge, and modelling capacity.

5.1 Biodiversity Maps

Mapping habitats and ecosystems is the first step in characterising biodiversity across the NBRACER regions. This process serves as the biophysical foundation for understanding ES provisioning and identifying areas suitable for NbS implementation. In this sense, as pointed out in section 3.1, it is also very relevant to assess the potential distribution of habitats and ecosystems, not just their current extent. This information is crucial when planning NbS focused on restoration or ecological expansion, as it provides insight into the environmental suitability and feasibility of proposed interventions.

Fine-scale roadmap: high-resolution mapping based on botanical data and remote sensing

The fine-scale roadmap relies on detailed, often site-specific information to generate high-resolution vegetation maps. These maps can depict vegetation patterns across different levels of ecological organisation, including habitat types (e.g., sensu EUNIS or national typologies), plant formations, and ecosystem units. This approach is especially useful in areas where fine ecological gradients, structural diversity, or localised conservation values require more precise spatial delineation.

Fine-scale mapping techniques may vary in terms of technological sophistication and data requirements, and they can be combined to enhance accuracy. Ordered from lower to higher levels of technical sophistication—which also correlates with a reduced manual workload and greater capacity to map large areas more automatically—these methods include:

- Floristic inventories and ground-based vegetation surveys, which provide detailed species-level data, are essential for defining habitat types or characterising functional traits (The Nature Conservancy, 1994).
- Photointerpretation, often based on aerial photographs or drone imagery, which allows for manual classification of vegetation units (Campos et al., 1999).
- Remote sensing-based classification, using satellite imagery (e.g., Sentinel, Landsat) and machine learning algorithms to distinguish between vegetation types (Xie et al., 2008).
- Species/habitats distribution modelling (SDM), which integrates occurrence records with environmental variables to predict the potential distribution of habitats or key species, especially when survey data is sparse (Elith and Leathwick, 2009).

Importantly, these methods are not mutually exclusive. For example, species distribution models require floristic inventories as input data, and can be enriched with biotic or abiotic variables derived from remote sensing. Table 1 below summarises a selection of European cartographic resources that align with the level of detail expected in this roadmap, serving as complementary or substitute datasets for ad-hoc initiatives implemented using some of the methodologies outlined above.

Table 1: Pan-European products for mapping biodiversity distribution at a fine scale (developed in September 2025).

Product	Description	Characteristics	Source
Forest Type	Products from remote sensing that provide, at a pan-European level, a forest classification for three thematic classes (all non-forest areas/broadleaved forest/coniferous forest). This product uses the Food and Agriculture Organization's (FAO) definition of forests to filter out things like street trees, orchards and patches smaller than half a hectare.	*Spatial resolution*: 10 m, 100 m *Temporal extent:* 2012, 2015, 2018, 2021 *Sensor:* Sentinel-1, Sentinel-2	Copernicus Land Monitoring Service
Small Woody Features	Products from remote sensing that show linear structures whose width is ⩽ 30 m and length is ⩾ 30 m, as well as patchy structures whose area is between 200 m^2 and 5,000 m^2.	*Spatial resolution*: 5 m, 100 m *Temporal extent:* 2017, 2019 *Sensor:* Pleiades 1A/1B, SuperView-1, KOMPSAT-3/3A, PlanetScope	Copernicus Land Monitoring Service
High Resolution Layer Grasslands	Products from remote sensing that map the location and size of permanent and temporary grasslands.	*Spatial resolution*: 10 m, 100 m *Temporal extent:* 2017, 2018, 2019, 2020, 2021 *Sensor:* Landsat, Sentinel-1, Sentinel-2	Copernicus Land Monitoring Service
EUNIS habitat suitability	Probability distribution maps (i.e., habitat distribution modelling) were modelled for the following EUNIS habitat groups (level 3 in the hierarchy of the EUNIS habitat classification): • Littoral biogenic habitat types (salt marshes) • Coastal habitat types • Wetlands habitat types • Grassland and lands dominated by forbs, mosses or lichens habitat types • Heathland, scrub and tundra habitat types • Forest and other wooded land habitat types	*Spatial resolution*: 100 m *Temporal extent:* 2021 *Sensor:* Sentinel-1, Sentinel-2 *Algorithm*: Maxent *Environmental variables:* Climatic properties, soil properties, Remote Sensing-enables	European Environment Agency

	• Inland habitats with no or little soil and mostly with sparse vegetation	Essential Biodiversity Variables	
Regional and national maps	National and regional administrations may have established some form of land use and land cover mapping system that could be used to characterise the distribution of certain habitats or ecosystems, depending on the approach and level of detail.	Depending on the resource	Various (e.g., LULC Cantabrian map)

To map the potential extent of ecosystems, SDMs can be applied to model the potential niche of a habitat using only abiotic factors—such as slope, climate, and soil—yielding suitability maps for target restoration areas. This approach has been successfully applied by Álvarez-Martínez et al. (2018), who modelled the area of occupancy of specific habitat types using remote sensing for incorporating biotic interactions and abiotic drivers, and, alternatively, using only abiotic drivers to estimate the potential niche. Other complementary resources (Table 2), such as bioclimatic zoning maps (e.g., Rivas-Martínez et al., 2004), can also be used to define altitudinal and climatic envelopes for natural vegetation units. However, these zoning maps typically offer a coarser spatial resolution than ad-hoc potential niche models and therefore may be less suitable for fine-resolution restoration planning, though they remain valuable for regional-scale assessments.

Table 2: Pan-European products for mapping the potential distribution of habitats and ecosystems (developed in September 2025).

Product	Description	Characteristics	Source
Map of the natural vegetation of Europe	The map provides information about the form, natural variety and the spatial distribution of the main vegetation units of the natural vegetation cover in the individual regions of Europe (natural biological diversity). In addition, it shows the location and total extent of areas with similar site qualities and environmental conditions, and thereby the comparable natural growth potential, the entire range and the geographical differentiation of a unit (e.g. the further subdivision of beech forests according to trophy and altitudinal belts, as well as into geographic and ecological forms).	*Scale*: 1:2500000 m	Wageningen Environmental Research (Bohn et al., 2003) *After installing the software, shapefiles are also accessible in their respective Program Files folder.*
A phytoclimatic map of Europe	A high-resolution quantitative phytoclimatic map of Europe that shows fifty different phytoclimatic stages.	*Spatial resolution*: 1000 m	(Botti, 2018) *GIS files may be available upon request.*

The main advantage of this roadmap is its ecological fidelity and spatial resolution, which makes it highly suitable for local to regional assessments and for tracking dynamic or fine-scale habitat changes over time. However, it is also more demanding in terms of data, requiring taxonomic expertise, reference databases, and ground-truthing, which may limit its feasibility in large or data-poor regions. Additionally, vegetation typologies and classes generated through each method may differ, creating challenges for comparability. To address this, translation frameworks are needed to homogenise vegetation maps into common ecosystem or habitat classes that can later be linked to ES provision (Step 5.2). In this deliverable, Appendix 1: Land Cover and Habitat Classification Bridge provides such a framework, offering a crosswalk between EUNIS habitat classes and CORINE Land Cover categories, both of which are important as they are entry points to the relational tables proposed later in sections 5.2 and 6.

Coarse-scale roadmap: baseline mapping using CORINE Land Cover

In data-limited contexts, or where technical capacity for processing and GIS-based analysis is restricted, a coarse-scale roadmap provides a more accessible alternative. This approach relies on the CORINE Land Cover (CLC) dataset, a harmonised cartographic resource covering the whole of Europe. CLC offers a general yet standardised overview of vegetation and land cover patterns, with sufficient spatial resolution to support the characterisation and quantification of ES at regional scales (Burkhard et al., 2009).

The CLC dataset, developed under the European Environment Agency's Copernicus Land Monitoring Service, has been a flagship resource for more than three decades. It provides information on land cover and land use, updated at six-year intervals, and is widely used for both scientific applications and territorial management. Its relative simplicity and broad availability make it an indispensable tool for cross-regional comparability. Table 3 summarises the main specifications of CORINE, including thematic detail, spatial resolution, and update frequency.

Table 3: Pan-European product for mapping biodiversity distribution at a coarse scale (developed in September 2025).

Product	Description	Characteristics	Source
CORINE Land Cover (CLC)	This remote sensing product offers a pan-European land cover and land use inventory with 44 thematic classes, ranging from broad forested areas to individual vineyards (Appendix 2: Land Use-Cover Classification).	*Spatial resolution*: 100 m *Temporal extent:* 1990, 2000, 2006, 2012, 2018 *Sensor:* Sentinel-2 and Landsat-8 for gap filling	Copernicus Land Monitoring Service

Although CLC classes are generic, they can be linked to habitat types through translation tables bridging coarse land cover categories with more detailed ecological typologies (e.g., EUNIS habitats) (Appendix 1: Land Cover and Habitat Classification). Within our methodology, this link is critical: CLC categories always serve as the baseline reference in the relational tables presented in Section 5.2. In this way, the connection to potential ES provision is preserved even when biodiversity mapping is limited to higher-level hierarchical classes (land cover and broad vegetation physiognomies).

Finally, in relation to potential ecosystem extent, coarse-scale approaches can make use of existing global or European datasets (i.e., biogeographical zoning; Table 2) or simple proxies based on environmental gradients (e.g., elevation bands, climatic envelopes). Although less precise than fine-scale SDMs, these methods still provide useful guidance for identifying where restoration-based NbS could potentially expand or re-establish suitable habitats.

While coarse-scale datasets lack the ecological fidelity and spatial granularity required for local-scale NbS planning, they are extremely valuable for initial screenings, upscaling analyses, and cross-regional comparisons. They also provide a practical entry point for replication regions within NBRACER. Moreover, they can be enriched by combining with functional trait databases, ecosystem condition indicators, or local expert knowledge, enhancing their capacity to support relational assessments between biodiversity and ES.

5.2 Biodiversity and Ecosystem Services Tables

The primary goal of this step is to produce a relational table linking the outputs from Step 5.1—habitat, ecosystem, and land cover maps—with the provision of regulating ES. This table serves as the central tool for translating spatial biodiversity information into ES provisioning potential. To achieve this, it is necessary to characterise three key dimensions:

1. Spatial components that determine the potential regulation of abiotic flows involved in a given ecosystem. These are primarily defined by functional units (see Section 3.1). For example, in hillside environments, abiotic processes such as erosion or runoff dominate, whereas in coastal zones, erosion and deposition dynamics are linked to littoral processes. Understanding these units is essential for situating ecosystems within their relevant process domains.
2. Ecosystem properties and functions that directly influence ES provision. As exposed in Section 3.2, this includes both the structural role of key species (e.g., riparian tree cover intercepting sediment flows, dune vegetation stabilising coastal sediments) and functional traits (e.g., rooting depth favouring infiltration, leaf area index influencing evapotranspiration, plant phenology affecting seasonal water regulation).
3. Spatial dynamics within ES flows, as introduced in Section 4.1. Ecosystems can play different roles depending on whether they generate the ES within SPA, facilitate its transmission through SCA, or are located within SBA, where society ultimately receives the benefits. Capturing this role is critical for identifying whether NbS should focus on protecting existing service sources or restoring potential service providers in strategically located areas.

Classifying ES

Standardising the typology of ES is essential to harmonise these relationships across regions. The Common International Classification of Ecosystem Services (CICES) offers a comprehensive framework, with 90 ES categories across four hierarchical levels (Figure 11). However, for practical application in NBRACER, this list must be simplified to reflect the diversity of landscapes and ES relevant to the project's scope.

Following previous works (e.g., Bastian et al., 2017; Burkhard et al., 2009), ES can be aggregated into a smaller number of categories, such as ecological integrity, provisioning, regulating, and cultural services. Two grouping strategies are possible:

- Strategy A: Aggregate ES at the "Group" or "Division" levels within the CICES hierarchy for a straightforward standardisation.
- Strategy B: Define new categories tailored to the NBRACER context, following examples from other EU projects (e.g., REST-COAST, Baptist et al., 2024; Galparsoro et al., 2014).

This approach improves comparability with other Horizon Europe initiatives while retaining flexibility to adapt to local priorities.

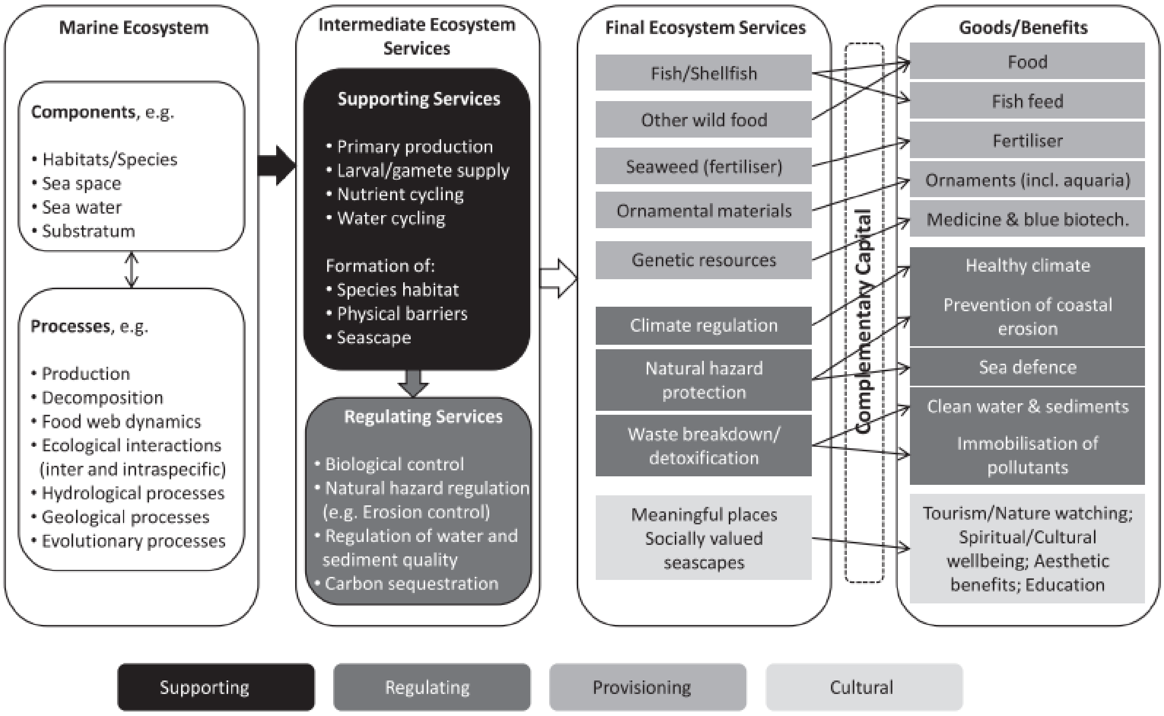

Figure 11: Schematic showing the ES categorisation based on ecosystem components and functions from Potts et al. (2014).

Therefore, the categorisation of ES for NBRACER should be closely aligned with the natural features and environmental contexts specific to the NBRACER regions. An example of this categorisation, as applied in the REST-COAST project (Baptist et al., 2024), resulted in the selection of five ES: i) food provisioning, ii) carbon sequestration, iii) regulation of water and sediment quality, iv) natural hazard regulation, and v) coastal erosion prevention. However, it is essential to note that this selection in REST-COAST reflects the project's marine and coastal focus. In contrast, the NBRACER regions also cover rural and urban landscapes, thus ES considered in NBRACER must capture its landscape diversity.

Key abiotic and biotic attributes for characterising the provision of ES

The final output of this step 5.2 is a multi-entry relational table (Table 4) in which each ES category includes:

- Ecosystem or habitat type providing the service (linked to CORINE, EUNIS, or other standardised land cover classes).
- Land cover category in which the habitat is mapped.
- Associated geomorphological functional units relevant to the ES (e.g., floodplains for flood regulation, slopes for erosion control).
- Key functional traits or biological attributes enabling the ES provision (e.g., canopy cover, rooting depth, vegetative density, growth form).
- Role in the ES flow (SPA, SCA, SBA).

Table 4: Relational table showing some examples of links between ES and biodiversity.

Ecosystem Services (CICES v5.1)	Biophysical Process	Habitat / Ecosystem Type	Land Cover Category (CORINE EUNIS)	Functional Unit (Geomor-phological Setting)	Key Biological Features and Traits	Role in ES Flow (SPA / SCA / SBA)	Description of Service Provision
Control of erosion rates (2.2.1.1)	Control of erosion at source	Hillside forest	CLC 311 EUNIS G1.6	Hillslope	Presence of tree cover; root structure	SPA	Trees stabilise soil, reducing sediment loss compared to other covers
Filtration by plants and animals (2.1.1.2)	Sediment filtering	Riparian forest	CLC 313 EUNIS G1.1	Riparian buffer	Tree density and canopy cover	SPA/SCA	Dense vegetation traps sediment, improving water quality
Hydrological cycle regulation (2.2.1.3)	Water storage and flood attenuation	Floodplain	CLC 411 EUNIS C2.3	Floodplain	Large storage volume; wetland vegetation	SPA/SBA	Reduces flood peaks by temporary water storage
Coastal erosion prevention	Wind and wave energy dissipation	Coastal dunes	CLC 331 EUNIS B1.3	Coastal buffer	Deep-rooted dune vegetation	SPA/SBA	Vegetation stabilises dunes, reducing erosion risk

By combining these dimensions, the relational table becomes a pivotal tool for linking biodiversity information with ES regulation potential, enabling consistent and comparable assessments across all NBRACER regions, regardless of whether they follow the coarse or fine roadmap. The central idea is that the structure of the relational table allows the identification of the abiotic and biotic features of ecosystems that are most relevant for ES provision. However, these links need to be expanded, informed, and validated through expert and local knowledge, in order to determine which elements are most critical for each ES and how these elements can be quantified or ranked in subsequent steps. This information then provides the basis for the quantitative or qualitative characterisation of ES in Step 5.3.

Importantly, much of the information required to populate these tables can be co-generated through the conceptualisation and development of the CRICs. The participatory construction of the CRICs helps specify the links between the physical processes that need to be regulated, the ecosystem services involved in that regulation, and the ecosystems that provide them. Through this process, different expert groups can collectively identify: (i) the functional connections between areas under risk and the areas where ES are generated; (ii) the ecosystems involved in regulating the impacts of the hazard; (iii) the abiotic factors that trigger the processes to be regulated; and (iv) the key biological properties and functional traits of ecosystems that underpin their regulatory capacity. This co-produced knowledge can then be directly translated into the relational tables, strengthening their relevance and applicability for subsequent modelling and hotspot identification.

For instance, in the case of flood regulation through runoff reduction, the presence of deep roots and soil litter has been identified as key functional traits. These traits are associated with natural and especially mature forests, which therefore should receive a higher weighting in the categorisation of this ES compared to other land cover types such as shrubland or grassland. In the fine-resolution roadmap, ecological experts within the regions are expected to quantify this differential effect through various means (e.g., prioritisation of ecosystem types, habitats, and land cover classes according to functional traits), which can then inform biophysical models or serve directly as proxies for ES provision. In the coarse-resolution roadmap, the absence of specialised ecological expertise may constrain this differential analysis of traits. As a result, biotic interactions are considered at a broader level (e.g., distinguishing between forest, shrubland, or grassland), providing a more generalised but still operational proxy for service provision.

In this way, the relational table serves as an intermediate bridge: it translates ecological structure and processes into operational categories that can be mobilised for ES characterisation. They also ensure flexibility by allowing each region to adapt the level of detail to its own data availability and technical capacity, while preserving a common methodological backbone across NBRACER.

5.3 Ecosystem Services Characterisation

Once the spatial characterisation of biodiversity has been completed (Step 5.1), providing the distribution of habitats and ecosystems, and the relational tables have been built (Step 5.2), specifying which biological components, functional traits, and functional (geomorphological) units underpin the provision of each service, the next step is to characterise the ES themselves. This stage is concerned with translating the identified relationships into spatially explicit outputs that describe the type and, when possible, the magnitude of ES delivery.

