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# Sub-Regional Biophysical and Monetary Evaluation of Ecosystem Services: An Experimental Spatial Planning Implementation

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**Abstract:** Preserving soil is crucial for addressing the key challenges of the new millennium, like climate change and biodiversity loss. Spatial planning plays a pivotal role in stopping soil consumption and degradation, thereby safeguarding soils that provide valuable ecosystem services. With the advent of the System of Environmental-Economic Accounting by the UN, countries are developing a shared protocol for the biophysical and monetary quantification of ecosystem services. However, downscaling efforts are necessary and must be conditioned by the national context, policies, economic dynamics, and data availability. Therefore, this research proposes a soil quality assessment methodology based on its ecosystem value at the sub-regional level in northern Italy, building upon national guidelines. This study includes modeling and mapping outputs involving six ecosystem services through eight biophysical indicators and the monetary quantification of these services. Both assessments have been conducted over two time periods to highlight the impacts of land cover transformation.

**Keywords:** land planning; land cover changes; ecosystem quality; ecosystem accounting

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## 1. Introduction

The Introduction provides an overview of the general background necessary to comprehend this study's findings. It outlines the following points:

- The concept of ecosystem services (Section 1.1);
- The loss of natural capital (Section 1.2);
- Ecosystems and the monetization of ecosystem services for natural resources conservation and management (Section 1.3);
- The payment of ecosystem services (Section 1.4);
- Downscaling global principles to local contexts (Section 1.5);
- Mapping ecosystem services: a literature review (Section 1.6).

### *1.1. Ecosystem Services: A Rapidly Growing Concept*

The definition of "Ecosystem Services" is 160 years old and is first attributed to Marsh. In his "Report on the Artificial Propagation of Fish", Marsh criticized members of a community for their "mistaken prejudices" against "birds, quadrupeds, and reptiles" because of the supposed damage these animals inflict upon crops. Instead, Marsh argued

that they "much more than compensate the little injury they inflict upon the crops" by consuming "vast numbers of noxious insects" [1,2]. However, the topic of ecosystem services (ESs) has remained dormant for a long time.

Global interest in ecosystem health and the services ecosystems provide to humans has grown in both the public and private sectors, influencing research and policy [3] only after the publication of the Millennium Ecosystem Assessment (MEA) by the United Nations in 2005. Since then, the most commonly accepted definition of ecosystem services refers to the MEA and regards the benefits that people derive from ecosystems, namely "the support of sustainable human well-being that ecosystems provide" [4,5]. The MEA was followed by another initiative, The Economics of Ecosystems and Biodiversity (TEEB), which expanded awareness of ecosystem services, particularly highlighting the importance of biodiversity in decision-making at all levels [6,7].

Recognition of the priority function of ESs necessarily stems from an awareness of the importance of protecting and restoring ecosystems themselves as assets that can provide these services.

This priority is currently clearly embodied in many international and European strategies and policies. The European Biodiversity Strategy for 2030, based on the Aichi Biodiversity Targets, recognizes the valuation of biological diversity, as well as its protection and restoration, as a priority. The European Green Deal clearly outlines the European efforts to enhance and restore ecosystems since they are a prior carbon stockholder.

The Common Agricultural Policy plays a crucial role in promoting sustainable agricultural practices in Europe. Similarly, the UN Paris Agreement contributes to climate change mitigation since oceans and forests are the main basins for carbon stock.

The UN Agenda 2030 is pivotal for sustainable development, with formal reference in this context to Goals 14 (Life of Water) and 15 (Life on Earth), Goal 2 (Zero Hunger), Goal 6 (Clean Water and Sanitation), Goal 7 (Affordable and Clean Energy), Goal 11 (Sustainable Cities and Communities), Goal 12 (Responsible Consumption and Production), and Goal 13 (Climate Action) in terms of sustainable ecosystem management. Additionally, it holistically encompasses social and economic implications, which include Goal 1 (No Poverty), Goal 3 (Good Health and Well-Being), Goal 9 (Industry, Innovation, and Infrastructures), Goal 10 (Reduced Inequalities), and Goal 16 (Peace, Justice, and Strong Institutions).

More recently and incisively, the newly approved Nature Restoration Regulation seeks to enhance biodiversity and ecosystem resilience across the EU, aiming to restore at least 20% of land and sea areas by 2030 and all degraded ecosystems by 2050, including binding targets and an implementation framework for national restoration plans.

These documents are just a few examples showing the widespread acknowledgment of the importance of ESs in maintaining livelihoods and the dependency of natural land and agricultural systems on the soil. It is common, both here and in the literature, to refer to many ecosystem services as soil ecosystem services [8].

Various frameworks have been developed to support ecosystem conservation and enhancement. Authors emphasize that a shared understanding of how ecosystems underpin economic activity and human well-being is essential for effectively designing, implementing, and monitoring ecosystem restoration policies, as well as for informed planning, policymaking, and financial decisions [9]. Over the past decade, there has been growing interest in creating an inventory and spatially mapping the current state of ecosystems, as well as their potential to provide ESs. Recently, the System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA) was finalized by the United Nations (UN) in 2021 as a framework designed to evaluate and monetize ecosystems and their services [10]. Developed through collaborative, international efforts, it builds on earlier

versions from 2012, along with practical recommendations issued in 2017, which have guided ecosystem service measurement and valuation efforts [10].

### 1.2. Natural Capital: How to Face the Loss

Alongside ESs, natural capital is defined as the world's stock of natural assets, which supplies a wide range of goods and services, including natural income over time, which directly or indirectly creates value for people [11,12].

Costanza et al. [7] highlight the relationship between natural capital, human beings, and ecosystem services, noting that the latter can reach humans only after the interaction between natural capital and social capital.

Ecosystem services are mechanisms through which natural capital benefits humans, connecting these benefits to the socio-economic system. Biodiversity, particularly at the community level, plays a crucial role in supporting the productivity and stability of ecosystems, ensuring the quality and quantity of natural capital [13–15]. Maintaining the stock and diversity of natural capital is essential for sustaining the flow of ecosystem services, which are vital for current and future human prosperity [6]. The debate over substituting natural capital for human capital distinguishes weak and strong sustainability. Weak sustainability assumes that the two are interchangeable, focusing on maintaining total capital stock. In contrast, strong sustainability emphasizes natural capital's limited substitutability, advocating for its preservation to avoid net loss [16,17]. Biodiversity offsetting markets, with a "no net loss" strategy, aim to balance environmental damage by restoring habitats. However, this approach risks viewing diverse natural capital as interchangeable, potentially overlooking unique, irreplaceable ecological functions and neglecting critical, non-substitutable aspects of ecosystems [16].

Conversely, due to the delicate and complex equilibrium at the basis of natural capital preservation and its relationships with human systems through ecosystem services, assessing natural capital and its benefits should be highly site-specific. The development of markets or compensation systems must begin with an awareness of the area's challenges and potentials [18], rather than relying on a complete computation of interchangeable components. In this context, the spatial assessment and mapping of ecosystems and their services—including their monetary value—are essential. This mapping should involve homogeneous and interconnected territorial, environmental, and ecosystem realities, facilitating an integrated, informed, and context-specific management of natural resources. This same spirit and scope have driven the present research (yet from the choice of the case study at the wide-area scale) and should guide the use and interpretation of its results.

### 1.3. Ecosystems and ES Monetization for Enhancing Natural Resources Conservation and Management

The economic dimensions of ecosystems were first explored in the early 1990s [19], as concepts such as "natural capital" and "ecosystem services", and along with their valuation, gained prominence in response to global biodiversity loss and its associated social and economic impacts [5,11,20,21]. This period also marked a growing need to establish economic mechanisms that would promote conservation efforts, such as implementing Payment for Ecosystem Services (PESs) schemes [22,23]. In 1997, global ecosystem services were valued at USD 33 trillion per year, significantly exceeding THE global GDP [5]. By 2014, Costanza et al. adjusted this figure based on dollar revaluation to USD 145 trillion in 2007 but revised it to USD 124 trillion after accounting for land-use changes, indicating a net loss of USD 20.2 trillion since 1997. Beyond land use, pressures such as pollution and urban sprawl also degrade ecosystems, with urban expansion negatively impacting water quality, carbon sequestration, and ecosystem health [21–25]. Soil ecosystems are especially

affected, with 60–70% of European soils degraded due to unsustainable practices, costing over USD 6 trillion annually in lost ecosystem services [26,27]

Ecosystem conservation is crucial for both environmental and economic sustainability. In 2018, Credit Suisse reported USD 52 billion in global conservation spending, far short of the USD 300–400 billion needed annually to safeguard natural capital like clean air, water, and biodiversity [28,29]. Despite high costs, the benefits of conservation outweigh the expenses, with a reported 100:1 benefit–cost ratio for global wildlife conservation [30]. Restoration, while valuable, often results in suboptimal outcomes compared to original ecosystems. The sustainable management and protection of natural capital remain the most cost-effective solutions to ensure long-term human well-being [7,31–33].

### 1.4. PES and Other Market Mechanisms

Many authors have discussed the reasons and utility for valuing ES, which can be summarized as follows: improving an understanding and awareness of ecosystem services' role in our society; completing national and global accounts, such as national income and well-being accounts, or full-cost accounts; creating innovative institutional and market instruments allowing for sustainable ecosystem management, e.g., through the Payment of Ecosystem Services (PESs) or common asset trusts; and informing policy and decision-making, as well as territorial and urban planning in land-use transformations [7,34,35].

Scholars highlight a gap between scientific research on ecosystem services (ESs) and its practical impact on policy and urban planning. This gap may result from the traditional focus of ES research, which must integrate both natural and social sciences in a site-specific manner [36,37]. Salzman argues that passing environmental laws or policies alone is insufficient to improve ES provision; policies must be transformed into actionable laws and applied through individual decisions [38]. The key point is the need to integrate ESs into decision-making and ecosystem management, such as introducing market-based instruments like PESs [39–41]. These instruments aim to obtain economic resources from ES beneficiaries to compensate those responsible for managing the services (sellers or providers), ensuring the maintenance of the site and the environmental quality of the ecosystem [42,43]. The basic concept of the PESs scheme is as follows: if some ESs are defended by land owners as providers of market-based benefits and goods and, thus, have direct private revenue, other services have a good public characteristic but are not traded in the market [44–46]. Therefore, an effort is needed to find instruments to compensate land owners and managers for the production and conservation of these services [47–50]. PESs mechanisms are structured to offer monetary incentives to communities or individuals in order to adopt interventions and behaviors that improve the provision of Ess. These mechanisms are characterized by voluntary transactions between service users and providers [18].

Another option proposed by some authors is conservation easements (CEs), defined as legal contracts that result in restrictions on the use of private lands to preserve nature in exchange for potential tax benefits [51,52]. The primary goal is to prevent the future conversion of natural areas and low-intensity agricultural lands into more intense land uses, such as industrial or urban zones. Additionally, CEs aim to maintain and improve the provision of ESs, thereby benefiting the local and regional communities [53,54]. A notable example of a program reflecting elements of conservation easements is the Australian Biodiversity Conservation Strategy. Over the past few decades, it has aimed to double the value of complementary markets for ecosystem services by 2015. It sought to achieve this goal by increasing incentives for private sector participation through financial rewards for actions that protect or enhance biodiversity [55]. Similarly, in another part of the world, Canadian provinces allow a 100% property tax reduction for maintaining and protecting lands with features deemed essential for provincial natural heritage conservation [56].

Such solutions inevitably introduce complexities in balancing economic efficiency, social acceptance, and environmental benefits [57]. Significant challenges remain, particularly regarding landowners' willingness to participate, the management and monitoring of private conservation efforts, and the financial burdens faced by both governments and participants [58,59]. These financial and fiscal instruments, widely discussed in the literature and implemented in various countries, should be tailored to each nation's specific context, taking into account its internal markets and fiscal structures. For instance, in Italy, property tax exemptions for agricultural landowners already benefit direct farmers (https://www.finanze.gov.it/it/fiscalita/fiscalita-regionale-e-locale/Imposta-municipale-propria-IMU/disciplina-del-tributo/esenzioni/, last consultation: 31 October 2024). Thus, new incentives for adopting sustainable or conservation-oriented farming practices should be implemented through alternative fiscal or regulatory tools, such as economic incentives, rather than relying solely on property tax relief. This approach aligns with Italy's CAP Strategic Plan for 2023–2027, which has introduced 34 voluntary schemes designed to compensate farmers for the additional costs and income losses incurred by adopting more environmentally and climate-friendly practices. These practices include reducing fertilizer and pesticide use, implementing biodiversity-preserving techniques, and adopting soil conservation practices [60].

National targets for ecological conservation or restoration should ideally be translated into actionable goals at lower levels of government or the local scale through negotiations with ecosystem service (ES) "sellers", such as landowners, to enhance effectiveness, as suggested by Ding et al. [61]. For instance, in British Columbia, tax incentive programs for land conservation are being explored at the local government level, where authorities have been empowered to implement tax-based conservation initiatives [56]. To achieve this goal and to appropriately tailor the initiative based on the territorial criticalities and potentialities, it is evident that local authorities need to be provided with local assessment and mapping outputs regarding the condition of ecosystem services across the territory. This can help identify and value strategic or vulnerable areas, as well as the effect of potential policies, transformative scenarios, or management regimes [62,63].

### *1.5. Downscaling Global Principles to Local Context*

In response to the call for the rapid implementation of SEEA EA, the European Commission incorporated ecosystem accounts into its extension of Regulation 691/2011 on European Environmental Accounts. This extension, expected to include data on national ecosystem conditions and some biophysical ecosystem services, was approved by the European Council and Parliament in 2023 [17]. After the approval, the European statistical community proactively worked to address methodological gaps. In 2021, Eurostat formed a Task Force to support the coordination of legal, methodological, and practical aspects critical to the rollout of SEEA EA. Italy, for instance, is adapting SEEA EA in national projects through the National Institute of Statistics (ISTAT) and the National Institute for Environmental Protection and Research (ISPRA), focusing on quantifying and valuing ecosystem services for economic analysis [17]. This initiative reflects the broader international drive needed to integrate SEEA EA into policy frameworks and recognize the importance of monetary accounting of nature. Although SEEA EA was fully published in 2021, its preliminary version and decade-long development have fostered significant progress in ecosystem service valuation and early monetization efforts [10]. These efforts, often highlighted in the scientific and technical literature, provide valuable practices and insights that are essential to adapting global principles in local contexts during the ongoing transition phase. Downscaling efforts of SEEA EA are necessarily conditioned by the national context and policies that regulate land use and conservation strategies. These policies are influenced by specific urban geographies and regional economic dynamics that

strongly impact nature degradation and must be assessed with tools that quantify the loss of ecosystem services in the national context. An interesting example is the set of guidelines for the biophysical and monetary assessment of ecosystem services [64], which were employed by the Italian National System for Environmental Protection (SNPA) in 2018. These guidelines serve as the primary methodological reference for this research, which focuses on a case study within the Italian context.

Considering trends in land-use dynamics, particularly soil sealing, reversing the current practice of consuming agricultural or natural land—rather than addressing degraded areas—also requires a monetary valuation of soil ecosystem services.

Although the cost of such transformations is substantial, it remains unclear without a coherent monetary valuation of ecosystem services (ESs), which must be grounded in biophysical quantification.

Monetizing natural resources is a strategy to address nature's "economic invisibility", which is a key factor that can lead to more sustainable use and the conservation of nature through efficient resource allocation. Many ecosystem goods and services are not reflected in market prices due to their free accessibility, leading to a lack of recognition of both their benefits and the costs of their degradation [17]. A robust valuation framework at the national and regional levels is essential to integrate environmental considerations into economic decisions, promoting sustainable use and the conservation of ecosystems [17].

Furthermore, the effective management of environmental resources in planning and decision-making requires understanding spatial dynamics to address modern challenges across various sectors, from urban planning to natural resource protection. As Morya and Punia [65] emphasize, "the physical assessment of ecosystem services is not sufficient to mitigate the increasing pressure of urbanization on resources".

Urban dynamics are complex and site-specific, just as the pressures on land are driven by both economic and social factors that characterize the territory. The research focuses on the emblematic case of Italy, where land consumption and ES protection remain largely unresolved, partly due to the lack of a national regulatory framework on these issues.

### *1.6. Mapping ES Exercises: A Literature Review for the Italian Context*

To better understand the current state of the art in research and the ongoing debate among scholars, the topic of ES biophysical and monetary mapping has been examined through a literature review focused specifically on Italy. This review targeted local contexts within Italy, utilizing the Scopus and Web of Science databases. The results were systematically aggregated and are presented in the following section. The research began by focusing on exercises related to the biophysical mapping of ecosystem services in local case studies from Italy. In this context and referring to the European Union's Nomenclature of Territorial Units for Statistics (NUTS) framework, which categorizes regions from the national (NUTS0) to local levels (Regulation (EC) No. 1059/2003), the Provincial and Municipal levels (NUTS3 and LAU, respectively) correspond to the sub-regional, local scale within Italy's spatial planning framework.

During the literature review, scientific papers addressing soil ESs were examined, initially focusing on those that performed spatial mapping of either biophysical or monetary aspects. Subsequently, studies assessing the simultaneous mapping of both biophysical and monetary aspects were considered. Finally, papers evaluating multiple ESs concurrently, including scenario development, were selected as relevant to the research objectives.

Marine and water ES mapping exercises were excluded as the present research focuses on quantifying soil ESs. Similarly, papers at excessively broad or narrow scales (e.g., national assessments or neighboring ones) were excluded, as they did not fit with the identified spatial categories (NUTS3 and LAU). An overview of the results is presented in Table 1, which clearly

shows that only five papers were found with the same features of the current research: La Notte, 2012; Häyhä et al., 2015; Manes et al., 2016; Marino et al., 2021; Sebastiani et al., 2021 [66–70].

**Table 1.** The literature review results. Source: own elaboration by authors.

| **Search 1. Biophysical assessment and mapping exercises of ecosystem services in the Italian context**<br>Search string: (biophysical AND ecosystem AND services) AND (mapping OR quantification OR evaluation OR valuation OR assessment OR accounting) AND TITLE-ABS-KEY (mapping OR spatial) AND TITLE-ABS-KEY (Italy OR Italian). | | |
|---|---|---|
| **Reference** | **Assessment features** | **Exclusion motivation** |
| **La Notte, 2012** [66] | 1 scenario<br>1 ES | |
| **Schirpke et al., 2012** [71] | | No ES mapping |
| **Petrosillo et al., 2013** [72] | | No ES mapping |
| **Ferrari and Geneletti, 2014** [73] | | Biophysical OR monetary assessment |
| **Rova et al., 2015** [74] | | Biophysical OR monetary assessment |
| **Häyhä et al., 2015** [67] | 1 scenario<br>>1 ES | |
| **Arcidiacono et al., 2016** [75] | | Only biophysical assessment |
| **Franzese et al., 2017** [76] | | Water ecosystems |
| **Picone et al., 2017** [77] | | Water ecosystems |
| **Mancini et al., 2018** [78] | | National scale |
| **Salata et al., 2019** [79] | | No ES mapping |
| **Sacchelli and Bernetti, 2019** [80] | | No ES mapping |
| **Salizzoni et al., 2020** [81] | | No ES mapping |
| **Capriolo et al., 2020** [82] | | National scale |
| **Buonocore et al., 2020** [83] | | Water ecosystems |
| **Buonocore et al., 2020** [84] | | Water ecosystems |
| **Pacetti et al., 2020** [85] | | Water ecosystems |
| **Masiero et al., 2022** [86] | | Too-small scale (neighbourhood scale) |
| **Marino et al., 2021** [69] | 1 scenario<br>>1 ES | |
| **Di Pirro et al., 2021** [87] | | No ES mapping |
| **Zulian et al., 2022** [88] | | National scale |
| **Boschetto et al., 2023** [89] | | National scale |
| **Marino et al., 2023** [90] | | Too-wide scale (national scale) |
| **Catucci et al., 2023** [91] | | Water ecosystems |
| **Pignatti et al., 2024** [92] | | No ES mapping |
| **Search 2. Monetary assessment and mapping exercises of ecosystem services in the Italian context**<br>**Search string: (monetary AND ecosystem AND services) AND (mapping OR quantification OR evaluation OR valuation OR assessment OR accounting) AND TITLE-ABS-KEY (mapping OR spatial) AND TITLE-ABS-KEY (Italy OR Italian)** | | |
| **Reference** | **Assessment features** | **Exclusion motivation** |
| **La Notte, 2012** [66] | 1 scenario<br>1 ES | |
| **Häyhä et al., 2015** [67] | 1 scenario<br>>1 ES | |
| **Pelerosso et al., 2016** [93] | | No ES mapping |
| **Manes et al., 2016** [68] | 1 scenario<br>1 ES | |
| **Schirpke et al., 2017** [94] | | No ES mapping |
| **Franzese et al., 2017** [76] | | Water ecosystems |
| **Picone et al., 2017** [77] | | Water ecosystems |
| **Appolloni et al., 2018** [95] | | Water ecosystems |
| **Buonocore et al., 2020** [83] | | Water ecosystems |

**Table 1.** *Cont.*

| | | |
|---|---|---|
| **Capriolo et al., 2020** [82] | | Too-wide scale (national scale) |
| **Sebastiani et al., 2021** [70] | 1 scenario<br>>1 ES | |
| **Lai et al., 2021** [96] | | Only biophysical assessment |
| **Marino et al., 2021** [69] | 1 scenario<br>>1 ES | |
| **Boschetto et al., 2023** [89] | | Too-wide scale (national scale) |
| **Search 3. Biophysical and monetary assessment and mapping exercises of ecosystem services in the Italian context**<br>Search string: (monetary AND ecosystem AND services) AND (mapping OR quantification OR evaluation OR valuation OR assessment OR accounting) AND TITLE-ABS-KEY (mapping OR spatial) AND TITLR-ABS-KEY (biophysical) AND TITLE-ABS-KEY (Italy OR Italian) or (biophysical AND ecosystem AND services) AND (mapping OR quantification OR evaluation OR valuation OR assessment OR accounting) AND TITLE-ABS-KEY (mapping OR spatial) AND TITLR-ABS-KEY (monetary) AND TITLE-ABS-KEY (Italy OR Italian) | | |
| **Reference** | **Assessment features** | **Exclusion motivation** |
| **La Notte, 2012** [66] | 1 scenario<br>1 ES | |
| **Häyhä et al., 2015** [67] | 1 scenario<br>>1 ES | |
| **Franzese et al., 2017** [76] | | Water ecosystems |
| **Picone et al., 2017** [77] | | Water ecosystems |
| **Buonocore et al., 2020** [83] | | Water ecosystems |
| **Capriolo et al., 2020** [82] | | Too-wide scale (national scale) |
| **Marino et al., 2021** [69] | 1 scenario<br>>1 ES | |
| **Boschetto et al., 2023** [89] | | Too-wide scale (national scale) |

Interestingly, none of these papers involved a multi-scenario and multi-service mapping exercise focused on a sub-regional territory. The term "sub-regional", as mentioned, refers to a geographical area smaller than a region (NUTS2). It strikes a balance between being large enough to address environmental and ecological issues comprehensively yet focused enough to avoid a perspective fragmented by local administrative borders. This scale is crucial for supporting integrated and comprehensive planning and offering a wide-area vision while enabling effective planning tools. These tools can involve strategic synergies between municipalities sharing common criticalities or territorial potentialities to enhance and preserve ecosystems. Additionally, a multi-scenario approach is vital to understanding the ecosystemic effects of territorial evolution, particularly the changes in land use. Finally, soil's role in providing diverse ecosystem services highlights the trade-offs in land-use decisions, making a multi-service and holistic perspective essential. Therefore, the aim of this paper is to fill the gap in the literature by proposing a multi-scenario, multi-service mapping approach that integrates both biophysical and economic dimensions, with the goal of enhancing sustainable soil management policies at the sub-regional level.

