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D6.3 – Assessment of ecosystem services

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Executive Summary

Ecosystem services — the benefits people derive from nature — are central to understanding the full value of Nature-based Solutions (NbS). These services encompass provisioning services (e.g. food, freshwater), regulating services (e.g. flood regulation, climate control, water purification), and cultural services (e.g. recreation, well-being, sense of place). A comprehensive evaluation of these services is essential, as incomplete knowledge of the benefits delivered by NbS can lead to underestimate their environmental, social and economic value, constraining investment, policy uptake and large-scale implementation.

However, despite growing recognition of NbS as effective instruments for climate adaptation and disaster risk reduction, there is no yet a standardized or common methodology for assessing their full range of benefits and co-benefits. Existing approaches span biophysical modelling, field monitoring, economic valuation, stakeholder-based methods and multi-criteria assessments. While this methodological diversity allows flexibility across contexts and scales, it also hampers comparability across studies and sectors, particularly for non-market and intangible benefits such as biodiversity, human well-being and cultural values. These challenges are further amplified when assessing long-term NbS performance and their evolution under future climate-change scenarios.

In this context, this report explores available methods for a comprehensive assessment of ecosystem services and NbS benefits, extending beyond disaster risk reduction. Focusing on the Po River Basin District, the study builds on representative case studies identified in Deliverable D6.2. The selected cases cover a wide range of NbS typologies, ecosystem services, assessment methods and spatial scales, providing a robust basis for methodological reflection. Using a multi-method, case-study approach, the report examines NbS through four complementary assessment lenses: (i) risk-reduction assessment; (ii) ecological assessment; (iii) economic valuation; and (iv) social assessment.

The analysis confirms that, although detailed, site-specific assessments provide accurate evidence of NbS effectiveness, they are often difficult to replicate at a basin scale. Conversely, model-based, spatially explicit, open-access tools offer greater scalability and comparability, albeit with lower spatial resolution and higher uncertainty. This trade-off highlights the need for a tiered assessment framework comprising local studies for validation and calibration combined with

basin-scale screening tools to support strategic planning, prioritization, and scenario analysis. Based on the Po River Basin context and expert knowledge, the report presents a portfolio of scalable methods that are particularly suitable for flood risk reduction, ecological and environmental assessment, and economic evaluation of ecosystem services.

The report concludes with the discussion of methodological indications and guidance for assessing the impacts of a Blue-Green Infrastructure (BGI) Network at basin scale, framing NbS as interconnected system components that deliver multiple benefits across space and time. By combining large-scale screening with targeted local validation, the proposed approach can support more informed decision-making, strengthen the evidence base for NbS implementation, and contribute to integrated climate-resilience and adaptation planning in the Po River Basin District.

Riassunto in italiano

I servizi ecosistemici, ovvero i benefici che la società trae dalla natura, sono fondamentali per comprendere il reale valore delle soluzioni basate sulla natura (NbS). Essi comprendono servizi di approvvigionamento (es. cibo, acqua dolce), servizi di regolazione (es. regolazione delle inondazioni, controllo del clima, depurazione dell'acqua) e servizi culturali (es. attività ricreative, benessere, senso di appartenenza). Una valutazione completa di questi servizi è essenziale, poiché una conoscenza incompleta dei benefici offerti dalle NbS rischia di sottovalutarne il valore ambientale, sociale ed economico, limitando così gli investimenti, l'adozione di politiche associate e l'attuazione su larga scala.

Tuttavia, nonostante il crescente riconoscimento delle NbS come strumenti efficaci per l'adattamento ai cambiamenti climatici e la riduzione del rischio di catastrofi, non esiste ancora una metodologia standardizzata per valutare l'intera gamma dei loro benefici e co-benefici. Gli approcci esistenti spaziano dalla modellizzazione biofisica al monitoraggio sul campo, dalla valutazione economica ai metodi di coinvolgimento degli stakeholder e degli esperti, fino alle valutazioni multicriterio. Sebbene questa diversità metodologica consenta flessibilità in contesti e scale diversi, essa compromette anche la comparabilità tra studi e settori, in particolare per i benefici immateriali come la biodiversità, il benessere umano e i valori culturali. Queste sfide sono ulteriormente amplificate quando si valuta la performance a lungo termine delle NbS e la loro evoluzione in scenari futuri di cambiamento climatico.

In questo contesto, questo report esplora i metodi disponibili per una valutazione completa e inclusiva dei servizi ecosistemici e dei benefici delle NbS, che va oltre la riduzione del rischio di catastrofi. Concentrandosi sul distretto del bacino del fiume Po, lo studio si basa su casi di studio rappresentativi identificati nel Deliverable D6.2. I casi selezionati coprono un'ampia gamma di tipologie di NbS, servizi ecosistemici, metodi di valutazione e scale spaziali, fornendo una solida base per la riflessione metodologica. Utilizzando un approccio multimodale basato su casi studio, il rapporto esamina le NbS attraverso quattro lenti di valutazione complementari: (i) valutazione della riduzione del rischio; (ii) valutazione ecologica; (iii) valutazione economica; e (iv) valutazione sociale.

L'analisi conferma che, sebbene le valutazioni dettagliate e specifiche per sito forniscano prove dell'efficacia delle NbS, esse sono spesso dispendiose in termini di risorse e difficili da replicare su scala di bacino. Al contrario, gli strumenti basati su modelli spazialmente espliciti e ad accesso libero offrono una maggiore scalabilità e comparabilità, sebbene con una risoluzione spaziale inferiore e un'incertezza maggiore. Questo compromesso evidenzia la necessità di un quadro di valutazione a più livelli che comprenda studi su scala locale per la convalida e la calibrazione, combinati con strumenti di screening su scala di bacino per supportare la pianificazione strategica, la definizione delle priorità e l'analisi degli scenari. Sulla base del contesto del bacino del fiume Po e delle conoscenze degli esperti, il report presenta una serie di metodi scalabili adatti alla riduzione del rischio di alluvioni, alla valutazione ecologica e ambientale e alla valutazione economica dei servizi ecosistemici.

Il report conclude con la discussione e proposta di indicazioni metodologiche e linee guida per valutare gli impatti di una rete di infrastrutture blu-verdi (BGI) su scala di bacino, inquadrando le NbS come componenti di un sistema interconnesso che offre molteplici benefici nello spazio e nel tempo. Combinando uno screening su larga scala con una convalida locale mirata, l'approccio proposto può supportare un processo decisionale più informato, rafforzare la base di dati scientifici per l'implementazione delle NbS e contribuire a una pianificazione integrata della resilienza climatica e dell'adattamento nel distretto idrografico del fiume Po.

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1. Introduction

Ecosystem services (ES) are the benefits that people obtain from nature (MAE, 2005). They are typically classified into provisioning, regulating and cultural services, according to the type of benefits provided to society. These include tangible resources and products (provisioning services), such as food, freshwater and fibre; benefits derived from regulation of ecosystem processes (regulating services), such as air and water purification, climate and thermal control, water management and pollination; and all non-material benefits that enrich human life and behaviour (cultural services), such as spiritual and religious values, education, inspiration, aesthetic values, sense of place and recreational opportunities.

Building on this concept, the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019) introduced the concept of *nature's contributions to people* (NCP). NCP includes all positive and negative contributions of living nature (i.e., diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to the quality of life for people. It extends the ES framework by explicitly accounting for the multiple values and knowledge systems of indigenous peoples and local communities (Díaz et al., 2015; Kadykalo et al., 2019). Although conceptually distinct, ES and NCP are complementary and mutually reinforcing approaches to understanding the interdependencies between human nature and the natural world.

These concepts are highly relevant to nature-based solutions (NbS), which rely on ecosystem functions and processes to deliver multiple benefits to society. NbS contribute to human well-being while simultaneously addressing global challenges such as climate change adaptation, disaster risk reduction, and sustainable development (EEA, 2021). The benefits generated by NbS are often described as co-benefits, defined as "the goals of a natural hazard adaptation project that are additional to the project's primary function, but complementary to its objective of increasing community resilience" (Jones and Doberstein, 2022). By restoring and enhancing ecological processes (i.e. the physical, chemical, and biological functions underpinning ecosystem services), NbS can address social, economic, and environmental challenges in an integrated manner (Lozano et al., 2025). The outcomes of NbS extend beyond ecological performance, encompassing socioeconomic dimensions such as well-being and livelihood security. These include employment opportunities, poverty alleviation, and income stability, as well as fair distribution of costs and benefits, improved food security, health, cultural, and recreational values.

The range and magnitude of benefits provided by NbS depend on their landscape context, type and scale of implementation, each tailored to address specific societal challenges. A complex riverine landscape such as the Po River Basin

District, for example, requires specific NbS with associated benefits and services. Table 1 illustrates some examples of the direct and indirect environmental, economic, and social co-benefits associated with ecosystem services provided by river restoration measures such as floodplain reconnection, re-meandering, the creation of vegetated buffer strips, the restoration of riparian vegetation and the construction of water retention basins. This list is indicative rather than exhaustive, as co-benefits are closely linked to the characteristics and design of each intervention. Furthermore, it should be noted that many benefits may arise through a chain of highly context-specific, interconnected effects. For instance, measures aimed at improving water regulation can also enhance public safety, reduce economic losses from flood damage, and generate new recreational opportunities. Similarly, biodiversity restoration can strengthen ecosystem resilience, reduce dependence on pesticide, and improve social well-being through enhanced aesthetics and connection with nature.

Table 1 - Overview of ecosystem services and associated environmental, economic and social co-benefits delivered by river-restoration

NbS	**ECOSYSTEM SERVICES**	**Environmental Co-BENEFITS**	**Economic Co-BENEFITS**	**Social Co-BENEFITS**
River restoration (floodplain restoration, re-meandering, vegetated buffer strips, riparian vegetation restoration, water retention basins)	Water Regulation	Reduction of flood risk and flood peaks; decreased surface runoff and flow velocity; enhanced groundwater recharge and water availability	Lower post-flood recovery and emergency response costs; reduced maintenance costs for dams, levees, and irrigation systems; decreased operational costs for pumps and hydraulic infrastructure	Improved safety and protection for local populations; reduced damage to downstream infrastructure; lower losses of life, livestock, and crops
	Erosion Control	Sediment sequestration; riverbank stabilization	Reduced costs for riverbank maintenance and soil loss prevention	Enhanced safety; improved landscape aesthetics and recreational value
	Water Purification	Nutrient retention and pollutant filtration; reduced eutrophication	Decreased water treatment and plant maintenance costs; lower medical and sanitation expenses	Improved public health and water quality awareness

	Biodiversity	Habitat creation; increased species richness and biomass; wildlife species protection; pollination and natural pest control	Biomass products; reduced pesticide use; increased property values; enhanced opportunities for fisheries and hunting	Strengthened connection with nature; aesthetic enhancement; increased recreational opportunities
	Climate Regulation	Carbon sequestration; shading; temperature reduction (air and water); wind flow reduction; enhanced evapotranspiratio n control	Reduced agricultural production losses	Improved comfort; enhanced recreational and tourism potential
	Air Quality	Absorption of pollutants and particulate matter; carbon sequestration	Reduced healthcare and sanitation costs	Improved respiratory health and well-being

Together, the concepts of ES, NCP, NbS and societal co-benefits can provide the foundation for the Nature Futures Framework (NFF), a forward-looking approach proposed by IPBES to envision desirable futures for people and nature. The NFF integrates diverse value perspectives and highlights how different relationships with nature (living from, in, and as nature) can guide transformative pathways toward sustainable and equitable futures (Raymond et al., 2017).