The identification of abiotic variables (linked to functional units) and biotic variables (linked to functional traits) in Step 5.2 provides the foundation for this task. These variables define the ecological mechanisms by which ecosystems regulate flows of energy, matter, and organisms, and therefore constitute the essential inputs for models, empirical indicators, or proxy-based approaches. In practice, the greater the number and precision of these variables that can be represented—both in terms of spatial resolution and ecological detail—the greater the capacity of the characterisation to capture the relevant biotic–abiotic interactions that determine ES provision.

Depending on the technical capacity of the regions and the precision required by the planning objectives, ES characterisation can follow two main options: quantitative, where the amount of service provided by ecosystems is estimated or modelled; or qualitative, where relationships are inferred based on the assumed capacity of ecosystems and habitats to provide specific services. Each option offers distinct strengths and limitations, but both are valid within the NBRACER framework as pathways to support regional climate adaptation planning. Accordingly, NBRACER considers two parallel roadmaps for each option: a fine-scale roadmap, which leverages detailed ecological data and modelling capacity, and a coarse-scale roadmap, which builds on harmonised datasets and proxy-based methods. These roadmaps are presented not as rigid alternatives but as extremes of a continuum, allowing regions to position their approach according to data availability, technical expertise, and decision-making needs.

5.3.1 Quantitative (Option Quan)

The quantitative characterisation of ES aims to measure the biophysical relationship between biological and physical system components. This represents the ideal scenario for ES assessment, as it provides not only a binary indication of whether a service is present or absent, but also a measure of the magnitude of service provision (de Groot et al., 2010). Such evaluations build directly upon the identification of abiotic and biotic variables in Step 5.2, which determine the ecological processes underlying service delivery.

These interactions can be quantified through different approaches. On the one hand, empirical data—derived from field measurements or remote sensing observations—can provide direct or indirect estimates of ecosystem functions that underpin services (e.g., aboveground biomass as a proxy for carbon sequestration; Houghton 2005). On the other hand, process-based models simulate the interactions between abiotic flows (e.g., hydrology, sediment, climate) and the biological components that regulate them (Villa et al., 2014). Depending on model sophistication, these interactions may be represented with varying precision: for instance, hydrological models may capture runoff dynamics in great detail while treating vegetation effects more generically (e.g., land-cover categories ranked by infiltration potential based on literature values or conceptual models).

Ultimately, the resolution of input data, the ability of models to explicitly represent biophysical interactions, and the degree of ecological detail included will determine the precision of the resulting ES estimates (Martínez-Harms & Balvanera, 2012). In practice, both empirical/remote sensing indicators and process-based models offer complementary pathways, each with specific strengths and limitations. While process-based approaches are often better suited for mechanistic understanding and scenario analysis, they demand high levels of data and expertise. Empirical or statistical methods (e.g., machine learning) can achieve high predictive accuracy based on the data-driven predictive power, but are often constrained by data availability, spatial transferability, and scaling issues.

Building on this conceptual foundation, two complementary roadmaps are proposed within NBRACER for quantitative ES characterisation: a fine-scale roadmap, based on process-based models and high-resolution indicators, and a coarse-scale roadmap, based on hybrid proxy methods and harmonised EU-scale ES datasets.

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Fine-scale roadmap: biophysical process-based model and empirical indicators

The fine-scale roadmap is designed for regions with sufficient technical and data capacity to quantify ES directly through biophysical modelling and empirical indicators. In this context, two complementary resources are presented:

1) Existing ES modelling tools and platforms, which allow regions to directly quantify services through established models. These tools integrate ecological and physical processes, are widely applied at European and global levels, and can be adapted for regional or local analyses. They provide a relatively standardised entry point for regions that want to apply well-developed methods for ES quantification.
2) An operational methodological framework, which provides a structured way to couple empirical datasets and/or process-based models with the spatial distribution of habitats and abiotic flows. This framework is particularly useful for regions with modelling expertise that wish to build more ad-hoc ES characterisations, aligning habitat maps, functional traits, and physical processes into tailored outputs.

Table 5 below summarises a set of modelling platforms and tools (e.g., ARIES, InVEST, Co$ting Nature, INCA) that can be directly employed by regions aiming at explicit ES modelling. These tools differ in terms of data needs, scale, and user expertise, but all allow the quantification of biophysical interactions underpinning ES.

Table 5: Free models and tools for ES characterisation at a fine scale (developed in September 2025 and based on Neugarten et al. (2018). We also incorporate a set of ES that can be assessed by each tool. Although ES names were derived from the tools, it is not a comprehensive list of all ES (provisioning ES, regulating ES and cultural ES). Abbreviations: *TR*- Time requirements, *DI*- Data input demand, *SR*- Skill requirement, *IN*- Interface, *US*- User support, *M/N*- Monetary/Nonmonetary.

Product	**Description**	**General summary/insights and *considered ES***	**Characteristics**	**Developers and source**
Artificial Intelligence for Ecosystem Services (ARIES)	ARIES is an ecosystem services modelling platform. ARIES' underlying software, k.LAB is designed for integrated socioeconomic-environmental modelling, which includes ES. ARIES can accommodate a range of different users and user needs, including scenarios, spatial assessment and economic valuation of ES, optimisation of payments for ecosystem services programs, and spatial policy planning. Using ARIES currently requires modelling skills and GIS	Spatially explicit ES trade-off, flow and uncertainty maps; currently time-consuming for new applications, unless using global models *Marine fish aquaculture; Water (provision, supply, quantity, yield)* *Terrestrial carbon storage; Coastal blue carbon; Flood regulation; Landslide risk; Soil stabilisation; Pollination; Sediment regulation* *Recreation and nature tourism; Scenic quality and aesthetic viewsheds*	*TR*: Low for global models; high for new case studies *DI:* Low to high *SR:* Low to high *IN*: Specialised software (k.LAB/Eclipse) and web application *US:* Moderate *M/N:* Biophysical values, can be monetised	BC3 (Villa et al., 2014) Link
Co$ting Nature v.3 (C$N)	C$N is a web-based tool for spatially analysing ES and assessing the impacts of human interventions such as land use change scenarios. It provides a globally or locally relative index of service provision that can be used for ES assessment, conservation prioritisation, analysis of co-benefits, pressures and threats. Version 3 includes economic/ monetary valuation. Using C$N does not require modelling skills or GIS.	Rapid analysis of indexed, bundled services based on global data, along with conservation priority maps *Fisheries; Freshwater aquaculture; Fuelwood; Harvested wild goods and hunting; Livestock grazing; Timber; Water (provision, supply, quantity, yield)*	*TR*: Low *DI:* Low *SR:* Low *IN*: Web application	King's College London, AmbioTEK and UNEP-WCMC

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		Carbon sequestration; Terrestrial carbon storage; Coastal protection; Erosion; Flood regulation; Landslide risk; Soil stabilisation; Pest and disease regulation; Pollination; Seasonal water yield; Water quality *Cultural values and heritage; Recreation and nature tourism*	*US:* Moderate *M/N:* Outputs indexed, bundled ES values	(Mulligan et al., 2010) Link
Integrated Valuation of Ecosystem Services and Tradeoffs 3.4.2 (InVEST)	InVEST is a suite of software models for mapping and quantifying ES in biophysical or economic terms under different scenarios (e.g., policy or management options). InVEST models are based on simple, generalised production functions and require commonly available input data. Using InVEST requires GIS but not modelling skills	Spatially explicit ecosystem service trade-off maps; currently, they are relatively time-consuming to parameterise *Fisheries; Marine fish aquaculture; Water (provision, supply, quantity, yield)* *Carbon sequestration; Terrestrial carbon storage; Coastal protection; Pollination; Sediment regulation; Seasonal water yield; Water quality* *Recreation and nature tourism; Scenic quality and aesthetic viewsheds*	*TR*: Moderate to high *DI:* Moderate to high *SR:* Moderate to high *IN*: Desktop application; Python API (optional) *US:* High *M/N:* Biophysical values, can be monetised	Stanford: Natural Capital Project (Sharp et al., 2018) Link
The Integrated system for Natural Capital Accounting (INCA)	INCA developed the first comprehensive set of EU-wide ecosystem accounts. Ecosystem accounting is a statistical framework for organising data, tracking changes in the extent and the condition of ecosystems, measuring ES and linking this information to economic and other human activities. It aims to illustrate the benefits society receives from ecosystems and their services.	ES accounts in a systematic way that can be applied at the regional or continental level in Europe. The tool is based on the availability of official European statistical inputs *Wood provision; Crop provision*	*TR*: Low *DI:* Low *SR:* Low *IN*: QGIS plugin and web application	European Commission (La Notte et al., 2022) Link

		Air filtration; Global climate regulation; Local climate regulation; Flood control, Soil retention *Nature tourism*	*US:* Moderate *M/N:* Biophysical values, can be monetised	
Multiscale Integrated Models of Ecosystem Services (MIMES)	MIMES is an analytical framework designed to integrate different ecological and economic models to understand and visualise ES values. MIMES relies on SIMILE software, and each MIMES application is customised to a specific socio-ecological system. Using MIMES requires modelling skills and GIS.	Dynamic modelling and valuation using input–output analysis, ecosystem trade-off and decision making, is highly time-consuming to develop *Any provisioning ES* *Any regulating ES* *Any cultural ES*	*TR*: High for new case studies *DI:* Moderate to high *SR:* High *IN*: MIDAS/SIMILIE (not open source) *US:* Moderate *M/N:* Monetary valuation via input–output analysis	AFORDable Futures LLC (Boumans et al., 2015)
Social Values for Ecosystem Services (SolVES)	SolVES is an ArcGIS-dependent application that allows the user to identify, assess and map the perceived social values that people attribute to cultural ES, such as aesthetic or recreational values. Combining spatial and points-allocation responses from surveys (which can be undertaken in person, online or through mailing), it produces points-based social-values metric and raster maps of social value intensities. Using SolVES requires GIS.	Provides maps of social values for ES; time-consuming for new studies, but lower cost for value transfer *Cultural values and heritage; Research/Knowledge; Recreation and nature tourism; Scenic quality and aesthetic viewsheds; Wilderness and iconic values*	*TR*: Low to high *DI:* Low to moderate *SR:* Moderate *IN*: ArcGIS (add-in toolbar) *US:* Moderate *M/N:* Nonmonetary preferences (rankings) of relative	USGS (Sherrouse et al., 2014) Link

			values for stakeholders	
WaterWorld v.2 (WW)	WW is a web-based tool for modelling hydrological services associated with specific activities under current conditions and under scenarios for land use, land management and climate change. It provides quantitative biophysical results or relative indices that can be used to understand hydrological ecosystem services, water resources and water risk factors. Using WW does not require GIS or modelling skills.	Rapid analysis of detailed biophysical assessment based on global data, along with conservation priority maps *Water (provision, supply, quantity, yield)* *Erosion; Flood regulation; Sediment regulation; Seasonal water yield; Water quality*	*TR*: Low *DI:* Low *SR:* Low *IN*: Web application *US:* Moderate *M/N:* Biophysical values only	King's College London and AmbioTEK (Mulligan, 2013) Link

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These tools are especially valuable for analysing synergies and trade-offs, exploring dynamic feedback between services, and evaluating how land-use or climate changes may alter service provision. However, they typically require high-resolution spatial input data, expert calibration, and substantial computational capacity—resources that may not be available across all NBRACER regions.

On the other hand, the methodological framework proposed by Pérez-Silos (2021) illustrates how empirical and modelling efforts can be operationalised in a stepwise manner: (i) mapping areas of potential abiotic flow for each physical process (e.g., runoff, erosion); (ii) overlapping these with habitat occurrence to define potential extents for conservation or restoration; and (iii) restricting management extents to those areas where ecological functions effectively contribute to service-benefiting areas. This framework ensures that conservation and restoration priorities are explicitly tied to the biophysical interactions between biodiversity and physical flows.

A complementary but critical dimension of this roadmap concerns the characterisation of biodiversity attributes—particularly functional traits—that influence ES provision. High-resolution datasets derived from satellite products, ecological databases, or in-situ surveys can greatly improve model performance by representing the biological mechanisms that regulate physical processes. For instance, canopy cover, rooting depth, or vegetation density strongly influence infiltration, evapotranspiration, or sediment retention, and therefore determine the accuracy of ES models.

Table 6 presents key data sources and trait databases that can be integrated into ES modelling, from Copernicus HR layers to global trait databases such as TRY. These datasets provide valuable proxies for ecological processes and allow regions to better parameterise models according to local biodiversity characteristics.

Table 6: Tools and data sources to characterise biological and functional traits for ES modelling at a fine scale.

Product	Description	Characteristics	Source
Copernicus Land Monitoring Service (e.g., HR-VPP, HRL)	Satellite-derived indicators of vegetation phenology, productivity, and land cover dynamics.	High spatial (10–30 m) and temporal (5–10 days) resolution; pan-European.	Copernicus (EU)
GEDI LiDAR	Canopy height and structure derived from spaceborne LiDAR.	Global coverage; fine vertical structural detail; limited temporal coverage.	NASA GEDI
TRY database	Global trait database with millions of plant trait records (e.g., rooting depth, SLA, growth form).	Species-level data; ecological breadth; variable geographic coverage.	(Kattge et al., 2011)

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GlobBiomass / ESA CCI	Biomass estimates derived from remote sensing products.	Global; moderate spatial resolution (~100 m); consistent time series.	(Santoro et al., 2018)
LUCAS soil & land survey	Field survey data on soils, land cover, and land use across the EU.	Harmonised EU dataset; ground-truthing resource.	European Commission

In summary, the fine-scale roadmap for ES quantification offers two complementary pathways. On the one hand, established modelling tools and platforms provide regions with ready-to-use approaches for simulating ES flows, ensuring comparability and reducing methodological uncertainty, but often at the cost of flexibility and local specificity. On the other hand, the operational methodological framework (see the Appendix 5: Guidelines,) allows regions with higher technical capacity to develop more tailored, ad-hoc models, explicitly coupling biodiversity patterns, functional traits, and abiotic drivers, albeit requiring greater expertise, data availability, and processing effort. In both cases, the integration of biodiversity characterisation—particularly functional traits and structural ecosystem attributes—represents a cross-cutting dimension that enhances the ecological realism of models and strengthens the robustness of ES quantification.

Coarse-scale roadmap: hybrid proxy-based methods and EU ES databases and maps

In many cases, decision-makers and practitioners cannot rely on fine-resolution models because they require dense field data, heavy computation, and strong local expertise, which may not always be available. A more pragmatic path is to work with coarse-scale, hybrid proxy-based approaches that draw on existing European datasets and harmonised indicators. Instead of modelling every biophysical process directly, these approaches use land cover, land use, and other available data as proxies for the quantification of ES.

Consequently, we explored this coarser pathway by linking CORINE Land Cover maps with CICES-based classifications of ES. Here, land cover classes act as surrogates for the presence or potential of particular services (for example, forests linked with carbon storage and erosion control, wetlands with water regulation, and agricultural land with food provision). This type of mapping does not quantify exact service flows in biophysical units, but it provides a consistent way to approximate where services are likely to be supplied across regions.

Once CORINE land cover was reclassified into ES categories, we moved beyond the usual one-to-one mapping. Instead of assuming that all land cover types contribute equally, we developed a normalised scoring system. This allowed us to assign weighted values to each class, reflecting their relative potential to provide different services. For example, forests could receive higher scores for regulating ES, such as climate regulation or erosion control, while croplands might receive higher scores for provisioning ES. By expressing these scores on a 0–1 scale, we created a common baseline that made different services comparable and easier to combine.

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Building on this, we further refined the proxy approach by introducing abiotic covariates to adjust the service potentials according to the characteristics of where they occur. This step is important because not every pixel of the same class performs equally. Slope, for instance, can increase the importance of erosion control in steep areas, while it may reduce the effectiveness of flood regulation in the same locations. Aspect adds another layer of differentiation, since cooler and moister orientations can enhance drought and heat mitigation potential. Elevation was also considered, as uplands are more relevant for soil protection and erosion control, while lowlands often matter more for water regulation. These covariate adjustments acted as light-weight mathematical corrections rather than a full model application. They introduced nuance into the quantitative coarser roadmap while keeping the approach simple, with open data and reproducibility.

5.3.2 Qualitative (Option Qual)

In large-scale or data-scarce contexts, direct modelling may not be feasible. In such cases, ES can be approximated using relational assessments that link land cover types or habitat classes to their potential for service provision. This approach relies on existing harmonised land cover maps (e.g., CORINE Land Cover, EUNIS habitat map), along with expert-based or literature-derived rankings of each land cover or habitat type's capacity to deliver a given ES.

Pioneering work by Burkhard et al. (2009) and Maes et al. (2012) has established matrix-based methods that score the service supply potential of land cover classes on a relative scale (e.g., low to high). These scores can be regionally adapted using local knowledge or supplemented with ecosystem condition indicators (e.g., canopy cover, NDVI, or fragmentation metrics). Furthermore, ES selection should be linked to the risk profile of the region—particularly to the hazard types (e.g., drought, fire, floods) and their biophysical mechanisms—using relational tables that match ES to the regulating processes involved.

Fine-scale roadmap: high-detailed proxy matrix method

This method is based on habitat rankings depending on the assumed ability of the ecosystem-habitat to generate an ES. These rankings reflect each habitat's multi-functional value, based on combined indicator scores and literature-informed weighting schemes. These ES can be achieved through several methodological approaches, including expert-based scoring, literature-based scoring, spatial analysis, and ES modelling. Normally, these scores are purely derived from land cover and habitat maps, but in this approach, they can be supplemented with local datasets such as those exposed in Table 6 (e.g., species composition, ecosystem structure) and expert judgment to better reflect the ecological potential. This ranked mapping could identify zones critical for ES provision, especially for those not controlled mainly by abiotic processes.

The expert-based scoring method involves constructing a matrix or scorecard, where ecosystem types are listed in each row and ES in the columns (Figure 12). Each cell in the matrix is filled out with a score, indicating the expert judgement of the relative importance of each ecosystem type (e.g., EUNIS habitat) in providing the respective ES. These scores are based on expert consultation and represent either qualitative or semi-quantitative estimations. For instance, Galparsoro et al. (2014) categorised ES provision for Atlantic marine benthic habitats into three qualitative classes:

high, low, and negligible. Moreover, Potts et al. (2014) assessed ES provided by UK protected habitats and species, classified using EUNIS, and validated the results through both internal and external expert reviews.

Habitat name	EUNIS code	Food	Raw material	Air quality	Disturbance	Photosynthesis	Nutrient	Reproduction	Biodiversity	Wate	Cognitive	Leisure	Feelgood
Infralittoral rock and other hard substrata	A3*	H	H	H	H	H	L	H	H	H	H	H	H
Atlantic and Mediterranean high energy infralittoral rock	A3.1*	H	H	H	H	H	L	H	H	H	H	H	H
High energy infralittoral seabed		H	H	H	H	H	L	H	H	H	H	H	H
High energy infralittoral mixed hard sediments		H	H	H	H	H	L	H	H	H	H	H	H
Atlantic and Mediterranean moderate energy infralittoral rock	A3.2*	H	H	H	L	H	H	H	H	H	H	H	L
Moderate energy infralittoral seabed		H	H	H	L	H	H	H	H	H	H	H	L
Moderate energy infralittoral mixed hard sediments		H	H	H	L	H	H	H	H	H	H	H	L
Atlantic and Mediterranean low energy infralittoral rock	A3.3*	H	H	H	L	H	H	H	H	H	H	H	L
Low energy infralittoral seabed		H	H	H	N	H	H	H	H	H	H	H	L
Low energy infralittoral mixed hard sediments		H	H	H	N	H	H	H	H	H	H	H	L
Silted kelp on low energy infralittoral rock with full salinity	A3.31	H	H	H	N	H	H	H	H	H	H	H	L
Circalittoral rock and other hard substrata	A4*	H	H	L	H	N	H	H	H	H	H	L	L
Atlantic and Mediterranean high energy circalittoral rock	A4.1*	H	H	L	H	N	H	H	H	H	H	L	L
High energy circalittoral seabed		H	H	L	H	N	H	H	H	H	H	L	L
High energy circalittoral mixed hard sediments		H	H	L	H	N	H	H	H	H	H	L	L
Very tide-swept faunal communities on circalittoral rock or mixed faunal turf communities on circalittoral rock	A4.11 or A4.13*	H	H	N	H	N	H	H	H	H	L	L	L

Figure 12: ES assessment for each ecosystem type using a qualitative approach, where H = high, L = low, N = negligible (Galparsoro et al., 2014).