Section 2 provides an overview of the methodology employed for the assessment and mapping of a selection of ecosystem services in the case study of the Province of Brescia. The details of the case study, along with the mapping outputs (Figures) and Tables, are presented in Section 3. In Section 4, a critical evaluation of the results is presented. This is accompanied by their contextualization, drawing on dynamic information regarding the variations in ecosystem services over the specified time frame. Finally, Section 5 outlines the limitations and strengths of the analysis, as well as potential directions for further developments and applications of the research.

## 2. Materials and Methods

### *2.1. Ecosystem Services*

The ecosystem services chosen for analysis in the Province of Brescia are listed in Table 2, with reference to the MEA classes and denominations [4].

**Table 2.** ES denomination and classification. Source: own denomination and MEA's categories (2005).

| ES Common Denomination | MEA ES Class and Denomination |
|---|---|
| Carbon storage and sequestration (CSS) | Regulating. Climate regulation |
| Habitat quality (HQ) | Supporting. Provisioning habitats |
| Crop pollination (CP) | Regulating. Pollination |
| Wood provision (WP) | Provisioning. Food and fibre |
| Particulate removal (PR) | Regulating. Air quality maintenance |
| Hydrological regime regulation (HRR) | Regulating. Water regulation |

These services can be included in the already cited category of soil ES (hereinafter simply referred to as ES), which should be assessed on the basis of soil properties like carbon content, nutrient cycling, and moisture retention. However, as is common in the literature, this analysis uses Land Use and Land Cover (LULC) as a proxy [8].

It is necessary to specify, in advance, that certain ecosystem services are more relevant to specific contexts: some are better suited to urban environments, such as microclimate regulation, while others are more applicable to rural or non-urban settings, like timber production. In particular, urban development relies heavily on surrounding rural areas for essential resources such as food, water, and raw materials [97]. However, given their higher population and activity density, the demand for ecosystem services is stronger in urban contexts for regulation services, whose supply is spatially constrained to the location where the demand exists (consider, for example, the service of hydrogeological regulation). Effective policies should focus on maintaining these linkages and protecting rural ecosystems to ensure equitable development for both areas [97]. As an initial analytical experiment, this research primarily focuses on the non-urban context. Notably, due to this focus, some ecosystem services have been excluded from this analysis. Microclimate regulation, which relates to the mitigation of the "urban heat island" effect caused by the accumulation of heat on artificial surfaces, was not examined as it primarily pertains to urban contexts, whereas this thesis focuses on rural areas. Similarly, water purification processes, particularly relevant near urban settlements where water quality is critical, were excluded as follows: this service, which involves the filtration of water as it infiltrates the soil, is more appropriately studied at broader geographical scales, such as watershed areas, rather than within the administrative boundaries of a province.

In any case, the justification for selecting these ecosystem services for the present analysis is closely tied to the territorial characteristics of the case study, as will be made explicit in Section 3: there, specific ecosystem services are presented in relation to their relevance within the context of the Province of Brescia.

For all ecosystem services, the analysis was conducted both in biophysical and monetary terms and in two distinct temporal scenarios—except for the pollination service, which was evaluated solely in monetary terms under a single scenario for reasons that will be discussed below. Biophysical quantification provides a tangible measure of ecosystem services in physical units, while economic quantification converts these benefits into monetary values, providing an estimate of the economic contribution of these services to society. As outlined in the SEEA EA guidelines [10], monetary estimates of ecosystem services are typically derived by assigning prices to individual ecosystem services and multiplying these prices by the physical quantities recorded in the ecosystem services flow account. In this analysis, however, habitat quality and pollination services follow a different methodology.

The decision to use a dual scenario enhances the static and spatial analysis of ESs and trade-offs at specific moments, as well as their changes and evolution in response to land transformations. As will be clarified further below, due to modeling, parameter, and data restrictions, it was not possible to analyze ESs under identical temporal scenarios. Some scenarios refer to 2006–2012 (CSS, WP), while others refer to 2012–2018 (HQ, CP, PR, HRR).

### 2.2. Biophysical Assessment of Ecosystem Services

The methodology applied for the biophysical assessment of the chosen ES is hybrid, focusing on manageable models and tools that are not overly sector-specific. The application of such models and tools requires a multidisciplinary approach involving experts from various fields. The analysis was partially conducted in alignment with the Italian SNPA guidelines for the ecosystem services assessment, titled "Mapping and Impact Assessment of Land Consumption on Ecosystem Services: Methodological Proposals for the Land Consumption Report" [64]. This was performed using Q-GIS 3.34.5 software and the InVEST model. For the biophysical assessment of the remaining three services, the methodology from the LIFE+ "Making Good Natura" EU project was used [98] (Figure 1).

#### 2.2.1. The InVEST Model

InVEST is a suite of free, open-source software models developed by Stanford University as part of the Natural Capital Project (https://naturalcapitalproject.stanford.edu/software/InVEST, last consultation: 26 October 2024), specifically designed for territorial and town planning evaluation and the comparison of the impacts of land-use alternatives. It is also used by various regional authorities in Italy, such as the Lombardy Region [99,100]. It is particularly useful for assessing soil ecosystem services from a spatial planning perspective. It analyzes ESs through various sub-models, providing biophysical results (e.g., carbon sequestration in tons) and monetary values (e.g., net present value of carbon). In this research, InVEST was used for biophysical aspects, while monetary quantification was evaluated separately. The model requires specific calibration and high-quality data to function effectively [100], and the availability of detailed, open-source data is a major challenge at the planning level. Due to lower-resolution data, InVEST is better suited for regional planning, with sub-regional applications (such as the ones conducted here) needing additional calibration effort.

In this case, the input data and parameters required depend on the ecosystem service being analyzed and, therefore, on the InVEST sub-model used. Typically, a Land Use and Land Cover (LULC) map and calibration parameter tables are necessary. For the ESs analyzed in this paper, LULC maps were selected from the Corine Land Cover (CLC) database as referred to for the years 2006, 2012, and 2018, and from which only land cover (LC) information was used for the services analyzed. Parameters were set according to exercises in the literature, as close as possible to the spatial and morphological context of the case study. The ecosystem services selected for analysis in the Province of Brescia using InVEST software include (Figure 1) the following:

- Carbon sequestration and storage (CSS);
- Habitat quality (HQ);
- Crop pollination (CP).

#### 2.2.2. LIFE+ "Making Good Natura" EU Project—LIFE11 ENV/IT/000168 ("Project MGN")

For the biophysical quantification of ecosystem services that were not analyzed using InVEST, the ES-specific methodology from the "Making Public Goods Provision the Core Business of Natura 2000" (LIFE+ MGN) project was utilized [98]. Launched in 2013 and supported by the European Commission under the LIFE+ program, the LIFE+ MGN

primarily aims to enhance the governance of agro-forestry sites within this network by identifying key ecosystem services (ESs), conducting the biophysical quantification and economic valuation of various ES, developing and implementing PES frameworks, and evaluating site management effectiveness [101].

The project proposes a simplified (parametric) methodology for analyzing specific ecosystem services—in this research, used only for biophysical assessment—across 21 Natura 2000 sites. Although the findings pertain solely to the analyzed sites, the methodology (detailed in [98]) can be replicated in other contexts.

The ecosystem services examined using the LIFE+ MGN methodology include (Figure 1) the following:

- Wood provision (WP);
- Particulate removal (PR);
- Hydrological regime regulation (HRR).

### 2.3. Monetary Assessment of Ecosystem Services

The cited SNPA guidelines [64] also include an approach for the monetary assessment of ESs. The methodology proposed differs from service to service and relies on different parameters in the literature, sometimes with a very high range of values. The monetary assessment of ecosystem services in this analysis is aligned with it, as reported synthetically in Figure 1.

As explained in the following sections, this research, chosen chose to refine the method, narrowing the range on the basis of statistical evaluations and re-evaluating the coefficients by applying the monetary revaluation coefficient for the year 2024 using ISTAT (https://rivaluta.istat.it/, last consultation: 28 October 2024). Additionally, where deemed necessary, the proposed parameter references were also updated.

Please note that all results reported in the tables, both in Section 3 and in Appendix A, have been rounded to the nearest whole unit.

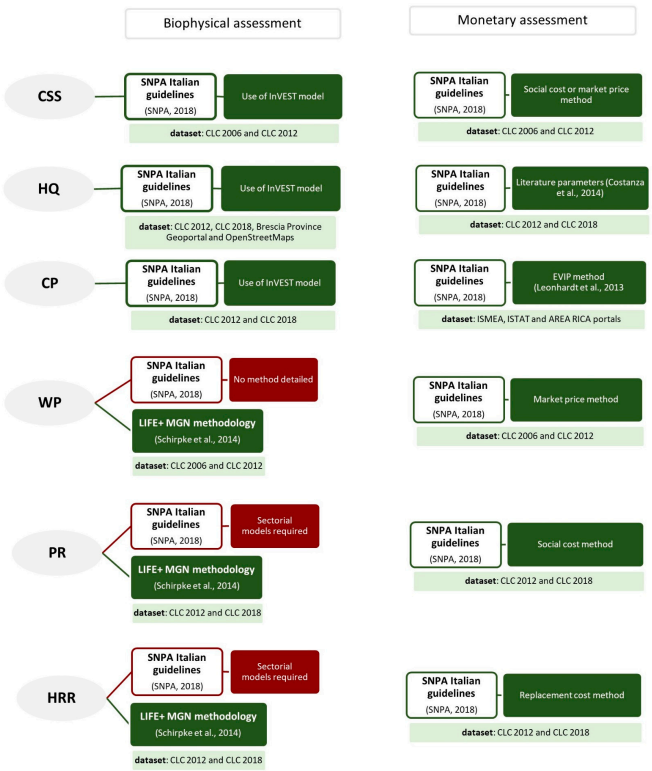



**Figure 1.** Sources and methodology followed for the biophysical and monetary assessment of six ecosystem services. The assessment path chosen is highlighted in green, while discarded approaches are shown in red. Source: elaborations by the authors following [64,98,102].

## 3. Results

### *3.1. Study Area*

The case study of this biophysical and monetary assessment exercise is the Province of Brescia (NUTS3), located in Lombardy, Northern Italy (Figure 2). The Province of Brescia provides an ideal case study as it encompasses diverse territorial systems, from plains to lakes and mountains. The northern part features three main valleys—Valle Camonica, Valle Trompia, and Valle Sabbia—which have a distinct morphology compared to the southern plains. The province is also characterized by three main lakes—Lake Garda, Lake Iseo, and Lake Idro—further adding to its geographical complexity. Addressing this complexity requires an integrated planning and management approach, particularly when defining the relationships and priorities between different systems. These features support a wide range of ESs, making this territory an ideal case study for a comprehensive and integrated ES assessment. Agriculture is a key economic activity in the area, with notable products such as olives from Lake Garda and wines from renowned regions such as Franciacorta and Lugana. The area holds a variety of tourism-related services, ranging from lakes, mountains, and valleys to agricultural productivity, all while retaining cultural and historical significance in Brescia's landscape. Finally, northern forests play a vital role in carbon sequestration and timber production while serving as essential biodiversity hotspots. The areas near major rivers and wetlands hold significant ecological importance but are increasingly vulnerable to hydrogeological and natural risks, like those in mountainous zones. Environmental and socioeconomic pressures in Brescia mirror challenges in other regions of Italy. For example, the Province of Brescia is marked by intense industrial activity and heavy traffic, experiencing high levels of PM10, ozone, and GHG emissions, exacerbated by the Po Valley's stagnant air conditions and the Alpine range acting as a barrier [103,104]. Urbanization has significantly increased land consumption, particularly in the plains, emphasizing the urgent need for strategic analysis to safeguard critical ecosystems and natural resources. These aspects also specifically justify the selection of the ecosystem services analyzed in this study. Given these characteristics, using Brescia as a case study is both significant and comprehensive, as it provides valuable insights for developing planning frameworks applicable to other regions facing similar territorial complexities and diverse environmental, economic, and social dynamics. It can be stated that the varied features of Brescia Province reflect the heterogeneity of the Italian landscape, making it a microcosm for broader national challenges and enhancing the application of the method to other contexts.

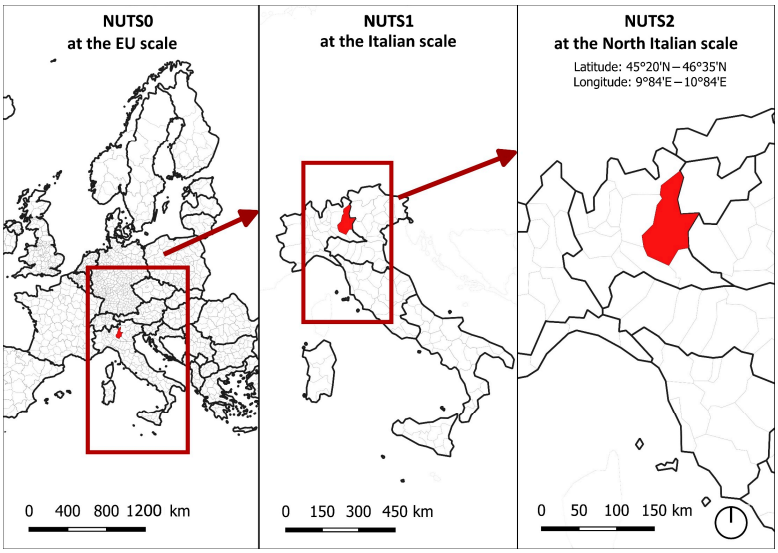



**Figure 2.** Administrative framework and spatial collocation of the case study (Brescia Province, NUT3). Source: own elaboration by authors already in [105].

### 3.2. ES Assessment

#### 3.2.1. Carbon Storage and Sequestration

The forestry sector holds one of the highest potentials for cost-effective $CO_2$ reduction compared to other mitigation activities by absorbing carbon dioxide from the atmosphere and storing it in woody biomass (both aboveground and belowground), litter, and soil [106,107]. The factors influencing the amount of carbon stored and the future uptake potential across different compartments vary, with climate and soil consumption being predominant, particularly in areas with forest cover or high natural integrity [108,109]

In the case of the Province of Brescia, approximately one-third of the area is covered by forests, mainly concentrated in the northern valleys of Valle Camonica, Valle Trompia, and Valle Sabbia, making this ecosystem service especially relevant for the region.

##### Biophysical Assessment

Carbon storage and sequestration biophysical analysis were performed using the InVEST software, as proposed in [64], specifically the "Carbon storage and sequestration" sub-model. InVEST estimates the carbon content of various land-use categories based on storage parameters (tC/ha) for the four primary carbon pools recognized by the Intergovernmental Panel on Climate Change [110]: aboveground biomass, belowground biomass, soil, and dead organic matter. For the carbon storage assessment, the software requires input to an LC map for each scenario analyzed and carbon storage parameters for each LC category. Carbon sequestration is then calculated from the differences in LC among reference years, namely from differences in carbon storage. Carbon stored in permanent crops and tree plantations was not considered.

For this analysis, the Corine Land Cover (CLC) 2012 dataset was used, rasterized at a 10-meter resolution using QGIS software; the 2018 mapping was avoided due to the absence of a V-level classification for forestry land uses, which was considered necessary in this case for a precise ES assessment. Carbon storage parameters (tC/ha) for forest types have been obtained from the National Inventory of Forests and Forest Carbon Pools (INFC), for which the correspondence between CLC categories was established based on Marchetti et al.'s work [111] (see Table A1 in Appendix A). More precisely, the values for aboveground biomass were derived from the INFC 2015 database, while belowground biomass was not calculated due to a lack of data in the INFC databases. Soil carbon values were calculated by subtracting the litter carbon content in the INFC 2005 database (declared as a quite static parameter and, thus, not uploaded in the 2015 version) from the total soil carbon in the INFC 2015 (litter carbon + soil carbon). Similarly, dead organic matter values were calculated by summing litter and fine necro-mass (not uploaded in the 2015 version) with coarse deadwood in the INFC 2015 database. See Table A2 in Appendix A for the detailed parameters used for each carbon pool and forest type.

The same analysis was performed for 2006, using the CLC 2006 dataset and the same parameters as before, with the aim of isolating the effects of land-use change on carbon storage and sequestration services, which is the purpose of this analysis.

Carbon storage and sequestration biophysical mapping outputs are reported in Figure 3 for both the years considered, together with the variation in time, which in this case represents the carbon sequestration service.

##### Monetary Assessment

The monetary valuation of carbon sequestration and storage can be performed through two main approaches, as demonstrated in SNPA guidelines [64]: the social cost and the market value of emission permits.

The social cost approach estimates the global damage avoided by carbon sequestration. In this paper, it was assumed that the unit monetary value of EUR 101.85/tC proposed

in the Interagency Working Group on Social Cost of Greenhouse Gases, United States Government [112], would be accurate, adjusted for inflation to EUR 145.74/ton of carbon for 2024 (through Rivaluta ISTAT, https://rivaluta.istat.it/, last consultation: 28 October 2024).

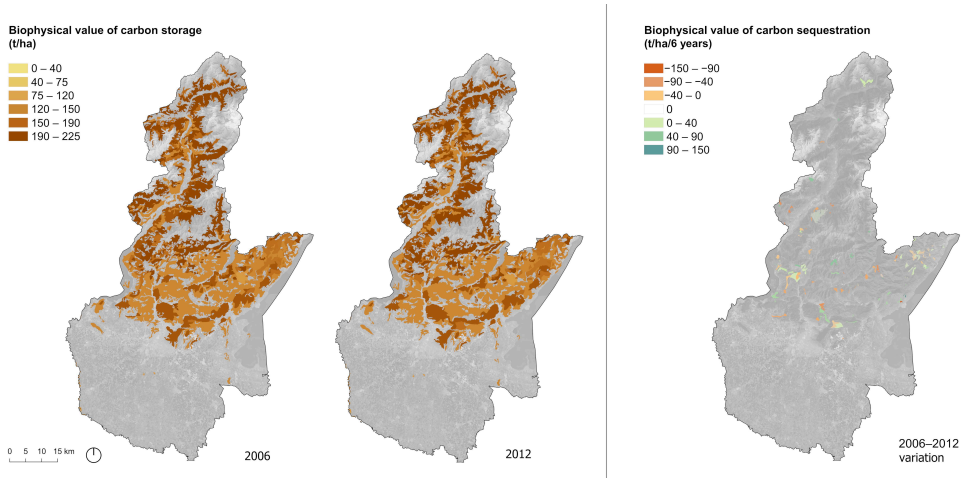
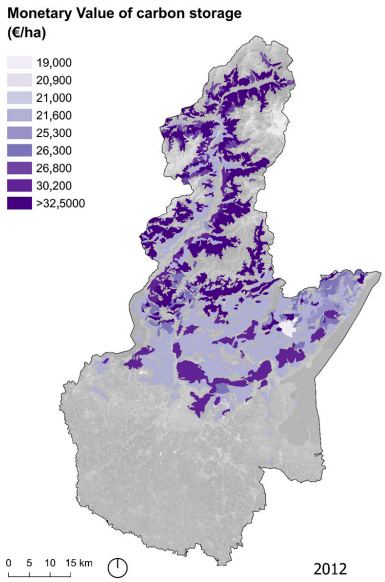



**Figure 3.** Maps of the biophysical assessment of carbon storage in 2012 and 2006 and carbon sequestration in 2006–2012. Source: own elaboration by authors.