In this context, the evaluation and assessment of ecosystem services and their benefits are fundamental. Incomplete knowledge of the range of benefits delivered by NbS could hinder their widespread adoption, leading to an underestimation of their true environmental, social, and economic value and limiting both investment and policy uptake (Jones and Doberstein, 2022). Quantifying the multiple co-benefits of NbS can enhance their attractiveness compared to traditional grey infrastructure to address disaster risk and climate change adaptation, supporting evidence-based decision-making, implementation and investments. Therefore, a comprehensive understanding of both risk-reduction benefits and other co-benefits is essential to evaluate the cost-effectiveness of NbS and to enable meaningful comparisons with traditional engineered solutions.

At present, there is no standardized or widely accepted methodology for assessing all NbS, ecosystem services, and associated co-benefits. Instead, a broad range of methods is available, including field observations and monitoring, modelling approaches, software tools, statistical analyses, stakeholder-based methods, multi-criteria assessments, and economic valuation techniques (Staccione et al., 2024). In principle, these approaches can be applied individually or in combination to produce quantitative or semi-quantitative evaluations, are adaptable to different spatial scales and geographical contexts, and can also help identify potential disservices. However, the heterogeneity of existing assessment methodologies makes it difficult to compare the effectiveness and value of NbS across studies and sectors, limiting their uptake in various domains, including investment and decision-making processes (Chausson et al., 2020; Ommer et al., 2022). This challenge is particularly difficult for intangible and non-market benefits, such as biodiversity conservation, human well-being, and cultural values (Viti et al., 2022), as well as for assessing the performance of NbS and their dynamic evolution over time, particularly under future climate-change conditions (Sudmeier-Rieux et al., 2021; Vicarelli et al., 2024).

1.1 Aim and structure of the report

Given the diverse ways in which people value nature and the absence of a single, all-encompassing methodology able to capture this diversity, this report aims to explore available approaches for a comprehensive and inclusive evaluation of nature and its benefits, including and beyond disaster risk-reduction. The study focuses on the Po River Basin District, drawing on representative case studies (based on D6.2 – Climax Po, 2025) to explore relevant ecosystem-service and benefit assessment methods. The selected case studies are designed to cover a broad range of ecosystem services, encompassing different landscape and ecosystem categories, assessment types and methods, geographical contexts, and spatial scales. The appraisal aims to support the discussion and identification of suitable methods for subsequent analyses aimed at developing the Blue-Green Infrastructure (BGI) network in D6.4, based on their scalability and usability. The approach may also provide supporting information for defining guidance and policy recommendations for comparing NbS and grey solutions (T6.4).

In the following sections, the report presents the methodology and approach adopted in this study. First, relevant case studies drawn from Deliverable D6.2 are described to illustrate different examples of ecosystem services and NbS co-benefits assessment across the area of interest. This is followed by an overview of potential methods and tools available for assessing ecosystem services and NbS co-benefits at a broader scale. Finally, the report concludes with a discussion of the key findings, the potential methodological approaches for future analyses of the BGI network at the Po River Basin District scale and future developments of this work.

2. Methods

The methodology adopted in this report follows a multi-method case-study approach designed to present the range of available methods and approaches for assessing ecosystem services in the low-lying areas of the Po River Basin District, extended to the plain areas of the Veneto region for ecological continuity. Building on the inventory developed in Deliverable D6.2, this broader scope allows for a more comprehensive representation of ecological and landscape connectivity. As part of the ecosystem services assessment, the report considers both the disaster risk-reduction functions delivered by NbS and the broader portfolio of co-benefits they generate.

The selection aims to capture a diverse set of cases in terms of types of NbS, categories of ecosystem services and benefits, assessment methods applied, landscape typologies and geographical distribution, availability and quality of underlying data. The case study and project description aim to provide examples of the potential types of assessment and results related to the different evaluation components in the area of interest.

Recognising that the ecosystem services and benefits associated with each case are interconnected and may overlap, the description of the case study focuses on the assessment of NbS and ecosystem services delivered, both in terms of results and methodologies, building on multiple assessment lenses, looking at:

- risk-reduction assessment, i.e. biophysical modelling capable of detecting changes in hazard, exposure or vulnerability;
- ecological assessment, focusing on habitat status, biodiversity and ecosystem integrity;
- economic valuation, examining monetary benefits generated, avoided damages and cost-effectiveness;

- social assessment, considering usability, governance, stakeholder engagement and well-being.

For each assessment category, the report provides a structured overview of potential methods and tools applicable at a wider spatial scale and potentially suitable for implementation within the Po River Basin District, with the aim of extending the assessment to the wider BGI network. The tools and models considered include open-access or readily accessible instruments that are appropriate for large-scale analyses, ensure coverage of northern Italy, and demonstrate a clear relevance to ecosystem services and NbS. This constitutes both a methodological discussion and a proposal, informed by real case examples, for the follow-up analysis of the Po BGI Network.

The overall approach is meant to be in line with the definition of nature-based solutions - *solutions that are inspired and supported by nature, cost-effective, and that simultaneously deliver environmental, social and economic benefits while strengthening resilience* (EC) - and consider all the key NbS elements. NbS aim to benefit both people and nature by addressing key challenges such as climate change, disaster risk, water security and biodiversity loss. They work with nature, using ecosystem structures, functions and services to deliver effective and sustainable solutions. This also aligns with the IUCN Global Standard for NbS (IUCN, 2020), which defines what NbS are and why they are important. According to the Standard, effective NbS:

1. address clearly defined societal challenges;
2. are designed with explicit consideration of scale;
3. result in a net gain for biodiversity and ecosystem integrity;
4. are economically viable;
5. are grounded in inclusive, transparent and empowering governance;
6. balance trade-offs and ensure the provision of multiple benefits;
7. are managed adaptively based on evidence;
8. are sustainable and embedded in an appropriate jurisdictional context.

This framing is closely connected to the established categories of ecosystem services (regulating, provisioning and cultural) and to the three sustainability pillars (environmental, social, economic), which together underpin the classification, interpretation and comparison of the assessment presented throughout the report.

3. Case studies and Projects

This chapter synthesises the relevant case studies and projects implemented within the Po River Basin District and, more broadly, across the Padan Plain, as identified in the inventory presented in Deliverable D6.2. The selected case studies provide a comprehensive overview across diverse landscapes, spatial scales, and societal challenges, illustrating how NbS and ecosystem services are assessed in terms of their environmental, social, risk-reduction, and economic co-benefits. Table 2 summarises assessment types and methods, highlighting multi-method and multi-scale approaches relevant for the evaluation and development of the BGI network.

Table 2 - Overview of selected case studies in the Po River Basin District and adjacent areas.

Case study/project	Location	Landscape	NbS	Challenge	Ecosystem services	Assessment type	Assessment methods
Oasi Lycaena	Veneto (Salzano, VE)	Peri-urban, agricultural, river	Wetland restoration, water ponds, phytodepuration/vegetated buffer, protected areas	Environmental degradation, water pollution	Biodiversity, water quality, habitat quality, education	Ecological & environmental, social	In-situ monitoring, observation and field sampling
Forested Infiltration Areas (Bosco Limite & Agrifloor)	Veneto (Medio-Brenta, VI)	Agricultural	Forested Infiltration Areas (managed aquifer recharge + afforestation)	Groundwater depletion, water pollution	Groundwater recharge, water quality, biodiversity, climate regulation, education, carbon sequestration	Risk reduction/hydrological, environmental &, ecological, economic	Infiltration monitoring; nutrient analysis; biodiversity surveys; ecosystem-service valuation
Lowering of the Gussola Lanca di Retropennello	Lombardia (Gussola, CR)	River - floodplain	River naturalisation (morphological reconnection + floodplain restoration)	Flood risk, pollution, altered river dynamics	Nutrient cycling, sediment dynamics, water quality, flood risk reduction, habitat quality, biodiversity	Risk reduction/hydrological, environmental & ecological	In-situ monitoring; satellite images; hydrological and morphological modelling
Gorla Maggiore Water park	Lombardia (Gorla Maggiore, VA)	Peri-urban	Constructed wetlands, water retention ponds, phytodepuration, urban park	Water pollution, flood risk	Water quality, flood risk reduction, biodiversity, recreation	Risk reduction/hydrological, environmental & ecological, social, economic	Water-quality monitoring; hydraulic modelling; biodiversity surveys; multi-criteria analysis
Retention basins of the Lura River	Lombardia (CO)	Sub-urban river basin	Flood retention basins, riparian afforestation, phytodepuration	Flash floods, water-quality degradation	Flood regulation, water quality, biodiversity	Risk reduction/hydrological, environmental & ecological	Pre- and post-intervention monitoring; habitat surveys; land-use analysis

Case study/project	**Location**	**Landscape**	**NbS**	**Challenge**	**Ecosystem services**	**Assessment type**	**Assessment methods**
Ronco River Restoration	Emilia-Romagna (FC)	River, urban/peri-urban	Floodplains, detention basins, riparian restoration, vegetated buffer	Flood risk, river degradation	Flood-risk reduction, habitat quality, recreation	Risk reduction/hydrological, environmental & ecological	Hydraulic modelling; scenario analysis; landscape and environmental assessment
LIFE AGREE – Goro Coastal Lagoon	Emilia-Romagna (Goro, FE)	Coastal lagoon, wetland	Lagoon restoration, sediment management, Protected area, ICZM	Eutrophication, water pollution, sediment imbalance	Water quality, coastal protection, biodiversity, fisheries productivity	Risk reduction/hydrological, environmental &, ecological, economic	Hydrodynamic surveys; water-quality monitoring; habitat mapping; economic assessment (ROI)
LIFE IP GESTIRE 2020 – Natura 2000 Network	Lombardia	Protected areas	Habitat restoration, ecological corridors, protected areas	Habitat fragmentation, biodiversity loss	Biodiversity, ecological connectivity, habitat quality	Environmental &, ecological, social	Habitat and species monitoring; management indicators; qualitative governance assessment
MAB Po Grande	Emilia-Romagna, Lombardia, Veneto	River basin	Wetland restoration, riparian forests, NbS networks	Floods, droughts, habitat degradation	Flood regulation, biodiversity, water quality, cultural services and recreation	Risk reduction/hydrological, environmental &, ecological, social	Habitat surveys; water-quality monitoring; floodplain analysis; stakeholder assessment
SINCERE – Forest Ecosystem Services Innovation	Lombardia (BS, MN)	Forest	Agroforestry, Payments for ecosystem services (PES), FSC-based conservation schemes	Under-provision of non-market forest services; biodiversity loss; limited incentives for conservation	Biodiversity conservation, carbon sequestration, water regulation, recreation, cultural values, timber production	Economic, environmental &, ecological, social	Inventory of innovative mechanisms; monitoring of Innovation Actions; stakeholder surveys; ecological and socio-economic

Case study/project	Location	Landscape	NbS	Challenge	Ecosystem services	Assessment type	Assessment methods
							assessments; financial-flow analysis; cross-case learning

3.1 Oasi Lycaena [1]

The Oasi Lycaena is a nature reserve located in the Venetian plain, within the municipality of Salzano (VE), between the Marzenego River and the Rio Roviego. Spanning around 60 hectares, the site evolved from abandoned clay extraction quarries becoming a diverse landscape of shallow water bodies, wetlands, reed beds, and riparian woodlands. It is now an ecologically valuable inland wetland system and is designated as part of the Natura 2000 network, being both a Site of Community Importance and a Special Protection Area.