An example of application of this methodological approach in EU Horizon projects is REST-COAST, where the expert-based approach was implemented to link ecosystem types, classified according to the EUNIS system, with specific ES (Figure 13; Baptist et al., 2024). In REST-COAST, a semi-quantitative scoring system was applied using a scale adapted from Burkhard et al. (2014): 0 = none; 1 = very low contribution; 2 = low contribution; 3 = moderate contribution; 4 = high contribution; 5 = very high contribution; Blank = not assessed.

Code	EUNIS Name	WP	CCR	FP	RCE	RFR
MA22	Atlantic littoral biogenic habitat	2	2	3	2	1
MA222	High marsh	4	5	1	3	1
MA223	Brackish marsh	4	5	1	3	1
MA224	Atlantic mid-low saltmarshes	4	4	2	3	1
MA225	Atlantic pioneer saltmarshes	3	3	2	2	1
MA52	Atlantic littoral sand	2	2	1	1	1
MA523	Barren or amphipod-dominated Atlantic littoral sand	2	2	1	1	1
MA525	Polychaete/bivalve-dominated Atlantic littoral muddy sand	2	2	1	1	1
MA621	Faunal communities of full salinity Atlantic littoral mud	3	3	2	1	1
MA622	Faunal communities of variable salinity Atlantic littoral mud	3	3	2	1	1
MB12	Atlantic infralittoral rock	0	0	4	3	2
MB52	Atlantic infralittoral sand	1	2	3	1	0
MC52	Atlantic circalittoral sand	1	2	3	1	0
X02-2012	Saline coastal lagoons	4	3	3	2	1
X01-2012	Estuaries	3	2	2	1	1

Figure 13: Semi-quantitative rank-scores for the five selected REST-COAST ES (water purification (WP), climate change regulation (CCR), food provisioning (FP), reduction of coastal erosion risk (RCE), reduction of coastal flooding risk (RFR)) applied to EUNIS ecosystem types.

While this method has low data requirements, making it useful in data-poor regions, it is somewhat subjective and lacks empirical validation. Furthermore, it presents limitations for representing the abiotic processes involved in ES provision.

Coarse-scale roadmap: Proxy matrix method

This represents the most basic approximation among those presented in this Deliverable. As outlined above, it consists of a direct reclassification of a land cover map—typically CORINE in the coarse roadmap—into a value of ES provision. Each land cover class is assigned a score reflecting its assumed capacity to deliver a given service, based either on expert judgement or values reported in the literature. Unlike the more refined approaches, no additional adjustments are made to account for landscape position, geomorphological setting, ecological condition, or biological attributes.

This method is included here as the simplest possible pathway to illustrate how a qualitative ES characterisation can be carried out when only general land cover information is available. Its main advantage is its ease of application: it allows large areas to be assessed quickly and with minimal data and processing requirements. This makes it accessible to regions with limited technical capacity or those working at broad planning scales.

However, this simplicity comes with important limitations. Because no abiotic filters are applied, the assumed ES provision may be highly inaccurate for services that depend strongly on physical processes (e.g., water flow regulation, sediment retention). Likewise, the biological component is treated in a very coarse way, as general land cover classes do not capture key ecological differences (e.g., maturity, structure, species composition) that influence service delivery. As a result, this approach tends to overestimate ES provision and may identify excessively large areas as suitable for NbS implementation. It is therefore most appropriate for preliminary screening or upscaling exercises, rather than for detailed planning or prioritisation.

6 A Relational Approach Linking Land Use, Ecosystem Services, Hazards and Nature-based Solutions

A relational table was created to analyse and illustrate the links between natural hazards, ES, land Use-Cover (LULC), and NbS. By linking these components, the table supports regional planning efforts by highlighting both ecological opportunities and constraints that influence the feasibility and effectiveness of NbS implementation. This enables planners and decision-makers to identify where certain solutions may be most appropriate or where additional ecological support may be needed. Additionally, the table is intended to facilitate cross-sectoral dialogue, serving as a shared reference point for ecologists, spatial planners, and policymakers working toward integrated and sustainable land management strategies.

6.1 Structure of the Relational Table

The relational table is structured around four key components: land Use-Cover, ES, hazards and NbS.

- Land Use-Cover (LULC): The Coordination of Information on the Environment (CORINE) Land Cover dataset was used to represent land use and ecosystem types across Europe. This Europe-wide land use data set comprises five broad Level 1 classes (artificial surfaces, agricultural areas, forests and semi-natural areas, wetlands, and water bodies), which are further divided into Level 2 and Level 3 classes, resulting in a total of 44 detailed land use-cover classes (Appendix 2: Land Use-Cover Classification). CORINE is widely used in environmental assessments, spatial planning, and biodiversity studies, as it provides a consistent basis for linking land use to ecological processes and services. In the relational table, the CORINE Level 3 classes are used as a link between the other three components.
- ES: The Common International Classification of Ecosystem Services (CICES) is a standardised framework designed to categorise the benefits people derive from ecosystems (version 5.1). The framework is organised into four levels (section, division, group, and class), with its main sections comprising the different types of services directly used or appreciated by humans. These sections are Provisioning services (such as food, water and material provisioning), Regulation and Maintenance services (such as climate regulation, pollination and water purification) and Cultural services (such as aesthetic value, recreation and religious significance). The three main sections comprise a total list of ninety services (Appendix 3: Ecosystem Services), which are used in the relational table.
- Natural Hazards: Eight natural hazards were considered in the relational table (fires, flooding, sea level rise, droughts, heat waves, erosion, and salinisation). These hazards were selected based on input from the regions in the NBRACER project gathered through interviews and questionnaires.
- NbS: The relational table incorporates a total of 90 NbS entries, reflecting a diverse range of strategies aimed at addressing environmental hazards while enhancing ES (Appendix

4: Nature-based Solutions). These NbS were selected based on input from regional partners involved in the NBRACER project, gathered through a questionnaire which was finalised in September 2024. The list of NbS includes various types for a range of landscapes, such as ecosystem restoration, sustainable land management, green infrastructure, and water retention measures.

Linking ES and LULC

To explore the relationship between LULC and ES, each CORINE land cover class was assessed for its ecological structure and functional role. This analysis helped identify which ES each land use type is capable of supplying. The relational table also considers which ES require specific ecological conditions, and therefore, which land use types are most likely to support them. All possible combinations were made, based on information from CICES and CORINE, literature and expert knowledge.

For example, biomass production such as cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes (CICES Code 1.1.1.1, Appendix 3: Ecosystem Services) is typically associated with vegetated, human-managed habitats such as pastures (CORINE Level 3 code 2.3.1, Appendix 2: Land Use-Cover Classification) or areas with complex cultivation patterns (CORINE 2.4.2, Appendix 2: Land Use-Cover Classification). These land covers involve active vegetation management, which supports the provisioning of food and raw materials. This bidirectional mapping ensures that both the supply and demand sides of ES are considered, providing a more comprehensive understanding of how land-use decisions influence ecological outcomes.

Connecting hazards with ES and LULC

The relational table captures two key dimensions of the interaction between natural hazards and ES. First, it identifies ES and its coupled LULC that can help mitigate hazard impacts. For example, flood regulation (CICES 2.2.1.3, Appendix 3: Ecosystem Services) is provided by inland marshes (CORINE 4.1.1, Appendix 2: Land Use-Cover Classification) or control of erosion rates by broad-leaved forests (CORINE 3.1.1, Appendix 2: Land Use-Cover Classification). Second, it highlights how certain hazards can threaten the provision of ES, such as droughts reducing water availability or heat stress affecting pollination.

These relationships are grounded in underlying ecosystem functions, the biological, chemical, and physical processes that support ES delivery. Examples include water flow regulation, carbon cycling, and nutrient retention. Understanding these functional links helps regions assess the vulnerability and resilience of ecosystems under hazard pressure, which is essential for informed planning and adaptation.

To define the relationship between ES and LULC and hazards for the relational table, we simplified it into two streams: 1) the ES/LULC mitigates the effect of a hazard, and 2) a hazard impacts the state of an ES/LULC.

Integrating NbS

NbS were linked to land cover types based on two main criteria: their implementation potential and the enabling ecological conditions that support their effectiveness. This means identifying where NbS can be introduced to enhance ES provision or mitigate hazards, and where existing ecosystems already provide a suitable foundation for NbS success.

All of the NbS were linked to LU based on the information further given in the survey by the regional partners. For example, the NbS initiative of stream valley restoration in the Linde, Fryslân, is linked to LULC types such as water courses and pastures.

Value of the relational table for regional decision-making

The relational table serves as a decision-support tool that enables regional stakeholders to identify critical ES and their ecological sources, assess hazard mitigation potential, and select suitable NbS based on land use and ecosystem context. It also integrates biodiversity considerations by qualitatively classifying land cover types into levels of biodiversity (e.g., low, medium, high), helping users factor ecological richness into planning decisions.

By translating complex ecological data into an accessible format, the table empowers non-specialists to engage with environmental planning and supports spatial mapping and scenario development for NbS implementation. It is particularly valuable for fostering collaboration across disciplines and sectors, ensuring that ecological knowledge informs practical planning and policy processes.

Each NbS entry in the relational table includes its geographic location (Figure 14), associated land cover types, and the ES it targets. This structure allows users to explore context-specific strategies and understand how NbS can be tailored to local ecological and spatial conditions. The table also supports comparative analysis across regions, helping identify transferable practices and locally adapted solutions.

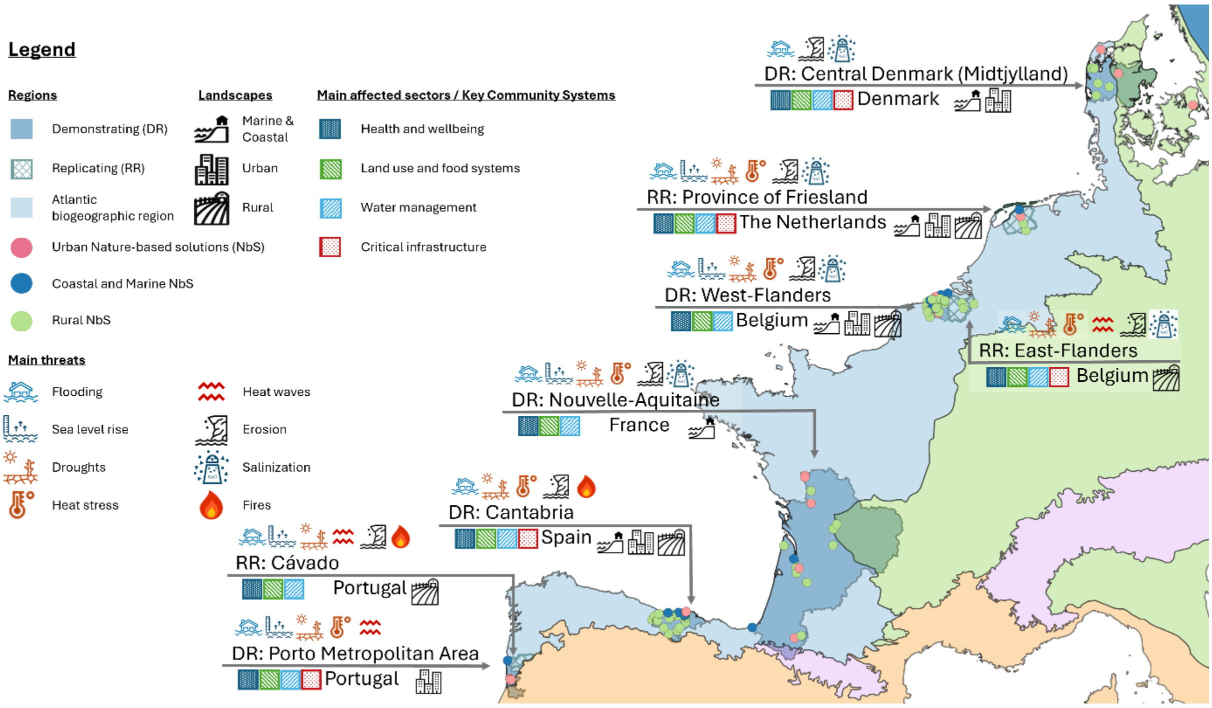

Figure 14: The location of the NbS examples from the NBRACER survey (figure from the NBRACER Regional Protocol).

The relational table can be used as a decision-support tool for regions to link ecosystems with specific ES, hazards, underlying ecosystem functions, and land cover types for later spatial mapping. It allows non-specialists to identify ecosystems that provide critical services, assess their role in hazard mitigation or vulnerability, and explore relevant NbS. Within the scope of this deliverable, the table is a key step in the Operative Framework described in Figure 3 for providing a list of potential NbS that could be implemented in the functional hotspots (see also an exemplification in section 7). Different CORINE classes correspond to specific ecosystem types with varying species compositions (e.g., beech forest vs. coastal forest). These can be later qualitatively classified into biodiversity levels (e.g., low, medium, high), making the relational table a key step for biodiversity assessment within the broader methodological framework presented in this deliverable.

To enhance the usability and consistency of the relational table across regions and disciplines, several recommendations are proposed for NBRACER and possible other European users. First, it is advisable to adopt a more concise list of ES, such as the classification developed by Burkhard et al. (2009), which offers a comprehensive yet manageable framework for assessing ES. This would enhance comparability and simplify regional applications. Second, the inclusion of natural hazards should be tailored to the specific context of the region the relational table will be used for, as the current list was made for a targeted analysis of the NBRACER regions. Regional differentiation ensures that the table remains relevant and responsive to local environmental challenges. Lastly, the selection of NbS should be based on a more standardised and externally validated list. While the current NbS entries reflect valuable insights from NBRACER partners, a harmonised reference list would strengthen the transferability of the table, facilitating broader application and policy alignment.

6.2 Enhancing Usability of the Relational Table with Power BI

While the relational table developed provides a comprehensive framework linking hazards, LU, ES and NbS, its complexity and size make it challenging to navigate and apply directly. To address this, an interactive dashboard was created using Power BI (Relational table - WIP_NBRACER_OST - Power BI; Figure 15). Power BI is an analytics tool that enables users to visualise data, share insights and make data-driven decisions through interactive dashboards.

Through dropdown menus and filters, users can explore the table based on specific regional needs. For example, users can filter by natural hazards affecting their area, such as flooding or drought, and identify suitable NbS that have been implemented in similar contexts across NBRACER regions. Alternatively, users can start from LULC types present in their regions and discover associated ES and NbS options. This functionality allows for a tailored exploration of the data, making it accessible for stakeholders from the NBRACER regions.

The Power BI tool also complements the results from the NbS hotspot identification as described in Section 7. Once hotspot areas are identified based on hazard probability and ES provision, the dashboard can be used to explore relevant NbS strategies that are already in place in other NBRACER regions with similar characteristics.

Hazards affected by ES	Land use	ES	NbS
Flooding	Water courses	Mass flows	CA-1
Flooding	Water courses	Mass flows	CA-2
Flooding	Water courses	Mass flows	DK-1
Flooding	Water courses	Mass flows	EF-1
Flooding	Water courses	Mass flows	EF-2
Flooding	Water courses	Mass flows	EF-3
Flooding	Water courses	Mass flows	EF-4
Flooding	Water courses	Mass flows	EF-5
Flooding	Water courses	Mass flows	ES-11
Flooding	Water courses	Mass flows	ES-16
Flooding	Water courses	Mass flows	ES-20
Flooding	Water courses	Mass flows	ES-24
Flooding	Water courses	Mass flows	ES-4
Flooding	Water courses	Mass flows	FRI-1
Flooding	Water courses	Mass flows	FRI-2
Flooding	Water courses	Mass flows	FRI-5
Flooding	Water courses	Mass flows	NA-1
Flooding	Water courses	Mass flows	NA-17
Flooding	Water courses	Mass flows	NA-3
Flooding	Water courses	Mass flows	NA-4
Flooding	Water courses	Mass flows	NA-8
Flooding	Water courses	Mass flows	NA-9
Flooding	Water courses	Mass flows	PO-2
Flooding	Water courses	Mass flows	WF-1
Flooding	Water courses	Mass flows	WF-10

Figure 15: A snapshot of the interactive Power BI tool.

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7 A Comparative Application of Both Roadmaps for an NBRACER Region

To test and illustrate the applicability of the dual-roadmap approach described in Section 5, we carried out a comparative exercise in one of the NBRACER regions—Cantabria (Northern Spain). The objective was to replicate the methodology for biodiversity and ES characterisation at two levels of detail—a fine-resolution approach and a coarse-resolution approach, each with its respective quantitative and qualitative options—in order to explore differences in spatial accuracy, thematic granularity, and interpretative potential. This exercise is framed within the full analytical pathway envisioned in NBRACER for completing Level 1 of the analysis: from risk assessment to the identification of functional hotspots for NbS implementation, where biodiversity and ES characterisation play a central role. Each roadmap integrates distinct data sources, analytical techniques, and ecosystem classification systems, which can ultimately lead to different outcomes when identifying functional hotspots for NbS.

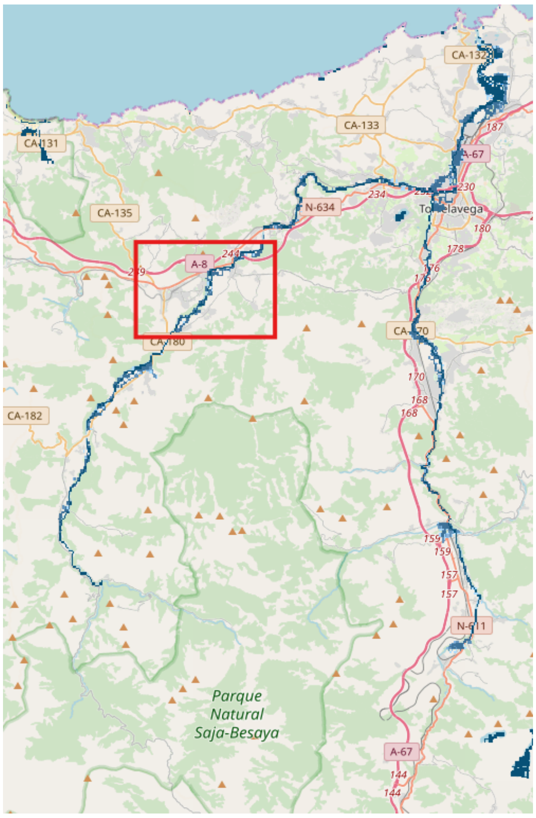
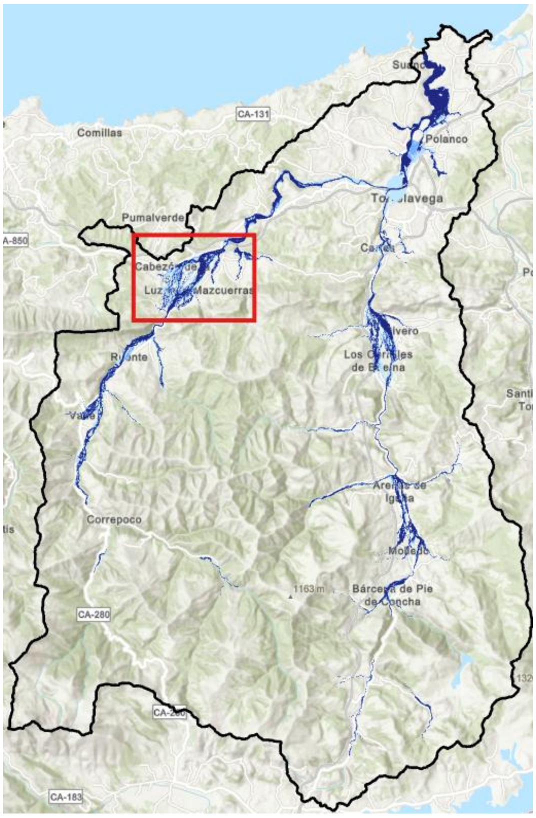
Given the context-specific nature of climate risks and the need to tailor NbS selection accordingly, the comparative analysis focuses exclusively on flood risk in Cantabria. This allows for a more targeted comparison and avoids conflating analytical steps that would differ significantly across other risk types. By narrowing the scope to a single hazard, the exercise can better highlight the methodological contrasts between the coarse and fine roadmaps, as well as between the quantitative and qualitative ES characterisation options.