For the market value approach, the price of carbon emission permits in the Italian voluntary market was used, with a current unit monetary value of EUR 28.00/tC [113].

The total economic value for carbon storage and sequestration (EUR) is calculated by multiplying the total stored or sequestered carbon obtained by the biophysical assessment by these unit monetary values.

In Figure 4, a map of the unit monetary values (EUR/ha) of carbon storage in 2012 with the social cost method is proposed, together with the results for the monetary assessment using the LC typology with both methods. See Table A3 in Appendix A for more detailed information about the parameters and results.




| CLC—Code | Monetary value (EUR) | | | |
|---|---|---|---|---|
| | Social cost | | Market price | |
| | 2006 | 2012 | 2006 | 2012 |
| **3111** | 0 | 0 | 0 | 0 |
| **31311** | | | | |
| **3112** | 28,178,392 | 28,690,726 | 5,413,716 | 5,512,147 |
| **31312** | | | | |
| **3116** | 2,599,637 | 4,138,623 | 499,450 | 795,124 |
| **31316** | | | | |
| **3117** | 2,429,369 | 2,219,941 | 466,738 | 426,502 |
| **31317** | | | | |
| **3113** | 1,350,367,087 | 1,316,529,931 | 259,436,520 | 252,935,626 |
| **31313** | | | | |
| **3122** | 121,954,868 | 110,717,221 | 23,430,330 | 21,271,320 |
| **31322** | | | | |
| **3115** | 222,101,202 | 246,927,355 | 42,670,740 | 47,440,414 |
| **31315** | | | | |
| **3124** | 155,095,925 | 151,788,574 | 29,797,488 | 29,162,070 |
| **31324** | | | | |
| **3114** | 700,830,111 | 653,458,796 | 134,645,554 | 125,544,437 |
| **31314** | | | | |
| **3123** | 1,496,008,421 | 1,514,695,932 | 287,417,564 | 291,007,864 |
| **31323** | | | | |
| **3121** | 0 | 0 | 0 | 0 |
| **31321** | | | | |
| Total | 4,079,565,011 | 4,029,167,098 | 783,778,100 | 774,095,504 |

**Figure 4.** Mapping and results of the monetary assessment of carbon storage and sequestration in 2006 and 2012. The monetary assessment of carbon sequestration can be derived by subtracting the values between the two years. The map on the left shows the unitary monetary values related to LC in 2012, obtained using the social cost method. Source: own elaborations.

### 3.2.2. Habitat Quality

Above other pressure forms, soil sealing, especially through road construction, poses significant threats not only by reducing habitat areas but also by creating barriers to species migration and movement [114].

In the case of Brescia Province, a region with a rich variety of ecosystems, including agricultural lands, forests, and wetlands, all of which are vital for local biodiversity, the increasing pressure from urbanization and infrastructure construction has threatened to fragment habitats and diminish their ecological quality, jeopardizing the integrity of the Ecological Network [115].

#### Biophysical Assessment

The assessment of the habitat quality ecosystem service was conducted using the "Habitat quality" sub-model within the InVEST software suite, as suggested in [64]. The model operates under the premise that regions with higher habitat quality can support a greater diversity of native species; conversely, reductions in both habitat extent and quality lead to diminished species persistence [116]. InVEST calculates habitat quality by assessing the capacity of land cover types to sustain life and by evaluating the impact of different threats (such as urbanization or road networks), and habitat sensitivity to those threats. The model incorporates different spatial data layers to map these threats and quantify their influence on habitat integrity. The primary input required is a raster map, with the Corine Land Cover (CLC) 2018 dataset used in this analysis, rasterized at a 10-meter resolution using QGIS software. Two additional tables—the "sensitivity table" and the "threat table"—are essential for running the model. The sensitivity table assigns habitat values on a scale from 0 (non-habitable) to 1 (optimal habitat) while also indicating each habitat type's vulnerability to different threats. These parameters were sourced from the work of Sallustio et al. [117], which provides a comprehensive analysis of habitat values across Italy. The habitat types were previously associated with the LC map starting from the description of each field, seeking a logical link between the various categories (see Table A4 in Appendix A; for the sensitivity table, see Table A5). Simultaneously, the threat table (see Table A6 in Appendix A) details the characteristics of each threat, including its spatial extent (the radius of influence in kilometers), its weight or impact on habitat quality, and its decay pattern (whether effects decrease exponentially or linearly with distance). In particular, the radius of influence and the impact weights have on the habitat were obtained for each threat and habitat type identified by Sallustio et al. [117], while the decay pattern was assumed to be linear for safety. Each threat is required as raster input data; in this analysis, intensive agriculture, extensive agriculture, the soil consumed, and roads were considered, as outlined by Sallustio et al. [117]. Specifically, intensive and extensive agriculture, as well as the soil consumed, were obtained from the Brescia Province Geoportal, while road and railway network data were extracted from OpenStreetMap (OSM) and classified as proposed by Sallustio et al. [117] in order to maintain consistent reference parameters. A key parameter in the model is the semi-saturation constant (k), which modulates how habitat quality decreases as degradation intensifies. A low k value (0.05, the default in InVEST) means that even small increases in degradation will significantly reduce habitat quality. The same analysis was performed for 2012, using the CLC 2012 dataset and the same parameters as before, with the aim of isolating the effects of land-use change on habitat quality service.

The output consists of two raster maps, shown in Figures 5 and 6 for the two years considered, along with the period variation: one representing habitat quality and the other showing the level of degradation. These outputs provide relative values from 0 to 1, allowing for comparative analysis between the different locations but not yielding direct

biophysical measurements. Further processing would be required to translate these results into more specific ecological metrics.

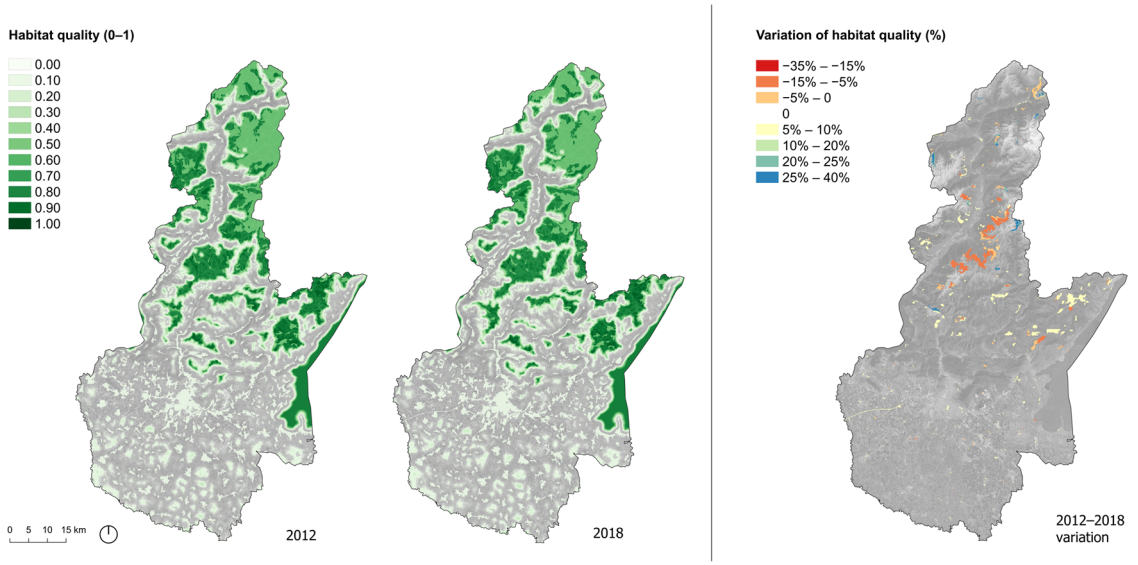



**Figure 5.** Maps of the biophysical assessment of habitat quality in 2012 and 2018. Source: own elaboration by authors.

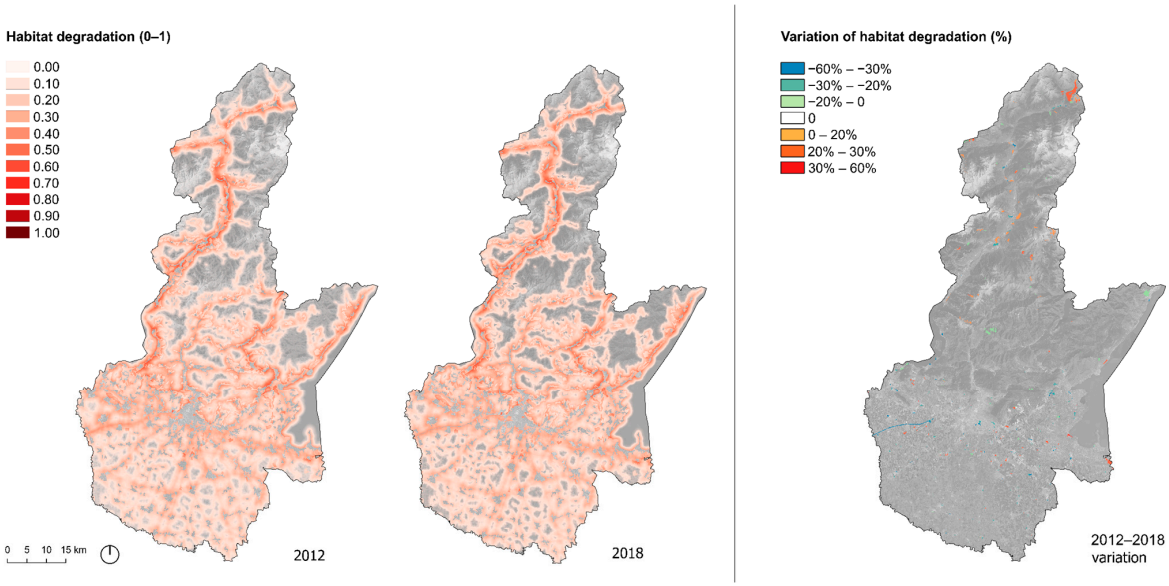
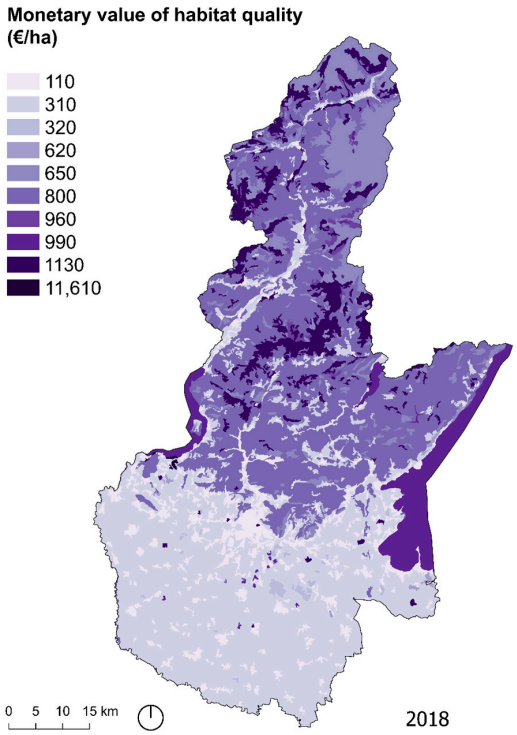



**Figure 6.** Maps of habitat degradation in 2012 and 2018. Source: own elaboration by authors.

Monetary Assessment

To assess the monetary value of habitat quality, the methodology proposed in the SNPA guidelines [64] follows the approach developed by Costanza et al. [5,7], which estimates economic value based on various parameters related to different habitat types for certain ecosystems. In the SNPA proposal, a range of coefficients was derived for the missing ecosystems, using the surfaces across the Italian territory as weights [64]. In the present analysis, the complete list of coefficients thus obtained (in EUR/ha) was adjusted for inflation using the ISTAT revaluation coefficient for 2018–2024. To calculate the total monetary value of the service, the unit monetary value (in EUR/hectare) is multiplied by the area of the specific land cover type, expressed in hectares.

In Figure 7, a map of the unit monetary values (EUR/ha) of habitat quality in 2018 is provided, together with the results for the monetary assessment by LC typology. See Table A7 in Appendix A for more detailed information about the parameters and results.




| CLC Code | Habitat category | Monetary value (EUR) 2012 | 2018 |
|---|---|---|---|
| 111 | Buildings and other artificial areas or impervious soils | 113,133 | 113,133 |
| 112 | Buildings and other artificial areas or impervious soils | 2,968,272 | 3,015,384 |
| 121 | Buildings and other artificial areas or impervious soils | 937,006 | 982,302 |
| 122 | Buildings and other artificial areas or impervious soils | 10,469 | 34,506 |
| 124 | Open urban areas | 295,812 | 297,735 |
| 131 | Open urban areas | 543,231 | 588,099 |
| 133 | Open urban areas | 31,729 | 29,165 |
| 141 | Grasslands | 91,676 | 61,117 |
| 142 | Grasslands | 490,069 | 837,532 |
| 211 | Intensive agricultural lands | 44,673,671 | 4,440,085 |
| 221 | Extensive agricultural lands | 340,716 | 430,834 |
| 222 | Extensive agricultural lands | 0 | 15,431 |
| 223 | Extensive agricultural lands | 321,582 | 315,410 |
| 231 | Grasslands | 5,120,263 | 5,033,115 |
| 241 | Extensive agricultural lands | 33,331 | 33,331 |
| 242 | Intensive agricultural lands | 3,101,014 | 2,979,417 |
| 243 | Intensive agricultural lands | 6,904,447 | 6,938,703 |
| 311 | Broadleaf forests | 61,230,302 | 69,942,130 |
| 312 | Conifer forests | 32,470,262 | 36,730,145 |
| 313 | (Broadleaf forests + Conifer forests)/2 | 30,441,975 | 16,636,931 |
| 321 | Grasslands | 30,616,322 | 31,271,634 |
| 322 | Shrublands | 3,588,206 | 4,816,965 |
| 323 | Shrublands | 42,305 | 84,609 |
| 324 | Inland unvegetated or sparsely vegetated areas | 11,032,512 | 10,555,932 |
| 332 | Inland unvegetated or sparsely vegetated areas | 9,576,004 | 8,682,252 |
| 333 | Inland unvegetated or sparsely vegetated areas | 7,499,941 | 8,012,428 |
| 334 | Inland unvegetated or sparsely vegetated areas | 0 | 34,601 |
| 335 | Inland unvegetated or sparsely vegetated areas | 1,282,850 | 1,261,959 |
| 411 | Wetlands | 2,995,148 | 2,704,920 |
| 511 | Water bodies | 66,994 | 66,994 |
| 512 | Water bodies | 23,543,563 | 23,573,120 |
| **Total** | | 280,362,804 | 280,480,684 |

**Figure 7.** Mapping and results of the monetary assessment of habitat quality in 2012 and 2018. The map on the left shows unit monetary values related to LC in 2018. Source: own elaborations by authors.

### 3.2.3. Crop Pollination

A European assessment indicates that approximately 9.2% of bee species are at risk of extinction due to land consumption, agricultural intensification, the widespread use

of pesticides, herbicides, and fertilizers, as well as habitat fragmentation, which affects the pollination network [117,118]. The enhancement and protection of this service, which is so essential for environmental balance and human activities, has become even more important today.

This ecosystem service is particularly crucial for the Province of Brescia, where agricultural areas cover about half of its total surface, mainly in the southern region, which corresponds to the Po Valley. However, this area faces significant land consumption, which threatens the integrity of its pollination ecosystem service.

Biophysical Assessment

To assess the biophysical value of the crop pollination ecosystem service, an analysis was conducted using the InVEST software, specifically the "Crop pollination" sub-model, as described in [64]. The software requires raster input data, for which the CLC 2018 dataset was used, and was rasterized in QGIS with a grid size of 10 m. The model also required two CSV tables as the input: a "biophysical table" and a "pollinator table". The biophysical table includes a nesting availability index and a flower abundance index for each LC class. The required parameters were obtained from the "JRC ESTIMAP: Ecosystem services mapping at European scale" report [119], which provides general parameters for Europe. It is considered a suitable reference for this case study. The pollinator table maps the characteristics of the analyzed pollinator species, in this case only including the "solitary bee", as in [119]. Parameters include the following: a nesting suitability index (set to one for a generic substrate); a foraging activity index calculated from temperature and solar radiation; the medium distance traveled by the analyzed species (set to 200 m, as in [119]); and a relative abundance value (set to one since only one pollinator type was analyzed). Parameters were obtained with the methodology reported in [119], using values of T (temperature) = 12.59 °C and R (radiation) = 177.9 W/m$^2$ obtained from the ARPA database of the Lombardy Region using the average annual daily mean values from 1 January 2023 to 1 January 2024 (https://www.arpalombardia.it/temi-ambientali/meteo-e-clima/form-richiesta-dati/, last consultation: 8 January 2024).

The same analysis was performed for 2012, using the CLC 2012 dataset and the same parameters as before, with the aim of isolating the effects of land-use change on the crop pollination service.

The software generated two output maps, reported in Figures 8 and 9 for the two years considered, along with the period variation. One map represents the abundance of the generic bee, while the other indicates its potential supply based on relative abundance, habitat suitability, and the floral resources available, taking into account the bee's travel capacity. The values in these maps range from 0 to 1, enabling comparative analysis between pixels, but they do not provide a direct biophysical analysis without further processing.

Monetary Assessment

For the monetary assessment of pollination services, as outlined in the SNPA guidelines [64], this methodology adopted the approach proposed by Leonhardt et al. [102], specifically the calculation of the overall economic value of pollination (EVIP) based on the global valuation of the pollination service in relation to the agricultural production value. The EVIP was determined using the methodology described in [102], deriving the crop-dependency ratio on pollinators from Klein et al. [120].

For the valuation of the parameter $Q_{ict}$, ISTAT data for Brescia Province were used (https://esploradati.istat.it/databrowser/#/it/dw/categries/IT1,Z1000AGR,1.0/AGR_CRP/DCSP_COLTIVAZIONI/IT1,101_1015_DF_DCSP_COLTIVAZIONI_1,1.0, last consultation: 28 October 2024). Concerning $P_{ict}$, data were obtained from the ISMEA

(Istituto di Servizi per il Mercato Agricolo Alimentare) and the AREA Rica (Analisi dei Risultati Economici Aziendali) portals.

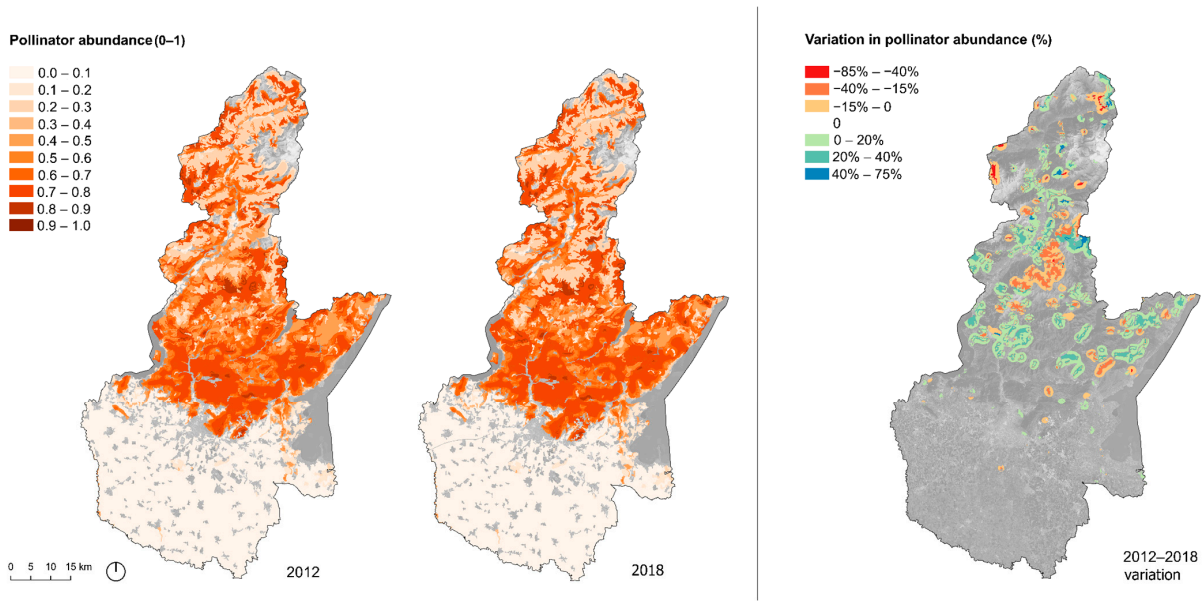



**Figure 8.** Maps of pollinator abundance in 2012 and 2018. Source: own elaboration by authors.

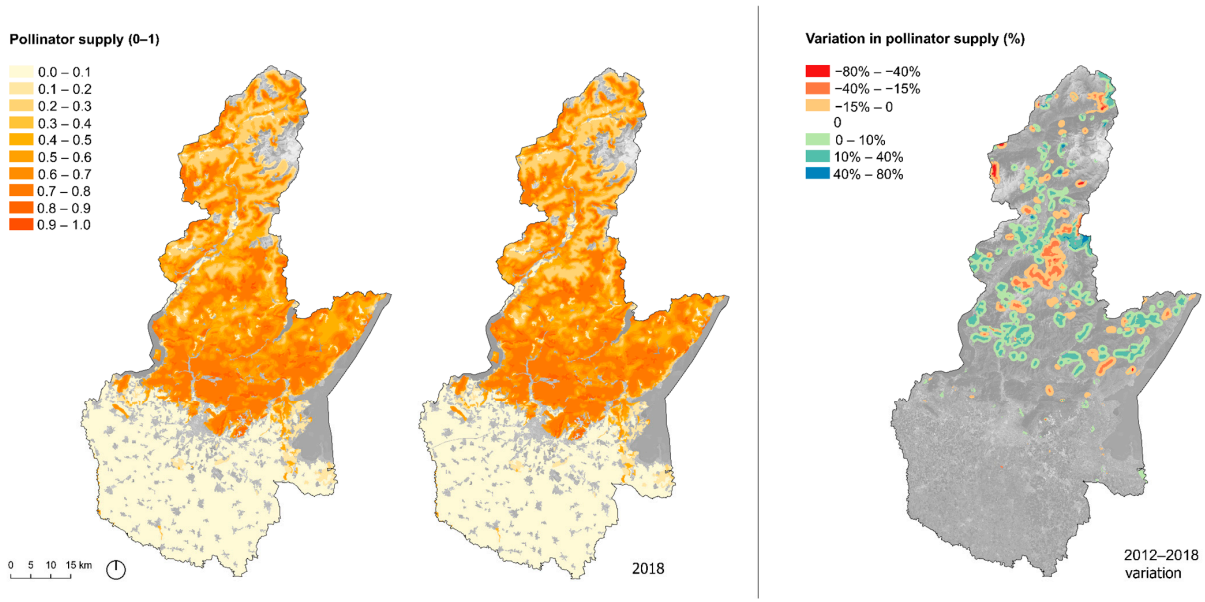



**Figure 9.** Maps of the biophysical assessment of crop pollination in 2012 and 2018. Source: own elaboration by authors.