The introduction of NbS as part of restoration actions has reinforced ecological processes. In 2006, phytodepuration systems were installed in the central part of the oasis (covering approximately 20 hectares). These systems are hydraulically connected to the Marzenego River and are managed by the Consorzio di Bonifica Acque Risorgive. This system uses wetland soils and plant communities to support the retention of nutrients, the removal of suspended solids and the purification of water, while maintaining hydrological conditions suitable for long-term wetland dynamics.

The assessment of this intervention uses a combination of operational water-quality monitoring, habitat-based ecological surveys and biodiversity monitoring of indicator species to evaluate restoration performance. The ecological assessment documented habitat development and vegetation dynamics, as well as the presence of species, while the monitoring of water quality focused on the retention of nutrients and the reduction of suspended solids associated with phytodepuration processes. Biodiversity monitoring highlighted how wetland-dependent species, particularly birds and invertebrates, respond to changes in the habitat, which serves as an indicator of its quality and ecological integrity. Monitoring results specifically indicated that the restored wetland mosaic supports a high diversity of bird species of conservation interest, including the common tern (*Sterna hirundo*), the black-crowned night heron (*Nycticorax nycticorax*), the great egret (*Ardea alba*), the little egret (*Egretta garzetta*), the black kite (*Milvus migrans*), as well as the kingfisher (*Alcedo atthis*). This reflects improved habitat availability for nesting, feeding and resting. The presence of *Lycaena dispar*, a wetland-associated butterfly whose population is declining across Europe, further

[1] Città Metropolitana Venezia; Lipu

illustrates the site's role in supporting species that are dependent on high-quality marsh habitats.

In addition to its ecological benefits, the site provides social and cultural advantages through controlled public access, environmental education, and nature observation. Managed collaboratively by the Metropolitan City of Venice and local environmental associations, Oasi Lycaena combines conservation objectives with community engagement to raise awareness of the value of wetlands in a densely populated area.

3.2 Forested Infiltration Areas (Medio-alto vicentino: Bosco Limite e Agrifloor)[2]

Forested Infiltration Areas (FIAs) are nature-based interventions designed to enhance groundwater recharge and improve water quality, delivering a range of ecological and socio-economic benefits.

In the Medio Brenta Plain (Vicenza province), an area of strategic importance for the regional water supply characterized by karst resurgences, FIAs are widely used to counteract the long-term depletion of groundwater reserves caused by intensive agricultural and industrial activity, as well as the extraction of drinking water. FIAs are a form of managed aquifer recharge (MAR), whereby surface water is channelled into designated areas of tree and/or shrub planting during non-irrigation months. The FIA collects water from a watercourse and, via a system of channels allowing for slow water flow, enables water to infiltrate soil and reach groundwater aquifers. In addition to strengthening water security and improving water quality, FIAs contribute to broader ecological and societal benefits by enhancing local biodiversity, creating more resilient landscape structures, and providing new spaces for recreation, environmental education and community engagement. They also support climate change mitigation by increasing carbon sequestration and providing economic opportunities linked to sustainable biomass production and payments for ecosystem services.

There are several FIAs in the Medio Brenta Plain, with Agrifloor and Bosco Limite providing two complementary examples. These were assessed using a combination of monitoring and modelling to quantify water volumes and

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[2] BoscoLimite; AQUOR part I – part II; RiduCaReflui; Mezzalira et al. 2014

infiltration dynamics: measure of water and suspended-solid flows, geophysical surveys and modelling infiltration. Water purification performance was evaluated using hydrogeological analyses, root growth investigations, and nitrogen mass balance/dynamics.

Agrifloor is a 1.7-hectare technical, productivity-oriented FIA composed of four monospecific patches supplied by channels from the Brenta River. It mainly targets aquifer recharge and water purification. Monitoring under the RiduCaReflui project indicated that approximately 425,000 m^3/ha infiltrate out of around 500,000 m^3 entering the system despite partial clogging, alongside measurable reductions in nitrogen. The results suggest wide variability in performance, with reported infiltration rates ranging from approximately 1,090,000 m^3/ha/year at 1 mg/L N, to a worst-case scenario of approximately 5,600 m^3/ha/year at 20–25 mg/L N. This is compared to an average aquifer concentration of approximately 6 mg/L N.

Bosco Limite takes a more multifunctional and naturalistic approach. The 2.5-hectare site (converted from maize cultivation) comprises 2,300 trees from 15 native species, 1,200 metres of infiltration channels, and a sedimentation pond that removes suspended solids before infiltration. This enables the infiltration of ~2–3 million m^3 per year, thereby increasing aquifer recharge and water availability. Shifting the land use from monoculture to forest has substantially improved biodiversity, creating nesting habitat for multiple bird species and strengthening ecological connectivity with the nearby Natura 2000 site, '*Grave e Zone Umide della Brenta*'. The conversion has also reduced the landowner's irrigation demand by about 12,000 m^3/year and delivers climate benefits through an estimated ~50 t CO_2 sequestered per year. Public access supports education and outreach activities, such as school visits, open days and tree adoption schemes. The site also benefits economically from payments for ecosystem services, including a 10-year agreement with the Land Reclamation Board for infiltration services (€1,200 per hectare per year) and the cancellation of the Land Reclamation Board tax. This is complemented by municipal contributions linked to public and educational functions.

3.3 Lowering of the Gussola Lanca di Retropennello[3]

The river restoration pilot project in Gussola (CR) is a nature-based intervention along the Po River. It aims to restore fluvial and floodplain processes through morphological reconnection. Located in the Isola Maria Luigia area, the site is part of a stretch of the river that has been historically modified by mid-20th-century navigation infrastructure. This has constrained lateral connectivity and disrupted the natural dynamics of oxbow lakes (*lanche*). These alterations have reduced floodplain–river interactions and altered sediment regimes, impairing the ecological functioning of riparian habitats.

The restoration intervention involved the lowering of the back-channel embankment (*pennello*) to re-establish hydraulic connectivity between the main river channel and the adjacent oxbow lake system. This enables more frequent and dynamic water exchange during seasonal flows and flood events, reactivating inundation processes that support nutrient cycling, sediment deposition, and the development of wetland habitats.

Its assessment is based on integrated pre- and post-intervention monitoring, which was designed to evaluate the impact of restored connectivity on the structure and function of ecosystems. Pre-intervention monitoring (up to May 2023) established a robust ecological and functional baseline. This baseline documented the poor conservation status of the biological communities and associated processes in the lateral channel. This baseline is used to evaluate the effectiveness of the embankment-lowering intervention over time, and to estimate the recovery potential and expected response times of key ecosystem components.

Although post-intervention monitoring currently covers just over one year, it already allows a first evaluation of the effects of restored hydrological connectivity between the Lanca and the Po River. The results showed that different ecosystem components respond at different timescales, emphasising the need for long-term, spatially differentiated monitoring strategies. The findings support the adoption of an integrated methodological approach that combines traditional metrics with innovative, multidisciplinary tools. They also confirm that extended monitoring across different formative flow conditions is essential to produce robust evidence

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[3] ADBPO; REWET

of ecosystem recovery. Of the indicators monitored, odonates, ostracods, habitat characteristics, and physicochemical water and sediment quality were particularly effective in describing the system's response. Initial findings regarding water and sediment quality suggest a rapid system response to the inflow of Po River water, indicating its high capacity to metabolise external nutrient loads (phosphorus, nitrogen) through sedimentation and the mediation of primary producers and microbial communities. The assessment also integrates remote sensing techniques. Sentinel-2 satellite imagery analysed across multiple seasons (spring, summer, and autumn) was found to be suitable in terms of spatial and spectral resolution for assessing water quality conditions in the lateral channel and adjacent river stretches. These results confirm the strong potential of Earth observation and remote sensing as complementary tools for monitoring fluvial environments and scaling up assessment efforts.

3.4 Gorla Maggiore Water Park[4]

The Gorla Maggiore (VA) Water Park, located along the Olona River, is an example of constructed wetlands as multifunctional green infrastructure for urban water management. Developed between 2009 and 2012 on an area that had previously been used for growing poplars, the site combines nature-based wastewater treatment with ecological restoration and public use.

The infrastructure consists of a treatment area with sedimentation and filtration units feeding four vertical subsurface-flow wetlands, complemented by a surface-flow wetland acting as both secondary treatment and flood-retention basin, and a surrounding riparian park. These components intercede and combine sewer overflow (CSO) and stormwater runoff before discharge into the Olona River, relying on sedimentation and microbial processes.

The assessment of the park took a mix ecosystem-services approach, combining hydrological, water-quality, ecological, social and economic evaluations. Water quality performance was evaluated using event-based monitoring of CSO inflows and outflows to quantify reductions in dissolved organic carbon and nitrogen loads. Hydrological performance was evaluated using hydraulic modelling to estimate reductions in peak flow and downstream flood mitigation under different return periods. Ecological assessments included habitat mapping and biodiversity

[4] Gorla Maggiore Water Park; Liquete et al. 2016; Reynaud et al. 2017

surveys of macroinvertebrates, amphibians, birds and macrophytes, as well as landscape diversity metrics. Social benefits were evaluated through visitor surveys and recreational use indicators. Economic aspects were addressed through construction and maintenance cost analysis, as well as a multi-criteria analysis (MCA) that integrates stakeholder preferences.

Monitoring and modelling results demonstrated the robust performance of the Gorla Maggiore system across multiple ecosystem service dimensions. Monitoring based on events indicated that pollutant removal efficiencies of over 70% were achieved in terms of substantial reductions in dissolved organic carbon and nitrogen loads before discharge into the Olona River during combined sewer overflow events. These values are comparable to, and in some cases exceed, those of conventional grey CSO treatment facilities. Hydrological modelling and field observations demonstrated reductions in peak flow of 20–30% during intense rainfall events, which contribute to reducing flood risk downstream and improving system resilience. Ecological assessments documented clear improvements in habitat quality and biodiversity, including increased habitat diversity, the establishment of permanent and seasonal wetlands, and significant increases in bird and amphibian richness. This has transformed the site into a local biodiversity hotspot. Economic and multi-criteria evaluations further confirmed the effectiveness of NbS: construction and maintenance costs are comparable to those of grey infrastructure, while the wetland option consistently ranks first in multi-criteria analyses. This outperforms both grey infrastructure and the 'do nothing' scenario across environmental, social, and economic criteria, including biodiversity and recreational benefits.