The results are presented through a series of maps that illustrate the outputs of this comparative application. We begin with a simplified flood risk analysis (see D5.2; Bishop et al., 2024), which is then progressively linked to the core component of this D5.3—the characterisation of biodiversity and ES—to reach the identification of potential hotspots for NbS implementation. The exercise is performed at two levels of detail (coarse vs. fine), and ES characterisation is showcased under both the quantitative and qualitative approaches, thus offering a practical demonstration of how the proposed dual-roadmap framework can be operationalised in regional contexts.

7.1 Results Comparisons for Both Road Maps

***Box 1*- Climate hazard and risk assessment**

Only the flood hazard has been mapped, without carrying out the full risk analysis (i.e., the overlay with KCS and their respective vulnerability and exposure assessment). This provides an approximate view of the spatial extent that coarse- and fine-scale approaches can reach. The fine-scale method typically captures greater detail and a wider hazard extent, whereas the coarse-scale method may omit certain flood-prone areas, potentially underestimating risk. In both approaches, flood hazard is represented for four different return periods: 10, 50, 100, and 500 years.

COARSE roadmap	FINE roadmap
Flood inundation map for different return periods	*Flood inundation map for different return periods*
	

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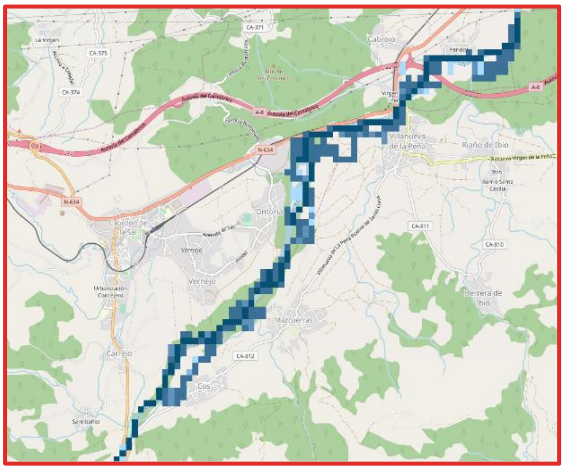
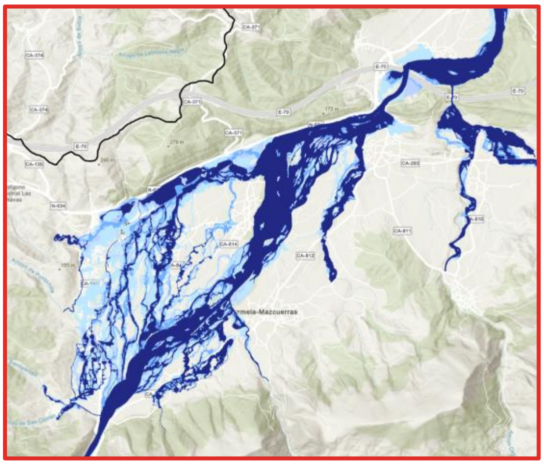
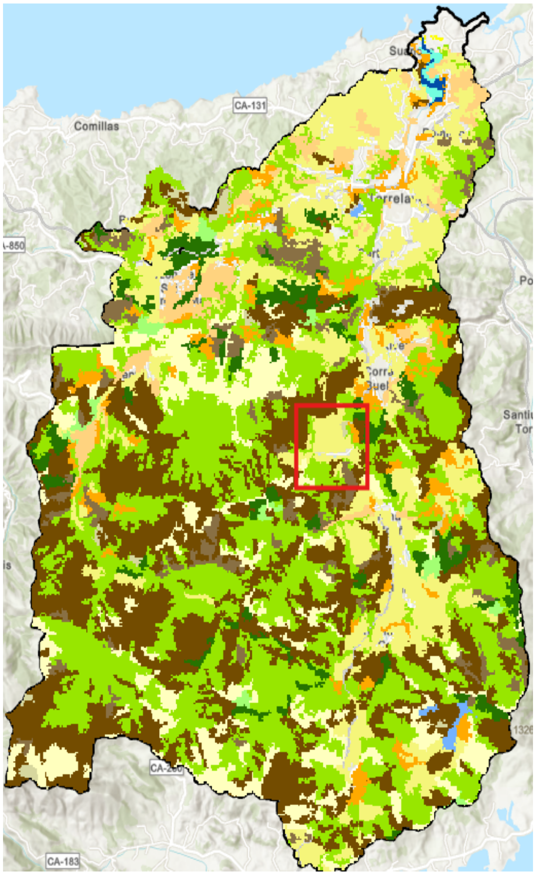
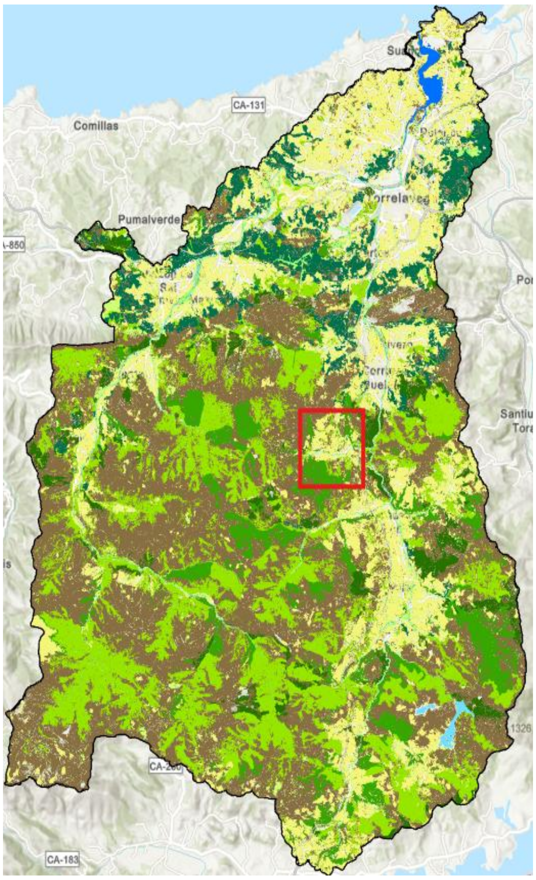
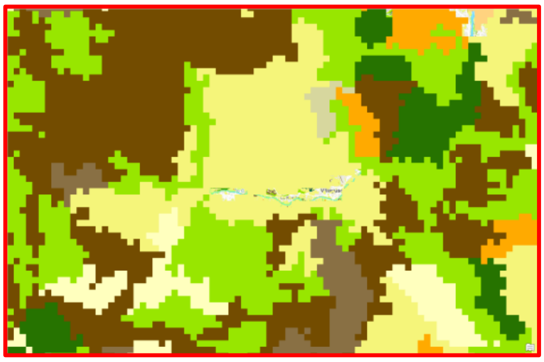
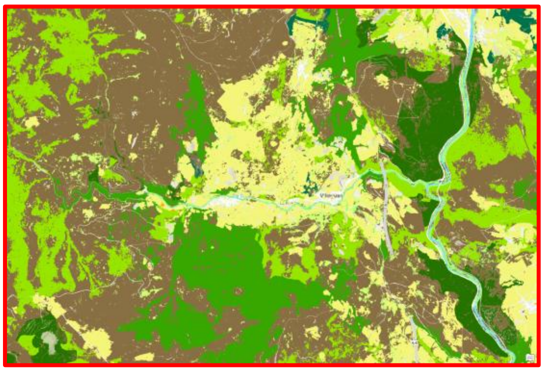
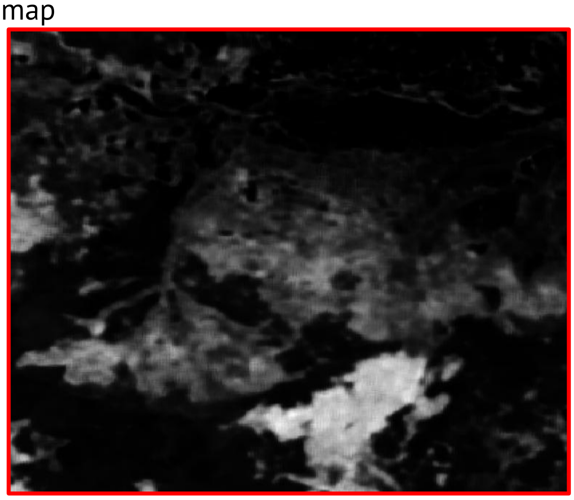
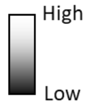
	
10 yr Return Period (10% AEP) 50 yr Return Period (2% AEP) 100 yr Return Period (1% AEP) 500 yr Return Period (0.2% AEP)	10 yr Return period 50 yr Return Period 100 yr Return Period 500 yr Return Period
We used the European Flood Awareness System (EFAS), part of the Copernicus Emergency Management Service. EFAS produces flood inundation maps by combining GloFAS and EFAS re-analyses to generate flood event hydrographs for different return periods, which are then input into the two-dimensional hydraulic flood inundation model LISFLOOD. The methodology is detailed in Alfieri et al. (2014). The resulting datasets provide flood hazard information for river basins larger than 500 km², with a spatial resolution of 90 m. *EFAS Flood Inundation Maps:* Efas-IS	We relied on the flood hazard maps produced by the Cantabrian River Basin Authority (CHC). These maps are based on detailed topographic, hydrological, hydraulic, and geomorphological studies. Hydraulic simulations were carried out using HEC-RAS, developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers, for one-dimensional flows, and InfoWorks RS-ICM for two-dimensional simulations. The maps provide high-resolution flood hazard data at 5 m spatial resolution, representing one of the most detailed official datasets available for the region. *CHC Flood Hazard Maps:* Visor CHC

***Box 2*- Biodiversity mapping**

Biodiversity was mapped using remote-sensing–based products and classification tools, as described in Section 5.1. All maps allow the spatial distribution of ecosystems and habitats to be delineated, but they differ significantly in their resolution, thematic precision, and taxonomic or structural categorisation of the mapped units.

COARSE roadmap	**FINE roadmap**
Vegetation map (CLC)	*Vegetation map (Cantabrian map)*
	
	

Pastures (231) Complex cultivation patterns (242) Agricultural areas with natural vegetation (243) Broad-leaved forest (311) Coniferous forest (312) Mixed forest (313) Moors and heathland (322) Transitional woodland-shrub (324) Beaches, dunes, sands (331) Sparsely vegetated areas (333) Salt marshes (421) Inland water bodies (512) Estuaries (522)	Pastures Complex cultivation patterns Broad-leaved atlantic forest Broad-leaved mediterranean forest Riparian forest Broad-leaved planted forest Mixed forest Coniferous planted forest Shrubland Rocks Beaches, dunes and sands Rivers Lakes Reservoirs Estuaries Sea
We employed the CORINE Land Cover (CLC 2018) dataset, produced within the Copernicus Land Monitoring Service. CLC provides harmonised land use/land cover (LULC) information across Europe at a 100 m spatial resolution. Its classification system comprises 44 classes, largely defined at the physiognomic level (e.g., three forest types, two shrubland classes depending on vegetation density, grasslands differentiated by use). While this dataset facilitates consistent analyses across regions, it provides only a simplified representation of vegetation types and limited ecological detail. *CLC product:* [CORINE Land Cover 2018 (vector/raster 100 m), Europe, 6-yearly — Copernicus Land Monitoring Service]	We used the Cantabrian land use and land cover map, which has a 5 m spatial resolution and includes fewer than 50 LULC classes. Natural ecosystems are represented with 18 distinct categories, offering finer discrimination than CLC. Although the classification remains primarily physiognomic, this dataset allows the differentiation of vegetation types of greater ecological relevance, such as Eurosiberian vs. Mediterranean forests. In addition, the map incorporates data from the National Forest Inventory, enabling the identification of dominant tree species in each vegetation polygon, thus offering a closer link to functional biodiversity attributes. *Cantabrian LULC product:* https://mapas.cantabria.es/
	Asperulo-Fagetum beech forest suitability map 

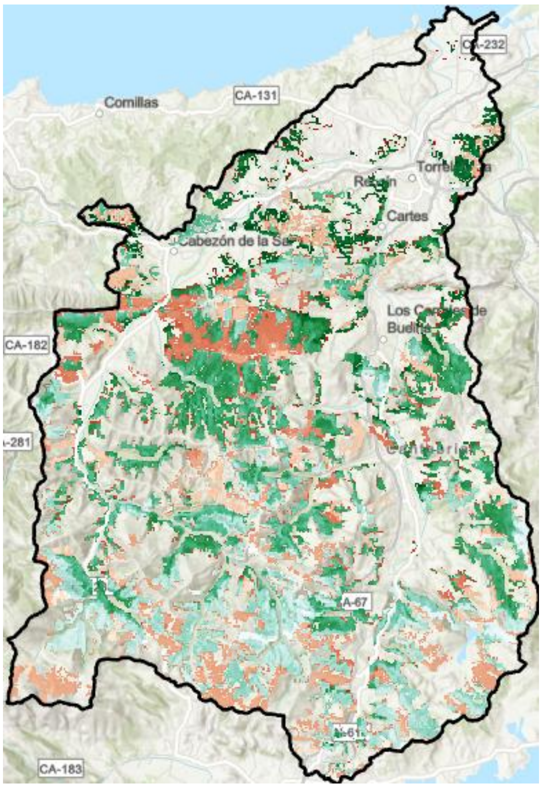
	 Probability of ocurrence of habitat 9130 (Asperulo-Fagetum beech forests) The fine-scale roadmap has also been exemplified, in the same area above, with another resource that enables the spatial mapping of biodiversity. In this case, it involves modelling the distribution of a specific habitat (beech forests on siliceous substrates) through the construction of a species distribution model. Using habitat occurrence data, abiotic variables, biotic variables derived from remote sensing, and the MaxEnt algorithm, a probability map of habitat occurrence was produced at a 5 m resolution. The lighter the pixel, the higher the probability of habitat presence. These methods allow biodiversity to be modelled at a finer taxonomic scale (e.g., at the level of habitat or species) and can also be linked to indicators of ecological relevance such as maturity, conservation status, or habitat quality.

***Box 3*- Ecosystem Services characterisation**

ES was mapped using more and less process-based and hybrid models, as well as proxy-derived methods, as described in Section 5.3. All maps estimate ES provision from the biodiversity maps used (see previous box), but they differ significantly in their spatial resolution and their ability to accurately consider abiotic processes and biotic features that influence and determine ES provision. The rationale behind the selection of variables used in the modelling process, as well as the target ecosystems providing the ES, derives from the conceptual links established in the relational table developed in Step 5.2 (Table 4: biodiversity–ES relational table).

COARSE roadmap (Quantitative option)

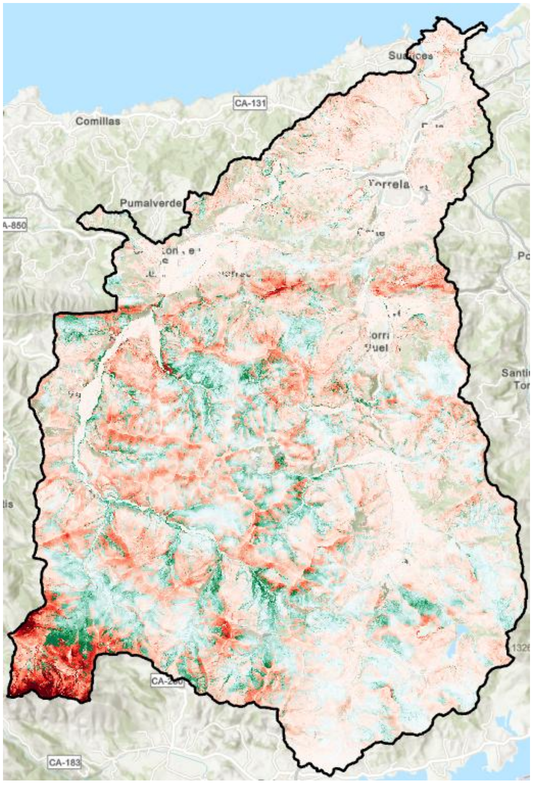
Runoff regulation ES map



We applied a coarse-resolution method using CORINE Land Cover (100 m) as the base dataset. Each land-cover type was reclassified into hazard-specific mitigation scores ranging from 0 (no regulation) to 1 (high regulation), based on literature values and expert knowledge of its capacity to attenuate flood hazards. These scores were then adjusted using simple abiotic covariates such as slope, aspect, and elevation, in order to better reflect the influence of geomorphological settings on flood regulation potential. The resulting map highlights, with darker green tones, the zones where land-cover characteristics and terrain

FINE roadmap (Quantitative option)

Runoff regulation ES map



We applied a tailored methodology (5 m resolution; Pérez-Silos, 2021) that integrates slope, geological maps, and annual precipitation to model the most likely areas of surface runoff generation. The resulting runoff susceptibility map was overlaid with a high-resolution vegetation map to distinguish areas with ecosystems that regulate runoff flows (forests) from those with low regulatory capacity (other land cover types). ES provision is represented by the intensity of colour (the darker the green or red colour, the higher the real or potential ES provision): in green, the actual service provided by existing forests, and