In this case, it was not possible to generate a map for the monetary valuation of the service, as there is no agricultural land-use map available for Brescia Province. The CLC dataset only provides broad land-use categories without specifying individual crop types, which can vary frequently across the region. Consequently, the monetary valuation could not be geo-referenced. However, Table 3 presents the results of the monetary assessment performed by cultivation type. For more detailed information about the parameters and results, see Table A8 in Appendix A.

**Table 3.** Monetary value of crop pollination for crops dependent on the service based on the 2023 production in Brescia Province. Source: own elaboration by authors from ISMEA, AREA Rica, and ISTAT databases.

| Crop Type | Total Production (t/Year) | Unit Monetary Value for Crop Production (EUR/t) | Dependency Ratio | Monetary Value for Crop Pollination (EUR/Year) |
|---|---|---|---|---|
| Apple | 1811 | 729 | 0.65 | 858,142 |
| Chestnut | 1075.9 | 1920 | 0.25 | 516,480 |
| Cocumber | 205 | 291 | 0.65 | 38,776 |
| Green Bean | 2474.5 | 1097 | 0.05 | 135,754 |
| Lemon | 8 | 760 | 0.05 | 304 |
| Melon | 1845 | 597 | 0.95 | 1,046,392 |
| Peach | 788 | 512 | 0.65 | 262,246 |
| Pear | 185 | 1423 | 0.65 | 171,116 |
| Pepper | 234 | 493 | 0.05 | 5768 |
| Strawberry | 371 | 3023 | 0.25 | 280,383 |
| Plum | 72 | 308 | 0.65 | 14,414 |
| Tomato | 44,886 | 676 | 0.05 | 1,517,147 |
| Watermelon | 1280 | 164 | 0.95 | 199,424 |
| Zucchini | 8087.8 | 503 | 0.95 | 3,864,755 |
| **Total** | | | | 8,911,046 |

#### 3.2.4. Wood Provision

To evaluate this ecosystem service, the annual biomass of timber produced in a specific region must be estimated [98]. Land-use changes in forested areas can entirely eliminate this service, while other influencing factors include climate conditions, management practices, and the prevalence of diseases like the Bosforo bacterium, which has affected Northern Italy. The assessment of wood provision is particularly significant for Brescia Province, where forests cover approximately one-third of the territory, primarily in the northern region. This area encompasses three major valleys: Valle Camonica, Valle Trompia, and Valle Sabbia.

##### Biophysical Assessment

The "LIFE+ MGN" parametric methodology was applied to biophysically assess wood provision ecosystem services [98]. The annual biomass increment values were obtained from the INFC 2015 database, which provides specific growth rates for various forest types based on CLC classifications. As with carbon storage and sequestration service, the CLC 2012 dataset was used and rasterized at a 10-meter resolution using QGIS software. A correspondence between CLC classes and INFC classifications was established based on Marchetti et al.'s work [111]. Similar to the previous analysis, only tall tree forest areas were considered. The annual biomass increment values for each forest type were sourced from the INFC 2015 database. This approach estimates the wood provision service by calculating the annual production of forest biomass that can be sustainably harvested without distinguishing between different timber product types. The assessment focused on the volume of biomass produced annually within the limits of natural regeneration [98].

The same analysis was performed for 2006, using the CLC 2006 dataset and identical parameters, with the goal of isolating the effects of land-use change on the wood provision service.

Figure 10 reports the biophysical mapping results of wood provision in 2006 and 2012, along with the variation in the ES during the period.

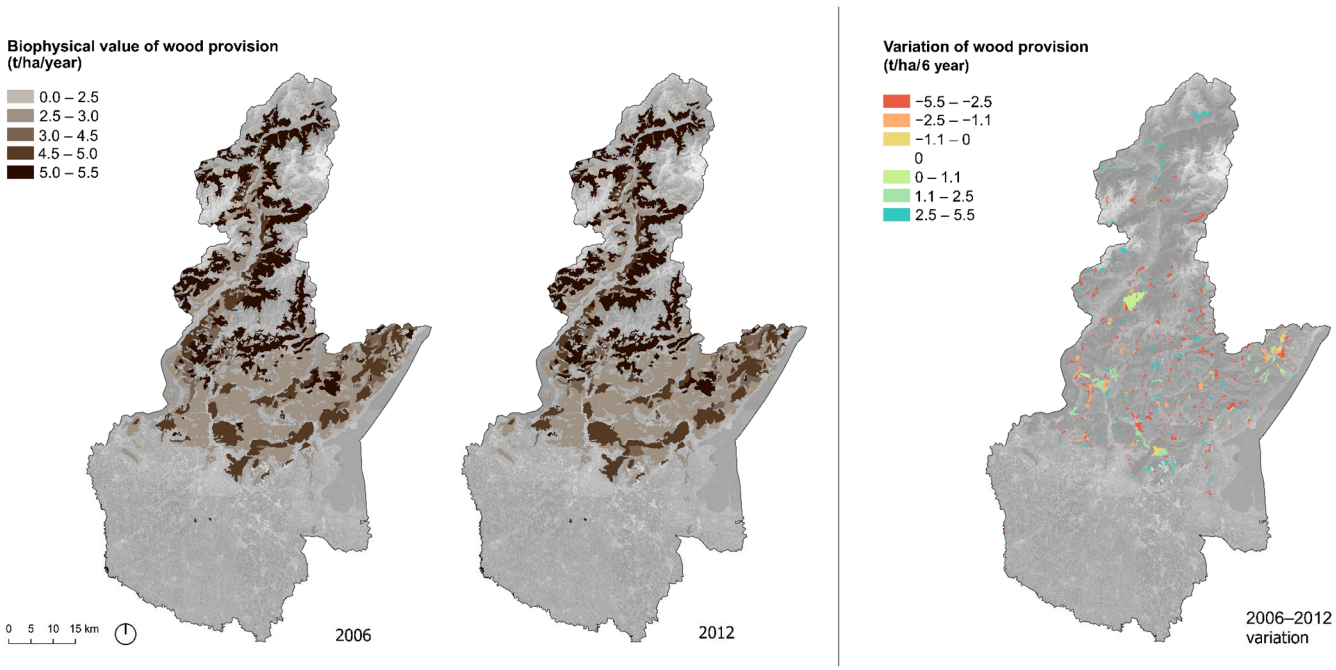


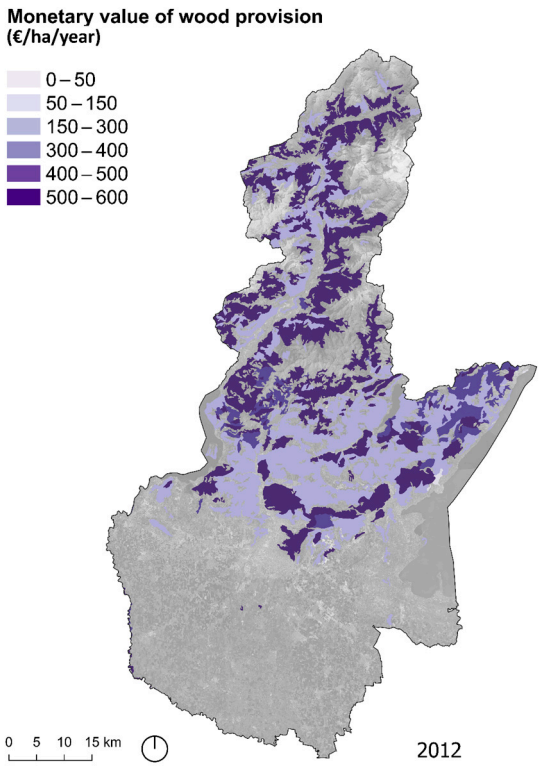

**Figure 10.** Maps of the biophysical assessment of wood provision in 2006 and 2012. Source: own elaborations by authors.

See Table A9 in Appendix A for further details about the parameters used.

Monetary Assessment

For the monetary assessment of wood provision, the SNPA guidelines [64] recommend using market prices for the assessed biomass volumes.

In the absence of specific data for the Province of Brescia, data from the ISPAT portal for the Trentino Alto Adige region were utilized. This portal provides valuable insights into regional timber utilization percentages and average prices based on the latest update from 2021. According to these findings, timber products are primarily used for construction (76.5%), while the remaining 23.5% is allocated for firewood. The respective average prices are EUR 63/m$^3$ for construction timber and EUR 50/m$^3$ for firewood. These prices are weighted averages derived from the production of softwood and hardwood in Trentino Alto Adige. By calculating a weighted average of these results, the overall price was estimated at EUR 60/m$^3$, which was adjusted for inflation to approximately EUR 70/m$^3$. The monetary value of wood production was determined by multiplying the wood increment coefficient (at the basis of the biophysical assessment) by the area of the respective land cover type, yielding wood provision values in tons or cubic meters. These results were then multiplied by the unit monetary value (EUR/t or EUR/m$^3$) to obtain the total economic value in euros. Figure 11 presents a map of the unit monetary values (EUR/ha/year) of the wood provision in 2012, alongside the results of the monetary assessment by LC typology. See Table A9 in Appendix A for more detailed information about the parameters and results.




| CLC—Code | Monetary value (EUR/year) | |
|---|---|---|
| | 2006 | 2012 |
| **3124** | 1,466,710 | 1,435,700 |
| **31323** | 7,905,310 | 7,285,670 |
| **3123** | 17,942,820 | 18,887,960 |
| **3122** | 280,700 | 549,500 |
| **31322** | 2,134,720 | 1,642,970 |
| **3121** | 0 | 0 |
| **31321** | 0 | 0 |
| **3125** | 0 | 0 |
| **31325** | 0 | 0 |
| **3115** | 2,995,510 | 3,124,520 |
| **31315** | 782,320 | 1,076,320 |
| **3112** | 864,920 | 881,230 |
| **31312** | 0 | 0 |
| **3114** | 11,152,610 | 10,132,290 |
| **31314** | 1,160,670 | 1,348,060 |
| **3113** | 14,769,930 | 13,706,560 |
| **31313** | 3,188,010 | 3,801,910 |
| **3116** | 51,660 | 81,760 |
| **31316** | 0 | 0 |
| **3117** | 52,850 | 48,720 |
| **31317** | 0 | 0 |
| **3111** | 0 | 0 |
| **31311** | 0 | 0 |
| Total | 64,748,740 | 64,003,170 |

**Figure 11.** Mapping and results of the monetary assessment of wood provision in 2006 and 2012. The map on the left shows unitary monetary values related to LC in 2012. Source: own elaborations.

### 3.2.5. Particulate Removal

Particulate and ozone removal by forests is a vital ecosystem service, particularly in the spatial context of this analysis, as exposure to air pollutants is the leading environmental risk factor in Europe [121]. Italy, in particular, has the highest estimated number of premature deaths attributed to air pollution [122].

This air quality service plays a crucial role in maintaining urban air quality and is equally significant for broader regions like Brescia Province. Forest ecosystems in this province are extensive, covering about one-third of its surface, predominantly in the northern areas, including Valle Camonica, Valle Trompia, and Valle Sabbia. These forests are particularly valuable in mitigating pollution levels, which can be notably high in the region.

#### Biophysical Assessment

The capacity of forest ecosystems to remove pollutants was assessed using the "LIFE+ MGN" parametric methodology, which estimates PM10 removal based on average capture coefficients specific to different vegetation types [98]. The CLC 2018 dataset was utilized for the LC map, rasterized at a 10-meter resolution using QGIS software. PM10 sequestration values were assigned to various forest types following the parameters provided by Schirpke et al. [98]. Specifically, broadleaf forests were assigned a value of 160 kg/ha/year, while the coniferous forest was assigned a value of 490 kg/ha/year. Mixed forests were assigned a value of 325 kg/ha/year, calculated as the average of the previous two.

The same analysis was conducted for 2012 using the CLC 2012 dataset and the same parameters to isolate the effects of land-use change on the capacity of forests to remove PM10. Figure 12 presents the biophysical mapping results for particulate removal in 2012 and 2018, with variation in the ES during this period.

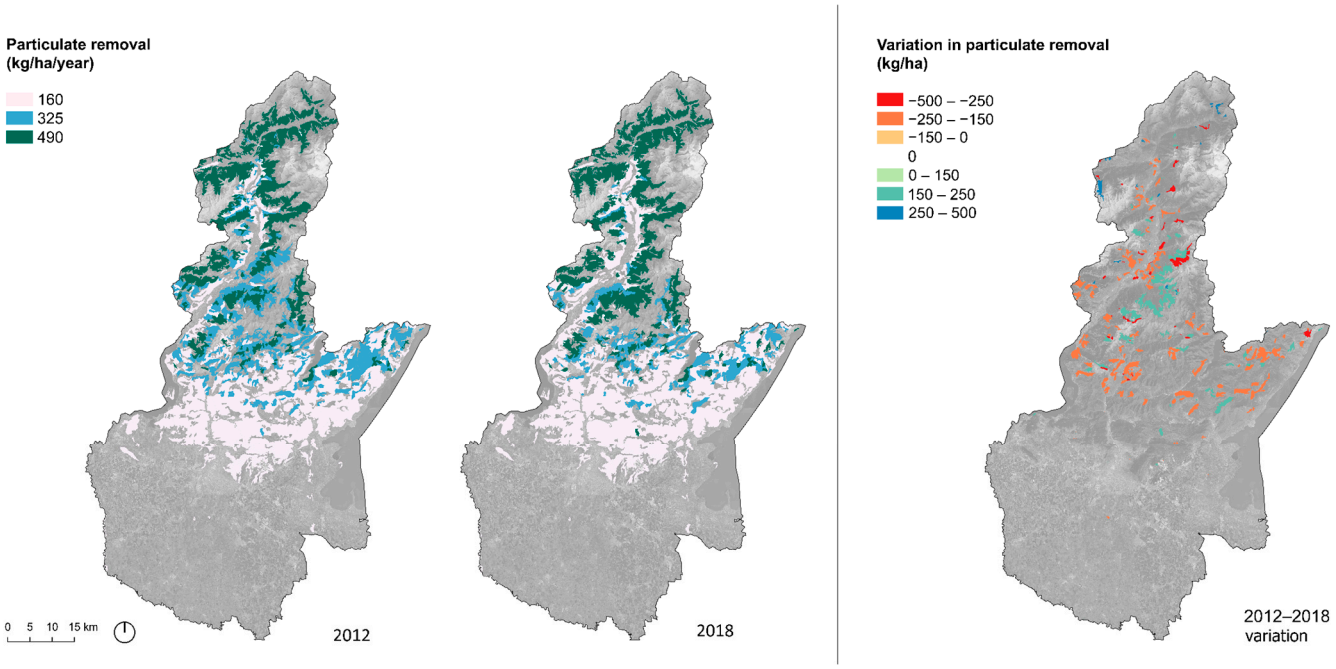



**Figure 12.** Maps of the biophysical assessment of particulate removal in 2012 and 2018. Source: own elaborations by authors.

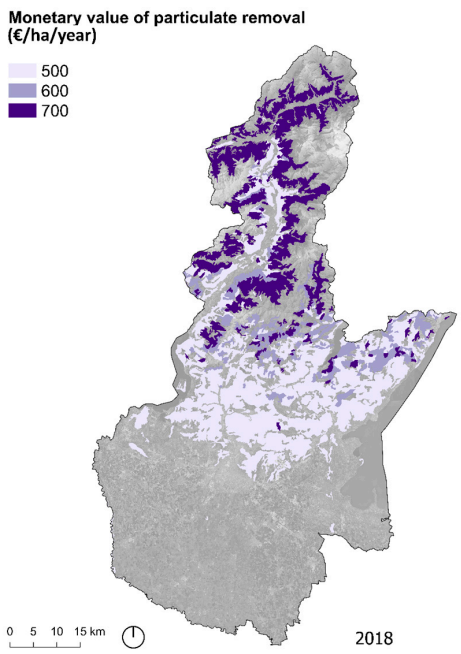
For more detailed information about the parameters used, refer to Table A10 in Appendix A.

Monetary Assessment

The monetary assessment of particulate removal was conducted based on the societal costs of PM10 pollution, which include health and environmental impacts, as outlined in the SNPA guidelines [64]. The range of unit monetary values (EUR/ha) from the European Environment Agency (EEA) was used, as referenced in the SNPA report, adjusted to 2024 values to account for inflation [121]. Due to the broad range of available values, a filtering approach was employed to narrow the range. In the absence of site-specific criteria for further refinement, a statistical method was adopted: values below the 25th percentile and above the 75th percentile were excluded. This resulted in a refined range of unit monetary values set between EUR 500/ha (for broadleaf forests) and EUR 700/ha (for coniferous forests), with mixed forests assigned a mid-range value of EUR 600/ha. The total monetary value of particulate removal in 2018 was calculated by multiplying these unit monetary values by the respective forest areas in Brescia Province. The results, categorized by land cover typology, are presented in Figure 13, alongside a map illustrating the spatial distribution of unit monetary values across the province (EUR/ha/year). For further details about the parameters and results, refer to Table A10 in Appendix A.

### 3.2.6. Hydrological Regime Regulation

In the Province of Brescia, hydrological regulation plays a vital role due to the region's diverse geomorphology, which encompasses mountainous, hilly, and lowland areas. These landscapes are particularly vulnerable to hydrogeological risks, including floods and landslides, especially during extreme weather events. The region's balance between agricultural land, natural areas, and increasing urbanization underscores the critical need to monitor and preserve water infiltration processes. Effective spatial planning in this region must prioritize strategies that enhance water infiltration and minimize soil sealing, both of which are essential for sustainable water management and mitigating hydrological hazards [98].




| CLC | | Monetary value (EUR/year) | |
|---|---|---|---|
| Code | Description | 2006 | 2012 |
| 311 | Broadleaf forests: | 38,097,500 | 43,520,072 |
| 312 | Coniferous forests | 28,284,200 | 14,491,946 |
| 313 | Mixed forests | 22,729,200 | 27,424,051 |
| Total | | 89,110,900 | 85,436,059 |

**Figure 13.** Mapping and results of the monetary assessment of particulate removal in 2012 and 2018. The map on the left shows unitary monetary values (absorption coefficients) related to LC in 2018. Source: own elaborations by authors.

Biophysical Assessment

The soil's capacity to regulate the hydrological regime was assessed using the "LIFE+ MGN" parametric methodology, which simplifies the evaluation by assigning coefficients (ranging from 0 to 5) for water retention based on land cover typologies [98]. The CLC 2018 dataset was utilized for the LC map and rasterized at a 10-meter resolution using QGIS software. Retention coefficients for the LC typologies were sourced from Nedkkov e Burkhard [123] and aligned with the CLC classification (refer to Table A11 in Appendix A). Nedkkov e Burkhard also provided literature-based insights into the water retention capacity of different land cover types, expressed as a percentage of average annual precipitation (%). In particular, by comparison with the work of Tate [124], the dimensionless LC coefficients were first converted into annual absorption percentages and subsequently converted into the annual absorbed volume by hectare ($m^3$/ha/year).

A similar analysis was conducted for 2012, using the CLC 2012 dataset and identical parameters to isolate the effects of land-use change on the hydrological regime regulation service. Figure 14 presents the biophysical mapping results for the hydrological regime regulation in 2012 and 2018, along with the observed variations in the ES during this period. Additional details on the parameters used can be found in Table A11 in Appendix A.

Monetary Assessment

For the monetary assessment of this service, the SNPA guidelines [64] were followed, assigning a unit monetary value of EUR 750 /$m^3$/100 years for flood prevention infrastructure. This value was updated for 2024 using the ISTAT monetary revaluation coefficient, resulting in EUR 10.27/$m^3$/year. The water volume absorbed by various land types, as determined in the biophysical assessment, was multiplied by the surface area of the corresponding land cover type, expressed in hectares (ha). This calculation yielded the total water absorption volume, expressed in cubic meters ($m^3$), which is critical for estimating the overall monetary value of the ecosystem service. The results of this assessment are presented in Figure 15 for 2012 and 2018. Additionally, Figure 15 includes a map of the unit

monetary values (EUR/ha/year) for 2018. Further details on the parameters and results can be found in Table A11 in Appendix A.