3.5 Retention basins of the Lura River[5]

The Lura River Retention Basins constitute a large-scale, nature-based intervention aimed at hydraulic stabilisation, reducing flood risk and restoring the riparian ecosystem in the southern part of the Lura River basin, within the northern Milan metropolitan area. The project is located within a highly urbanised and fragmented suburban landscape characterised by dense settlements, infrastructure corridors, and scattered open spaces. Decades of unregulated urban expansion led to

[5] Parco Lura; PPA Lura

increased runoff generation, resulting in frequent flash flooding and the deterioration of river water quality.

The intervention comprises two interconnected flood-retention basins, an open drainage ditch, and a permanently flooded pond that is fed by groundwater. During periods of intense rainfall, floodwaters are diverted from the Lura River into the basins via natural inlets. This temporarily stores excess water and reduces flood peaks downstream. The permanently flooded pond supports wetland vegetation all year round, ensuring continuous phytodepuration and water quality regulation. Extensive riparian and floodplain areas have been restored through the planting of native species, enhancing the area's ecological structure and continuity.

The assessment approach applied in the Lura restoration integrates hydrological, ecological and land-use monitoring. This is implemented through a dedicated Environmental Monitoring Plan, which includes an evaluation of the effectiveness of the basins in reducing flood peaks and stabilising flow conditions during extreme events. The plan also evaluates habitat quality, vegetation development and the responses of fauna, while land-use monitoring tracks changes in naturalness and landscape structure before and after intervention.

Monitoring carried out in the pre-intervention (2015) and post-intervention (2019) phases between Lomazzo and Bregnano provideed evidence of the project’s outcomes. Although the area initially showed a high level of ecological alteration, the results indicated that residual biodiversity was present in riparian and wooded zones, which responded positively to restoration measures. Post-intervention monitoring revealed increased habitat naturalness, improved riparian vegetation structure, and greater ecological connectivity along the river corridor. Surveys of amphibian communities in particular revealed a marked increase in species richness and abundance, indicating improved wetland functionality and habitat suitability. From a risk-reduction perspective, the retention basins significantly mitigated the risk of flash flooding, reducing hydraulic pressure on downstream urban areas during high-intensity rainfall events. The net zero balance of earthworks, whereby excavated material was reused to create embankments and dikes, minimised environmental disturbance further and supported landscape integration.

3.6 Ronco River restoration[6]

The Ronco River project is a large-scale, nature-based, hybrid approach to reducing flood risk and improving the river environment in the central Emilia-Romagna region, along the stretch of the river between Forlimpopoli and Forlì. The river has been heavily modified over time due to gravel extraction, channel straightening, and bank reinforcement. These modifications have simplified the river's morphology, reduced floodplain connectivity, and substantially increased the risk of flooding in urban areas, particularly in the city of Forlì. They have also degraded riparian ecosystems, including those within the Natura 2000 site '*Meandri del Fiume Ronco*'.

The intervention focused on increasing the river's detention capacity by returning floodwaters to the former floodplains. This involved creating and restoring six natural detention basins outside the riverbed, reconnecting and rehabilitating three floodplains, and selectively raising and reinforcing riverbanks in critical urban areas. During flood events, water is diverted into the basins and floodplains via natural spillways, where it is stored temporarily, and excess volumes are reduced, thereby reducing downstream peak discharges. The system provides an additional flood storage capacity of approximately 11.2 million cubic metres, which is designed to manage events with return periods of 30 and 200 years.

The assessment framework, which is based on detailed hydraulic modelling, scenario comparison and environmental evaluation, was developed primarily in the ex-ante phase. Hydraulic simulations were used to assess the effectiveness of individual measures and integrated intervention packages in reducing flood levels and protecting urban areas. Landscape and ecological assessments informed the design of floodplain reconnection, vegetation restoration, and riverbank treatment to enhance biodiversity, improve habitat quality, and promote ecological continuity, particularly within protected areas.

Although a structured post-intervention monitoring programme was not formally implemented, field inspections and qualitative observations suggested that the outcomes following implementation are positive. The restored detention basins and floodplains have improved hydraulic stability during high-flow events, reducing pressure on the urban river corridor. Riparian renaturation and vegetation

[6] Riqualificazione fluviale in Romagna; Provincia Forlì-Cesena

measures have enhanced habitat quality and the natural appearance of the landscape, supporting improved ecological conditions and recreational use through the creation of walking and cycling paths alongside the river.

3.7 Life Agree - coAstal laGoon long teRm managEmEnt[7]

The LIFE AGREE project focused on the long-term ecological management and sustainable development of the Goro coastal lagoon (Sacca di Goro), which is located in the Po Delta in the Province of Ferrara and has been designated a Natura 2000 Special Protection Area and Special Area of Conservation. Based on the principles of Integrated Coastal Zone Management (ICZM), the project considered the lagoon to be a coupled socio-ecological system in which ecological processes, hydraulic dynamics, and human activities are closely interconnected. The overarching objective was to restore the ecological functioning of the lagoon, counteract eutrophication and sediment imbalance, and safeguard the ecosystem services that underpin local livelihoods.

The project implemented a set of ecosystem-based interventions designed to realign the lagoon's morphology with natural processes. Key measures included dredging and reconfiguring internal channels and regulatory canals to enhance water circulation and tidal exchange, reshaping shallow areas to improve hydrodynamics and sediment transport, and restoring nesting and resting habitats for avifauna within Natura 2000 areas. A distinctive NbS element was the guided, ecosystem-driven growth of an outer sandbank. This was designed to provide coastal protection and regulate sediment distribution, while maintaining natural morpho-dynamics and replacing a planned hard engineering structure.

The assessment framework integrated ecological, physical and socio-economic monitoring, combining quantitative measurements with qualitative, participatory evaluations. Hydrodynamic and morphological surveys were conducted to assess changes in water circulation, sediment transport and lagoon–sea exchange. Water-quality monitoring focused on oxygen levels, nutrient concentrations and salinity gradients, while biodiversity assessments evaluated the extent of habitats, benthic communities and avifauna. Socio-economic analyses examined aquaculture productivity and avoided economic losses, as well as broader local

[7] LIFE Agree

economic effects. These analyses were complemented by stakeholder and expert evaluations.

The monitoring results demonstrated substantial and measurable benefits. The project achieved the complete elimination of anoxic crises for five consecutive years, starting in 2016. Quantitative habitat assessments documented a significant expansion of protected Natura 2000 habitat types, including Mediterranean salt meadows (an increase of 65.9 hectares), Salicornia and other annual vegetation on mud and sand (an increase of 19.1 hectares), halophilous scrub (an increase of 9.0 hectares) and annual vegetation of drift lines (an increase of 0.9 hectares). This contributed to ecological improvements across approximately 1,000 hectares of the lagoon environment. Water-quality data showed enhanced circulation and reduced stagnation following channel restoration, while benthic and faunal surveys indicated the recovery of key biological communities. From a socio-economic perspective, restoring the functionality of the lagoon stabilised shellfish farming conditions and significantly reduced production losses previously associated with anoxic events (estimated at 5–30% of annual output). An economic assessment estimated a return on investment (ROI) of approximately 1:4, meaning that for every euro invested, about four euros of potential economic damage was avoided. Improved environmental conditions also supported the growth of nature-based tourism and strengthened governance capacity through sustained collaboration among public authorities, producer organisations, and scientific institutions.

3.8 Po Grande – UNESCO MAB Reserve and the Po River MAB Network[8]

The Po Grande project is part of the UNESCO Man and Biosphere (MAB) Programme and supports the integrated ecological restoration and sustainable development of the middle Po River. The project spans the regions of Emilia-Romagna, Lombardy and Veneto. It is embedded within a broader network of MAB reserves along the Po, including Monviso, Collina Po, Ticino Val Grande Verbano and Delta Po. The project aims to establish a coordinated governance system throughout the entire river basin. The Po Grande Reserve comprises a variety of agricultural, riverine and

[8] MAB Po Grande

wetland landscapes, forming a dynamic socio-ecological system that is susceptible to climate-related hazards and long-term pressures.

The project's main goal is to promote biodiversity conservation, ensure sustainable river and territorial management, and support the socio-economic development of local communities, while enhancing resilience to climate change and hydrological extremes. The project addresses several key challenges, including anthropogenic pressures such as intensive agriculture, land reclamation, urbanisation and infrastructure development, the degradation of riparian and floodplain habitats, and climate-related risks including droughts, floods and hydrological variability. It also aims to reconcile conservation goals with local economic activities and address institutional fragmentation across multiple regions, provinces and municipalities.

The project implements NbS and ecosystem-based interventions to restore natural processes and increase the resilience of the riverine system. This includes restoring and managing wetlands, oxbow lakes and riparian forests to improve flood management and biodiversity, as well as renaturing riverbeds and banks, creating ecological corridors alongside the river, promoting sustainable agriculture and multifunctional land use. It foresees developing green infrastructure to adapt to climate change, improve energy efficiency and prevent fires. Additional interventions focus on education, community participation and stakeholder engagement to ensure that conservation measures are locally supported and co-designed with communities, coupled with coordinated governance across the five Po River MAB Reserves.

The expected benefits of the project are ecological and socio-economic. In ecological terms, the interventions will contribute to increased biodiversity, improved water quality, restored habitats and enhanced ecosystem resilience. In terms of risk management, flood mitigation and drought resilience are improved through NbS and adaptive landscape planning. In terms of socioeconomic benefits, the project supports sustainable tourism, enhances local products and value chains, promotes employment in green sectors and strengthens the connection between communities and their environment. Institutional benefits include more effective governance and coordination across multiple administrative levels, enabling integrated river basin policies. Overall, the project aims to harmonise ecological conservation, human well-being and sustainable development in a densely populated, highly modified landscape.

The evaluation of project outcomes relies on a combination of ecological, hydrological and socio-economic monitoring, integrating quantitative and qualitative methods. Ecological monitoring involves assessing habitat status, conducting biodiversity surveys, measuring water quality, and analysing floodplain dynamics. Hydrological and geomorphological surveys assess river processes, sediment transport and flood regulation capacity. Socio-economic assessments examine the impact on local communities, sustainable agriculture, tourism development and stakeholder satisfaction. Early results from the Po Grande project suggest strengthened ecological connectivity and improved governance mechanisms through the MAB network, as well as the pilot implementation of NbS for climate adaptation and habitat restoration.

3.9 LIFE GESTIRE 2020 – Integrated Nature Management for Lombardy[9]

LIFE IP GESTIRE 2020 is an integrated conservation project that aimed to strengthen the ecological effectiveness and governance of the Natura 2000 network in the Lombardy region. Adopting a systemic, long-term approach to biodiversity conservation, the project recognises that the performance of Natura 2000 sites depends not only on measures implemented at the site level, but also on regional-scale coordination, connectivity, and management capacity.

A central objective of LIFE IP GESTIRE 2020 was to assess conservation effectiveness across multiple sites, taking into account both ecological outcomes and institutional performance. The project addressed key challenges affecting the network, such as fragmented management, insufficient ecological connectivity, sub-optimal conservation status of priority habitats and species, and pressures from land use change and invasive alien species. The assessment activities were designed to support compliance with the EU Habitats and Birds Directives, while also enabling evidence-based adaptive management.