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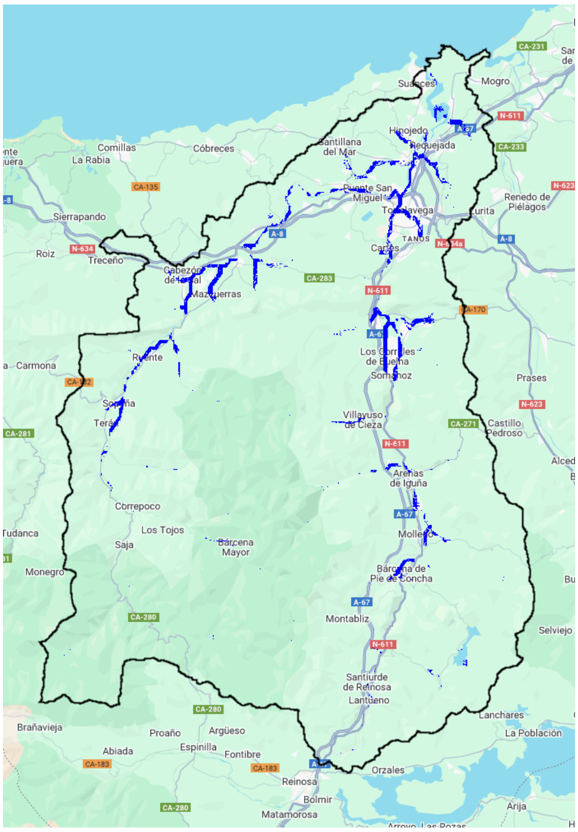
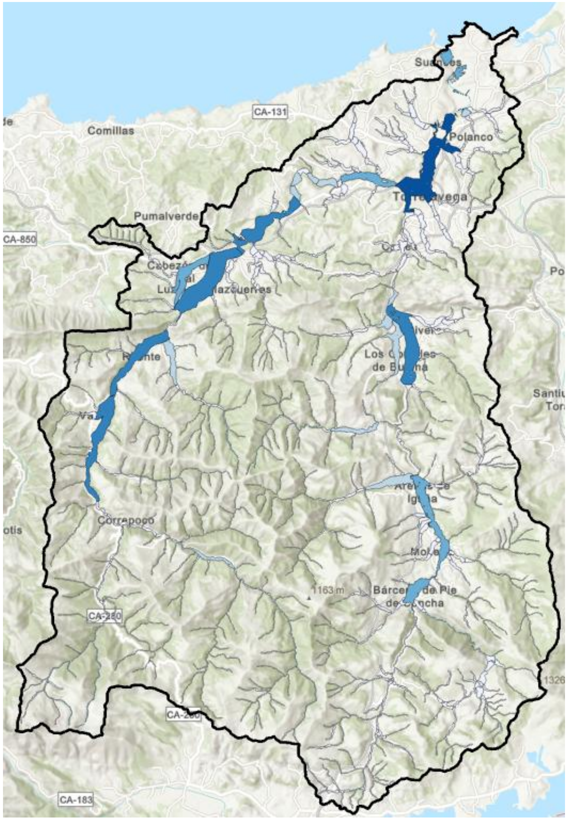
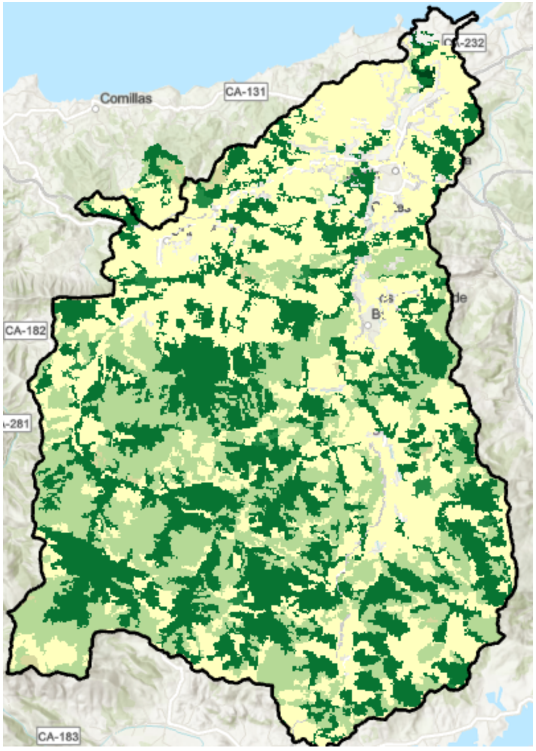
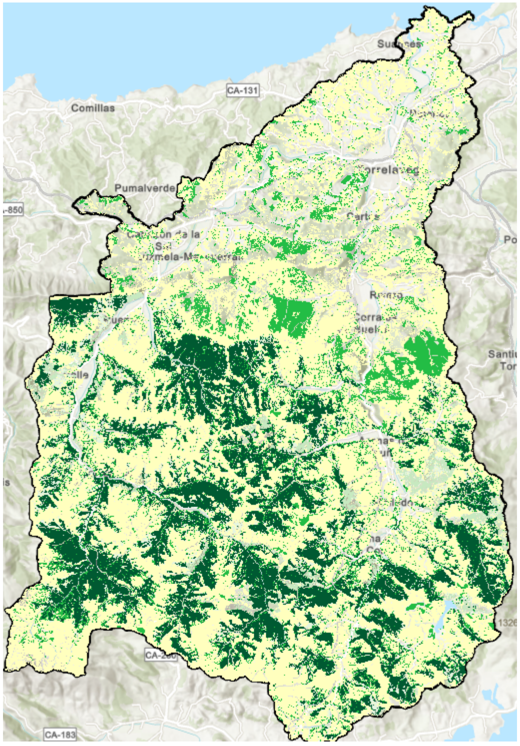
jointly are providing the greatest capacity to attenuate runoff and reduce flood peaks; white and red tones, the zones where land-cover and terrain provide the potential service if forest ecosystems were restored.	in red, the potential service if forest ecosystems were restored.
Temporal water storage capacity ES map 	*Temporal water storage capacity ES map* 
Floodplain extent was intersected with low-slope terrain (<3°) to identify coarse-resolution zones with potential for temporary water storage. This approach relies on geomorphological proxies rather than hydraulic simulations, making it suitable for large-scale or data-limited contexts. Areas with darker blue intensity represent floodplains with a higher estimated capacity for temporary water retention, thereby contributing to downstream flood attenuation and reduced risk.	Floodplain mapping was conducted using a geomorphology-based model (Benda et al., 2011) that delineates floodplains at 5 m resolution along the river network. For each mapped floodplain unit, we estimated the potential water storage volume in the event of river overflow. ES intensity is shown in shades of blue, where darker tones indicate higher floodwater storage capacity and therefore stronger flood regulation, by dissipating flood peaks and reducing the magnitude and probability of downstream inundation.
Runoff regulation ES map	*Runoff regulation ES map*

	
We reclassified CORINE data into hazard-specific mitigation scores, reflecting the relative capacity of different land use/cover types to provide regulating ES, specifically runoff regulation. Each CORINE class is assigned a score between 0 and 1 based on literature and expert knowledge regarding its effectiveness. ES intensity is expressed in green for higher regulatory capacity in forests and wetlands, and yellow for shrub–grassland systems with lower regulatory potential.	We used a proxy-based methodology to score high-resolution land cover classes (5 m) according to their expected contribution to infiltration and runoff regulation (forest = 1, forest plantations = 0.5, shrub/grassland = 0.25, other land uses = 0). Two refinements were introduced to improve representation: (i) only vegetation patches located on hillslopes were retained, given their greater potential to regulate runoff, and (ii) forest classes were refined by integrating forest maturity, derived from remote-sensing indicators following Belmar et al. (2018). Forest maturity encapsulates a set of functional traits linked to hydrological regulation (e.g., rooting depth, canopy cover, litter production), so we score as 2. ES intensity is expressed in green for higher regulatory capacity in mature forests, and yellow for shrub–grassland systems with lower regulatory potential.

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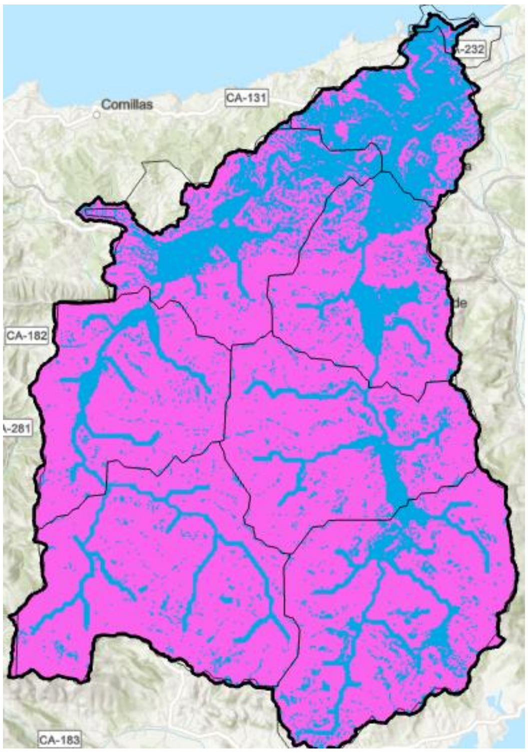
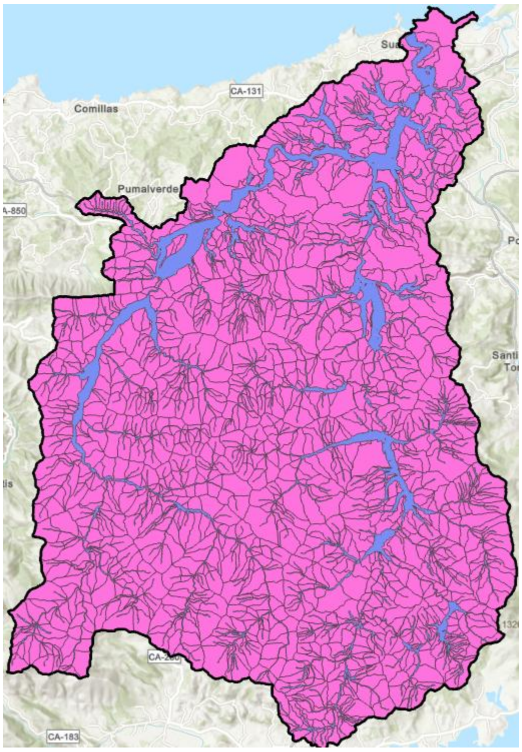
***Box 4* - Functional Units**

As exposed in D5.1, functional units are spatial entities that capture the scale at which ecosystems interact with physical processes to generate ES (Pérez-Silos et al., 2025). Defined primarily by geomorphological criteria, they determine the types of abiotic flows (e.g., runoff, sediment transport) and the structure of biological communities that can develop. By linking the spatial occurrence of ES with their role in the ES flow—whether as SPA, SCA or SBA—functional units are a key element for identifying functional hotspots (see box 5). Functional units implied in each ES flow are identified in the relational table developed in Step 5.2 (Table 4: biodiversity–ES relational table).

Functional units are commonly mapped using topographic and geomorphological analyses, which, depending on the databases and models used, can provide greater spatial resolution and accuracy when defining them.

COARSE roadmap	FINE roadmap
Floodplains (purple) and hillslopes (pink) functional units	*Floodplains (purple) and hillslopes (pink) functional units*
	
River reaches (dark blue) functional units	*River reaches (dark blue) functional units*

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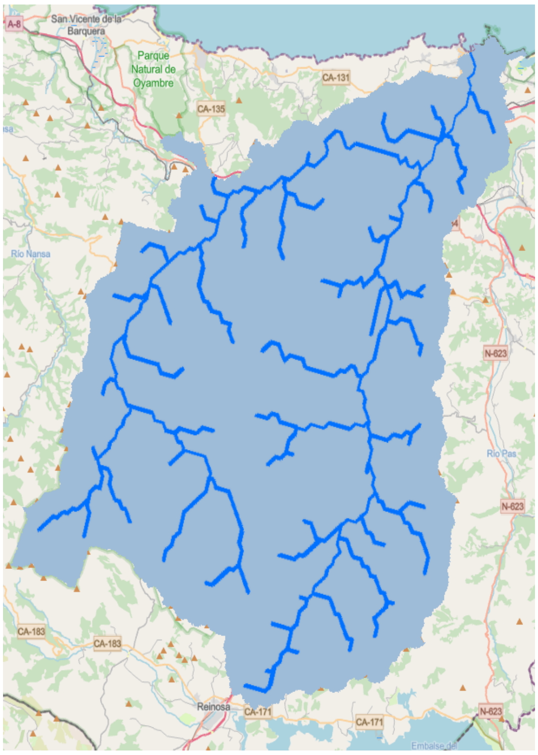
<table>
<tr>
<td>
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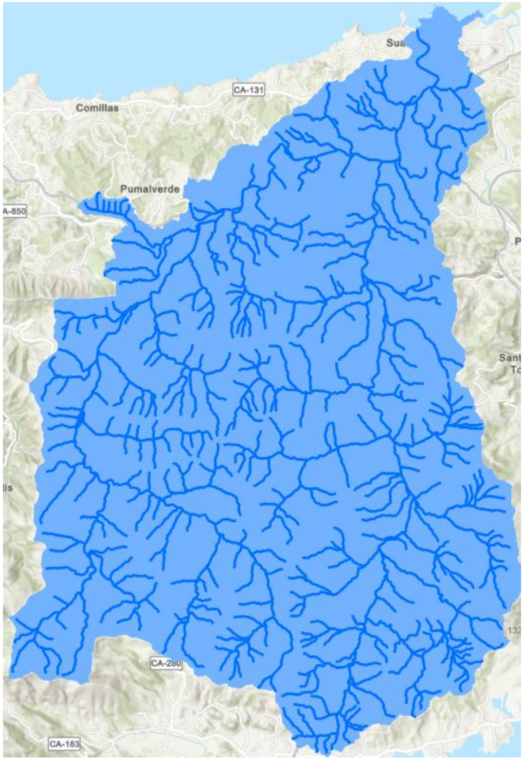
<td>
</td>
</tr>
<tr>
<td>We delineated functional units using a 100 m resolution DEM and HydroSHEDS sub-catchments (level 12) to generate hydrological divisions. Three broad unit types were identified: river reaches, floodplains and hillslopes.</td>
<td>We built a digital framework (Virtual Watersheds), using the NetMap suite of tools, that was capable of identifying terrestrial-fluvial interactions at the catchment scale. We derived synthetic river networks (Benda et al., 2011) independently in each catchment using a 5m DEM. Each river reach was hydrologically connected to the terrestrial environment through three types of functional units: hillslopes, riparian zones and floodplains.</td>
</tr>
</table>

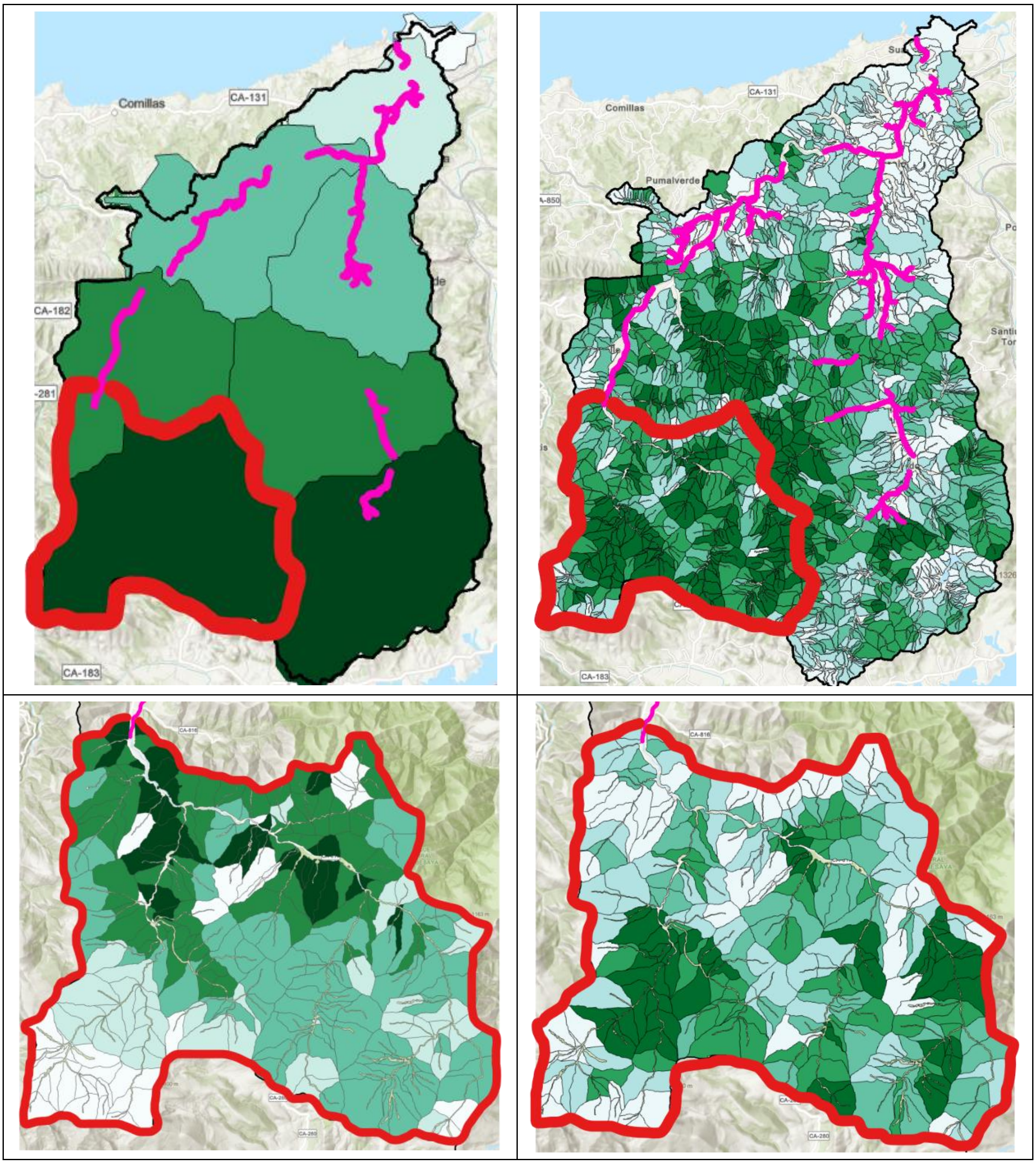
***Box 5*- Functional hotspots for NbS implementation**

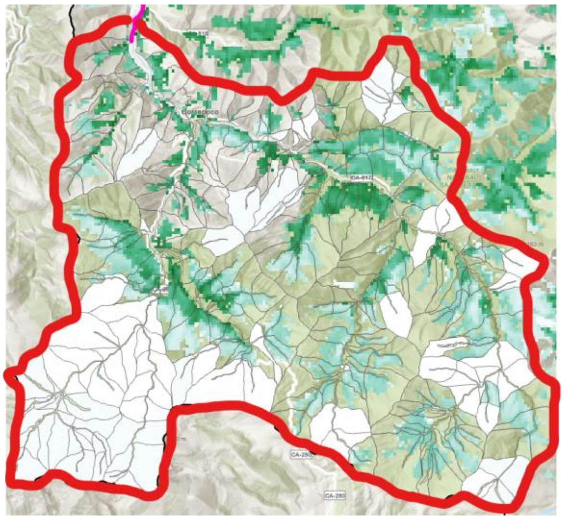
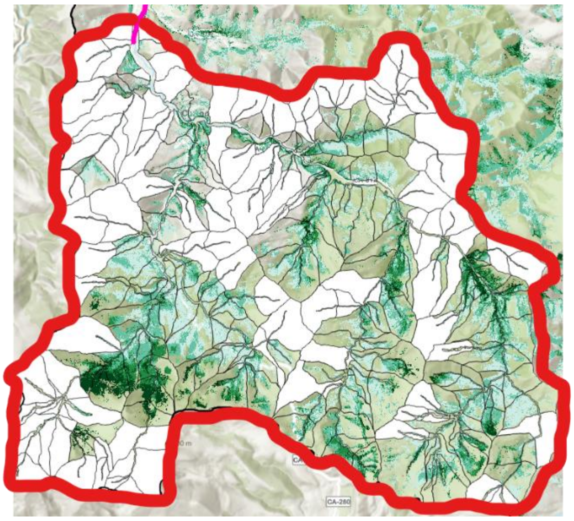
The identification of suitable locations for NbS implementation requires integrating the outputs generated in the previous steps. In this regard, we refer to functional hotspots as territorial units that, from a biophysical perspective, emerge as priority candidates for NbS implementation because of their capacity to regulate hazards and mitigate associated impacts. The accuracy and reliability of hotspot identification depend directly on the quality of prior steps—biodiversity mapping, biodiversity-ES relational tables, and ES characterisation—meaning that the type of roadmap chosen (fine vs. coarse) will condition the entire analysis.

In general terms, the identification of functional hotspots should begin by aggregating ES model outputs into spatial units with a functional meaning, such as functional units. In this way, the amount of ES provided by each functional unit can serve as a biophysical criterion for prioritisation, identifying those units acting as SPA. In parallel, risk analysis indicates which locations demand the ES, which can also be aggregated at the level of functional unit to identify SBA (presence of KCS under a risk). By tracing functional connections between SPA and SBA, it becomes possible to identify not only which units are generating regulating services, but also the amount of ES provision, as well as the extent of the benefits they deliver downstream. Several methods can then be applied to prioritise SPA, ranging from quartile-based ranking to inflexion-point analysis, benefit accumulation curves, or participatory processes, and can be conveniently explored in MMTF. While prioritisation is conducted at the functional unit scale, the underlying raster data allow for a finer spatial detail, identifying specific pixels where NbS could be implemented most effectively.

The relational table developed in Section 6 can be used to select which types of NbS could potentially be implemented in these functional hotspots, depending on the type of ES required to regulate the risk and its impacts on the KCS (Relational table - WIP_NBRACER_OST - Power BI).