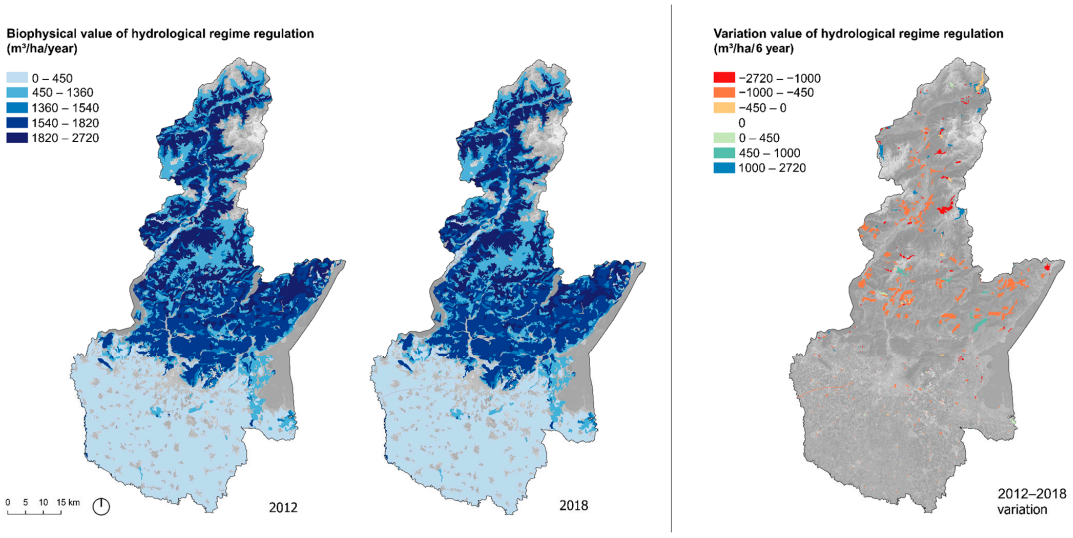
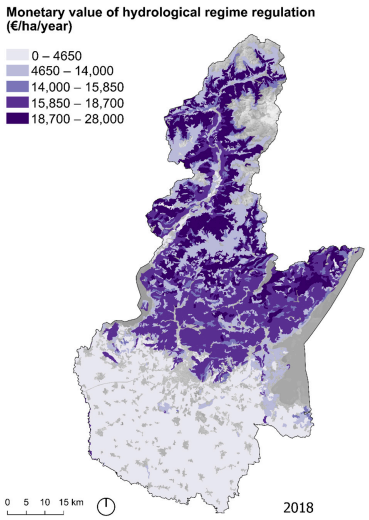



**Figure 14.** Maps of the biophysical assessment of hydrological regime regulation in 2012 and 2018. Source: own elaboration by authors.



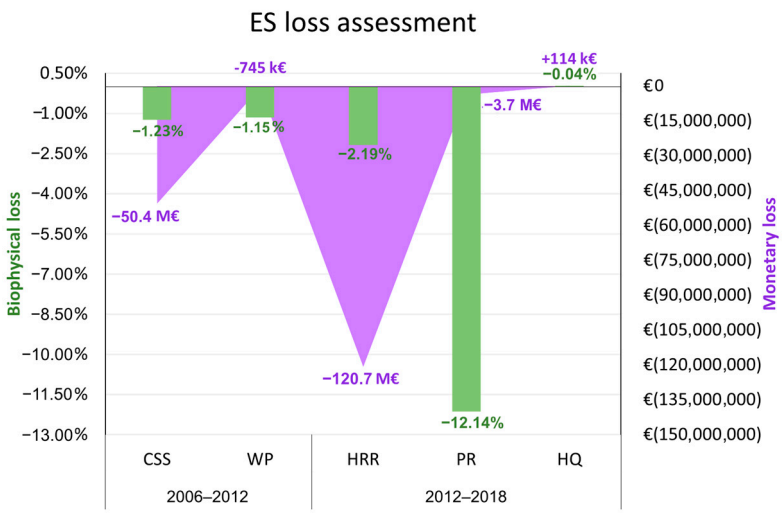

| CLC Code | Absorption coefficient | | Monetary value 2012 | Monetary value 2018 |
|---|---|---|---|---|
| 111 | 0% | 0 | 0 | 0 |
| 112 | 0% | 0 | 0 | 0 |
| 121 | 0% | 0 | 0 | 0 |
| 122 | 0% | 0 | 0 | 0 |
| 124 | 0% | 0 | 0 | 0 |
| 131 | 0% | 0 | 0 | 0 |
| 133 | 0% | 0 | 0 | 0 |
| 141 | 0% | 0 | 0 | 0 |
| 142 | 0% | 0 | 0 | 0 |
| 221 | 17% | 3 | 8,730,322 | 11,039,428 |
| 222 | 17% | 3 | 0 | 395,395 |
| 223 | 17% | 3 | 8,240,032 | 8,081,874 |
| 224 | 17% | 3 | 63,263 | 63,263 |
| 231 | 15% | 2 | 63,145,711 | 62,112,138 |
| 241 | 15% | 2 | 754,229 | 754,229 |
| 242 | 15% | 2 | 140,356,393 | 134,839,349 |
| 243 | 15% | 2 | 312,502,133 | 314,024,558 |
| 322 | 15% | 2 | 52,167,492 | 69,975,672 |
| 323 | 15% | 2 | 614,557 | 614,557 |
| 324 | 17% | 3 | 267,302,836 | 255,725,670 |
| 332 | 0% | 0 | 0 | 0 |
| 333 | 0% | 0 | 0 | 0 |
| 334 | 0% | 0 | 0 | 0 |

| CLC Code | Absorption coefficient | | Monetary value 2012 | Monetary value 2018 |
|---|---|---|---|---|
| 335 | 0% | 0 | 0 | 0 |
| 411 | 0% | 0 | 0 | 0 |
| 511 | 0% | 0 | 0 | 0 |
| 512 | 0% | 0 | 0 | 0 |
| 2111 | 5% | 1 | 668,560,055 | 664,465,406 |
| 2112 | 5% | 1 | 425,178 | 425,178 |
| 3111 | 20% | 4 | 5,196,209 | 4,691,541 |
| 3112 | 20% | 4 | 28,280,088 | 76,017,924 |
| 3113 | 20% | 4 | 896,009,642 | 925,224,300 |
| 3114 | 20% | 4 | 357,697,322 | 410,500,527 |
| 3115 | 20% | 4 | 131,288,394 | 203,624,112 |
| 3116 | 20% | 4 | 3,700,897 | 4,299,022 |
| 3117 | 20% | 4 | 1,999,980 | 2,467,265 |
| 3121 | 30% | 5 | 0 | 1,033,573 |
| 3122 | 30% | 5 | 30,839,578 | 4,6147,629 |
| 3123 | 30% | 5 | 940,048,429 | 915,745,501 |
| 3124 | 30% | 5 | 157,801,426 | 313,870,918 |
| 3131 | 30% | 5 | 511,171,586 | 306,663,843 |
| 3132 | 30% | 5 | 546,983,486 | 271,634,106 |
| 3211 | 15% | 2 | 277,863,477 | 294,959,330 |
| 3212 | 15% | 2 | 99,907,382 | 90,954,406 |
| 3231 | 15% | 2 | 0 | 614,557 |
| **Total** | | | 5,511,650,093 | 5,390,965,269 |

**Figure 15.** Mapping and results of the monetary assessment of the hydrological regime regulation in 2012 and 2018. The map on the left shows the unitary monetary values related to LC in 2018. Source: own elaborations by authors.

### 3.3. Overview and Evaluation of Results

The analyses revealed a total monetary loss solely attributed to land-use changes in the Province of Brescia, amounting to over EUR 51 million for the period 2006–2018 (with CSS assessed using the social cost method) and nearly EUR 125 million for the period 2012–2018. This variation is primarily due to differences in the ecosystem services analyzed rather than changes in land use across the periods examined. Figure 16 schematically illustrates the percentage change in the biophysical contribution of ecosystem services during the considered periods for the entire Province of Brescia. It shows that the most significant negative variation (representing a loss of ecosystem services) occurred for particulate removal, which decreased by −12.14% between 2012 and 2018. The only service that recorded a positive percentage variation was habitat quality, which will be discussed in more detail later. This service showed a slight increase of +0.04% in the period 2012–2018. This value, however, was derived from Figure 7 rather than the biophysical assessment in order to assign a value for each LC type. As shown in Figure 16, this positive change does not correlate to a proportional monetary loss (or gain). The service that exhibited the largest variation in monetary contribution (negative, indicating a loss) was hydrological regime regulation. Despite a −2.19% decrease in its biophysical contribution during 2012–2018, this service accounted for a total monetary loss of approximately EUR 121 million for the Province of Brescia. This loss is equivalent to roughly 0.2% of the province's GDP in 2018, with GDP calculated based on the per capita GDP for the Lombardy Region in 2018 (Territorial Economic Accounts 2019–2021 Lombardy (https://www.polis.lombardia.it/wps/wcm/connect/70f033b4-6ffb-468f-87ee-bd3676e8b233/WP-02+-+Conti+economici+territoriali+Lombardia_+2017-2019_Ancona_edgen2021.pdf?MOD=AJPERES&CACHEID=ROOTWORKSPACE-70f033b4-6ffb-468f-87ee-bd3676e8b233-nG.lDP6, last consultation: 2 November 2024).




| ES | Biophysical loss in the period (%) | Monetary loss in the period (EUR) |
|---|---|---|
| CSS | −1.23% | −50,398,100 |
| WP | −1.15% | −745,500 |
| HRR | −2.19% | −120,684,800 |
| PR | −12.14% | −3,675,600 |
| HQ | 0.04% | 113,600 |

Note: CSS: carbon storage and sequestration; WP: wood provision; HRR: hydrological regime regulation; PR: particulate removal; HQ: habitat quality. Please note that the reported losses refer to different time periods, as detailed in Figure 16.

**Figure 16.** Total biophysical and monetary loss in Brescia Province for the analyzed periods and ecosystem services. Source: own elaboration by authors.

## 4. Discussion

### 4.1. Critical Analysis of the Results

The analysis examined both the biophysical and monetary quantification of six ecosystem services: carbon storage and sequestration (CSS), habitat quality (HQ), crop pollination (CP), wood provision (WP), particulate removal (PR), and hydrological regime regulation (HRR). Each service was evaluated using different methods, reflecting variations in the available data and the specific requirements of each assessment.

The assessments relied on LC maps as proxies for soil data, particularly for soil-related ecosystem services, in line with established methodologies [8]. This approach assumes that the LC classification accurately represents variations in soil-related ecosystem services.

The time periods used for each assessment were determined by data availability and methodological requirements. For CSS and WP, the years 2006 and 2012 were selected. For HQ, CP, PR, and HRR, the years 2012 and 2018 were chosen. The different timeframes were necessary because some datasets, especially the Corine Land Cover (CLC) database, did not provide a detailed land cover (LC) map for 2018, which is crucial for assessing certain services.

Biophysical assessments for CSS, HQ, and CP employed modeling approaches using the InVEST model [64], while other services (WP, PR, and HRR) were assessed using a simpler parametric approach based on LC classes, following guidelines from the existing literature [98]. The use of InVEST enabled more detailed assessments, particularly for services such as HQ and CP.

The biophysical assessment resulted in additional maps for specific services. For example, the InVEST model provided a habitat degradation map for HQ and a map of pollinator abundance for CP. These maps added significant value to the biophysical analysis, enabling a more detailed understanding of ecosystem service dynamics.

The monetary valuation followed the guidelines provided by the SNPA [64], which involved associating parametric values with LC classes. These values were adjusted for inflation or updated when necessary. Five monetary maps were produced, corresponding to the most recent years for each service: 2012 for CSS and WP and 2018 for HQ, PR, and HRR.

A significant limitation in the monetary assessment arose for CP. Due to the absence of a crop land-use map for the Province of Brescia, the results for CP could not be mapped in monetary terms. Additionally, agricultural production data for the analysis were only available for the 2023–24 period from ISTAT, which made estimates for earlier years impossible.

Given these strengths and weaknesses, the critical interpretation of the results focuses on several key aspects. First, it examines the use of the InVEST model, particularly in the construction of habitat quality. This model generates output based on the type of input information (data) provided, which is often influenced by both the local value system and the planning objectives (Section 4.1.1). Additionally, the importance of a cross-critical interpretation of the outputs generated by the sub-models is emphasized to accurately assess the phenomena and the impact of land transformation actions on habitats (Section 4.1.2). Finally, the text highlights the necessity of verifying the LC data structure at different historical thresholds to avoid misinterpretations of ongoing phenomena, including the need to validate the outputs through detailed checks on known cases (Section 4.1.3).

#### 4.1.1. InVEST Model: Habitat Quality

A critical analysis of the InVEST model's operation for the evaluated ecosystem services reveals that, despite its more complex modeling approach compared to simple parametric associations, the sub-models for carbon storage and sequestration (CSS) and crop pollination (CP) (perhaps as they are not fully utilized in this analysis) calculate the required services using only geo-referenced LC data. These sub-models associate site-specific and ad hoc-calculated parameters with this information. The only service that incorporates an additional layer of geo-referenced information beyond LC is habitat quality (HQ), which yields results that are more substantial, informative, and nuanced in interpretation. This enhancement can be closely linked to spatial planning objectives. For example, agriculture can be considered both a threat and a habitat by planners. Ultimately, the threat inputs required by the model are still based on LC data. Variables reflecting climatic variations across the territory, or those related to point or diffuse pollution, disturbances, or other

local threats, were neither included in the model nor supported. Nevertheless, it is crucial to interpret the results for the HQ service in the context of the input data concerning threats to habitat quality in the area. As detailed by Sallustio et al. [117] and elaborated in Section 3, the threats considered in this analysis for the habitat quality assessment include the following: road and rail infrastructures, classified by functional type; intensive and extensive agriculture; and the soil consumed. Figure 17 illustrates these threats. In the Province of Brescia, a traditionally agricultural region, the most significant contribution to habitat threats, in distributive terms, arose from cultivated fields. However, the impact parameters may vary depending on the specific land use (habitat) considered.

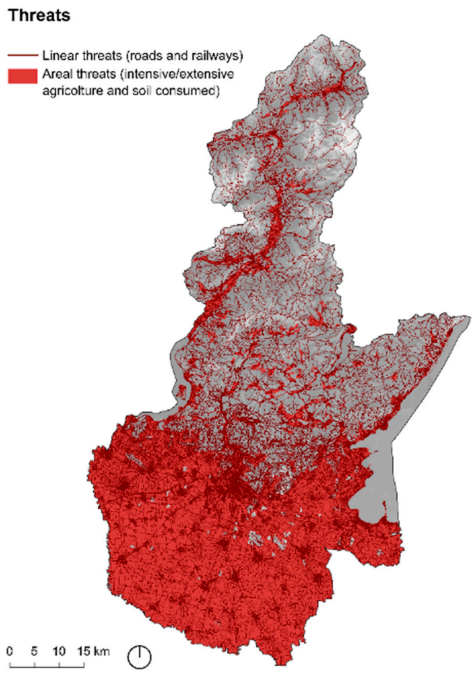



**Figure 17.** Threats considered in Brescia Province as inputs for the habit quality model. Source: own elaborations by authors.

This variation in impact explains the observed differences in HQ across the province. For instance, the habitat value in Po Valley (southern zone) is significantly lower compared to the hill and mountain regions further north. In contrast, the habitat degradation values follow an opposite pattern (see Figures 5 and 6 in Section 3).

#### 4.1.2. Cross-Critical Interpretation of the Model Outputs

Furthermore, a cross-critical interpretation of the ES maps is essential. For example, our analysis revealed a linear feature in the southwestern part of the province. A comparison of the HQ maps from 2012 and 2018 (in Figure 18) showed an increase in habitat quality in this area. This feature corresponds to the BreBeMi highway (A35), which was already completed by 2018 but did not exist in 2012, as confirmed by the LC maps.

This observed increase was likely due to the fact that, by 2018, the road was classified as "non-habitat" (Hj = 0) by the model. As a result, the degradation map value for that cell became zero, and no additional impacts were calculated. When a cell is classified as "non-habitat" by the model, it is not influenced by any threats within that cell since it is considered unsuitable for habitats. However, the suitability of adjacent habitat cells in 2018 may still contribute positively to the HQ value. In contrast, in 2012, the cell was still classified as a habitat and was, thus, impacted by mapped threats, resulting in a degradation value above zero and a lower habitat quality value.

These aspects highlight how the HQ model is more complex than other InVEST models. This increased complexity leads to a greater sensitivity to the quality of input data, requiring a critical a posteriori interpretation of the results. As demonstrated in the example above, such complexity can result in values that might initially seem illogical. In light of these considerations, a detailed analysis of the results suggests that the apparent improvement in habitat quality across the province from 2012 to 2018 is likely a consequence of this complexity.

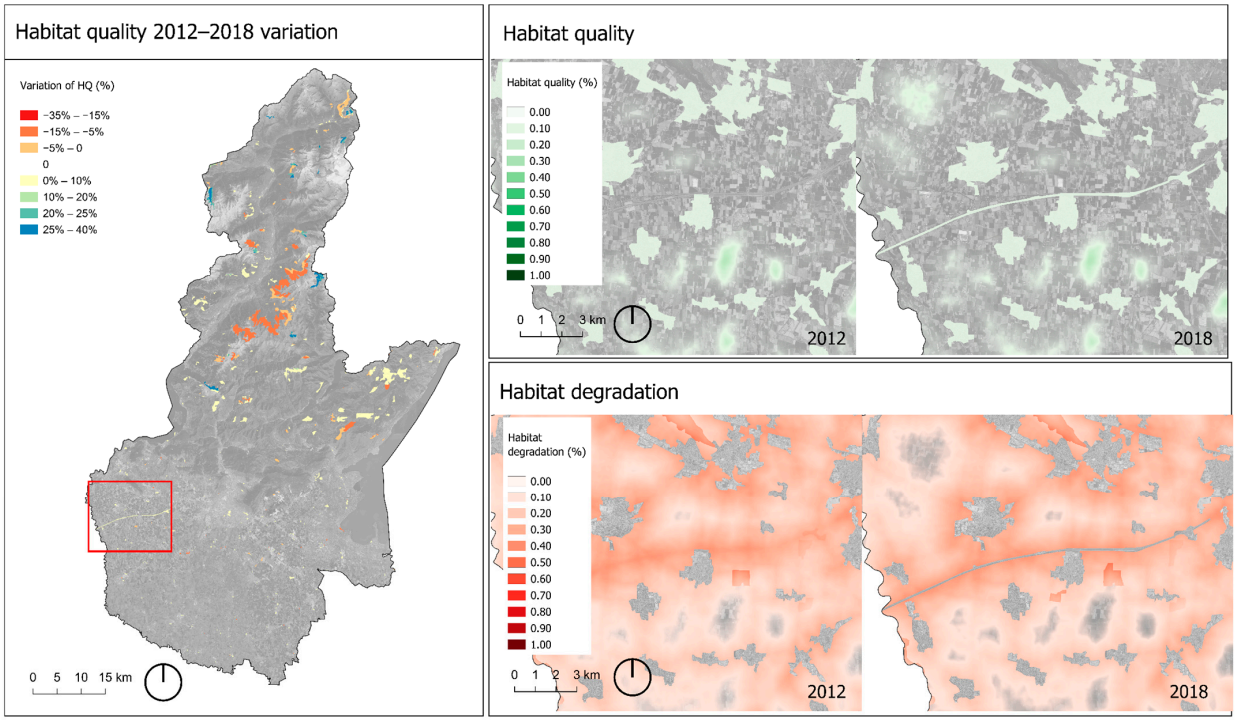



**Figure 18.** Details of habitat quality and habitat degradation maps in 2012 and 2018 in the area of highway construction (BreBeMi). Source: own elaborations by authors.

### 4.1.3. Land Cover Updates or Changes

For the remaining ecosystem services analyzed, the results can be more easily interpreted by examining the variation in LC across the area. For example, the percentage change in areas associated with LC classes from the CLC database is shown for the three years analyzed across the entire Province of Brescia (Figure 19). The most critical classes for evaluation are those related to forest land use, such as carbon storage and sequestration (CSS), wood provision (WP), and particulate removal (PR) services, which were derived exclusively from the assessment due to the variation in these classes. In our case, the most significant differences observed related to mixed forests (code 313) compared to broad-leaved forests (311) and coniferous forests (312). The total area designated for these three covers appeared to be unchanged across the three years considered. Notably, the absence of the mixed forest class in 2006 coincides with an increase in both broad-leaved and coniferous forests. It remains unclear whether this discrepancy arose from errors in the CLC 2006 input layer (despite class 313 being included in the legend) or if it reflects an actual increase in this forest type in subsequent years. Regardless, this variation likely played a substantial role in altering the provision of ecosystem services in the study area.

As emphasized throughout, the goal of this analysis should extend beyond simply raising awareness among policymakers about the importance of ESs. Future assessments should prioritize the preservation of these services. Moreover, these evaluations must provide policymakers with the necessary tools to assess land-use decisions. More importantly, they should highlight the crucial role and potential of ecosystems in the study area,

examining the impacts of transformations on the provision of essential ecosystem services not only for environmental health but also for human well-being, society, and the economy.