The interventions combined nature-based and ecosystem-based actions, such as restoring habitats in forests, wetlands, peatlands and moorlands, taking species-focused measures for amphibians, reptiles and bats, and creating or reinforcing ecological corridors, with governance and capacity-building measures. The latter

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[9] LIFE Gestire 2020

included providing technical assistance to site managers, establishing coordination mechanisms between authorities and deploying territorial facilitators to harmonise planning and financing across Natura 2000 sites.

The assessment incorporated ecological, connectivity and governance indicators. Ecological monitoring included surveys of habitat condition, assessments of species populations and evaluations of invasive species control measures. Landscape-scale analyses evaluated improvements in ecological connectivity between Natura 2000 sites. The outcomes of governance and capacity building were evaluated using qualitative and quantitative indicators related to stakeholder engagement, management effectiveness, coordination across institutions, and the mobilisation of additional funding sources.

Monitoring results indicated measurable improvements in habitat quality and species conservation status across multiple sites, as well as enhanced ecological coherence of the Natura 2000 network through restored corridors. From an institutional perspective, the project has strengthened management capacity and improved coordination between regional and local stakeholders, as well as increased the consistency of conservation actions across the network.

3.10 SINCERE - ECOPAY Connect[10]

The SINCERE project (Horizon 2020) aimed to develop and trial innovative policies and business models to enhance the delivery of forest ecosystem services (FES) across Europe. A core objective was to assess how governance and market-based mechanisms could enhance the delivery of non-market forest services and address the persistent imbalance between societal demand and the services that forests provide. Through a pan-European 'Learning Architecture', the project co-designed, implemented and evaluated 11 Innovation Actions (plus two international case studies), combining ecological, socio-economic and governance perspectives.

The assessment integrated quantitative and qualitative methods, including inventories of innovative mechanisms, ecological and socio-economic monitoring, stakeholder surveys, and cross-case learning processes. This approach enabled the comparative evaluation of the impact of different mechanisms, such as

[10] SINCERE; Ecopay;

payments for ecosystem services (PES), new governance arrangements and business models, on biodiversity conservation, carbon storage, water regulation, cultural services, landowner participation and economic viability.

Within the Po River Basin, SINCERE implemented the Ecopay Connect Innovation Action in the Oglio Sud Regional Park in Lombardy, which is a key ecological corridor located within an intensively farmed landscape dominated by poplar plantations. The assessment focused on evaluating an innovative PES scheme designed to support biodiversity conservation while maintaining the economic viability of private landowners. Under the FSC® (Forest Stewardship Council) framework, poplar growers are required to dedicate 10% of their land to conservation areas that are representative of the local ecosystem. Ecopay Connect enabled this obligation to be fulfilled collectively through conservation activities on land owned by the park, thereby reducing the opportunity costs and certification barriers faced by individual farmers.

The assessment of Ecopay Connect combined ecological and socio-economic indicators, including an analysis of habitat improvements, the enhancement of ecological connectivity, financial flows, landowner participation, and stakeholder engagement. The results showed that the mechanism reduced certification costs, increased the number of farmers adopting FSC standards, and enhanced the ecological value of the protected area. Expected outcomes included converting at least 100 hectares to FSC responsible management and mobilising a minimum of €40,000 to support conservation activities.

4. Ecosystem services assessment methodologies

The assessments carried out across the case studies confirm the wide range of methods available for evaluating different types of NbS and the ecosystem services and benefits they deliver. The case studies employed various diverse and complementary methodologies, such as in-situ monitoring of water quality, habitat condition and biodiversity, hydrological modelling to evaluate physical processes, particularly concerning flood risk reduction, economic valuation methods to estimate the monetary value of NbS and their benefits, and stakeholder engagement approaches to validate outcomes and support decision-making processes. Although assessment approaches are tailored to local contexts and site-specific conditions, collectively, the cases provide valuable lessons for NbS assessment and the delivery of measurable benefits.

Cases such as Oasi Lycaena and the Gorla Maggiore Water Park demonstrated how wetlands can be evaluated in terms of ecological recovery, improved water quality and biodiversity, while also providing recreational and community benefits in peri-urban and urban areas. The Gorla Maggiore Water Park, in particular, illustrates how integrated, multi-criteria assessment frameworks can support evidence-based decisions for sustainable urban water management. Similarly, the Medio Brenta Forested Infiltration Areas demonstrated how nature-based managed aquifer recharge can be systematically evaluated in terms of hydrological, ecological and socio-economic factors. This highlights the adaptability of such systems to different management objectives and their potential to strengthen groundwater water security.

NbS implemented in highly managed and urbanised river and floodplain basins showed consistent benefits but also highlighted the need for clear assessment. Projects such as the Gussola scheme, the Lura River retention basins, the Ronco River and the MAB Po River demonstrated how NbS and hybrid measures can restore river–floodplain connectivity, mitigate flood risk and promote biodiversity. However, these cases also highlighted the importance of robust, multi-scale, long-term quantitative monitoring and stable, participatory governance to demonstrate the performance, resilience and cascading co-benefits of NbS, which is particularly evident in the case of the Ronco River.

At larger spatial scales, integrated assessment approaches further support the implementation and scaling of NbS. The LIFE AGREE project demonstrated how a combination of ecological, hydraulic and socio-economic monitoring can capture the risk-reduction and wider co-benefits of NbS in coastal lagoons within an Integrated Coastal Zone Management framework. Similarly, the LIFE IP GESTIRE 2020 project demonstrated how multi-level ecological monitoring and governance evaluation can inform adaptive management and improve the effectiveness of protected area networks. Finally, SINCERE, and in particular Ecopay Connect, illustrated how integrating ecological outcomes with economic incentives and governance performance can inform the design of scalable, market-based NbS mechanisms in forest landscapes. This approach aligns conservation objectives with productive land uses, enabling more sustainable, multifunctional forest management.

However, challenges remain regarding the replicability and scalability of the methodological approaches used at the local level. This is particularly relevant in the context of basin-wide analysis for climate change adaptation and disaster risk reduction strategies, such as the potential BGI Network at the Po River Basin District scale. In this context, in-situ monitoring and sampling can be challenging, being needed to rely on databases and knowledge inventories to run models, software and tools. While the resolution and level of detail may be lower, this approach can provide more comprehensive information to inform landscape planning and strategies for enhancing resilience, biodiversity, environmental quality, and well-being.

Based on the case study description, the Po River Basin context and the methods listed in D6.2, as well as expert knowledge, we identified a set of methods that could be used to extend ecosystem services and NbS assessment at a larger scale.

Considering the specific context of the Po River Basin's restoration potential, the report aims to suggest a set of tools to address existing challenges in areas such as risk reduction (especially flood risk), ecological and environmental assessment (e.g. biodiversity improvement, water and habitat quality and suitability), and economic assessment of ecosystem services (e.g. reduced damage, improved agricultural productivity, water requirements, the value of nature and potential social benefits in terms of recreational value and well-being).

The report recognises that a wide range of models exists, with varying levels of specificity depending on the aspects being investigated; however, it is not possible to cover all available tools and models. The tools and models presented are therefore limited to open-access or easy-to-access instruments that are suitable for large-scale analysis, cover northern Italy, and have a strong link to ecosystem services and nature-based solutions.

4.1 Risk reduction assessment

4.1.1 Flood

InVEST®[11] is a free, open-source suite of spatially explicit models designed to map and quantify ecosystem services to inform decision-making on natural capital and nature-based solutions. It help to evaluate the trade-offs between different

[11] InVEST

management strategies and identify areas where investments in ecosystems can improve human well-being and conservation outcomes. The tool includes modular models covering terrestrial, freshwater, marine and coastal ecosystems, producing map-based outputs in both biophysical and economic terms. InVEST models are based on production functions, describing how changes in ecosystem structure and functioning influence the magnitude and value of ecosystem service flows across a landscape. The models are distributed as a standalone application that is independent of GIS software. InVEST is flexible in scale, ranging from the local to the global, and is supported by comprehensive user guidance detailing model structure, data requirements, outputs, and result interpretation.

For flood risk reduction, two sub-models of InVEST can be of interest, although they mostly focus on urban areas: stormwater retention and flood risk mitigation. The **InVEST® Stormwater Retention**[12] model evaluates two related ecosystem services for stormwater management - runoff retention and groundwater recharge - considering both water quantity and quality. It estimates the ability of permeable land uses to retain stormwater, reducing the transport of nutrients and pollutants to receiving water bodies, while also quantifying potential groundwater recharge through infiltration. The model also estimates surface runoff, representing stormwater not retained by the landscape and exported with associated nutrients or pollutants. Retention, groundwater recharge and runoff are calculated on an annual basis to assess overall hydrological services related to water quality and water supply. Outputs include the annual volume of stormwater retained and the associated avoided pollutant loads to receiving water bodies, which can be valued using replacement costs of grey stormwater infrastructure, as well as optional estimates of groundwater recharge and exported runoff. The **InVEST® Flood Risk Mitigation**[13] model, by contrast, focuses on landscape performance during a single extreme storm event, where flooding is the main concern. It applies a curve number approach based on land use/land cover (LULC) and soil characteristics to estimate rainfall–runoff reduction, expressed as the amount of runoff retained per pixel relative to the storm volume. At the watershed scale, the model also estimates potential economic damage to build infrastructure and the corresponding ecosystem service provided through flood risk mitigation.

[12] InVEST Stormwater Retention

[13] InVEST Flood Risk Mitigation

Safer_RAIN[14] (Samela et al., 2020) is a relevant tool for analysing pluvial flooding, but not only. It is a static filling-and-spilling hazard model that identifies flood-prone areas based on surface depressions capable of storing rainfall volumes. Designed specifically for pluvial flood risk assessment, Safer_RAIN accounts for factors such as rainfall intensity, land use and infiltration rates. The model is particularly effective for rapidly identifying hotspots of water accumulation and evaluating changes in water depth under different surface conditions, including scenarios with green infrastructure and NbS. It can operate at very high spatial resolution (up to 1–2 m, depending on scale) and produces pluvial flood hazard maps in the form of water-depth outputs, which are well suited for identifying risk hotspots and comparing alternative land-use or NbS scenarios.

SWMM[15] **(Storm Water Management Model)** is a widely used, open-source tool for planning, analysis and design of stormwater management. It supports decision-making at all levels, from local to national, by simulating the quantity and quality of runoff for individual events or over long periods. The aim is to reduce flooding and the discharge of pollutants into receiving waters. SWMM integrates hydrological, hydraulic and water-quality modelling, representing key processes such as precipitation, infiltration, runoff generation, groundwater interactions and flow routing through pipes, channels, storage units and other hydraulic structures. The model is organised into three main modules: a hydrological module that estimates runoff from sub-catchments, a hydraulic module that routes flows through the drainage network, and a water-quality module that simulates the generation and transport of pollutants. A key strength is its ability to evaluate both grey infrastructure and hybrid green–grey solutions, including Low Impact Development (LID) measures such as bioretention areas, permeable pavements, green roofs and vegetated swales. Typical applications include flood control and drainage system design, detention basin sizing, sewer overflow assessment, floodplain mapping, and evaluation of best management practices for runoff and pollutant load reduction, making SWMM a robust tool for urban and peri-urban water management.