COARSE roadmap (Quantitative)	FINE roadmap (Quantitative)
Functional hotspots for implementing forest preservation and conservation measures to mitigate flood risk by regulating runoff	*Functional hotspots for implementing forest preservation and conservation measures to mitigate flood risk by regulating runoff*


Comillas
CA-131
CA-182
-281
CA-183
Comillas
CA-131
Pumalverde
A-850
CA-183

	
We prioritised hillslope functional units according to their current capacity to regulate runoff by aggregating the raster outputs of the runoff regulation ES model at the functional unit scale. Prioritisation was conducted using a quartile-based analysis, highlighting those units with the highest regulatory potential. The darker the green colour, the higher the priority for NbS implementation aimed at conserving and sustainably managing existing forests to reduce flood risk in floodplains identified through the risk analysis (highlighted in pink; these areas come from the risk analysis exposed in box 1). In the zoomed example, the prioritisation of hillslope functional hotspots for runoff regulation is illustrated for a sub-area particularly exposed to flooding risk. In this case, the low resolution of the functional units doesn't allow for a good discretisation in this sub-area, for we now use the hillslope functional units delimited using the fine approach. Although functional hotspots are identified at the functional unit scale, the underlying raster data allow us to pinpoint the specific pixels within priority hillslopes where ES provision is highest (darker green pixels). These areas represent the most strategic locations where targeted NbS implementation would have the greatest impact. *For this analysis, we used the outputs produced following the coarse roadmap in the "climate*	We prioritised hillslope functional units according to their current capacity to regulate runoff by aggregating the raster outputs of the runoff regulation ES model at the functional unit scale. Prioritisation was conducted using a quartile-based analysis, highlighting those units with the highest regulatory potential. The darker the green colour, the higher the priority for NbS implementation aimed at conserving and sustainably managing existing forests to reduce flood risk in floodplains identified through the risk analysis (highlighted in pink; these areas come from the risk analysis exposed in box 1). In the zoomed example, the prioritisation of hillslope functional hotspots for runoff regulation is illustrated for a sub-area particularly exposed to flooding risk. Although functional hotspots are identified at the functional unit scale, the underlying raster data allow us to pinpoint the specific pixels within priority hillslopes where ES provision is highest (darker green pixels). These areas represent the most strategic locations where targeted NbS implementation would have the greatest impact. *For this analysis, we used the outputs produced following the fine roadmap in the "climate hazard and risk assessment", "biodiversity mapping", "Ecosystem Services characterisation: option Quantitative" and "Functional Units" steps.*

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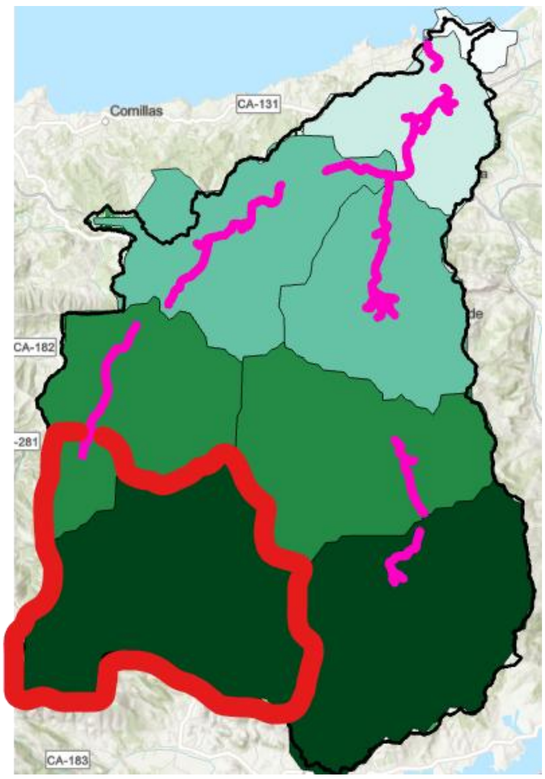
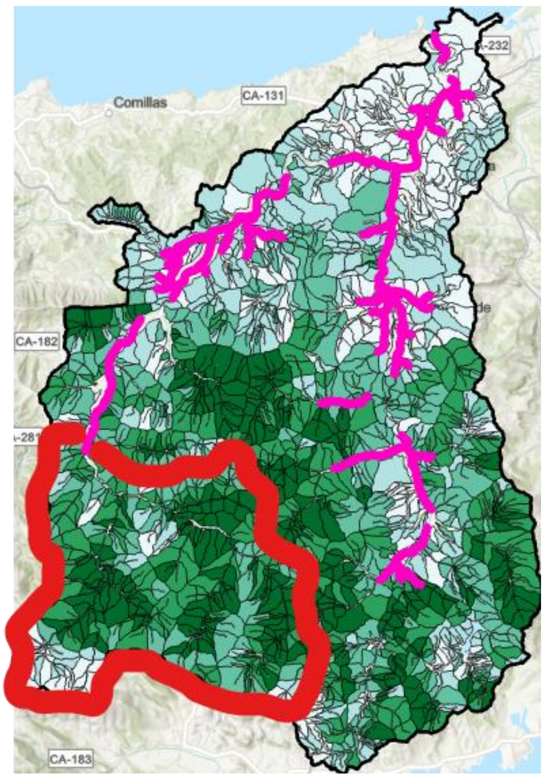
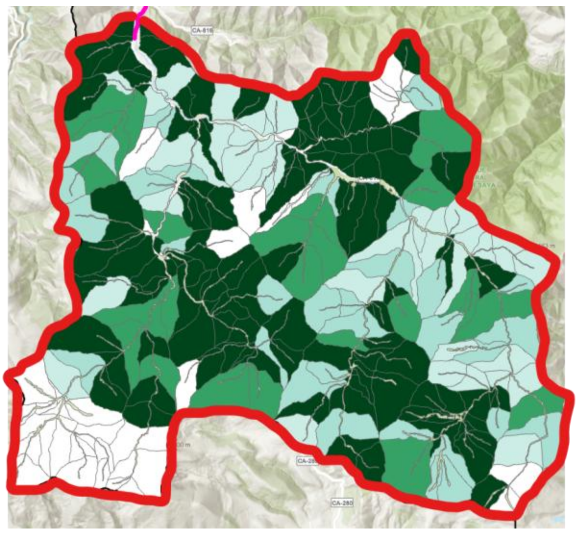
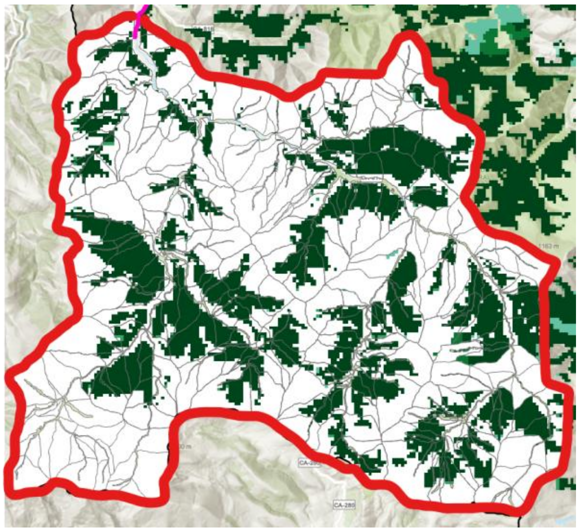
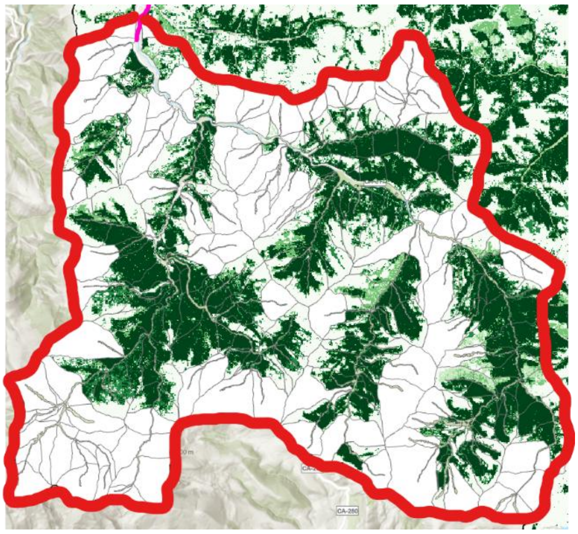
Functional hotspots for implementing forest preservation and conservation measures to mitigate flood risk by regulating runoff 	*Functional hotspots for implementing forest preservation and conservation measures to mitigate flood risk by regulating runoff* 
	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After presenting the comparative outputs of each analytical block, several overarching conclusions can be drawn from the application of both roadmaps:

1. The resolution of the methods directly conditions the precision of the analysis in three key ways:
   It determines (i) the level of spatial detail at which intervention areas can be identified—both for NbS implementation and for locating the KCS to be protected; (ii) the accuracy with which the magnitude and spatial distribution of ES provision can be estimated; and (iii) the degree of specificity with which ecological and functional relationships can be represented.
2. A major difference between the roadmaps lies in how physical processes are represented: The use of more generalised models or variables in the coarse approach can weaken the representation of biophysical dynamics. In fact, this limitation may be even more important than the use of a general land cover product such as CORINE. Even with a coarse land cover dataset, a good characterisation of abiotic processes can still allow for a meaningful differentiation of ES provision within the same land cover category.
3. Qualitative, proxy-based methods show important limitations, especially for ES driven primarily by abiotic processes:
   For ES such as flood regulation, the link between habitat, ecosystem or land cover and ES provision is not direct. As a result, qualitative approaches produce very coarse outputs and often overestimate actual service provision. This leads to excessively large areas being flagged as potentially suitable for NbS. In addition, these methods offer limited ability to identify ES potential—that is, the specific areas where the right ecosystems could be restored to recover regulatory functions.
4. The level of detail used to delineate functional units is critical for identifying functional hotspots and supporting territorial planning:
   Coarse approaches may be adequate for large-scale strategic planning (e.g., national or broad regional overviews), but they lose too much specificity at meso- or local scales. This loss of resolution weakens the functional connection between areas at risk and the ecosystems capable of regulating those risks, making them ineffective for site-level NbS planning.

8 Connection with Further Steps

The work completed in D5.3 provides a critical input for the subsequent stages of WP5 and the broader NBRACER implementation pathway. In particular, the outputs generated here—spatial characterisation of biodiversity and ES, and the hazard-NbS relational table for helping in the potential NbS to be implemented- will directly inform Task 5.5: Portfolio and Pathways Decision Support.

From biophysical characterisation to decision support

Task 5.5 will build upon the technical foundations laid by D5.3 to develop an open-source, GIS-based decision support tool complemented by operational guidance. This tool will enable regions to:

- Explore and assess solution portfolios and adaptation pathways.
- Integrate climate risks, NbS effectiveness, ES provision, and KCS exposure.
- Visualise different scenarios and strategies over time.
- Link enabling conditions, governance factors, and financing options.

The decision-support system will synthesise inputs from:

- WP5/WP6 (biophysical, ecological, and methodological frameworks).
- WP2, WP3, and WP4, especially Tasks 2.3, 3.3 and 4.3 on regional portfolio and pathway co-development.
- The conceptual logic outlined in D5.1/D5.2 and operationalised in D5.3.

In this sense, the methodological pathways and resources presented in this deliverable provide the ecological evidence base upon which adaptation pathways and NbS portfolios will be evaluated. As such, D5.3 acts as a bridge between the theoretical framing of climate risk regulation (D5.1/D5.2) and the practical design and assessment of NbS strategies in Task 5.5 and WP6. The transition from characterisation to decision support will be iterative and co-produced with the regions. By aligning technical modelling capacities, stakeholder needs, and existing planning tools, the next steps will ensure that biodiversity and ES insights effectively inform climate-resilient territorial planning.

Planned actions towards task 5.5

To effectively transition from characterisation to decision-making support, several actions will be undertaken:

- Build on existing outputs. D5.3 will be aligned with other WP5 and WP6 activities. For example, in T6.5, a stronger understanding of biodiversity-ES linkages can support the financing of NbS.
- Support regional implementation and monitoring. The outputs of this deliverable will contribute to the technical groundwork for D2.2, D3.2, and D4.2, helping regions operationalise biodiversity and ES insights in NbS planning and monitoring.

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- Identify regional needs and decision contexts. Co-design processes will gather information on specific requirements, priorities, and governance constraints across regions.
- Map existing decision support tools. An inventory will be conducted to detect relevant planning tools already used at local, regional, or national scales that can be integrated or complemented.
- Set up a generic decision support tool. The development will build on existing platforms such as the REST-COAST Quick-Scan Strategies Tool (QSST; Figure 15), Pathway Generator, P2R Toolbox and other relevant open-source modelling environments.
- Co-design regional portfolios and adaptation pathways. Regional workshops will support the integration of NbS options into place-based strategies, grounded in the biophysical insights developed in D5.3.

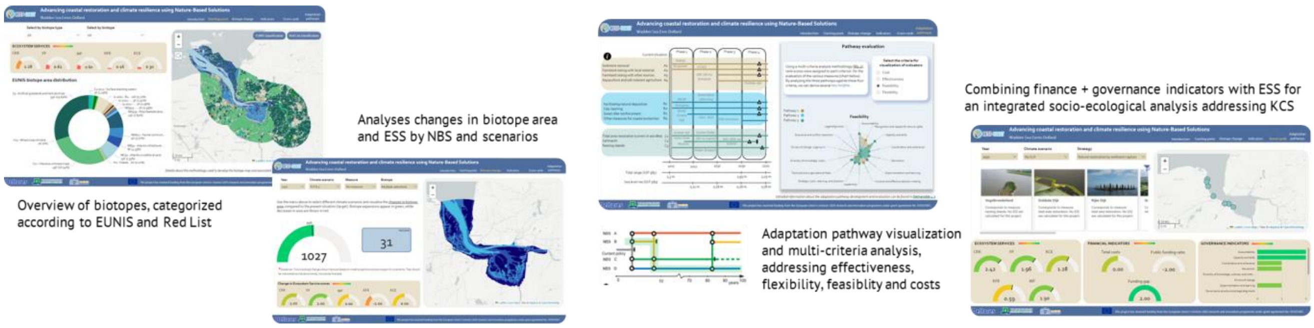

Figure 16: Impression of the REST-COAST Quick-Scan Strategies Tool, aiming to visualise and assess (for several scenarios) biotopes, ES, adaptation pathways (consisting of portfolios of measures and including financial and governance aspects), to support decision-making towards more climate resilience at local and regional levels.

9 References

Alfieri, L., Feyen, L., Dottori, F., & Bianchi, A. (2015). Ensemble flood risk assessment in Europe under high end climate scenarios. Global Environmental Change, 35, 199–212. https://doi.org/10.1016/j.gloenvcha.2015.09.004

Álvarez-Martínez, J. M., Jiménez-Alfaro, B., Barquín, J., Ondiviela, B., Recio, M., Silió-Calzada, A., & Juanes, J. A. (2018). Modelling the area of occupancy of habitat types with remote sensing. Methods in Ecology and Evolution, 9(3), 580–593. https://doi.org/10.1111/2041-210X.12925

Andrew, S. C., Gallagher, R. V., Wright, I. J., & Mokany, K. (2022). Assessing the vulnerability of plant functional trait strategies to climate change. Global Ecology and Biogeography, 31(6), 1194–1206. https://doi.org/10.1111/geb.13501

Angeler, D. G., Heino, J., Rubio-ríos, J., & Casas, J. J. (2023). Science of the Total Environment Connecting distinct realms along multiple dimensions: A meta-ecosystem resilience perspective. Science of the Total Environment, 889(January), 164169. https://doi.org/10.1016/j.scitotenv.2023.164169

Bastian, O., Syrbe, R.-U., Slavik, J., Moravec, J., Louda, J., Kochan, B., Kochan, N., Stutzriemer, S., & Berens, A. (2017). Ecosystem services of characteristic biotope types in the Ore Mountains (Germany/Czech Republic). International Journal of Biodiversity Science, Ecosystem Services & Management, 13(1), 51–71. https://doi.org/10.1080/21513732.2016.1248865

Baptist, M., Marijnissen, R., Różyński, G., Musumeci, R. E., Marino, M., Borzi, L., Di Stefano, A., Jolivet, M., Stocco, A., Horneman, F., Rova, S., Torresan, S., Furlan, E., Dabalà, C., Coccon, F., Critto, A., Pranovi, F., Bertomeu, F., Ibáñez, C., Caiola, N., Hineva, E., Andreeva, N., Eftimova, P., Prodanov, B., Doncheva, V., Valchev, V., Berg, S., Cognat, M. (2024). Scorecard methodology (tool) for coastal system restoration effects on ES and BDV. Deliverable D4.1. EU Horizon 2020 REST-COAST Project, Grant agreement No 101037097. https://doi.org/10.3897/arphapreprints.e128550

Bello, F., Lepš, J., Lavorel, S., & Moretti, M. (2007). Importance of species abundance for assessment of trait composition: An example based on pollinator communities. Community Ecology, 8(2), 163–170. https://doi.org/10.1556/ComEc.8.2007.2.3

Belmar, O., Barquín, J., Manuel, J., Martínez, Á., Peñas, F. J., & Jesus, M. D. (2018). The role of forest maturity in extreme hydrological events. Ecohydrology, January, 1–12. https://doi.org/10.1002/eco.1947

Benda, L., Miller, D., & Barquín, J. (2011). Creating a catchment scale perspective for river restoration. Hydrology and Earth System Sciences, 15(9), 2995–3015. https://doi.org/10.5194/hess-15-2995-2011

Bennett, E. M., Peterson, G. D., & Gordon, L. J. (2009). Understanding relationships among multiple ecosystem services. Ecology Letters, 12(12), 1394–1404. https://doi.org/10.1111/j.1461-0248.2009.01387.x

Bohn, U., Gollub, G., Hettwer, C., Neuhäuslová, Z., Raus, T., Schlüter, H., & Weber, H. (2003). Map of the Natural Vegetation of Europe. Bundesamt für Naturschutz Federal Agency for Nature Conservation.

Bolliger, J., & Silbernagel, J. (2020). Contribution of connectivity assessments to green infrastructure (GI). ISPRS International Journal of Geo-Information, 9(4). https://doi.org/10.3390/ijgi9040212

Botti, D. (2018). A phytoclimatic map of Europe. Environnement, Nature, Paysage, Document 867.

Boumans, R., Roman, J., Altman, I., & Kaufman, L. (2015). The Multiscale Integrated Model of Ecosystem Services (MIMES): Simulating the interactions of coupled human and natural systems. Ecosystem Services, 12, 30–41. https://doi.org/10.1016/j.ecoser.2015.01.004

Burkhard, B., Kroll, F., Müller, F., & Windhorst, W. (2009). Landscapes' capacities to provide ecosystem services—A concept for land-cover based assessments. Landscape Online, 15, 1–22. https://doi.org/10.3097/LO.200915

Campos, M., March, S., Salvat, A., & Pons, X. (1999). Vegetation mapping using digital colour orthoimages: A new methodology. SCIENTIA Gerundensis, 24, 13–25.

Carpenter, S. R., Mooney, H. A., Agard, J., Capistrano, D., DeFries, R. S., Díaz, S., Dietz, T., Duraiappah, A. K., Oteng-Yeboah, A., Pereira, H. M., Perrings, C., Reid, W. V., Sarukhan, J., Scholes, R. J., & Whyte, A. (2009). Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. Proceedings of the National Academy of Sciences, 106(5), 1305–1312. https://doi.org/10.1073/pnas.0808772106

Chan, K. M. A., Hoshizaki, L., & Klinkenberg, B. (2011). Ecosystem services in conservation planning: Targeted benefits vs. Co-benefits or costs? PLoS ONE, 6(9). https://doi.org/10.1371/journal.pone.0024378

De Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity, 7(3), 260–272. https://doi.org/10.1016/j.ecocom.2009.10.006

Díaz, S., Purvis, A., Cornelissen, J. H. C., Mace, G. M., Donoghue, M. J., Ewers, R. M., Jordano, P., & Pearse, W. D. (2013). Functional traits, the phylogeny of function, and ecosystem service vulnerability. Ecology and Evolution, 3(9), 2958–2975. https://doi.org/10.1002/ece3.601

Egoh, B., Reyers, B., Rouget, M., Richardson, D. M., Le, D. C., & Jaarsveld, A. S. V. (2008). Agriculture , Ecosystems and Environment Mapping ecosystem services for planning and management. 127, 135–140. https://doi.org/10.1016/j.agee.2008.03.013

Elith, J., & Leathwick, J. R. (2009). Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. Annual Review of Ecology, Evolution, and Systematics, 40(1), 677–697. https://doi.org/10.1146/annurev.ecolsys.110308.120159

Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. Ecological Economics, 68(3), 643–653. https://doi.org/10.1016/j.ecolecon.2008.09.014

Galparsoro, I., Borja, A., & Uyarra, M. C. (2014). Mapping ecosystem services provided by benthic habitats in the European North Atlantic Ocean. Frontiers in Marine Science, 1. https://doi.org/10.3389/fmars.2014.00023

Gonzalez, A., Mouquet, N., & Loreau, M. (2009). Biodiversity as spatial insurance: The effects of habitat fragmentation and dispersal on ecosystem functioning.

Hanski, I. (1999). Habitat connectivity, habitat continuity, and metapopulations in dynamic landscapes. Oikos, 87(2), 209–219.