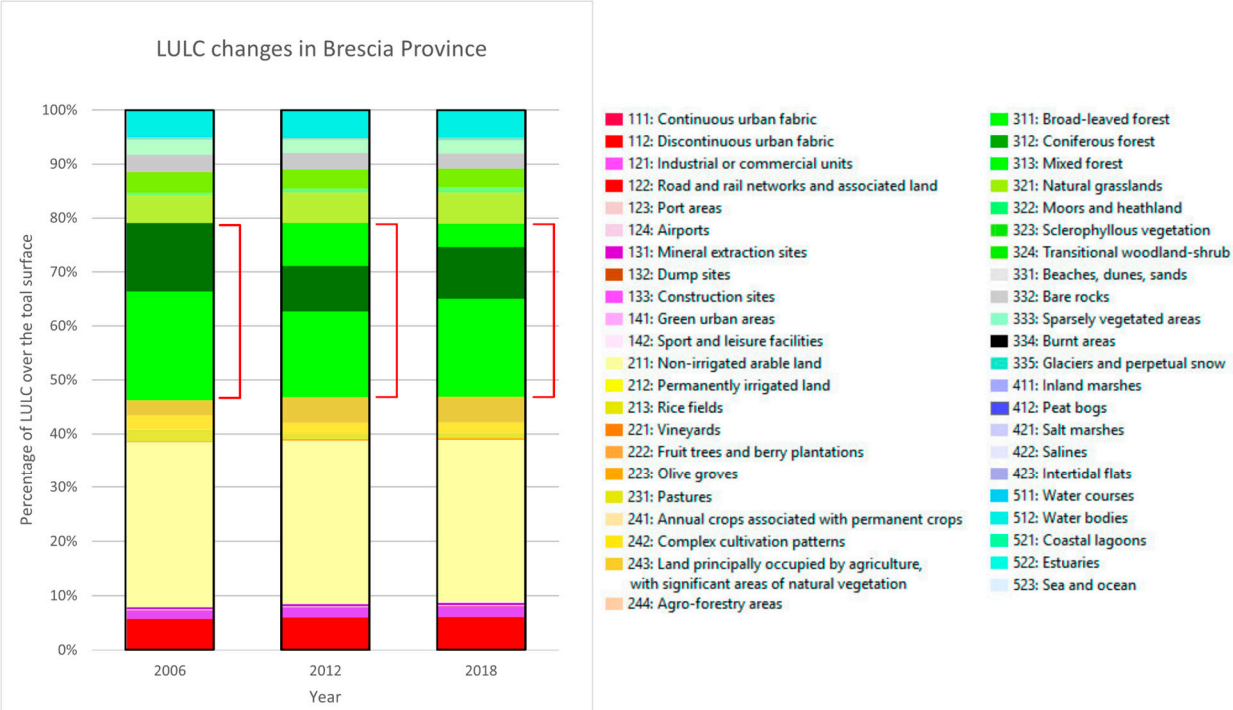



**Figure 19.** Variation in LC in Brescia Province during the years considered, with the most relevant variations highlighted by a red bracket. Source: own elaborations by authors.

In addition to the cumulative analysis, it is vital to interpret the spatial distribution of the results across the territory, from which contextualized conclusions can be drawn. These interpretations can guide planning, conservation, and land restoration strategies, supported by the economic and fiscal incentive tools discussed in the Introduction, which are well-documented in the literature.

## 5. Conclusions

The analysis presented in this paper introduces novel features, both in terms of the spatial context and the local scale (NUTS3) at which it was conducted. Despite limitations stemming from the scarcity and weaknesses of several input datasets—which constrained the analysis of ecosystem services to three different time scales and hindered the creation of a comprehensive depiction of their variations—the results offer valuable insights for local policymakers. Additionally, these findings open avenues for exploring potential tools to support territorial resource management and planning. The monetary valuation of ecosystem services, which complements the biophysical assessment, proved particularly beneficial in this context. It has the potential to engage stakeholders not only as direct beneficiaries of ESs managed in the form of private goods (e.g., food or timber supply for landowners) but also as indirect beneficiaries of the preservation of other ESs within the territory [57,125]. Moreover, governance models such as network governance provide promising frameworks for supporting PES programs. These models emphasize the "horizontal" structure of decision-making, fostering collective and inclusive processes that are sensitive to power dynamics among stakeholders. Such approaches are particularly valuable in the complex and uncertain contexts related to ecosystem services [18,126].

This inclusive governance model aligns with the evolving direction of ES trade-off analysis, emphasizing the importance of stakeholder engagement and the real flows of

ecosystem services. In contrast, simplified overlay analyses often fail to capture the intricate dynamics of ecosystem processes [18]. According to several authors, trade-offs among ESs most frequently occur between agricultural supply services and other services, such as those related to the regulation of hydrological regimes [65], or among forest ecosystem services (FESs). These FESs include carbon sequestration, the provision of timber and other raw materials, PM10 sequestration, and hydrological regulation [57]. Achieving a balance in the management of FESs is particularly complex and delicate, leading to the coining of the term Balanced Forest Ecosystem Services Management (BFESM) to describe this challenge [57].

Future analyses must delve deeper into these trade-offs and differentiate between the theoretical and actual flows of ecosystem services. The latter involves the intersection between the provision of ecosystem services (as assessed in the current study) and the presence of beneficiaries who demand and utilize these services [127]. This type of assessment is conceptually crucial. As noted by Costanza et al. [7], ecosystems cannot deliver benefits to people without the interplay of human capital (people), social capital (communities), and built capital (infrastructure and buildings). Additionally, it is well-documented in the literature that limiting assessments to theoretical flows of ecosystem services without accounting for actual flows can result in overestimations [128]. However, it is acknowledged that recent studies attempting to bridge this gap—by overlaying service delivery with service utilization—often lack theoretical, terminological, and methodological consistency [127,128]. These evaluations are inherently complex. While the delivery of ESs was effectively tested in the current case study, incorporating utilization metrics could provide more critical insights for future spatial planning research.

Burkhard's matrix model, published in 2014 [129,130], has garnered significant recognition for assessing the supply and demand of ecosystem services across various European and Asian regions [123,131,132]. However, applying matrices calibrated for overly generic spatial contexts—such as Burkhard's matrices for the European continent—introduces uncertainties in the results [133]. Furthermore, as previously mentioned, simple overlay methods fail to accurately map and value ecosystem services due to their inability to capture the complex spatial and temporal dynamics of service flows, which can vary significantly depending on scale and environmental factors [127,134–138].

Future research could focus on integrating assessments of the supply and demand for ecosystem services to provide a clearer understanding of the land-use dynamics, needs, and trade-offs that emerge between different ecosystem services.

Thus, the qualitative insights derived from Burkhard's framework can guide future analytical developments, emphasizing regions with a high ecosystem services demand or those experiencing transitions toward increased demand due to ongoing land cover changes.

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# Appendix A

## *Appendix A.1. Carbon Storage and Sequestration*

**Table A1.** Correspondence between CLC LC codes (2006/2012) and INFC forest inventory codes. Source: adaptation from [111].

| INFC | | CLC | |
|---|---|---|---|
| **Code** | **Description** | **Code** | **Description** |
| 1 | Larch and Swiss pine forests | 3124 | Forests predominantly of larch and/or Swiss pine |
| 2 | Spruce forests | 31323 | Mixed coniferous and broadleaf forests predominantly of fir |
| | | 3123 | Forests predominantly of fir |
| 3 | Silver fir forests | 31323 | Mixed coniferous and broadleaf forests predominantly of fir |
| | | 3123 | Forests predominantly of fir |
| 4 | Scots pine and mountain pine forests | 3122 | Forests predominantly of oro-Mediterranean and mountain pines |
| | | 31322 | Mixed coniferous and broadleaf forests predominantly of oro-Mediterranean and mountain pines |
| 5 | Black pine, Corsican pine, and Bosnian pine forests | 3122 | Forests predominantly of oro-Mediterranean and mountain pines |
| | | 31322 | Mixed coniferous and broadleaf forests predominantly of oro-Mediterranean and mountain pines |
| 6 | Mediterranean pine forests | 3121 | Forests predominantly of Mediterranean pines and cypresses |
| | | 31321 | Mixed coniferous and broadleaf forests predominantly of Mediterranean pines and cypresses |
| 7 | Other coniferous forests, pure or mixed | 3125 | Forests and former plantations predominantly of exotic conifers |
| | | 31325 | Mixed coniferous and broadleaf forests predominantly of exotic conifers |
| 8 | Beech forests | 3115 | Forests predominantly of beech |
| | | 31315 | Mixed coniferous and broadleaf forests predominantly of beech |
| 9 | Sessile oak, Downy oak, and English oak forests | 3112 | Forests predominantly of deciduous oaks |
| | | 31312 | Mixed coniferous and broadleaf forests predominantly of deciduous oaks |
| 10 | Turkey oak, Hungarian oak, Macedonian oak, Valonia oak forests | 3112 | Forests predominantly of deciduous oaks |
| | | 31312 | Mixed coniferous and broadleaf forests predominantly of deciduous oaks |
| 11 | Chestnut forest | 3114 | Forests predominantly of chestnut |
| | | 31314 | Mixed coniferous and broadleaf forests predominantly of chestnut |
| 12 | Hop-hornbeam and hornbeam forests | 3113 | Mixed forests predominantly of other native broadleaf specie |
| | | 31313 | Mixed coniferous and broadleaf forests predominantly of other native broadleaf species |
| 13 | Hygrophilous forests | 3116 | Forests predominantly of hygrophilous species |
| | | 31316 | Mixed coniferous and broadleaf forests predominantly of hygrophilous species |
| 14 | Other deciduous forests | 3117 | Forests and former plantations predominantly of exotic broadleaf species |
| | | 31317 | Mixed coniferous and broadleaf forests predominantly of exotic species |
| 15 | Holm oak forests | 3111 | Forests predominantly of oaks and other evergreen broadleaf species |
| | | 31311 | Mixed coniferous and broadleaf forests predominantly of oaks and other evergreen broadleaf species |
| 16 | Cork oak forests | 3111 | Forests predominantly of oaks and other evergreen broadleaf species |
| | | 31311 | Mixed coniferous and broadleaf forests predominantly of oaks and other evergreen broadleaf species |
| 17 | Other evergreen broadleaf forests | | / |
| 18 | Artificial poplar plantations | | / |
| 19 | Other broadleaf plantations | | / |
| 20 | Conifer plantations | | / |
| 21 | Subalpine shrublands | | / |
| 22 | Temperate shrublands | | / |
| 23 | Mediterranean scrub and shrublands | | / |

**Table A2.** C content (t/ha) in each of the four carbon pools considered for each CLC LC class in 2006 and 2012. Source: own elaborations from INFC 2005 and 2015 databases.

| CLC—Code | CLC Description | Aboveground Biomass (tC/ha) | Belowground Biomass (tC/ha) | Soil Organic Matter (tC/ha) | Dead Organic Matter (tC/ha) |
|---|---|---|---|---|---|
| 3111 | Forests predominantly of oaks and other evergreen broadleaf species | 0.0 | 0.0 | 0.0 | 0.0 |
| 3112 | Forests predominantly of deciduous oaks | 55.7 | 0.0 | 65.7 | 8.8 |
| 3113 | Mixed forests predominantly of other native broadleaf specie | 38.5 | 0.0 | 105.9 | 3.2 |
| 3114 | Forests predominantly of chestnut | 84.4 | 0.0 | 106.3 | 16.2 |
| 3115 | Forests predominantly of beech | 86.1 | 0.0 | 85.2 | 8.2 |
| 3116 | Forests predominantly of hygrophilous species | 43.3 | 0.0 | 86.8 | 12.6 |
| 3117 | Forests and former plantations predominantly of exotic broadleaf species | 54.7 | 0.0 | 82.1 | 6.9 |
| 3121 | Forests predominantly of Mediterranean pines and cypresses | 0.0 | 0.0 | 0.0 | 0.0 |
| 3122 | Forests predominantly of oro-Mediterranean and mountain pines | 59.5 | 0.0 | 102.0 | 11.0 |
| 3123 | Forests predominantly of fir | 102.6 | 0.0 | 95.9 | 24.5 |
| 3124 | Forests predominantly of larch and/or Swiss pine | 71.2 | 0.0 | 101.4 | 11.9 |
| 3125 | Forests and former plantations predominantly of exotic conifers | 67.5 | 0.0 | 74.4 | 9.0 |
| 31311 | Mixed coniferous and broadleaf forests predominantly of oaks and other evergreen broadleaf species | 0.0 | 0.0 | 0.0 | 0.0 |
| 31312 | Mixed coniferous and broadleaf forests predominantly of deciduous oaks | 55.7 | 0.0 | 65.7 | 8.8 |
| 31313 | Mixed coniferous and broadleaf forests predominantly of other native broadleaf species | 38.5 | 0.0 | 105.9 | 3.2 |
| 31314 | Mixed coniferous and broadleaf forests predominantly of sweet chestnut | 84.4 | 0.0 | 106.3 | 16.2 |
| 31315 | Mixed coniferous and broadleaf forests predominantly of beech | 86.1 | 0.0 | 85.2 | 8.2 |
| 31316 | Mixed coniferous and broadleaf forests predominantly of hygrophilous species | 43.3 | 0.0 | 86.8 | 12.6 |
| 31317 | Mixed coniferous and broadleaf forests predominantly of exotic species | 54.7 | 0.0 | 82.1 | 6.9 |
| 31321 | Mixed coniferous and broadleaf forests predominantly of Mediterranean pines and cypresses | 0.0 | 0.0 | 0.0 | 0.0 |
| 31322 | Mixed coniferous and broadleaf forests predominantly of oro-Mediterranean and mountain pines | 59.5 | 0.0 | 102.0 | 11.0 |
| 31323 | Mixed coniferous and broadleaf forests predominantly of fir | 102.6 | 0.0 | 95.9 | 24.5 |
| 31325 | Mixed coniferous and broadleaf forests predominantly of exotic conifers | 67.5 | 0.0 | 74.4 | 9.0 |

**Table A3.** Biophysical surfaces and monetary values for CSS for each CLC LC class in 2006 and 2012. Source: own elaborations by authors from INFC 2005 and 2015 databases.

| CLC—Code | Total C Stored (t/ha) | Surface (ha) | | Monetary Value | | | |
|---|---|---|---|---|---|---|---|
| | | | | Social Cost (EUR) | | Market Price (EUR) | |
| | | 2006 | 2012 | 2006 | 2012 | 2006 | 2012 |
| **3111** | 0 | 308 | 315 | 0 | 0 | 0 | 0 |
| **31311** | | | | | | | |
| **3112** | 130.2 | 1485 | 1512 | 28,178,392 | 28,690,726 | 5,413,716 | 5,512,147 |
| **31312** | | | | | | | |
| **3116** | 142.7 | 125 | 199 | 2,599,637 | 4,138,623 | 499,450 | 795,124 |
| **31316** | | | | | | | |
| **3117** | 143.7 | 116 | 106 | 2,429,369 | 2,219,941 | 466,738 | 426,502 |
| **31317** | | | | | | | |
| **3113** | 147.6 | 62,775 | 61,202 | 1,350,367,087 | 1,316,529,931 | 259,436,520 | 252,935,626 |
| **31313** | | | | | | | |
| **3122** | 172.5 | 4851 | 4404 | 121,954,868 | 110,717,221 | 23,430,330 | 21,271,320 |
| **31322** | | | | | | | |
| **3115** | 179.5 | 8490 | 9439 | 222,101,202 | 246,927,355 | 42,670,740 | 47,440,414 |
| **31315** | | | | | | | |
| **3124** | 184.5 | 5768 | 5645 | 155,095,925 | 151,788,574 | 29,797,488 | 29,162,070 |
| **31324** | | | | | | | |
| **3114** | 206.9 | 23,242 | 21,671 | 700,830,111 | 653,458,796 | 134,645,554 | 125,544,437 |
| **31314** | | | | | | | |
| **3123** | 223 | 46,031 | 46,606 | 1,496,008,421 | 1,514,695,932 | 287,417,564 | 291,007,864 |
| **31323** | | | | | | | |
| **3121** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **31321** | | | | | | | |
| **Total** | | | | 4,079,565,011 | 4,029,167,098 | 783,778,100 | 774,095,504 |

## *Appendix A.2. Habitat Quality*

**Table A4.** Correspondence between CLC LC codes (2018) and habitat categories introduced in [117]. Source: own elaboration by authors.

| CLC—Code | CLC Description | Habitat Category Assigned |
|---|---|---|
| 111 | Continuous urban fabric | Buildings and other artificial areas or impervious soils |
| 112 | Discontinuous urban fabric | Buildings and other artificial areas or impervious soils |
| 121 | Industrial or commercial units and public facilities | Buildings and other artificial areas or impervious soils |
| 122 | Road and rail networks and associated land | Buildings and other artificial areas or impervious soils |
| 123 | Port areas | Buildings and other artificial areas or impervious soils |
| 124 | Airports | Open urban areas |
| 131 | Mineral extraction sites | Open urban areas |
| 132 | Dump sites | Open urban areas |
| 133 | Construction sites | Open urban areas |
| 141 | Green urban areas | Grasslands |
| 142 | Sport and leisure facilities | Grasslands |
| 211 | Non-irrigated arable land | Intensive agricultural lands |
| 212 | Permanently irrigated arable land | Intensive agricultural lands |
| 213 | Rice fields | Extensive agricultural lands |

**Table A4.** *Cont.*

| CLC—Code | CLC Description | Habitat Category Assigned |
|---|---|---|
| 221 | Vineyards | Extensive agricultural lands |
| 222 | Fruit tree and berry plantations | Extensive agricultural lands |
| 223 | Olive groves | Extensive agricultural lands |
| 231 | Pastures, meadows and other permanent grasslands under agricultural use | Grasslands |
| 241 | Annual crops associated with permanent crops | Extensive agricultural lands |
| 242 | Complex cultivation patterns | Intensive agricultural lands |
| 243 | Land principally occupied by agriculture, with significant areas of natural vegetation | Intensive agricultural lands |
| 244 | Agro-forestry areas | Extensive agricultural lands |
| 311 | Broad-leaved forest | Broadleaves forests |
| 312 | Coniferous forest | Conifer forests |
| 313 | Mixed forest | (Broadleaves forests + Conifer forests)/2 |
| 321 | Natural grassland | Grasslands |
| 322 | Moors and heathland | Shrublands |
| 323 | Sclerophyllous vegetation | Shrublands |
| 324 | Transitional woodland/shrub | Inland unvegetated or sparsely vegetated areas |
| 331 | Beaches, dunes, and sand plains | Beaches, dune and, sands |
| 332 | Bare rock | Inland unvegetated or sparsely vegetated areas |
| 333 | Sparsely vegetated areas | Inland unvegetated or sparsely vegetated areas |
| 334 | Burnt areas | Inland unvegetated or sparsely vegetated areas |
| 335 | Glaciers and perpetual snow | Inland unvegetated or sparsely vegetated areas |
| 411 | Inland marshes | Wetlands |
| 412 | Peatbogs | Wetlands |
| 421 | Coastal salt marshes | Wetlands |
| 422 | Salines | Water bodies |
| 511 | Water courses | Water bodies |
| 512 | Water bodies | Water bodies |
| 521 | Coastal lagoons | Water bodies |
| 522 | Estuaries | Water bodies |

**Table A5.** Sensitivity table for each CLC LC class in 2018 with reference to the threats considered. Source: [117].

| CLC—Code | Habitat Suitability | Sensitivity to Threats | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Intensive Agriculture | Extensive Agriculture | Soil Consumed | Railways | Road 1 | Road 2 | Road 3 | Road 4 |
| 111 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 112 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 121 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 122 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 123 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 124 | 0.27 | 0.31 | 0.21 | 0.56 | 0.46 | 0.56 | 0.52 | 0.46 | 0.19 |
| 131 | 0.27 | 0.31 | 0.21 | 0.56 | 0.46 | 0.56 | 0.52 | 0.46 | 0.19 |
| 132 | 0.27 | 0.31 | 0.21 | 0.56 | 0.46 | 0.56 | 0.52 | 0.46 | 0.19 |
| 133 | 0.27 | 0.31 | 0.21 | 0.56 | 0.46 | 0.56 | 0.52 | 0.46 | 0.19 |
| 141 | 0.86 | 0.75 | 0.52 | 0.72 | 0.60 | 0.80 | 0.71 | 0.63 | 0.42 |