[14] SaferPlaces

[15] SWMM

4.1.2 Habitat degradation

InVEST® Habitat Risk Assessment[16] (HRA) is a spatially explicit model designed to assess the cumulative risk that human activities pose to habitats and species, and to explore implications for biodiversity persistence and ecosystem service delivery. The model is based on an exposure–consequence framework, reflecting the idea that habitat condition strongly influences ecosystem services and that increasing risk to species can undermine long-term sustainability and recovery. HRA combines geospatial data on habitat or species distributions with spatial information on human activities (stressors) and tabular data describing their interactions. Exposure criteria typically capture the extent of spatial overlap, duration and intensity of stressors, as well as the effectiveness of management measures, while consequence criteria describe the severity of impacts, including habitat loss, structural change and recovery potential. These criteria are scored by users (based on literature, data or expert judgement) for each habitat–stressor or species–stressor interaction, allowing the model to accommodate both data-rich and data-poor contexts. Risk is calculated at the pixel level across the study area, producing continuous raster maps of exposure, consequence and cumulative risk. Model outputs include ecosystem-level risk maps, risk maps for individual habitats or species, plots showing the relative contribution of exposure and consequence to overall risk, and summary tables by habitat, species or subregion. These outputs support the identification of high-risk areas, key drivers of degradation, and trade-offs among ecosystem services, and can inform conservation prioritisation, evaluation of management strategies, and the design of spatial plans under current and future scenarios in both terrestrial and marine systems.

4.2 Ecological and environmental assessment

4.2.1 Carbon sequestration

InVEST® Carbon Storage and Sequestration[17] (see 4.1.1 for general description of InVEST tool) is a simple, spatially explicit model used to estimate carbon stored in terrestrial ecosystems and carbon sequestered over time, supporting climate-change mitigation assessments. The model combines LULC maps with carbon

[16] InVEST Habitat Risk Assessment

[17] InVEST Carbon Sequestration

stocks in four pools (aboveground biomass, belowground biomass, soil organic matter, and dead organic matter) to quantify baseline carbon storage or changes in sequestration between scenarios. Outputs are provided as raster maps and aggregate totals of carbon storage, sequestration and, optionally, their economic value. Carbon values are expressed in metric tons of carbon per hectare, while monetary valuation can be applied to sequestration or loss (not storage), using either market prices or social value of carbon. Valuation depends on scenario comparison and incorporates discount rates to account for time preferences and changes in the social cost of carbon. The model is intentionally simple: its only required inputs are a LULC map and carbon pool values per land-use class. As such, it does not represent biophysical dynamics such as vegetation growth, soil processes, or climate-driven changes over time. This simplicity makes it well-suited for large-scale assessments and scenario comparisons, but less appropriate for detailed process-based carbon modelling. In addition, **InVEST® Forest Carbon Edge Effect**[18] extends the standard InVEST Carbon model by accounting for the degradation of forest carbon stocks caused by forest fragmentation and edge effects. The model applies empirical relationships between above-ground carbon storage and distance from forest edges to estimate reductions in carbon density within forest patches, combining these estimates with carbon inventory data to generate spatially explicit carbon maps. Edge effects are modelled only for above-ground biomass. For these other carbon pools, as well as for non-tropical forests or when edge effects are not applied, the model follows the IPCC inventory-based approach used in the standard InVEST carbon model. Users define which land-cover classes represent forests, and the model applies pre-generated regression functions to estimate above-ground carbon as a function of distance from forest edges. The model can be run with or without edge effects and for above-ground carbon only or for all carbon pools, provided that carbon density values are supplied for each land-cover class.

i-Tree[19] is a state-of-the-art, peer-reviewed software suite developed by the USDA Forest Service to assess urban and rural forests and quantify the ecosystem services provided by trees applicable worldwide. Widely used by municipalities, practitioners, researchers and communities, i-Tree supports forest management,

[18] InVEST Carbon Forest Edge Effect

[19] i-Tree

planning and advocacy by linking tree structure and condition to tangible environmental and social benefits across scales, from individual trees to cities and regions. The suite includes multiple free tools and modules that quantify ecosystem services such as carbon sequestration and storage, air pollution removal and related health benefits, stormwater runoff reduction, energy savings, microclimate regulation and biodiversity support. i-Tree integrates field data, land cover information, and local meteorological and air-quality data, and is adaptable to many international contexts through dedicated databases and support systems. By providing robust, accessible and policy-relevant indicators, i-Tree enables evidence-based decision-making for urban forestry, nature-based solutions and climate adaptation strategies. A core component is **i-Tree Eco,** the most comprehensive module of the suite, which uses field-based tree inventories or statistically representative plots combined with local air-quality and meteorological data to assess urban forest structure, ecosystem services and their economic value. i-Tree Eco estimates a wide range of benefits, including carbon storage and sequestration, pollution removal, avoided runoff, building energy effects, tree biogenic emissions, UV radiation mitigation and, in plot-based applications, avian habitat suitability, while also providing detailed structural analyses and management-oriented outputs such as planting scenarios, pest and extreme event impacts, mortality adjustments and cost–benefit analyses. Complementary tools include **i-Tree Design**, which assesses the benefits of individual trees or planting scenarios at the parcel level over time; **i-Tree Landscape**, a web-based tool integrating land-cover and socio-demographic data to support spatial analysis and planting prioritisation; **i-Tree Hydro**, a vegetation-specific urban hydrology model evaluating the effects of tree cover and impervious surfaces on runoff and water quality; and **i-Tree Canopy**, which provides rapid, statistically robust estimates of tree cover and associated benefits from aerial imagery. Additional tools such as **i-Tree Species** and **i-Tree MyTree** support evidence-based species selection and effective communication of tree benefits to practitioners, decision-makers and the public.

4.2.2 Habitat quality & Biodiversity

InVEST® Habitat Quality[20] models habitat quality and rarity as proxies for biodiversity, estimating the extent of habitat types across a landscape and their

[20] InVEST Habitat Quality

level of degradation. Habitat quality is determined by four main factors: the relative impact of different threats, the sensitivity of each habitat type to those threats, the distance between habitats and threat sources, and the degree of legal protection. The model assumes that legal protection is effective and that threats act cumulatively. By combining LULC data with spatially explicit information on threats, the model produces habitat quality maps that support an initial assessment of conservation status and changes over time. The habitat rarity component evaluates the extent and spatial distribution of natural land-cover types in the current or future landscape relative to a user-defined baseline, identifying habitats that have become rare or fragmented. Together, habitat quality and rarity outputs enable rapid, landscape-scale assessments of biodiversity trends where detailed species data are limited or unavailable, under the assumption that higher-quality habitats are more likely to support biodiversity persistence and resilience. The model is particularly suited for scenario analysis, allowing users to compare current conditions with alternative land-use futures to assess potential changes in habitat extent, quality and rarity, and to identify conservation needs and opportunities. A key strength of the approach is its ability to differentiate the sensitivity of habitat types to multiple threats and to weight the relative impact and spatial influence of those threats, making it a flexible tool for strategic biodiversity and land-use planning.

4.2.3 Water quality

InVEST® Nutrient Delivery Ratio[21] maps nutrient sources within watersheds and their transport to streams, supporting the assessment of nutrient retention services provided by natural vegetation. The model focuses primarily on nitrogen and phosphorus but can be adapted to other contaminants (e.g. pathogens or persistent pollutants) where data on loading and filtration rates are available. Nutrient retention is particularly relevant for surface water quality and can be valued in economic or social terms, such as avoided water treatment costs or improved drinking water security. The model applies a simplified mass-balance approach to represent long-term, steady-state nutrient flows rather than detailed biogeochemical cycles. Nutrient loads are derived from LULC maps and associated loading rates and can be partitioned into sediment-bound and dissolved fractions transported via surface and subsurface flows (the latter optional). Delivery factors

[21] InVEST Nutrient Delivery Ratio

are calculated at the pixel level based on flow paths, slope and land-use retention efficiency, and nutrient export is aggregated at the watershed or sub-watershed outlet, providing spatially explicit insights into sources, pathways and retention of nutrients across the landscape. In addition, **InVEST Sediment Delivery Ratio**[22] (SDR) could be of interest in this context. The model quantifies and maps land sediment generation and delivery to streams, supporting the assessment of sediment retention services provided by vegetation. By identifying where sediment is produced, retained or exported, the model helps water and land managers design strategies to reduce sediment loads through land-use and management changes. This is particularly relevant given the widespread impacts of increased sediment loads on water quality, reservoir capacity, irrigation systems, recreation and water treatment, as well as the loss of soil productivity in agricultural areas. The SDR model focuses exclusively on overland erosion and does not represent gully, bank or mass erosion processes. Outputs include annual sediment export to streams, total sediment eroded within the catchment, and sediment retained by vegetation and topographic features. While the model provides biophysical results only, these outputs can be combined externally with valuation approaches, such as avoided mitigation or replacement costs, to estimate the economic benefits of sediment retention, depending on context and beneficiaries.

4.2.4 Pollination

InVEST® Pollination[23] models pollination services with a focus on wild bees, recognising their key role in supporting agricultural production and ecosystem functioning. The model estimates pollinator supply by mapping the availability of nesting sites and floral resources within bee flight ranges, producing an index of wild bee abundance across the landscape. It then combines information on bee foraging behaviour, flight distances and floral quality to estimate pollinator visitation to each location, including crop fields. Using LULC data, the model assigns suitability scores (0–1) to each land-cover class based on its capacity to provide nesting substrates and floral resources, which are assumed to be the two limiting factors for bee persistence. Pollinator visitation to crops is weighted by distance and floral quality, reflecting central-place foraging behaviour. Where data are

[22] InVEST Sediment Delivery Ratio

[23] InVEST Pollination

available, the model can also estimate an index of crop yield contribution based on crop pollination dependence and the combined effects of wild and managed pollinators. The Pollination model is well-suited to assessing how changes in land use, habitat conservation and agricultural management affect pollination services and potential crop yields. However, it does not account for pollinator population dynamics over time or the effects of land parcel size.

4.3 Economic assessment

The Veneto Region and ANBI Veneto[24] have adopted and proposed a structured, multi-step, replicable methodology for estimating the economic value of the ecosystem services provided by irrigation networks managed by Veneto Water Boards. This approach ensures consistency on a regional scale while remaining grounded in the physical, ecological, and socio-economic characteristics of the irrigation infrastructure. The methodology comprises three main steps. First, key ecosystem services are identified and contextualised based on their relevance to irrigation networks and their contribution to regional environmental performance and societal benefits. The assessment focuses on a selected set of provisioning, regulating and cultural services, including water regulation and availability, groundwater recharge, flood mitigation, microclimate regulation, habitat maintenance, water quality improvement, recreation, landscape quality and cultural identity. Primary agricultural production is explicitly excluded to avoid double-counting. Secondly, service-specific valuation methods are selected according to the nature of each service, the availability of data and the spatial scale. Cost- and price-based approaches (avoided cost, replacement cost and market prices) were applied to provisioning and regulating services with a clear biophysical basis. Meanwhile, demand-based valuation, primarily through Discrete Choice Experiments (DCEs), was used to estimate societal willingness to pay for non-market services, such as water quality, habitat conservation, recreation, landscape aesthetics and cultural heritage. Finally, service-level estimates are aggregated across the regional irrigation network to derive the total economic value at a regional scale. Conservative assumptions were applied to address uncertainties and minimise overlap among services. The resulting valuation

[24] Servizi Ecosistemici e Attività Irrigua - Vol. 3

provides an integrated, policy-relevant estimate of the multifunctional benefits delivered by irrigation networks.