Houghton, R. A. (2005). Aboveground Forest Biomass and the Global Carbon Balance. Global Change Biology, 11(6), 945–958. https://doi.org/10.1111/j.1365-2486.2005.00955.x

Kattge, J., Díaz, S., Lavorel, S., Prentice, I. C., Leadley, P., Bönisch, G., Garnier, E., Westoby, M., Reich, P. B., Wright, I. J., Cornelissen, J. H. C., Violle, C., Harrison, S. P., Van Bodegom, P. M., Reichstein, M., Enquist, B. J., Soudzilovskaia, N. A., Ackerly, D. D., Anand, M., … Wirth, C. (2011). TRY – a global database of plant traits. Global Change Biology, 17(9), 2905–2935. https://doi.org/10.1111/j.1365-2486.2011.02451.x

Keeler, B. L., Polasky, S., Brauman, K. A., Johnson, K. A., Finlay, J. C., & Neill, A. O. (2012). Linking water quality and well-being for improved assessment and valuation of ecosystem services. PNAS, 109(45), 18619–18624. https://doi.org/10.1073/pnas.1215991109

La Notte, A., Grammatikopoulou, I., Zurbaran Nucci, M., Marques, A., Ferrini, S., Cerilli, S., & Tamborra, M. (2022). LInking accounts for ecosystem Services and Benefits to the Economy THrough bridging (LISBETH) Part II. EUR 31185 EN, Publications Office of the European Union, Luxembourg.

Laca, E. A. (2021). Multi-Scape Interventions to Match Spatial Scales of Demand and Supply of Ecosystem Services. Front. Sustain. Food Syst, 4, 607276. https://doi.org/10.3389/fsufs.2020.607276

Lamb, D. (2018). Undertaking large-scale forest restoration to generate ecosystem services. Restoration Ecology, 26(4), 657–666. https://doi.org/10.1111/rec.12706

Lartey, D., Lomans, A., Zarei, S., Lomans, A., Skevich, M., & Van Hasselaar, D. (2025). Key plant traits for sustainable urban greening: A framework for plant selection. Journal of Environmental Management, 393, 127065. https://doi.org/10.1016/j.jenvman.2025.127065

Lee, H., & Lautenbach, S. (2016). A quantitative review of relationships between ecosystem services. Ecological Indicators, 66, 340–351. https://doi.org/10.1016/j.ecolind.2016.02.004

Leibold, M. A., Holyoak, M., Mouquet, N., Amarasekare, P., Chase, J. M., Hoopes, M. F., Holt, R. D., Shurin, J. B., Law, R., Tilman, D., Loreau, M., & Gonzalez, A. (2004). The metacommunity concept: A framework for multi-scale community ecology. Ecology Letters, 7(7), 601–613. https://doi.org/10.1111/j.1461-0248.2004.00608.x

Lindborg, R., Gordon, L. J., Malinga, R., Bengtsson, J., Peterson, G., Bommarco, R., Deutsch, L., Gren, A., Rundlof, M., & Smith, H. G. (2017). How spatial scale shapes the generation and management of multiple ecosystem services. Ecosphere, 8(4). https://doi.org/10.1002/ecs2.1741

Loreau, M., Mouquet, N., & Holt, R. D. (2003). Meta-ecosystems: A theoretical framework for a spatial ecosystem ecology. Ecological Letters, 6, 673–679. https://doi.org/10.1046/j.1461-0248.2003.00483.x

Maes, J., Teller, A., Erhard, M., Liquete, C., Braat, L., Berry, P., Egoh, B., Puydarrieus, P., Fiorina, C., Santos, F., Paracchini, M. L., Keune, H., Wittmer, H., & Hauck, J. (2013). An analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020. In Publications office of the European Union, Luxembourg (Issue 127). https://doi.org/10.2779/12398

Manning, P., van der Plas, F., Soliveres, S., Allan, E., Maestre, F. T., Mace, G., Whittingham, M. J., & Fischer, M. (2018). Redefining ecosystem multifunctionality. Nature Ecology & Evolution, 2(3), 427–436. https://doi.org/10.1038/s41559-017-0461-7

Martínez-Harms, M. J., & Balvanera, P. (2012). Methods for mapping ecosystem service supply: A review. International Journal of Biodiversity Science, Ecosystem Services & Management, 8(1–2), 17–25. https://doi.org/10.1080/21513732.2012.663792

Mulligan, M. (2013). WaterWorld: A self-parameterising, physically based model for application in data-poor but problem-rich environments globally. Hydrology Research, 44(5), 748–769. https://doi.org/10.2166/nh.2012.217

Mulligan, M. A., Guerry, K., Arkema, K., Bagstad, K., & Villa, F. (2010). Capturing and quantifying the flow of ecosystem services in Silvestri S., Kershaw F., (eds.). Framing the flow: Innovative Approaches to Understand, Protect and Value Ecosystem Services Across Linked Habitats. UNEP World Conservation Monitoring Centre, Cambridge, UK.

Naidoo, R., Balmford, A., Costanza, R., Fisher, B., Green, R. E., Lehner, B., Malcolm, T. R., & Ricketts, T. H. (2008). Global mapping of ecosystem services and conservation priorities. 105(28), 9495–9500.

Neugarten, R. A., Langhammer, P. F., Osipova, E., Bagstad, K. J., Bhagabati, N., Butchart, S. H. M., Dudley, N., Elliott, V., Gerber, L. R., Gutierrez Arrellano, C., Ivanić, K.-Z., Kettunen, M., Mandle, L., Merriman, J. C., Mulligan, M., Peh, K. S.-H., Raudsepp-Hearne, C., Semmens, D. J., Stolton, S., & Willcock, S. (2018). Tools for measuring, modelling, and valuing ecosystem services: Guidance for Key Biodiversity Areas, natural World Heritage sites, and protected areas (C. Groves, Ed.; 1st ed.). IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2018.PAG.28.en

Nuñez, T. A., Lawler, J. J., Mcrae, B. H., Pierce, D. J., Krosby, M. B., Kavanagh, D. M., Singleton, P. H., & Tewksbury, J. J. (2013). Connectivity Planning to Address Climate Change. Conservation Biology, 27(2), 407–416. https://doi.org/10.1111/cobi.12014

Oliver, T. H., Isaac, N. J. B., August, T. A., Woodcock, B. A., Roy, D. B., & Bullock, J. M. (2015). Declining resilience of ecosystem functions under biodiversity loss. Nature Communications, 6(1), 10122. https://doi.org/10.1038/ncomms10122

Pérez-Silos, I. (2021). Towards dynamic and integrative landscape management in mountain catchments: Definition of an adaptive strategy to global change challenges. University of Cantabria.

Pérez-Silos, I., Álvarez-Martínez, J. M., & Barquín, J. (2019). Modelling riparian forest distribution and composition to entire river networks. Applied Vegetation Science, May, 1–14. https://doi.org/10.1111/avsc.12458

Pérez-Silos, I., Álvarez-Martínez, J. M., & Barquín, J. (2021). Large-scale afforestation for ecosystem service provisioning: Learning from the past to improve the future. Landscape Ecology, 36, 3329–3343. https://doi.org/10.1007/s10980-021-01306-7

Pérez-Silos, I., Barquín, J., & Datry, T. (2025). Ecosystem Services in Drying River Networks: A Meta-Ecosystem Conceptual Model. WIREs Water, 12(1), e70002. https://doi.org/10.1002/wat2.70002

Potts, T., Burdon, D., Jackson, E., Atkins, J., Saunders, J., Hastings, E., & Langmead, O. (2014). Do marine protected areas deliver flows of ecosystem services to support human welfare? Marine Policy, 44, 139–148. https://doi.org/10.1016/j.marpol.2013.08.011

Ramachandran, A., Dee, L., Hayden, M., & Suding, K. (2024). Leveraging plant functional traits in the design of nature-based solutions: A research agenda. Journal of Ecology, 112(11), 2492–2501. https://doi.org/10.1111/1365-2745.14371

Rivas-Martínez, S., Penas, A., & Díaz, T. E. (2004). Bioclimatic Map of Europe. In Bioclimates. León University, Cartographic Service.

Ruiz Diaz Britez, M., Sergent, A.-S., Martinez Meier, A., Bréda, N., & Rozenberg, P. (2014). Wood density proxies of adaptive traits linked with resistance to drought in Douglas fir (Pseudotsuga menziesii (Mirb.) Franco). Trees, 28(5), 1289–1304. https://doi.org/10.1007/s00468-014-1003-4

Santoro, M., Oliver, C., Mermoz, S., Bouvet, A., Le Toan, T., Carvalhais, N., & Frank, M. (2018). A detailed portrait of the forest aboveground biomass pool for the year 2010 obtained from multiple remote sensing observations. Geophysical Research Abstracts, 20, EGU2018-18932.

Scheffer, M., Carpenter, S., Foley, J. A., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. Nature, 413(6856), 591–596. https://doi.org/10.1038/35098000

Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., House, J., Srivastava, S., & Turner, B. (2021). Getting the message right on nature-based solutions to climate change. Global Change Biology, 27(8), 1518–1546. https://doi.org/10.1111/gcb.15513

Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M. Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., Denu, D., and Douglass, J., 2018. InVEST 3.7.0. post17+ug.hbeb7e1912b14 User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

Sherrouse, B. C., Semmens, D. J., & Clement, J. M. (2014). An application of Social Values for Ecosystem Services (SolVES) to three national forests in Colorado and Wyoming. Ecological Indicators, 36, 68–79. https://doi.org/10.1016/j.ecolind.2013.07.008

Sponseller, R. A., Heffernan, J. B., & Fisher, S. G. (2013). On the multiple ecological roles of water in river networks. Ecosphere, 4(2), 1–14. https://doi.org/10.1890/ES12-00225.1

Syrbe, R. U., & Walz, U. (2012). Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. Ecological Indicators, 21, 80–88. https://doi.org/10.1016/j.ecolind.2012.02.013

Terrado, M., Acuña, V., Ennaanay, D., Tallis, H., & Sabater, S. (2014). Impact of climate extremes on hydrological ecosystem services in a heavily humanized Mediterranean basin. Ecological Indicators, 37, 199–209.

The Nature Conservancy. (1994). Field Methods for Vegetation Mapping. Environmental Systems Research Institute, Inc.

Villa, F., Bagstad, K. J., Voigt, B., Johnson, G. W., Portela, R., Honzák, M., & Batker, D. (2014). A methodology for adaptable and robust ecosystem services assessment. PLoS ONE, 9(3). https://doi.org/10.1371/journal.pone.0091001

Violle, C., Navas, M., Vile, D., Kazakou, E., Fortunel, C., Hummel, I., & Garnier, E. (2007). Let the concept of trait be functional! Oikos, 116(5), 882–892. https://doi.org/10.1111/j.0030-1299.2007.15559.x

Wang, S., & Loreau, M. (2016). Biodiversity and ecosystem stability across scales in metacommunities. Ecology Letters, 19(5), 510–518. https://doi.org/10.1111/ele.12582

Wellmann, T., Andersson, E., Knapp, S., Lausch, A., Palliwoda, J., Priess, J., Scheuer, S., & Haase, D. (2023). Reinforcing nature-based solutions through tools providing social-ecological-technological integration. Ambio, 52(3), 489–507. https://doi.org/10.1007/s13280-022-01801-4

Wratten, S., Sandhu, H., Cullen, R., & Costanza, R. (2013). Ecosystem Services in Agricultural and Urban Landscapes. John Wiley & Sons, Ltd.

Xie, Y., Sha, Z., & Yu, M. (2008). Remote sensing imagery in vegetation mapping: A review. Journal of Plant Ecology, 1(1), 9–23. https://doi.org/10.1093/jpe/rtm005

Yang, D., Qin, Y., Xu, Y., Xing, K., Chen, Y., Jia, X., Aviso, K. B., Tan, R. R., & Wang, B. (2024). Sequestration of carbon dioxide from the atmosphere in coastal ecosystems: Quantification, analysis, and planning. Sustainable Production and Consumption, 47, 413–424. https://doi.org/10.1016/j.spc.2024.04.012

Zieritz, A., Sousa, R., Aldridge, D. C., Douda, K., Esteves, E., Ferreira-rodríguez, N., Mageroy, J. H., Nizzoli, D., Osterling, M., Reis, J., Riccardi, N., & Daill, D. (2022). A global synthesis of ecosystem services provided and disrupted by freshwater bivalve molluscs. Biological Reviews, 44, 1967–1998. https://doi.org/10.1111/brv.12878

Appendix 1: Land Cover and Habitat Classification Bridge

Example of a bridge between EUNIS classification, Habitat Directive and CLC. This resource has been developed by IHCantabria as part of an internal project and is available for consultation by the NBRACER Project consortium.

Level	Code	Name	Description	Source	Diagnostic species	Constant species	Dominant species	EUNIS 2012 relationship	EUNIS 2012 code	EUNIS 2012 name (scientific)	EUNIS 2012 name (english)	Resolution 4 relationship	Resolution 4 code	Resolution 4 name	Annex I relationship	Annex I code	Annex I name	Red List relationship	Red List code	Red List code (Web application)
3	T11	Temperate *Salix* and *Populus* riparian forest	Riparian forests dominated by willows (*Salix* spp.) and poplars (*Populus* spp.) of periodically-inundated terraces and shoals with deposition of nutrient-rich alluvium in the active floodplains of rivers through the lowlands of the temperate, submediterranean and steppe zones of Europe.	Schaminée et al 2019	*Salix alba*; *Salix euxina*; *Populus nigra*; *Humulus lupulus*; *Rubus caesius*; *Urtica dioica*; *Phalaroides arundinacea*; *Populus alba*; *Glechoma hederacea*; *Impatiens glandulifera*; *Calystegia sepium*; *Salix triandra*; *Symphytum officinale*; *Salix purpurea*	*Urtica dioica*; *Salix alba*; *Rubus caesius*; *Galium aparine*; *Salix euxina*; *Phalaroides arundinacea*; *Glechoma hederacea*; *Populus nigra*; *Calystegia sepium*; *Poa trivialis*; *Ranunculus repens*; *Humulus lupulus*; *Sambucus nigra*; *Cornus sanguinea*; *Solanum dulcamara*; *Aegopodium podagraria*; *Alnus glutinosa*; *Symphytum*	*Salix alba*; *Salix euxina*; *Urtica dioica*; *Populus nigra*; *Rubus caesius*; *Populus alba*; *Phalaroides arundinacea*	<	G1.1	Riparian and gallery woodland, with dominant *Alnus*, *Betula*, *Populus* or *Salix*	Riparian and gallery woodland, with dominant alder, birch, poplar or willow				#; *#*	91E0; *92A0*	' Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*); *Salix alba and Populus alba galleries*	=	G1.1	RLG1.1
3	T12	*Alnus glutinosa* – *Alnus incana* forest on riparian and mineral soils	Riparian and non-riparian forests dominated by alder (*Alnus glutinosa*, *Alnus incana*), and sometimes ash (*Fraxinus angustifolia*, *Fraxinus excelsior*), typically without many softwood willows in the canopy and occurring throughout Europe along streams and small to medium rivers. The field layer can be quite species-rich.	Schaminée et al 2019	*Alnus glutinosa*; *Alnus incana*; *Impatiens noli-tangere*; *Schedonorus giganteus*; *Carex remota*; *Chrysosplenium alternifolium*; *Prunus padus*; *Stachys sylvatica*; *Fraxinus excelsior*; *Plagiomnium undulatum*; *Filipendula ulmaria*; *Crepis paludosa*; *Aegopodium podagraria*; *Circaea lutetiana*; *Cirsium oleraceum*; *Athyrium filix-femina*; *Stellaria nemorum*; *Lamium galeobdolon*;	*Alnus glutinosa*; *Urtica dioica*; *Fraxinus excelsior*; *Athyrium filix-femina*; *Filipendula ulmaria*; *Deschampsia cespitosa aggr.*; *Oxalis acetosella*; *Ranunculus repens*; *Geum urbanum*; *Impatiens noli-tangere*; *Geranium robertianum*; *Aegopodium podagraria*; *Stachys sylvatica*; *Rubus idaeus*; *Lamium galeobdolon*; *Corylus avellana*; *Alnus incana*; *Plagiomnium undulatum*; *Caltha palustris*;	*Alnus glutinosa*; *Alnus incana*; *Fraxinus excelsior*; *Urtica dioica*	<	G1.2	Mixed riparian floodplain and gallery woodland	Mixed riparian floodplain and gallery woodland				#; *>*	91E0; *9030*	' Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*); ' *Natural forests of primary succession stages of landupheaval coast*;	=	G1.2a	RLG1.2a

Appendix 2: Land Use-Cover Classification

Land use-cover classification, as defined by the Coordination of Information on the Environment (CORINE), is used for the relation table.

Level 1	Code Level 1	Level 2	Code Level 2	Level 3	Code Level 3
Artificial Surfaces	1	Urban fabric	1.1	Continuous urban fabric	1.1.1
				Discontinuous urban fabric	1.1.2
		Industrial. commercial and transport units	1.2	Industrial or commercial units	1.2.1
				Road and rail networks and associated land	1.2.2
				Port areas	1.2.3
				Airports	1.2.4
		Mine. dump and construction sites	1.3	Mineral extraction sites	1.3.1
				Dump sites	1.3.2
				Construction sites	1.3.3
		Artificial. non-agricultural vegetated areas	1.4	Green urban areas	1.4.1
				Sport and leisure facilities	1.4.2
Agricultural areas	2	Arable land	2.1	Non-irrigated arable land	2.1.1
				Permanently irrigated land	2.1.2
				Rice fields	2.1.3
		Permanent crops	2.2	Vineyards	2.2.1
				Fruit trees and berry plantations	2.2.2
				Olive groves	2.2.3
		Pastures	2.3	Pastures	2.3.1
		Heterogeneous agricultural areas	2.4	Annual crops associated with permanent crops	2.4.1
				Complex cultivation patterns	2.4.2
				Land principally occupied by agriculture. with significant areas of natural vegetation	2.4.3
				Agro-forestry areas	2.4.4
Forest and seminatural areas	3	Forest	3.1	Broad-leaved forest	3.1.1
				Coniferous forest	3.1.2
				Mixed forest	3.1.3
		Shrub and/or herbaceous vegetation associations	3.2	Natural grassland	3.2.1
				Moors and heathland	3.2.2
				Sclerophyllous vegetation	3.2.3
				Transitional woodland/shrub	3.2.4
		Open spaces with little or no vegetation	3.3	Beaches, dunes, sands	3.3.1
				Bare rock	3.3.2
				Sparsely vegetated areas	3.3.3

				Burnt areas	3.3.4
				Glaciers and perpetual snow	3.3.5
Wetlands	4	Inland wetlands	4.1	Inland marshes	4.1.1
				Peatbogs	4.1.2
		Coastal wetlands	4.2	Salt marshes	4.2.1
				Salines	4.2.2
				Intertidal flats	4.2.3
Water bodies	5	Inland waters	5.1	Water courses	5.1.1
				Water bodies	5.1.2
		Marine waters	5.2	Coastal lagoons	5.2.1
				Estuaries	5.2.2
				Sea and ocean	5.2.3

Appendix 3: Ecosystem Services

ES, as classified by The Common International Classification of Ecosystem Services (CICES v5.1), are used in the relational table.