**Table A5.** *Cont.*

| CLC—Code | Habitat Suitability | Sensitivity to Threats | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Intensive Agriculture | Extensive Agriculture | Soil Consumed | Railways | Road 1 | Road 2 | Road 3 | Road 4 |
| 142 | 0.86 | 0.75 | 0.52 | 0.72 | 0.60 | 0.80 | 0.71 | 0.63 | 0.42 |
| 211 | 0.26 | 0.00 | 0.12 | 0.51 | 0.44 | 0.61 | 0.54 | 0.47 | 0.24 |
| 212 | 0.26 | 0.00 | 0.12 | 0.51 | 0.44 | 0.61 | 0.54 | 0.47 | 0.24 |
| 213 | 0.52 | 0.54 | 0.00 | 0.62 | 0.51 | 0.71 | 0.61 | 0.55 | 0.26 |
| 221 | 0.52 | 0.54 | 0.00 | 0.62 | 0.51 | 0.71 | 0.61 | 0.55 | 0.26 |
| 222 | 0.52 | 0.54 | 0.00 | 0.62 | 0.51 | 0.71 | 0.61 | 0.55 | 0.26 |
| 223 | 0.52 | 0.54 | 0.00 | 0.62 | 0.51 | 0.71 | 0.61 | 0.55 | 0.26 |
| 231 | 0.86 | 0.75 | 0.52 | 0.72 | 0.60 | 0.80 | 0.71 | 0.63 | 0.42 |
| 241 | 0.52 | 0.54 | 0.00 | 0.62 | 0.51 | 0.71 | 0.61 | 0.55 | 0.26 |
| 242 | 0.26 | 0.00 | 0.12 | 0.51 | 0.44 | 0.61 | 0.54 | 0.47 | 0.24 |
| 243 | 0.26 | 0.00 | 0.12 | 0.51 | 0.44 | 0.61 | 0.54 | 0.47 | 0.24 |
| 244 | 0.52 | 0.54 | 0.00 | 0.62 | 0.51 | 0.71 | 0.61 | 0.55 | 0.26 |
| 311 | 0.93 | 0.67 | 0.47 | 0.77 | 0.65 | 0.85 | 0.77 | 0.66 | 0.40 |
| 312 | 0.82 | 0.63 | 0.44 | 0.76 | 0.61 | 0.84 | 0.76 | 0.68 | 0.39 |
| 313 | 0.87 | 0.65 | 0.46 | 0.77 | 0.63 | 0.85 | 0.77 | 0.67 | 0.40 |
| 321 | 0.86 | 0.75 | 0.52 | 0.72 | 0.60 | 0.80 | 0.71 | 0.63 | 0.42 |
| 322 | 0.81 | 0.72 | 0.51 | 0.69 | 0.60 | 0.78 | 0.71 | 0.63 | 0.39 |
| 323 | 0.81 | 0.72 | 0.51 | 0.69 | 0.60 | 0.78 | 0.71 | 0.63 | 0.39 |
| 324 | 0.55 | 0.51 | 0.35 | 0.61 | 0.46 | 0.61 | 0.57 | 0.52 | 0.30 |
| 331 | 0.74 | 0.68 | 0.51 | 0.86 | 0.67 | 0.81 | 0.46 | 0.69 | 0.50 |
| 332 | 0.55 | 0.51 | 0.35 | 0.61 | 0.46 | 0.61 | 0.57 | 0.52 | 0.30 |
| 333 | 0.55 | 0.51 | 0.35 | 0.61 | 0.46 | 0.61 | 0.57 | 0.52 | 0.30 |
| 334 | 0.55 | 0.51 | 0.35 | 0.61 | 0.46 | 0.61 | 0.57 | 0.52 | 0.30 |
| 335 | 0.55 | 0.51 | 0.35 | 0.61 | 0.46 | 0.61 | 0.57 | 0.52 | 0.30 |
| 411 | 0.96 | 0.80 | 0.59 | 0.79 | 0.64 | 0.84 | 0.74 | 0.69 | 0.44 |
| 412 | 0.96 | 0.80 | 0.59 | 0.79 | 0.64 | 0.84 | 0.74 | 0.69 | 0.44 |
| 421 | 0.96 | 0.80 | 0.59 | 0.79 | 0.64 | 0.84 | 0.74 | 0.69 | 0.44 |
| 422 | 0.83 | 0.76 | 0.53 | 0.72 | 0.51 | 0.72 | 0.64 | 0.60 | 0.36 |
| 511 | 0.83 | 0.76 | 0.53 | 0.72 | 0.51 | 0.72 | 0.64 | 0.60 | 0.36 |
| 512 | 0.83 | 0.76 | 0.53 | 0.72 | 0.51 | 0.72 | 0.64 | 0.60 | 0.36 |
| 521 | 0.83 | 0.76 | 0.53 | 0.72 | 0.51 | 0.72 | 0.64 | 0.60 | 0.36 |
| 522 | 0.83 | 0.76 | 0.53 | 0.72 | 0.51 | 0.72 | 0.64 | 0.60 | 0.36 |

**Table A6.** Threat table for each threat considered. Source: [117].

| Threat | OSM Classification | Maximum Distance | Weight |
|---|---|---|---|
| Intensive agriculture | / | 1.60 | 0.69 |
| Extensive agriculture | / | 0.60 | 0.42 |
| Soil consumed | / | 1.70 | 0.79 |
| Railways | railways | 1.60 | 0.62 |
| Road 1 | highways, major roads, primary roads | 1.50 | 0.86 |
| Road 2 | secondary roads, tertiary roads | 1.00 | 0.69 |
| Road 3 | residential roads, service roads | 0.90 | 0.61 |
| Road 4 | dirt roads, bridleways | 0.30 | 0.28 |

**Table A7.** Surfaces and monetary values of HQ for each CLC LC class in 2012 and 2018. Source: own elaborations by authors.

| CLC—Code | Habitat Category | Surface (ha) | | Unit Monetary Value (EUR/ha) | Monetary Value (EUR) | |
|---|---|---|---|---|---|---|
| | | 2012 | 2018 | | 2012 | 2018 |
| 111 | Buildings and other artificial areas or impervious soils | 1059 | 1059 | 106.83 | 113,133 | 113,133 |
| 112 | Buildings and other artificial areas or impervious soils | 27,785 | 28,226 | 106.83 | 2,968,272 | 3,015,384 |
| 121 | Buildings and other artificial areas or impervious soils | 8771 | 9195 | 106.83 | 937,006 | 982,302 |
| 122 | Buildings and other artificial areas or impervious soils | 98 | 323 | 106.83 | 10,469 | 34,506 |
| 124 | Open urban areas | 923 | 929 | 320.49 | 295,812 | 297,735 |
| 131 | Open urban areas | 1695 | 1835 | 320.49 | 543,231 | 588,099 |
| 133 | Open urban areas | 99 | 91 | 320.49 | 31,729 | 29,165 |
| 141 | Grasslands | 81 | 54 | 1131.8 | 91,676 | 61,117 |
| 142 | Grasslands | 433 | 740 | 1131.8 | 490,069 | 837,532 |
| 211 | Intensive agricultural lands | 144,753 | 143,869 | 308.62 | 44,673,671 | 44,400,851 |
| 221 | Extensive agricultural lands | 552 | 698 | 617.24 | 340,716 | 430,834 |
| 222 | Extensive agricultural lands | | 25 | 617.24 | 0 | 15,431 |
| 223 | Extensive agricultural lands | 521 | 511 | 617.24 | 321,582 | 315,410 |
| 231 | Grasslands | 4524 | 4447 | 1131.8 | 5,120,263 | 5,033,115 |
| 241 | Extensive agricultural lands | 54 | 54 | 617.24 | 33,331 | 33,331 |
| 242 | Intensive agricultural lands | 10,048 | 9654 | 308.62 | 3,101,014 | 2,979,417 |
| 243 | Intensive agricultural lands | 22,372 | 22,483 | 308.62 | 6,904,447 | 6,938,703 |
| 311 | Broadleaves forests | 76,195 | 87,036 | 803.6 | 61,230,302 | 69,942,130 |
| 312 | Conifer forests | 40,406 | 45,707 | 803.6 | 32,470,262 | 36,730,145 |
| 313 | (Broadleaves forests + Conifer forests)/2 | 37,882 | 20,703 | 803.6 | 30,441,975 | 16,636,931 |
| 321 | Grasslands | 27,051 | 27,630 | 1131.8 | 30,616,322 | 31,271,634 |
| 322 | Shrublands | 3732 | 5010 | 961.47 | 3,588,206 | 4,816,965 |
| 323 | Shrublands | 44 | 88 | 961.47 | 42,305 | 84,609 |
| 324 | Inland unvegetated or sparsely vegetated areas | 16,899 | 16,169 | 652.85 | 11,032,512 | 10,555,932 |
| 332 | Inland unvegetated or sparsely vegetated areas | 14,668 | 13,299 | 652.85 | 9,576,004 | 8,682,252 |
| 333 | Inland unvegetated or sparsely vegetated areas | 11,488 | 12,273 | 652.85 | 7,499,941 | 8,012,428 |
| 334 | Inland unvegetated or sparsely vegetated areas | | 53 | 652.85 | 0 | 34,601 |
| 335 | Inland unvegetated or sparsely vegetated areas | 1965 | 1933 | 652.85 | 1,282,850 | 1,261,959 |
| 411 | Wetlands | 258 | 233 | 11,609.1 | 2,995,148 | 2,704,920 |
| 511 | Water bodies | 68 | 68 | 985.21 | 66,994 | 66,994 |
| 512 | Water bodies | 23,897 | 23,927 | 985.21 | 23,543,563 | 23,573,120 |
| **Total** | | | | | 280,362,804 | 280,480,684 |

### *Appendix A.3. Crop Pollination*

**Table A8.** Monetary value of crop pollination for crops dependent on the service based on 2023 production in Brescia Province. Source: own elaborations by authors from ISMEA, AREA Rica, and ISTAT databases.

| Crop | Production (t) | | | Crop Production | | Crop Pollination | |
|---|---|---|---|---|---|---|---|
| | Outdoor | Greenhouse | Total | Unit Monetary Value (EUR/t) | Monetary Value (EUR) | Dependency Ration | Monetary Value (EUR) |
| Apple | 1811 | 0 | 1811 | 729 | 1,320,219 | 0.65 | 858,142 |
| Chestnut | 1075.9 | 0 | 1076 | 1920 | 2,065,920 | 0.25 | 516,480 |
| Cucumber | 25 | 180 | 205 | 291 | 59,655 | 0.65 | 38,776 |
| Green Bean | 2364.5 | 110 | 2475 | 1097 | 2,715,075 | 0.05 | 135,754 |

**Table A8.** *Cont.*

| Crop | Production (t) | | | Crop Production | | Crop Pollination | |
|---|---|---|---|---|---|---|---|
| | Outdoor | Greenhouse | Total | Unit Monetary Value (EUR/t) | Monetary Value (EUR) | Dependency Ration | Monetary Value (EUR) |
| Lemon | 8 | 0 | 8 | 760 | 6080 | 0.05 | 304 |
| Melon | 595 | 1250 | 1845 | 597 | 1,101,465 | 0.95 | 1,046,392 |
| Peach | 788 | 0 | 788 | 512 | 403,456 | 0.65 | 262,246 |
| Pear | 185 | 0 | 185 | 1423 | 263,255 | 0.65 | 171,116 |
| Pepper | 120 | 114 | 234 | 493 | 115,362 | 0.05 | 5768 |
| Strawberry | 71 | 300 | 371 | 3023 | 1,121,533 | 0.25 | 280,383 |
| Plum | 72 | 0 | 72 | 308 | 22,176 | 0.65 | 14,414 |
| Tomato | 44,436 | 450 | 44,886 | 676 | 30,342,936 | 0.05 | 1,517,147 |
| Watermelon | 880 | 400 | 1280 | 164 | 209,920 | 0.95 | 199,424 |
| Zucchini | 7637.8 | 450 | 8089 | 503 | 4,068,767 | 0.95 | 3,864,755 |
| **Total** | | | | | | | 8,911,046 |

## *Appendix A.4. Wood Provision*

**Table A9.** Biophysical, surfaces and monetary value of wood provision for each CLC LC in 2006 and 2012. Source: own elaborations from INFC 2005 and 2015 databases.

| INFC | | CLC—Code | Annual Tree Biomass Increment per Surface | | Surface (ha) | | Annual Tree Biomass Increment ($m^3$/Year) | | Monetary Value (EUR/Year) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Code | Description | | (t/ha/Year) | ($m^3$/ha/Year) | 2006 | 2012 | 2006 | 2012 | 2006 | 2012 |
| **1** | Larch and Swiss pine forests | 3124 | 2.4 | 3.6 | 5771 | 5649 | 20,953 | 20,510 | 1,466,710 | 1,435,700 |
| **2 and 3** | Spruce forests and Silver fir forests | 31323 | 5.3 | 8.0 | 14,085 | 12,981 | 112,933 | 104,081 | 7,905,310 | 7,285,670 |
| | | 3123 | | | 31,969 | 33,653 | 256,326 | 269,828 | 17,942,820 | 18,887,960 |
| **4 and 5** | Scots pine and Mountain pine forests and Black pine, Corsican pine, and Bosnian pine forests | 3122 | 4.7 | 7.1 | 564 | 1104 | 4010 | 7850 | 280,700 | 549,500 |
| | | 31322 | | | 4289 | 3301 | 30,496 | 23,471 | 2,134,720 | 1,642,970 |
| **6** | Mediterranean pine forests | 3121 | 0 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 31321 | | | 0 | 0 | 0 | 0 | 0 | 0 |
| **7** | Other coniferous forests, pure or mixed | 3125 | 2.7 | 4.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 31325 | | | 0 | 0 | 0 | 0 | 0 | 0 |
| **8** | Beech forests | 3115 | 4.2 | 6.4 | 6735 | 7025 | 42,793 | 44,636 | 2,995,510 | 3,124,520 |
| | | 31315 | | | 1759 | 2420 | 11,176 | 15,376 | 782,320 | 1,076,320 |
| **9 and 10** | Sessile oak, Downy oak, and English oak forests and Turkey oak, Hungarian oak, Macedonian oak, Valonia oak forests | 3112 | 5.5 | 8.3 | 1485 | 1513 | 12,356 | 12,589 | 864,920 | 881,230 |
| | | 31312 | | | 0 | 0 | 0 | 0 | 0 | 0 |
| **11** | Chestnut forest | 3114 | 5 | 7.6 | 21,063 | 19,136 | 159,323 | 144,747 | 11,152,610 | 10,132,290 |
| | | 31314 | | | 2192 | 2546 | 16,581 | 19,258 | 1,160,670 | 1,348,060 |
| **12** | Hop-hornbeam and hornbeam forests | 3113 | 2.7 | 4.1 | 51,657 | 47,938 | 210,999 | 195,808 | 14,769,930 | 13,706,560 |
| | | 31313 | | | 11,150 | 13,297 | 45,543 | 54,313 | 3,188,010 | 3,801,910 |
| **13** | Hygrophilous forests | 3116 | 3.9 | 5.9 | 125 | 198 | 738 | 1168 | 51,660 | 81,760 |
| | | 31316 | | | 0 | 0 | 0 | 0 | 0 | 0 |
| **14** | Other deciduous forests | 3117 | 4.3 | 6.5 | 116 | 107 | 755 | 696 | 52,850 | 48,720 |
| | | 31317 | | | 0 | 0 | 0 | 0 | 0 | 0 |
| **15 and 16** | Holm oak forests and Cork oak forests | 3111 | 0 | 0.0 | 272 | 278 | 0 | 0 | 0 | 0 |
| | | 31311 | | | 37 | 37 | 0 | 0 | 0 | 0 |
| **Total** | | | | | | | | 64,748,740 | | 64,003,170 |

### *Appendix A.5. Particulate Removal*

**Table A10.** Biophysical surfaces and monetary value of particulate removal for each CLC LC class in 2012 and 2018. Source: own elaborations by authors.

| CLC | | Absorption Coefficient (kg/(ha Year)) | Unit Monetary Value (EUR/ha/Year) | Surface (ha) | | Monetary Value (EUR/Year) | |
|---|---|---|---|---|---|---|---|
| Code | Description | | | 2006 | 2012 | 2006 | 2012 |
| 311 | Broadleaf forests | 160 | 500 | 76,195 | 87,040 | 38,097,500 | 43,520,000 |
| 312 | Coniferous forests | 490 | 700 | 40,406 | 20,703 | 28,284,200 | 14,492,100 |
| 313 | Mixed forests | 325 | 600 | 37,882 | 45,707 | 22,729,200 | 27,424,200 |
| Total | | | | | | 89,110,900 | 85,436,300 |

### *Appendix A.6. Hydrological Regime Regulation Table*

**Table A11.** Biophysical surfaces and monetary value of hydrological regime regulation for each CLC LC class in 2012 and 2018. Source: own elaborations by authors from ARPA Lombardia data.

| CLC—Code | Absorption Coefficient | | Average Annual Absorption (m/Year) | Water Volume Absorbed ($m^3$/ha/Year) | Surface (ha) | | Monetary Value (EUR/Year) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 2012 | 2018 | 2012 | 2018 |
| 111 | 0% | 0 | 0.000 | 0 | 1059 | 1059 | 0 | 0 |
| 112 | 0% | 0 | 0.000 | 0 | 27,786 | 28,226 | 0 | 0 |
| 121 | 0% | 0 | 0.000 | 0 | 8771 | 9195 | 0 | 0 |
| 122 | 0% | 0 | 0.000 | 0 | 98 | 323 | 0 | 0 |
| 124 | 0% | 0 | 0.000 | 0 | 923 | 929 | 0 | 0 |
| 131 | 0% | 0 | 0.000 | 0 | 1692 | 1835 | 0 | 0 |
| 133 | 0% | 0 | 0.000 | 0 | 99 | 91 | 0 | 0 |
| 141 | 0% | 0 | 0.000 | 0 | 81 | 54 | 0 | 0 |
| 142 | 0% | 0 | 0.000 | 0 | 433 | 740 | 0 | 0 |
| 221 | 17% | 3 | 0.154 | 1540 | 552 | 698 | 8,730,322 | 11,039,428 |
| 222 | 17% | 3 | 0.154 | 1540 | 0 | 25 | 0 | 395,395 |
| 223 | 17% | 3 | 0.154 | 1540 | 521 | 511 | 8,240,032 | 8,081,874 |
| 224 | 17% | 3 | 0.154 | 1540 | 4 | 4 | 63,263 | 63,263 |
| 231 | 15% | 2 | 0.136 | 1360 | 4521 | 4447 | 63,145,711 | 62,112,138 |
| 241 | 15% | 2 | 0.136 | 1360 | 54 | 54 | 754,229 | 754,229 |
| 242 | 15% | 2 | 0.136 | 1360 | 10,049 | 9654 | 140,356,393 | 134,839,349 |
| 243 | 15% | 2 | 0.136 | 1360 | 22,374 | 22,483 | 312,502,133 | 314,024,558 |
| 322 | 15% | 2 | 0.136 | 1360 | 3735 | 5010 | 52,167,492 | 69,975,672 |
| 323 | 15% | 2 | 0.136 | 1360 | 44 | 44 | 614,557 | 614,557 |
| 324 | 17% | 3 | 0.154 | 1540 | 16,901 | 16,169 | 267,302,836 | 255,725,670 |
| 332 | 0% | 0 | 0.000 | 0 | 14,668 | 13,299 | 0 | 0 |
| 333 | 0% | 0 | 0.000 | 0 | 11,487 | 12,273 | 0 | 0 |
| 334 | 0% | 0 | 0.000 | 0 | 0 | 53 | 0 | 0 |
| 335 | 0% | 0 | 0.000 | 0 | 1965 | 1933 | 0 | 0 |
| 411 | 0% | 0 | 0.000 | 0 | 258 | 233 | 0 | 0 |
| 511 | 0% | 0 | 0.000 | 0 | 68 | 68 | 0 | 0 |
| 512 | 0% | 0 | 0.000 | 0 | 23,900 | 23,927 | 0 | 0 |
| 2111 | 5% | 1 | 0.045 | 450 | 144,663 | 143,777 | 668,560,055 | 664,465,406 |
| 2112 | 5% | 1 | 0.045 | 450 | 92 | 92 | 425,178 | 425,178 |
| 3111 | 20% | 4 | 0.182 | 1820 | 278 | 251 | 5,196,209 | 4,691,541 |
| 3112 | 20% | 4 | 0.182 | 1820 | 1513 | 4067 | 28,280,088 | 76,017,924 |

**Table A11.** *Cont.*

| CLC—Code | Absorption Coefficient | | Average Annual Absorption (m/Year) | Water Volume Absorbed ($m^3$/ha/Year) | Surface (ha) | | Monetary Value (EUR/Year) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 2012 | 2018 | 2012 | 2018 |
| 3113 | 20% | 4 | 0.182 | 1820 | 47,937 | 49,500 | 896,009,642 | 925,224,300 |
| 3114 | 20% | 4 | 0.182 | 1820 | 19,137 | 21,962 | 357,697,322 | 410,500,527 |
| 3115 | 20% | 4 | 0.182 | 1820 | 7024 | 10,894 | 131,288,394 | 203,624,112 |
| 3116 | 20% | 4 | 0.182 | 1820 | 198 | 230 | 370,0897 | 4,299,022 |
| 3117 | 20% | 4 | 0.182 | 1820 | 107 | 132 | 1,999,980 | 2,467,265 |
| 3121 | 30% | 5 | 0.272 | 2720 | 0 | 37 | 0 | 1,033,573 |
| 3122 | 30% | 5 | 0.272 | 2720 | 1104 | 1652 | 30,839,578 | 46,147,629 |
| 3123 | 30% | 5 | 0.272 | 2720 | 33,652 | 32,782 | 940,048,429 | 915,745,501 |
| 3124 | 30% | 5 | 0.272 | 2720 | 5649 | 11,236 | 157,801,426 | 313,870,918 |
| 3131 | 30% | 5 | 0.272 | 2720 | 18,300 | 10,978 | 511,171,586 | 306,663,843 |
| 3132 | 30% | 5 | 0.272 | 2720 | 19,581 | 9724 | 546,983,486 | 271,634,106 |
| 3211 | 15% | 2 | 0.136 | 1360 | 19,894 | 21,118 | 277,863,477 | 294,959,330 |
| 3212 | 15% | 2 | 0.136 | 1360 | 7153 | 6512 | 99,907,382 | 90,954,406 |
| 3231 | 15% | 2 | 0.136 | 1360 | 0 | 44 | 0 | 614,557 |
| **Total** | | | | | | | 5,511,650,093 | 5,390,965,269 |