InVEST® Crop Production[25] estimates crop yield and nutritional value based on user-supplied LULC data. The model includes two complementary approaches: a percentile-based yield model, which covers 172 crops globally and estimates yields primarily as a function of climate, and a regression-based model, which accounts for fertiliser application rates for 10 major crops. Together, these models support the assessment of agricultural production and its contribution to food and nutrient supply. Model outputs include spatially explicit estimates of crop yield and associated nutrient content for 33 macro- and micro-nutrients, paired with observed regional data to support quality control and result validation. By enabling comparison of alternative land-use and management scenarios, the InVEST crop production models support analysis of the costs and benefits of agricultural systems and their interactions with ecosystem services and nature-based solutions.

TESSA[26] (Toolkit for Ecosystem Service Site-based Assessment) is an easy-to-use, site-focused toolkit designed to assess ecosystem services by comparing a site under two alternative states (e.g. before and after restoration or land-use change). Originally developed for conservation practitioners, it is accessible to a wide range of users, including the private sector and non-experts, and strongly emphasises stakeholder engagement throughout the assessment process. TESSA is structured as an interactive workbook (PDF) that guides users step by step through: (i) selecting and scoping a site (typically 100–100,000 ha); (ii) identifying key ecosystem services, beneficiaries, pressures and drivers of change; and (iii) choosing appropriate assessment methods using service-specific decision trees. The toolkit provides links to simple, low-cost qualitative and quantitative methods, ranging from stakeholder mapping, household surveys and field measurements to basic modelling tools (e.g. WaterWorld, Co$tingNature), along with worked examples and guidance on data collection and result communication. The current version supports assessment of a broad set of services, including water provision, quality and flood control, coastal protection, global climate regulation, pollination,

[25] InVEST Crop Production

[26] TESSA; Peh et al. 2013

cultivated and wild goods, nature-based recreation and cultural services. TESSA enables comparison of ecosystem service delivery between site states, identification of winners and losers, and synthesis of results at the site scale. While relatively low-cost and applicable in both developed and developing country contexts (terrestrial and wetland systems), it is intended as a robust first-step assessment to inform decision-making, highlight trade-offs, and guide whether more detailed studies or instruments (e.g. PES or REDD+) are warranted.

4.4 Social assessment

4.4.1 Aesthetic

InVEST® Scenic Quality[27] assesses the visual impacts of nearshore and offshore developments by identifying where new features are visible from the surrounding landscape or seascape. The model generates viewshed maps that delineate the visual footprint of offshore infrastructure (e.g. renewable energy or aquaculture facilities) based on inputs such as topography and bathymetry, the location of offshore features, and viewer locations (e.g. population centres, parks or trails). The model supports the analysis of trade-offs between offshore development and visual amenities, helping decision-makers identify coastal areas most likely to be affected by changes to the seascape. While it does not directly quantify economic impacts, it can compute visibility metrics that can be used in subsequent valuation studies, including assessments of how visual impacts typically decrease with distance from shore. Key limitations include the lack of explicit representation of visual screening by vegetation or land-based infrastructure. Overall, the Scenic Quality model provides a simple, spatially explicit basis for incorporating visual considerations into coastal and marine planning.

4.4.2 Recreation opportunities

InVEST® Urban Nature Access[28] assesses access to nature in urban areas by quantifying the balance between the supply of urban nature and the demand from the urban population for recreational purposes. The model evaluates how accessible urban nature, such as parks, green spaces, wetlands or shorelines, is in

[27] InVEST Scenic Quality

[28] InVEST Nature Access;

relation to population needs, identifying areas with a surplus or deficit of access to nature relative to policy standards. Urban nature supply is determined by the type, size, quality, proximity and per-capita availability of accessible natural areas, while demand is defined as the amount of natural space per capita required, typically based on planning or policy benchmarks. The resulting supply–demand balance can be calculated at individual, administrative or city scales, highlighting spatial inequalities in access to urban nature. The model can be applied to the total urban population or extended through optional modules to support more detailed analysis. These include disaggregating results by population groups (e.g. age, income or other socio-demographic characteristics) to address equity considerations and incorporating differentiated travel distances to reflect how access varies by type of green space or by population mobility (e.g., car ownership versus reliance on public transportation).

InVEST® Recreation and Tourism[29] models nature-based recreation by estimating the spatial distribution of person-days of recreation across a landscape, reflecting the importance of recreation and tourism to economies, well-being and quality of life. The model predicts visitation patterns based on the location of natural habitats, accessibility and built features that influence where people choose to recreate. Visitation rates are estimated using a simple linear regression that quantifies the contribution of different environmental and infrastructural attributes. Where direct visitation data are unavailable, the model can be parameterised using proxies such as geotagged photographs and posts from social networks. These data are used to infer current recreational use and to predict how changes in natural or built features may affect future visitation. Model outputs include spatially explicit maps of current recreational use and, optionally, projected use under alternative scenarios. The Recreation model supports analysis of relative visitation rates across sites, identification of features driving recreational demand, and evaluation of how land-use or NbS scenarios may alter recreation and tourism patterns.

4.5 Summary

Table 3 summarises the key characteristics of the methods and tools presented above, highlighting their potential applicability for NbS and ecosystem services

[29] InVEST Recreation and Tourism

assessment at larger scale. The table compares tools in terms of method type, scale of application, required inputs and main output types, as well as their ability to incorporate climate change considerations, scalability potential, data and expertise requirements, and assessment purpose. The classifications used in the table are based on the following definitions: scalability is defined as high when methods are readily applicable at basin or regional scale, medium when they can be scaled with simplifications or good data availability, and low when they are mainly site-specific; data intensity and expertise range from low (standard GIS and basic datasets), to medium (GIS and modelling experience), to high (advanced modelling, calibration and field data); climate change consideration ranges from none (no explicit climate component), to implicit (indirect inclusion through proxies or land-use assumptions), to scenario-based (explicit use of climate scenarios), and dynamic or event-based (climate signals embedded in simulations); and level of detail ranges from low (qualitative or static comparisons), to medium (scenario-driven or simplified dynamics), to high (event-based or process-driven modelling); finally assessment purpose distinguishes between screening approaches for prioritisation and strategic planning and detailed assessments for design, validation and quantification.

Table 3 - Overview of presented assessment methods and tools.

Assessment type		Method name	Method type	Scale of application	Inputs	Outputs	Climate change consideration (possibility & level of detail)	Scalability	Data intensity / expertise required	Assessment purpose
Risk reduction	Flood risk reduction	**InVEST® Stormwater Retention**	Standalone, spatially explicit ES model	Local to regional	LULC; soils; precipitation ; nutrient loads	Stormwater retained; runoff; groundwater recharge; avoided pollutants	Scenario-based | Medium (via modified rainfall, LULC scenarios)	High	Medium	Screening
		InVEST® Flood Risk Mitigation	Event-based GIS model	Local to regional	LULC; soils; storm parameters; exposure	Runoff retained; avoided flood damages	Scenario-based |Medium (extreme storm scenarios)	Medium	Medium	Screening / Detailed
		Safer_RAIN	Static flood hazard model	Local to regional	High-resolution DEM; rainfall; land use	Water-depth maps; flood hotspots	Event-based | High (design storms, extreme rainfall)	Low	Medium–High	Detailed
		SWMM	Open-source hydrological –hydraulic software	Local to regional	Rainfall time series; drainage network; LID	Runoff; flooding; pollutant loads	Dynamic / event-based | High (time series, future rainfall)	Low	High	Detailed
	Habitat degradation	**InVEST® Habitat Risk Assessment**	Standalone, spatially explicit cumulative risk model	Local to regional	Habitat/ species maps; stressors; scores	Exposure; consequence; cumulative risk maps	Implicit | Low (climate via stressors/scenarios)	High	Medium	Screening

Ecological & Environmental assessment	Carbon sequestration	**InVEST® Carbon Storage & Sequestration**	Standalone, spatially explicit carbon accounting	Regional to national to global	LULC; carbon pool values	Carbon storage; sequestration; valuation	Scenario-based | Low–Medium (LULC change, carbon values)	High	Low–Medium	Screening
		InVEST® Forest Carbon Edge Effect	Standalone, spatially explicit carbon degradation model	Regional to national	Forest cover; edge distance; carbon density	Above-ground carbon loss	Implicit | Low (no climate dynamics)	Medium	Medium	Screening / Detailed
	Carbon & multiple ES	**i-Tree (Eco, Hydro, Landscape, Canopy)**	Software suite – field & GIS-based tools	Tree to local to regional	Tree inventory; land cover; climate	Carbon; runoff avoided; air quality; valuation	Scenario-based | Medium (future climate & planting scenarios)	Medium	Medium–High	Detailed
	Habitat quality & biodiversity	**InVEST® Habitat Quality**	Standalone, spatially explicit biodiversity proxy	Regional	LULC; threats; sensitivity; protection	Habitat quality & rarity maps	Implicit | Low (threat & land-use scenarios)	High	Medium	Screening
	Water quality	**InVEST® Nutrient Delivery Ratio**	Standalone, spatially explicit mass-balance model	Regional	LULC; nutrient loads; DEM	Nutrient export & retention	Scenario-based | Medium (precipitation, LULC scenarios)	High	Medium	Screening

		InVEST® Sediment Delivery Ratio	Standalone, spatially explicit erosion model	Regional	DEM; soils; rainfall; LULC	Sediment export; retention	Scenario-based | Medium (rainfall erosivity changes)	High	Medium	Screening
	Pollination	**InVEST® Pollination**	Standalone, spatially explicit ES model	Regional	LULC; nesting & floral suitability	Pollinator supply; crop visitation	Implicit | Low (habitat configuration only)	High	Medium	Screening
Economic assessment	Irrigation ES valuation	**Veneto Region / ANBI Veneto methodology**	Methodological framework – economic valuation	Regional	ES indicators; DCE surveys; cost data	Regional ES economic value	Scenario-based | Medium (hydro-climatic assumptions)	Medium	High	Detailed
	Crop production	**InVEST® Crop Production**	Standalone, spatially explicit agricultural production model	Regional to national to global	LULC; climate; fertiliser rates	Crop yield; nutrient content	Scenario-based | Medium (climate-driven yield change)	High	Medium	Screening
	Site-based ES valuation	**TESSA**	Participatory decision-support toolkit	Local to large sites	Stakeholder input; basic field data	ES comparison; trade-offs	Implicit | Low (scenario narratives)	Low	Low–Medium	Screening / Detailed
Social assessment	Aesthetic values	**InVEST® Scenic Quality**	Standalone, spatially explicit viewshed model	Local to regional	DEM; infrastructure; viewer points	Visibility & visual impact maps	None	Medium	Medium	Screening

	Recreation access	**InVEST® Urban Nature Access**	Standalone, spatially explicit accessibility model	Local to large sites	Green spaces; population; standards	Access deficit/surplus; equity metrics	Implicit | Low (population & land-use change)	High	Medium	Screening
	Recreation & tourism	**InVEST® Recreation & Tourism**	Standalone, spatially explicit recreation demand model	Regional to national	Natural features; access; social data	Person-days; visitation maps	Implicit | Low–Medium (proxy-based scenarios)	High	Medium	Screening

5. Discussion

Methodological reflection for ecosystem services assessment at large scale

Taking a broader view of the multiple benefits and services provided by NbS enables a more comprehensive understanding of their true value, possibly facilitating their wider uptake. In this respect, it is encouraging that case studies demonstrated the capacity to address multiple benefits simultaneously, spanning social, environmental, and economic dimensions.