Filter	Section	Division	Group	Class	Code	Class type
CICES	Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes	1.1.1.1	Crops by amount, type (e.g. cereals, root crops, soft fruit, etc.)
CICES	Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)	1.1.1.2	Material by amount, type, use, media (land, soil, freshwater, marine)
CICES	Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Cultivated plants (including fungi, algae) grown as a source of energy	1.1.1.3	By amount, type, source
CICES	Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in-situ aquaculture grown for nutritional purposes	1.1.2.1	Plants, algae by amount, type
CICES	Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.2.2	Plants, algae by amount, type
CICES	Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in-situ aquaculture grown as an energy source	1.1.2.3	Plants, algae by amount, type
CICES	Provisioning (Biotic)	Biomass	Reared animals for nutrition, materials or energy	Animals reared for nutritional purposes	1.1.3.1	Animals, products by amount, type (e.g. beef, dairy)
CICES	Provisioning (Biotic)	Biomass	Reared animals for nutrition, materials or energy	Fibres and other materials from reared animals for direct use or processing (excluding genetic materials)	1.1.3.2	Material by amount, type, use, media (land, soil, freshwater, marine)

CICES	Provisioning (Biotic)	Biomass	Reared animals for nutrition, materials or energy	Animals reared to provide energy (including mechanical)	1.1.3.3	By amount, type, source
CICES	Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for nutritional purposes	1.1.4.1	Animals by amount, type
CICES	Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.4.2	Animals by amount, type
CICES	Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture as an energy source	1.1.4.3	Animals by amount, type
CICES	Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	1.1.5.1	Plants, algae by amount, type
CICES	Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	1.1.5.2	Plants, algae by amount, type
CICES	Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy	1.1.5.3	Material by type/source
CICES	Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes	1.1.6.1	Animals by amount, type
CICES	Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic)	Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)	1.1.6.2	Material by type/source

			for nutrition, materials or energy			
CICES	Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used as a source of energy	1.1.6.3	By amount, type, source
CICES	Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population	1.2.1.1	By species or varieties
CICES	Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Higher and lower plants (whole organisms) used to breed new strains or varieties	1.2.1.2	By species or varieties
CICES	Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Individual genes extracted from higher and lower plants for the design and construction of new biological entities	1.2.1.3	Material by type
CICES	Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population	1.2.2.1	By species or varieties
CICES	Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals	Wild animals (whole organisms) used to breed new strains or varieties	1.2.2.2	By species or varieties
CICES	Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from organisms	Individual genes extracted from organisms for the design and construction of new biological entities	1.2.2.3	Material by type
CICES	Provisioning (Biotic)	Other types of provisioning service from biotic sources	Other	Other types of provisioning service from biotic sources	1.3.X.X	Use nested codes to allocate other provisioning services from

						living systems to appropriate Groups and Classes
CICES	Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals	2.1.1.1	By type of living system or by waste or subsistence type
CICES	Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	2.1.1.2	By type of living system, or by water or substance type
CICES	Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Smell reduction	2.1.2.1	By type of living system
CICES	Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Noise attenuation	2.1.2.2	By type of living system
CICES	Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Visual screening	2.1.2.3	By type of living system
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates	2.2.1.1	By reduction in risk, area protected
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Buffering and attenuation of mass movement	2.2.1.2	By reduction in risk, area protected
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	2.2.1.3	By depth/volumes

CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Wind protection	2.2.1.4	By reduction in risk, area protected
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Fire protection	2.2.1.5	By reduction in risk, area protected
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	2.2.2.1	By amount and pollinator
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Seed dispersal	2.2.2.2	By amount and dispersal agent
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)	2.2.2.3	By amount and source
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Pest control (including invasive species)	2.2.3.1	By reduction in incidence, risk, area protected by type of living system
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Disease control	2.2.3.2	By reduction in incidence, risk, area protected by type of living system
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of soil quality	Weathering processes and their effect on soil quality	2.2.4.1	By amount/concentration and source
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of soil quality	Decomposition and fixing processes and their effect on soil quality	2.2.4.2	By amount/concentration and source
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of freshwaters by living processes	2.2.5.1	By type of living system

CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of salt waters by living processes	2.2.5.2	By type of living system
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	2.2.6.1	By contribution of type of living system to amount, concentration or climatic parameter
CICES	Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of temperature and humidity, including ventilation and transpiration	2.2.6.2	By contribution of type of living system to amount, concentration or climatic parameter
CICES	Regulation & Maintenance (Biotic)	Other types of regulation and maintenance service by living processes	Other	Other types of regulation and maintenance service by living processes	2.3.X.X	Use nested codes to allocate other regulating and maintenance services from living systems to appropriate Groups and Classes
CICES	Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	3.1.1.1	By type of living system or environmental setting
CICES	Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	3.1.1.2	By type of living system or environmental setting
CICES	Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that	Intellectual and representative	Characteristics of living systems that enable scientific investigation or the	3.1.2.1	By type of living system or environmental setting

		depend on presence in the environmental setting	interactions with natural environment	creation of traditional ecological knowledge		
CICES	Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable education and training	3.1.2.2	By type of living system or environmental setting
CICES	Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage	3.1.2.3	By type of living system or environmental setting
CICES	Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable aesthetic experiences	3.1.2.4	By type of living system or environmental setting
CICES	Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	3.2.1.1	By type of living system or environmental setting
CICES	Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have sacred or religious meaning	3.2.1.2	By type of living system or environmental setting

CICES	Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems used for entertainment or representation	3.2.1.3	By type of living system or environmental setting
CICES	Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value	3.2.2.1	By type of living system or environmental setting
CICES	Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an option or bequest value	3.2.2.2	By type of living system or environmental setting
CICES	Cultural (Biotic)	Other characteristics of living systems that have cultural significance	Other	Other characteristics of living systems that have cultural significance	3.3.X.X	Use nested codes to allocate other cultural services from living systems to appropriate Groups and Classes
CICES	Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water for drinking	4.2.1.1	By amount, type, source
CICES	Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water used as a material (non-drinking purposes)	4.2.1.2	By amount & source
CICES	Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Freshwater surface water used as an energy source	4.2.1.3	By amount, type, source

CICES	Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Coastal and marine water used as energy source	4.2.1.4	By amount, type, source
CICES	Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground (and subsurface) water for drinking	4.2.2.1	By amount, type, source
CICES	Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as a material (non-drinking purposes)	4.2.2.2	By amount & source
CICES	Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as an energy source	4.2.2.3	By amount & source
CICES	Provisioning (Abiotic)	Water	Other aqueous ecosystem outputs	Other aqueous ecosystem outputs	4.2.X.X	Use nested codes to allocate other provisioning services from non-living systems to appropriate Groups and Classes
CICES Extended	Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for nutritional purposes	4.3.1.1	Amount by type
CICES Extended	Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for material purposes	4.3.1.2	Amount by type
CICES Extended	Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for as an energy source	4.3.1.3	Amount by type
CICES Extended	Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Non-mineral substances or ecosystem properties used for nutritional purposes	4.3.2.1	Amount by type

CICES Extended	Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Non-mineral substances used for materials	4.3.2.2	Amount by type
CICES Extended	Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Wind energy	4.3.2.3	Amount by type
CICES Extended	Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Solar energy	4.3.2.4	Amount by type
CICES Extended	Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Geothermal	4.3.2.5	Amount by type
CICES Extended	Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Other mineral or non-mineral substances or ecosystem properties used for nutrition, materials or energy	Other mineral or non-mineral substances or ecosystem properties used for nutrition, materials or energy	4.3.2.6	Use nested codes to allocate other provisioning services from non-living systems to appropriate Groups and Classes
CICES Extended	Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution by freshwater and marine ecosystems	5.1.1.1	Amount by type

CICES Extended	Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution by atmosphere	5.1.1.2	Amount by type
CICES Extended	Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)	5.1.1.3	Amount by type
CICES Extended	Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Mediation of nuisances by abiotic structures or processes	5.1.2.1	Amount by type
CICES Extended	Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Mass flows	5.2.1.1	Amount by type
CICES Extended	Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Liquid flows	5.2.1.2	Amount by type
CICES Extended	Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Gaseous flows	5.2.1.3	Amount by type
CICES Extended	Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Maintenance of physical, chemical, abiotic conditions	Maintenance and regulation by inorganic natural chemical and physical processes	5.2.2.1	Amount by type
CICES Extended	Regulation & Maintenance (Abiotic)	Other type of regulation and maintenance service by abiotic processes	Other	Other type of regulation and maintenance service by abiotic processes	5.3.X.X	Use nested codes to allocate other provisioning services from non-living systems to appropriate Groups and Classes
CICES Extended	Cultural (Abiotic)	Direct, in-situ and outdoor interactions with natural physical systems that depend on	Physical and experiential interactions with natural abiotic	Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions	6.1.1.1	Amount by type

		presence in the environmental setting	components of the environment			
CICES Extended	Cultural (Abiotic)	Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	Intellectual and representative interactions with abiotic components of the natural environment	Natural, abiotic characteristics of nature that enable intellectual interactions	6.1.2.1	Amount by type
CICES Extended	Cultural (Abiotic)	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with the abiotic components of the natural environment	Natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions	6.2.1.1	Amount by type
CICES Extended	Cultural (Abiotic)	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	Other abiotic characteristics that have a non-use value	Natural, abiotic characteristics or features of nature that have either an existence, option or bequest value	6.2.2.1	Amount by type
CICES Extended	Cultural (Abiotic)	Other abiotic characteristics of nature that have cultural significance	Other	Other abiotic characteristics of nature that have cultural significance	6.3.X.X	Use nested codes to allocate other provisioning services from non-living systems to appropriate Groups and Classes

Appendix 4: Nature-based Solutions

A list of NbS throughout the NBRACER regions. These NbS were selected based on input from regional partners involved in the NBRACER project, gathered through a questionnaire which was finalised in September 2024 (NbS ID: represents the NbS code in the questionnaire, mainly coded with the initials of the region).

NbS ID	NbS	Brief description (five keywords)
WF-1	Constructed wetland in the Provincial domain Bulskampveld - reed field	Constructed wetland, reed, water purification
WF-2	Willow Field Wetland Aquaduin Koksijde	Wetland; willow; concentrate; water production
WF-3	Oeverstroken (buffer strips) Kemmelbeek	Buffer strips; river bank;
WF-4	Plant-based dams - Robuuste Waterlopen Westhoek	Plant-based dams
EF-1	Sint-Rijkers Flood emergency profile with strip of wetland (two-staged channel)	Water quality, water safety, agricultural solutions, and biodiversity value are quite easy to implement
WF-5	Schuddebeurze - Wet nature reserve	Wet nature reserve dunes
WF-6	Reed field	IBA, rietveld
WF-7	Zwinpolder - Buffer ditch for salinisation	Saline intrusion parallel ditches
WF-8	The project Uitkerkse Polder consists of several NbS. (1) Implementation of natural banks at the Blankenbergse Vaart, (2) Water level rise and decision making on water level/compartment in the complete project, (3) infiltration ponds in different places for meadow birds	Water level control and compartmentalisation
EF-2	Moervaart - Wet nature conservation and creation	Impoverishment for nature installation and restoration
WF-9	The City River	Urban development, water retention, landscape-led design, interdisciplinary, climate test
WF-10	Kwetshage - Moeraskern Kreekrug (wet nature)	Natural swamp with a weir and a windmill
EF-3	NIR Blankaart - Water level increase for nature restoration in the Blankaart basin	Restoration and creation of a wet nature
EF-4	Berlare Broek - Donkmeer - Eendenkooi (wet nature)	Old recreational area with new natural value
EF-5	Beek.boer.bodem and Barbierbeek - Agricultural practices for climate smart farming	Smaller interventions on arable fields for erosion and water quality & quantity management
WF-11	Kreekruginfiltratie Kwetshage (managed recharge of phreatic aquifer) - example of failed NbS	Aquifer recharge, polder, fresh water, kreekruginfiltratie
WF-12	Grass buffer strips	Grass buffer strips along waterways, no fertilisation or pesticides in this zone
WF-13	Modular Small-Scale Wastewater Treatment Plants with helophytes	Water pollution, purification, helophytes, water quality

WF-14	Constructed wetland - reed field	Constructed wetland, reed, water purification
WF-15		
WF-16	Non-tillage agriculture (specifically in polder landscapes)	Natural soil structure, no tillage, polder
WF-17	Carbon farming	Storing carbon through different techniques
WF-18	Surface water constructed wetland INAGRO	Lower nitrate level drainage water
WF-19	Raising water levels by placing dams in water courses and ditches	Raising water levels, dams courses
WF-20	Differentiated mowing in the waterway	Mowing, water plants, Helophytes, recolonisation
WF-21	Natural Water Retention Measures (NWRM)	Excavating soil for the rewetting project
DK-1	Skødbækdalen ved Lemvig Sø	Water retention, ecosystem restoration, phosphorus sedimentation, and recreation
DK-2	Nørre Nissum Nature-based water retention for protection against sewage overflow at the coast of Lemvig	Water retention, natural purification, preventing sewage overflow, recreational value, ecosystem protection
DK-3	Tingstrup Sø / Tingstrup Lake	Dam, flood protection, nitrogen removal, water quality enhancement, recreational and handicap friendly.
DK-4		
DK-5	Haraldsminde	Flood protection, water retention, biodiversity enhancement, water quality improvement, and recreational values
DK-6	sØnæs	Water storage, water purification, recreational, learning activities, and a social gathering place
DK-7	Gjellerup Meadows Nature Projekt	Biodiversity, back to nature, outdoor life, recreational, wild stock
DK-8	Low land project Fuglkaer Stream / Lavbundsprojekt Fuglkær Å	Nature restoration, reducing greenhouse gas emissions, increasing groundwater level, improving water quality, and improving habitat.
DK-9	Klima lavbundsprojekt Damsø, Skjern Enge / Climate lowland project, Skjern Meadows	Wetland reduces CO2 emissions, water retention, and other problems, enhancing biodiversity.
ES-1	Creating butterfly gardens	Native flora, pollinator species, butterflies, bees, biodiversity
ES-2	Assisted natural regeneration of wetlands in the Picos de Europa National Park	Conservation, biodiversity, compensation, restoration, water
ES-3	Green filters in eucalyptus plantations	Sustainability, conservation, economy, forest holdings, good forest management practices
ES-4	The forest as an element to safeguard roads in winter	Forest, avalanches, snow accumulation
ES-5	Phytodepuration	Wetland, floating, phytodepuration, plants, treatment

ES-6	Restoration of relict holm oak forests	Relict holm oak, restoration, thinning, plantations, IAS elimination
ES-7	Environmental restoration of two inland wetlands	IAS removal, replacement plantations, stewardship, habitat restoration
ES-8	Environmental restoration of four littoral wetlands	IAS removal, replacement plantations, stewardship, concession, habitats restoration
ES-9	Environmental restoration of islands in the Bay of Santander	Islands, habitat restoration, IAS removal
ES-10	Sustainable forest management	Sustainable forest management, forest restoration and maintenance
ES-11	Riparian forest restoration of the Camesa River in Reinosilla	Bioengineering, vegetation, local, restoration, erosion
ES-12	Environmental restoration of Solvay quarries in Cuchía	Old quarry, renaturalisation, biodiversity improvement, IAS elimination, pond expansion, geomorphological remodelling
ES-13	ecoASTILLERO XXI	Restoration; extractive industry; infrastructure; marshes; waste and waste; IAS; ecological awareness industrial zone
ES-14	LIFE Econnect - Improving connectivity of Natura 2000 network in mountain areas LIFE 12 NAT/ ES/000766	Erosion control; soil restoration; vegetation restoration, protection of peatlands; planting of tree and shrub species; grey partridge; hen harrier; plant production unit
ES-15	Vaguada de las Llamas Park	Intertidal estuary; Freshwater habitat; Periurban; Agricultural areas/agrosystems; restoration
ES-16	Floodplain restoration of the Saja River	Restoration, floodplains, erosion
ES-17	Revegetation of the riverbanks of the Saja River	Plantation / exotics / renaturalisation / flooding / erosion
ES-18	Conservation of hillside forests in different parts of the Cantabria region	Ecosystem services, hydrological response, hillside forests, integrated watershed management, aquatic ecosystems
ES-19	Prescribed burning	Fire, grass, scrub, sustainable forest management, extensive livestock farming
ES-20	Conservation of riparian forests in the Saja catchment	Riparian forest; Erosion; Thermal regulation; Habitat creation; Flooding
ES-21	Restoration of the natural tidal regime in Oyambre estuary	Tide, dam, flows, invasive species, restoration
ES-22	Renaturalization urban intervention	Renaturalisation, green corridor, rain gardens, permeable soil
ES-23	Measures to conserve and increase biodiversity in urban green areas	Biodiversity, urban, habitats, pollinators, fauna
ES-24	Weir demolition	River connectivity, habitat fragmentation, aquatic diversity, permeability
NA-1	water recharge and reducing water flow	Water recharge, water levels, water storage, re-naturalisation, floods
NA-2	Regreening a former parking lot	It brings several protections: against coastal erosion, loss of biodiversity and for the well-being of the inhabitants.

NA-3	Urban Natural Park: creating a link between nature and city	Protection of wetland and riverbanks areas thanks to a protected natural space.
NA-4	New plantation systems and agricultural models to fight floods	Soil supporting with local and hardy plants to avoid flood risk (mainly).
NA-5	Design and management of a green zone for wastewater	Additional, filter, buffer zone
NA-6	Restoration and preservation of the sensitive natural space of Vallée de l'Eau Blanche	Public company, wetlands, agricultural policy
NA-7	The vegetal ingenuity in the service of a neighbourhood	Protection of the hill slope with vegetation and social link
NA-8	Remeandering the La Belle stream in Mareuil-en-Périgord	Limit the loss of biodiversity and improve the water cycle with meanders
NA-9	Granulometric charge and monitoring of the Bonnieure river	Granulometric charge to stop erosion and low water and to protect biodiversity
NA-10	Reopening an underground river and erasing a water body on a former industrial site	Underground river, industrial wasteland, pond, water quality, biodiversity
NA-11	Renaturation of the Thouet springs	Restoration, water body, biodiversity, water quality
NA-12	Agricultural activity in support of the restoration of a marsh	Agriculture, restoration, marsh, reserved area, biodiversity
NA-13	Creation and preservation of an ecological zone on a former quarry	Quarry, biodiversity, restoration
NA-14	Giving nature back a place in cemeteries	Cemeteries, nature, biodiversity, well-being
NA-15	Restoration of ecological continuity and morphology in the crossing through Mauleon town	River restoration, morphology, biodiversity, citizens' communication
NA-16	Restoration and development work on the Ouin and wetlands in the commune of Petite Boissière	Riverbed restoration, water quality, biodiversity, citizens' opposition
NA-17	Restoration of a mosaic of wetland habitats	Restoration of a natural wet meadow; change in agricultural practice; NATURA 2000; ecosystem services
FRI-1	Beekherstel Linde	Streamvalley renaturation, re-meandering, water storage, biodiversity, water quality
FRI-2	Flexible water level management	Peat oxidation, CO_2 emissions reduction, subsidence, water retention
FRI-3		
FRI-4	Building biobased	Regrowable, capture CO_2, circular
FRI-5	1DYK	Groene dijken; Samenwerken; Water safety; Nature; Verrijken
CA-1	Protection and Management of Risks, Floods and Floods and Construction of Interceptor System and diversion of the urban area of Esposende	Interceptor system risks, floods and flood
CA-2	Ecovia River Cávado and Homem	River, bank, valuation, water, quality of life, enjoyment

PO-1	GreenRoof – Falcão Elementary School	Greenroof; Bioclimatic comfort; Energy; School
PO-2	Rio Tinto Interconnector	Water quality; Connectivity; Green Park
PO-3	Asprela Park	Urban Park; Connectivity; Water retention; Biodiversity; Leisure
PO-4	Alameda de Cartes Park	Urban Park; Connectivity; Water retention; Safety; Social cohesion
PO-5	Intermodal Terminal of Campanhã (TIC)	Retention basin; Biodiversity support; Extensive green cover; Green-Grey integration
PO-6	FUN Porto	Trees; Plantation; Biodiversity; Air quality; Carbon sequestration
ES-25	Phytobatea	Phytobatea; plants; floating wetlands; water treatment; sewage

Appendix 5: Guidelines

Resources and guidelines to Finer and Coarser roadmaps

Roadmap Type	Scale	Core Approach	Example Tools / Resources	Links
Quantitative	**Finer**	Process-based, empirical, or simulation models (e.g., hydrological, ecological).	InVEST, ARIES, Co$ting Nature, SWAT, INCA, and workflow as applied in this deliverable	[Guideline]
Quantitative	**Coarser**	Proxy-based scoring refined with simple covariates (e.g., slope, aspect, elevation).	CORINE + covariates workflow (as applied in this deliverable).	[Guideline]
Qualitative	**Finer**	Expert-based matrices, refined with local indicators	REST-COAST ES matrices, Burkhard et al. (2009); Maes et al. (2012) and workflow as applied in this deliverable	[Restcoast-deliverable] [Guideline]
Qualitative	**Coarser**	Land cover → ES potential mapping using weighted scores (probability-like).	CORINE-based scoring matrices (as applied in this study).	[Guideline]