The analysis of case studies and methods highlights the vital role of local evidence in underpinning large-scale ecosystem services assessment. As shown in Section 3, site-specific assessments are essential to demonstrate the effectiveness of NbS and to quantify their ecological, hydrological and socio-economic co-benefits. Detailed and local monitoring and modelling approaches can deliver high-confidence results, but they typically require substantial data availability, high technical expertise, time and resources. Therefore, these approaches are not always directly transferable to wider scale applications. From this perspective, open and accessible software and tools (such as those described in Section 4) can facilitate a tiered approach. Local-scale assessments can serve for validation, calibration and proof of concept, while basin-scale assessments rely on simplified, harmonized and model-based methods to inform wider strategic planning and prioritization. This framework allows screening and detailed analysis to be combined, maintaining scientific robustness while ensuring feasibility and applicability at larger spatial scales, supporting decision-making, planning and investment processes.

Accuracy and applicability trade-offs emerged as a potential barrier to scalability. In-situ monitoring and bespoke modelling approaches offer high accuracy but can have limited scalability due to data, expertise and resource constraints. Conversely, spatially explicit and open-access tools facilitate large-scale screening, comparability, and scenario analysis, although at the expense of higher uncertainty and lower spatial resolution. Therefore, at the basin scale, assessment might need to prioritize comparability, consistency, and decision relevance over local-scale precision. Detailed local studies, however, remain indispensable, primarily as reference cases for validation and calibration.

Furthermore, the availability and fragmentation of data may also hinder transferability and scaling up, underlining the importance of harmonized, open, and long-term NbS data repositories at the basin level (see D6.2). Remote sensing and spatial modelling can be key enablers of scalability in this context, providing homogeneous spatial coverage and supporting temporal analyses, trend detection, and scenario-based evaluations. These approaches are particularly valuable in contexts where data is scarce. Although they cannot fully replace field-based observations, they offer a cost-effective, transparent and replicable foundation for basin-scale NbS assessment and planning.

Another critical limitation for large-scale applications relates to the knowledge and capacity requirements. Many advanced assessment methods require specialized expertise, which can limit their adoption on a wider scale. By contrast, more user-oriented tools and indicator-based approaches lower the entry barriers, facilitate institutional adoption, and support integration into planning and policy processes.

Explicit consideration of climate change in the assessment of NbS effectiveness and long-term performance remains limited. NbS analyses in climate change generally rely on proxies or modifications of input variables, rather than on explicit climate scenarios or dynamic representations of future conditions. In fact, although several approaches have the potential to incorporate climate information, most assessments focus on ex-post evaluations of observed benefits and effectiveness, strongly supported by local monitoring, rather than on ex-ante analyses of how future climate change may affect NbS performance and resilience. Moving beyond this limitation is essential, as NbS often require time to become fully effective or to recover after extreme events, and their performance can decline in the long term if management is inadequate. This issue also emerged in the work carried out within the Climax Po Task 6.1 on the effectiveness of freshwater riparian zones under climate change conditions (Vagheei and Boano, 2025), which highlighted the importance of integrating future climate projections into riparian management, conservation, and restoration strategies to ensure long-term ecosystem sustainability. Explicitly integrating future climate dynamics into assessment frameworks would therefore support more robust long-term planning and risk management for NbS.

Finally, the case studies emphasize the importance of integrating governance and economic factors as key enablers of scalability. Effective governance arrangements, economic instruments (e.g. payments for ecosystem services and return-on-investment analyses) and stakeholder engagement are critical for long-term effectiveness, climate resilience and replicability, alongside biophysical performance. Therefore, basin-scale methodologies should systematically integrate governance, economic, and climate-change indicators alongside environmental ones.

Next steps and further development – a methodological proposal

Following the suggestions and findings of this report, the assessment of ecosystem services and benefits of a Blue-Green Infrastructure (BGI) Network in the Po River Basin District may adopt a two-tier assessment approach. This would combine a screening-level analysis based on large scale tools to identify priority areas and strategic connections, with targeted local case studies to validate results and refine assumptions.

More specifically, the Po River Basin BGI Network analysis (D6.4) aims to assess the current conditions of the BGI Network, develop improvement scenarios and evaluate their impacts in terms of services and benefits provided to reduce disaster risk and enhance climate resilience. At the core of the approach is a basin-wide assessment, based on spatially explicit models, designed to identify areas at higher risk, areas in need of NbS enhancement, and areas that should be better connected, preserved, and managed in an integrated manner. For selected areas of high relevance, the approach can foresee a zoom-in analysis, enabling a more detailed assessment of NbS performance and ecosystem service provision at the local scale.

The analysis will particularly aim to assess the current condition of the BGI in terms of distribution and connectivity of NbS and nature protection elements, identifying both the areas critical for the network maintenance to be preserved, and those most in need of improvement due to fragmentation, risk exposure, or environmental degradation. This assessment will support the development of BGI improvement scenarios that could enhance climate resilience, landscape connectivity and environmental quality. The assessment of the network scenarios may include both connectivity improvements, disaster risk reduction, environmental and ecological improvements, as well as socio-economic benefits and opportunities.

To this end, connectivity analysis and scenarios will build on the framework developed in Staccione et al., 2022, 2023. This framework conceptualises the BGI network as a set of nodes (e.g. core areas) and links (e.g. corridors), including land cover information, protected areas and parks, key biodiversity areas, riparian buffer zones, river corridors, wetlands and floodplains, NbS case studies and projects, and ecological network components identified in D6.2. These elements can be characterised, for example, through Morphological Spatial Pattern Analysis (MSPA). MSPA identifies spatial structures acting as nodes and links based on their shape and relative distances, using mathematical morphology algorithms (Soille and Vogt, 2009). The resulting spatial patterns can be translated into a graph-based representation of the network, enabling the identification of connected and isolated areas. Connectivity can be assessed using landscape connectivity indices, such as the Integrated Index of Connectivity (Pascual-Hortal and Saura, 2006). This index evaluates the overall structural connectivity of a network by analysing the physical links between its landscape elements and ranking the contribution of each element to the network.

BGI scenarios can be developed by introducing new corridors or core areas, depending on the objectives and scope of the intervention. Potential connections can be identified and prioritised based on feasibility criteria such as distance, cost, and environmental constraints. Similarly, new nodes may be added to address risk hotspots, implement stepping-stone elements to improve connectivity, or support restoration and rewilding potential. In parallel, information on biodiversity and habitat quality, climate risk, and environmental restoration potential can be integrated to guide scenario development in relation to different policy objectives, including the EU Biodiversity Strategy, the Nature Restoration Regulation, and national climate change adaptation strategies. In this context, environmental, biodiversity, and climate indicators play a key role in shaping and comparing alternative scenarios.

Finally, the assessment of BGI impacts in terms of services and benefits can be supported by the tools reviewed in Section 4, which allow the visualisation and simulation of changes before and after scenario implementation. The overall approach aims to assess the BGI network across four complementary assessment dimensions (risk reduction, ecological and environmental impacts, economic benefits, and social outcomes) providing an integrated overview of the full value of NbS implementation in the Po River Basin District, conceived as a coherent and interconnected system at the basin scale.

In parallel, this approach is intended to be aligned and integrated with the CLIMAX Po WP3 operational workflows for climate adaptation in the Po River Basin District. In particular, the flood workflow, currently under development, will provide a technical and spatially explicit contribution to the hydrological hazard component of the Climate Risk Indices by combining satellite-based flood mapping and river flood hazard maps and coupling them with flood duration and flood depth estimation with high-resolution terrain data. The workflow is designed to reconstruct past flood events and support scenario-based analyses by producing consistent flood hazard layers that can be integrated with exposure and vulnerability information. High-resolution land cover, population, crop maps and other ecosystem asset datasets are applied in the modelling chain to derive sector-specific flood-induced damages and risks.

The modular structure of the flood workflow enables the derivation of event-specific indicators relevant for BGI and NbS assessment, including the highlighting of flood extent, water persistence, and potential impacts on ecosystems, agricultural areas, built-up environments, and critical infrastructure. These outputs can directly inform the identification of flood-prone areas, retention zones, floodplains, and priority locations for NbS enhancement and connectivity improvements.

In addition to the flood mapping module, further operational workflows addressing other key climate hazards, such as droughts and heatwaves, are being developed to support a comprehensive multi-hazard risk assessment framework. The open-source design of the approach, as well as the semi-automated code pipeline, will facilitate integration with exposure and vulnerability indicators, validation using local and regional data, and synergies with other Work Packages. This integrated approach will support monitoring, reporting, and evaluation of climate adaptation policies, while strengthening the analytical basis for assessing the role of BGI and NbS as strategic components of basin-scale climate resilience and long-term adaptation planning. In this context, the workflow can support the identification of key areas exposed to climate-related risks, as well as associated changes in exposure and vulnerability under current and future conditions.

6. Conclusions and final recommendations

The report investigated the potential for assessing ecosystem services and NbS benefits at the Po River Basin scale. It examined local case studies and projects, and explored potential open, large-scale tools. The aim was to provide an overall methodological indication for the assessment of the BGI Network impacts at a large scale, in terms of risk reduction and ecological, environmental, and socio-economic factors.

Key recommendations include adopting a multi-tier assessment framework that combines basin-scale screening analyses with targeted local case studies to ensure strategic coverage and context-specific validation of results. Prioritising open-access, scalable and transparent tools can support large-scale assessments, enabling replicability and comparability across regions, as well as long-term usability by public authorities and stakeholders. To this end, improving long-term data availability, continuity and standardisation is crucial, particularly for environmental, biodiversity and climate indicators, in order to support robust scenario analysis and monitoring over time.

Basin-scale assessments should, therefore, be used as decision-support tools rather than as substitutes for local monitoring. Their role in strategic prioritisation should be recognised, while the need for site-specific data, stakeholder engagement and adaptive management should also be acknowledged. This would strengthen the integration of ecological performance, governance structures and economic viability, ensuring that BGI and NbS assessments effectively inform implementation pathways and investment decisions.

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