## References


1. Marsh, G.P.; Vogt, K.; Haime, J.; Kellogg, E.C. *Report Made Under Authority of the Legislature of Vermont, on the Artificial Propagation of Fish*; Free Press Print: Burlington, VT, USA, 1857.
2. Craig, R.K. George Perkins Marsh: Anticipating the Anthropocene. *SSRN J.* **2019**, *346*, 6. [CrossRef]
3. Cox, L.M.; Almeter, A.L.; Saterson, K.A. Protecting Our Life Support Systems: An Inventory of U.S. Federal Research on Ecosystem Services. *Ecosyst. Serv.* **2013**, *5*, 163–169. [CrossRef]
4. *Ecosystems and Human Well-Being: Synthesis*; Millennium Ecosystem Assessment (Program), Ed.; Island Press: Washington, DC, USA, 2005; ISBN 978-1-59726-040-4.
5. Costanza, R.; d'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J.; et al. The Value of the World's Ecosystem Services and Natural Capital. *Nature* **1997**, *387*, 253–260. [CrossRef]
6. *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*, 1st ed.; Kumar, P., Ed.; Routledge: Oxfordshire, UK, 2012; ISBN 978-1-136-53880-3.
7. Costanza, R.; De Groot, R.; Sutton, P.; Van Der Ploeg, S.; Anderson, S.J.; Kubiszewski, I.; Farber, S.; Turner, R.K. Changes in the Global Value of Ecosystem Services. *Glob. Environ. Change* **2014**, *26*, 152–158. [CrossRef]
8. Adhikari, K.; Hartemink, A.E. Linking Soils to Ecosystem Services—A Global Review. *Geoderma* **2016**, *262*, 101–111. [CrossRef]
9. Farrell, C.A.; Aronson, J.; Daily, G.C.; Hein, L.; Obst, C.; Woodworth, P.; Stout, J.C. Natural Capital Approaches: Shifting the UN Decade on Ecosystem Restoration from Aspiration to Reality. *Restor. Ecol.* **2022**, *30*, e13613. [CrossRef]
10. United Nations. *System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA)*; Pre-edited Text Subject to Official Editing; United Nations: New York, NY, USA, 2021.
11. Costanza, R.; Daly, H.E. Natural Capital and Sustainable Development. *Conserv. Biol.* **1992**, *6*, 37–46. [CrossRef]
12. Smith, A.C.; Harrison, P.A.; Pérez Soba, M.; Archaux, F.; Blicharska, M.; Egoh, B.N.; Erős, T.; Fabrega Domenech, N.; György, Á.I.; Haines-Young, R.; et al. How Natural Capital Delivers Ecosystem Services: A Typology Derived from a Systematic Review. *Ecosyst. Serv.* **2017**, *26*, 111–126. [CrossRef]
13. Nunes, P.A.L.D.; Van Den Bergh, J.C.J.M. Economic Valuation of Biodiversity: Sense or Nonsense? *Ecol. Econ.* **2001**, *39*, 203–222. [CrossRef]
14. Turner, R.K.; Van Den Bergh, J.C.J.M.; Söderqvist, T.; Barendregt, A.; Van Der Straaten, J.; Maltby, E.; Van Ierland, E.C. Ecological-Economic Analysis of Wetlands: Scientific Integration for Management and Policy. *Ecol. Econ.* **2000**, *35*, 7–23. [CrossRef]
15. Sustainable Development Solutions Network; The Institute for European Environmental Policy. *The 2020 Europe Sustainable Development Report: Meeting the Sustainable Development Goals in the Face of the COVID-19 Pandemic*; Sustainable Development Solutions Network (SDSN) EU: Paris, France; Bruxelles, Belgium, 2020.
16. O'Neill, J. What Is Lost through No Net Loss. *Econ. Philos.* **2020**, *36*, 287–306. [CrossRef]
17. Femia, A.; Fullone, F.; Lecardane, G. *Ambiente e Territorio: Strumenti e Metodi per un'Analisi del Consumo di Risorse e Degli Ecosistemi*; Istituto Nazionale di Statistica (ISTAT): Rome, Italy, 2023.

18. Reed, M.S.; Allen, K.; Attlee, A.; Dougill, A.J.; Evans, K.L.; Kenter, J.O.; Hoy, J.; McNab, D.; Stead, S.M.; Twyman, C.; et al. A Place-Based Approach to Payments for Ecosystem Services. *Glob. Environ. Change* **2017**, *43*, 92–106. [CrossRef]
19. De Castro Pardo, M.; Martínez, P.F.; Martínez, J.M.G.; Martín, J.M.M. Modelling Natural Capital: A Proposal for a Mixed Multi-Criteria Approach to Assign Management Priorities to Ecosystem Services. *CE* **2020**, *14*, 22–37. [CrossRef]
20. Öberg, C.; Alexander, A.T. The Openness of Open Innovation in Ecosystems—Integrating Innovation and Management Literature on Knowledge Linkages. *J. Innov. Knowl.* **2019**, *4*, 211–218. [CrossRef]
21. Grimm, N.B.; Faeth, S.H.; Golubiewski, N.E.; Redman, C.L.; Wu, J.; Bai, X.; Briggs, J.M. Global Change and the Ecology of Cities. *Science* **2008**, *319*, 756–760. [CrossRef] [PubMed]
22. IPBES. *Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*; Zenodo; IPBES: Bonn, Germany, 2019.
23. Shah, M.I.; Abbas, S.; Olohunlana, A.O.; Sinha, A. The Impacts of Land Use Change on Biodiversity and Ecosystem Services: An Empirical Investigation from Highly Fragile Countries. *Sustain. Dev.* **2023**, *31*, 1384–1400. [CrossRef]
24. Nowak, D.J.; Walton, J.T. Projected Urban Growth (2000–2050) and Its Estimated Impact on the US Forest Resource. *J. For.* **2005**, *103*, 383–389. [CrossRef]
25. Song, X.-P.; Hansen, M.C.; Stehman, S.V.; Potapov, P.V.; Tyukavina, A.; Vermote, E.F.; Townshend, J.R. Global Land Change from 1982 to 2016. *Nature* **2018**, *560*, 639–643. [CrossRef] [PubMed]
26. European Commission; Directorate General for Research and Innovation. *Caring for Soil Is Caring for Life: Ensure 75% of Soils Are Healthy by 2030 for Food, People, Nature and Climate: Report of the Mission Board for Soil Health and Food*; Publications Office: Luxembourg, 2020.
27. Sutton, P.C.; Anderson, S.J.; Costanza, R.; Kubiszewski, I. The Ecological Economics of Land Degradation: Impacts on Ecosystem Service Values. *Ecol. Econ.* **2016**, *129*, 182–192. [CrossRef]
28. Jack, B.K.; Kousky, C.; Sims, K.R.E. Designing Payments for Ecosystem Services: Lessons from Previous Experience with Incentive-Based Mechanisms. *Proc. Natl. Acad. Sci. USA* **2008**, *105*, 9465–9470. [CrossRef]
29. Huwyler, F.; Käppeli, J.; Tobin, J. *Conservation Finance. From Niche to Mainstream: The Building of an Institutional Asset Class*; Credit Suisse, IUCN: Gland, Switzerland; Rockefeller Foundation: New York, NY, USA; McKinsey: Chicago, IL, USA, 2016.
30. Balmford, A.; Bruner, A.; Cooper, P.; Costanza, R.; Farber, S.; Green, R.E.; Jenkins, M.; Jefferiss, P.; Jessamy, V.; Madden, J.; et al. Economic Reasons for Conserving Wild Nature. *Science* **2002**, *297*, 950–953. [CrossRef] [PubMed]
31. International Institute for Environment and Development. *Reaping the Rewards: Financing Land Degradation Neutrality*; United Nations Convention to Combat Desertification: Bonn, Germany, 2015.
32. Crouzeilles, R.; Curran, M.; Ferreira, M.S.; Lindenmayer, D.B.; Grelle, C.E.V.; Rey Benayas, J.M. A Global Meta-Analysis on the Ecological Drivers of Forest Restoration Success. *Nat. Commun.* **2016**, *7*, 11666. [CrossRef] [PubMed]
33. Ekins, P.; Simon, S.; Deutsch, L.; Folke, C.; De Groot, R. A Framework for the Practical Application of the Concepts of Critical Natural Capital and Strong Sustainability. *Ecol. Econ.* **2003**, *44*, 165–185. [CrossRef]
34. Chee, Y.E. An Ecological Perspective on the Valuation of Ecosystem Services. *Biol. Conserv.* **2004**, *120*, 549–565. [CrossRef]
35. Daily, G.; Postel, S.; Bawa, K.; Kaufman, L. *Nature's Services: Societal Dependence on Natural Ecosystems*; Bibliovault OAI Repository, the University of Chicago Press: Chicago, IL, USA, 1997.
36. Chan, K.M.A.; Balvanera, P.; Benessaiah, K.; Chapman, M.; Díaz, S.; Gómez-Baggethun, E.; Gould, R.; Hannahs, N.; Jax, K.; Klain, S.; et al. Why Protect Nature? Rethinking Values and the Environment. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 1462–1465. [CrossRef]
37. Ruhl, J.; Salzman, J.; Arnold, C.A.; Craig, R.; Hirokawa, K.; Olander, L.; Palmer, M.; Ricketts, T.H. Connecting Ecosystem Services Science and Policy in the Field. *Front. Ecol. Environ.* **2021**, *19*, 519–525. [CrossRef]
38. Salzman, J. Teaching Policy Instrument Choice in Environmental Law: The Five P's. *23 Duke Environ. Law Policy Forum* **2013**, *23*, 363–376.
39. Bateman, I.J.; Harwood, A.R.; Mace, G.M.; Watson, R.T.; Abson, D.J.; Andrews, B.; Binner, A.; Crowe, A.; Day, B.H.; Dugdale, S.; et al. Bringing Ecosystem Services into Economic Decision-Making: Land Use in the United Kingdom. *Science* **2013**, *341*, 45–50. [CrossRef]
40. Pirard, R.; Lapeyre, R. Classifying Market-Based Instruments for Ecosystem Services: A Guide to the Literature Jungle. *Ecosyst. Serv.* **2014**, *9*, 106–114. [CrossRef]
41. Wunder, S. When Payments for Environmental Services Will Work for Conservation. *Conserv. Lett.* **2013**, *6*, 230–237. [CrossRef]
42. Marion, J.L. A Review and Synthesis of Recreation Ecology Research Supporting Carrying Capacity and Visitor Use Management Decisionmaking. *J. For.* **2016**, *114*, 339–351. [CrossRef]
43. Schirpke, U.; Scolozzi, R.; Da Re, R.; Masiero, M.; Pellegrino, D.; Marino, D. Enhancing Outdoor Recreation and Biodiversity through Payments for Ecosystem Services: Emerging Potentials from Selected Natura 2000 Sites in Italy. *Environ. Dev. Sustain.* **2020**, *22*, 2045–2067. [CrossRef]

44. *Ecosystems and Human Well-Being: A Manual for Assessment Practitioners*; Ash, N., Ed.; Island Press: Washington, DC, USA, 2010; ISBN 978-1-59726-711-3.
45. Heal, G. *Nature and the Marketplace: Capturing the Value of Ecosystem Services*; Island Press: Washington, DC, USA, 2000; ISBN 978-1-55963-795-4.
46. *Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of Teeb*; UNEP, Ed.; The Economics of Ecosystems & Biodiversity; UNEP: Geneva, Switzerland, 2010; ISBN 978-3-9813410-3-4.
47. Martin-Ortega, J.; Ojea, E.; Roux, C. Payments for Water Ecosystem Services in Latin America: A Literature Review and Conceptual Model. *Ecosyst. Serv.* **2013**, *6*, 122–132. [CrossRef]
48. *Water Ecosystem Services: A Global Perspective*; Martin-Ortega, J., Ferrier, R.C., Gordon, I.J., Khan, S., Eds.; International Hydrology Series; Cambridge University Press: Cambridge, UK, 2015; ISBN 978-92-3-100068-3.
49. Porras, I.; Asquith, N. *Ecosystems, Poverty Alleviation and Conditional Transfers*; International Institute for Environment and Development: London, UK, 2018.
50. Wunder, S. Revisiting the Concept of Payments for Environmental Services. *Ecol. Econ.* **2015**, *117*, 234–243. [CrossRef]
51. Rissman, A.R.; Lozier, L.; Comendant, T.; Kareiva, P.; Kiesecker, J.M.; Shaw, M.R.; Merenlender, A.M. Conservation Easements: Biodiversity Protection and Private Use. *Conserv. Biol.* **2007**, *21*, 709–718. [CrossRef] [PubMed]
52. Merenlender, A.M.; Huntsinger, L.; Guthey, G.; Fairfax, S.K. Land Trusts and Conservation Easements: Who Is Conserving What for Whom? *Conserv. Biol.* **2004**, *18*, 65–76. [CrossRef]
53. Loomis, J.; Kent, P.; Strange, L.; Fausch, K.; Covich, A. Measuring the Total Economic Value of Restoring Ecosystem Services in an Impaired River Basin: Results from a Contingent Valuation Survey. *Ecol. Econ.* **2000**, *33*, 103–117. [CrossRef]
54. Rissman, A.R.; Merenlender, A.M. The Conservation Contributions of Conservation Easements: Analysis of the San Francisco Bay Area Protected Lands Spatial Database. *Ecol. Soc.* **2008**, *13*, 40. [CrossRef]
55. Smith, F.; Smillie, K.; Fitzsimons, J.; Lindsay, B.; Wells, G.; Marles, V.; Hutchinson, J.; O'Hara, B.; Perrigo, T.; Atkinson, I. Reforms Required to the Australian Tax System to Improve Biodiversity Conservation on Private Land. *Environ. Plan. Law J.* **2016**, *33*, 443–450.
56. Schuster, R.; Law, E.A.; Rodewald, A.D.; Martin, T.G.; Wilson, K.A.; Watts, M.; Possingham, H.P.; Arcese, P. Tax Shifting and Incentives for Biodiversity Conservation on Private Lands. *Conserv. Lett.* **2018**, *11*, e12377. [CrossRef]
57. Asbjornsen, H.; Wang, Y.; Ellison, D.; Ashcraft, C.M.; Atallah, S.S.; Jones, K.; Mayer, A.; Altamirano, M.; Yu, P. Multi-Targeted Payments for the Balanced Management of Hydrological and Other Forest Ecosystem Services. *For. Ecol. Manag.* **2022**, *522*, 120482. [CrossRef]
58. Schuster, R.; Arcese, P. Efficient Routes to Land Conservation given Risk of Covenant Failure. *PeerJ PrePrints* **2015**, *3*, e1033v1.
59. Farmer, J.R.; Ma, Z.; Drescher, M.; Knackmuhs, E.G.; Dickinson, S.L. Private Landowners, Voluntary Conservation Programs, and Implementation of Conservation Friendly Land Management Practices. *Conserv. Lett.* **2017**, *10*, 58–66. [CrossRef]
60. Paladini, L. *In Sintesi: Il Piano Strategico della PAC dell'ITALIA*; Agriculture and Rural Development–European Commission: Brussels, Belgium, 2023.
61. Ding, Z.; Zheng, H.; Wang, J.; O'Connor, P.; Li, C.; Chen, X.; Li, R.; Ouyang, Z. Integrating Top-Down and Bottom-Up Approaches Improves Practicality and Efficiency of Large-Scale Ecological Restoration Planning: Insights from a Social–Ecological System. *Engineering* **2023**, *31*, 50–58. [CrossRef]
62. Masiero, M.; Franceschinis, C.; Mattea, S.; Thiene, M.; Pettenella, D.; Scarpa, R. Ecosystem Services' Values and Improved Revenue Collection for Regional Protected Areas. *Ecosyst. Serv.* **2018**, *34*, 136–153. [CrossRef]
63. Daily, G.C.; Polasky, S.; Goldstein, J.; Kareiva, P.M.; Mooney, H.A.; Pejchar, L.; Ricketts, T.H.; Salzman, J.; Shallenberger, R. Ecosystem Services in Decision Making: Time to Deliver. *Front. Ecol. Environ.* **2009**, *7*, 21–28. [CrossRef]
64. Assennato, F.; Braca, G.; Calzolari, C.; Capriolo, A.; di Leginio, M.; Marchetti, M.; Marino, D.; Mascolo, R.; Morri, E.; Pettenella, D.; et al. Mappatura e valutazione dell'impatto del consumo di suolo sui servizi ecosistemici: Proposte metodologiche per il Rapporto sul consumo di suolo. *Soil Consum. Territ. Dyn. Ecosyst. Serv.* **2018**, 1–44.
65. Morya, C.P.; Punia, M. Impact of Urbanization Processes on Availability of Ecosystem Services in National Capital Region of Delhi (1992–2010). *Environ. Dev. Sustain.* **2022**, *24*, 7324–7348. [CrossRef] [PubMed]
66. La Notte, A. Mapping and Valuing Habitat Services: Two Applications at Local Scale. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* **2012**, *8*, 80–92. [CrossRef]
67. Häyhä, T.; Franzese, P.P.; Paletto, A.; Fath, B.D. Assessing, Valuing, and Mapping Ecosystem Services in Alpine Forests. *Ecosyst. Serv.* **2015**, *14*, 12–23. [CrossRef]
68. Manes, F.; Marando, F.; Capotorti, G.; Blasi, C.; Salvatori, E.; Fusaro, L.; Ciancarella, L.; Mircea, M.; Marchetti, M.; Chirici, G.; et al. Regulating Ecosystem Services of Forests in Ten Italian Metropolitan Cities: Air Quality Improvement by $PM_{10}$ and $O_3$ Removal. *Ecol. Indic.* **2016**, *67*, 425–440. [CrossRef]
69. Marino, D.; Palmieri, M.; Marucci, A.; Tufano, M. Comparison between Demand and Supply of Some Ecosystem Services in National Parks: A Spatial Analysis Conducted Using Italian Case Studies. *Conservation* **2021**, *1*, 36–57. [CrossRef]

70. Sebastiani, A.; Marando, F.; Manes, F. Mismatch of Regulating Ecosystem Services for Sustainable Urban Planning: PM10 Removal and Urban Heat Island Effect Mitigation in the Municipality of Rome (Italy). *Urban For. Urban Green.* **2021**, *57*, 126938. [CrossRef]
71. Schirpke, U.; Leitinger, G.; Tappeiner, U.; Tasser, E. SPA-LUCC: Developing Land-Use/Cover Scenarios in Mountain Landscapes. *Ecol. Inform.* **2012**, *12*, 68–76. [CrossRef]
72. Petrosillo, I.; Semeraro, T.; Zaccarelli, N.; Aretano, R.; Zurlini, G. The Possible Combined Effects of Land-Use Changes and Climate Conditions on the Spatial–Temporal Patterns of Primary Production in a Natural Protected Area. *Ecol. Indic.* **2013**, *29*, 367–375. [CrossRef]
73. Ferrari, M.; Geneletti, D. Mapping and Assessing Multiple Ecosystem Services in an Alpine Region: A Study in Trentino, Italy. *Ann. Bot.* **2014**, *4*, 65–71. [CrossRef]
74. Rova, S.; Pranovi, F.; Müller, F. Provision of Ecosystem Services in the Lagoon of Venice (Italy): An Initial Spatial Assessment. *Ecohydrol. Hydrobiol.* **2015**, *15*, 13–25. [CrossRef]
75. Arcidiacono, A.; Ronchi, S.; Salata, S. Managing Multiple Ecosystem Services for Landscape Conservation: A Green Infrastructure in Lombardy Region. *Procedia Eng.* **2016**, *161*, 2297–2303. [CrossRef]
76. Franzese, P.P.; Buonocore, E.; Donnarumma, L.; Russo, G.F. Natural Capital Accounting in Marine Protected Areas: The Case of the Islands of Ventotene and S. Stefano (Central Italy). *Ecol. Model.* **2017**, *360*, 290–299. [CrossRef]
77. Picone, F.; Buonocore, E.; D'Agostaro, R.; Donati, S.; Chemello, R.; Franzese, P.P. Integrating Natural Capital Assessment and Marine Spatial Planning: A Case Study in the Mediterranean Sea. *Ecol. Model.* **2017**, *361*, 1–13. [CrossRef]
78. Mancini, L.D.; Corona, P.; Salvati, L. Ranking the Importance of Wildfires' Human Drivers through a Multi-Model Regression Approach. *Environ. Impact Assess. Rev.* **2018**, *72*, 177–186. [CrossRef]
79. Salata, S.; Giaimo, C.; Barbieri, C.A.; Garnero, G. The Utilization of Ecosystem Services Mapping in Land Use Planning: The Experience of LIFE SAM4CP Project. *J. Environ. Plan. Manag.* **2019**, *63*, 523–545. [CrossRef]
80. Sacchelli, S.; Bernetti, I. Integrated Management of Forest Ecosystem Services: An Optimization Model Based on Multi-Objective Analysis and Metaheuristic Approach. *Nat. Resour. Res.* **2019**, *28*, 5–14. [CrossRef]
81. Salizzoni, E.; Allocco, M.; Murgese, D.; Quaglio, G. From Ecosystem Service Evaluation to Landscape Design: The Project of a Rural Peri-Urban Park in Chieri (Italy). In *Values and Functions for Future Cities*; Mondini, G., Oppio, A., Stanghellini, S., Bottero, M., Abastante, F., Eds.; Green Energy and Technology; Springer International Publishing: Cham, Switzerland, 2020; pp. 267–283. ISBN 978-3-030-23784-4.
82. Capriolo, A.; Boschetto, R.G.; Mascolo, R.A.; Balbi, S.; Villa, F. Biophysical and Economic Assessment of Four Ecosystem Services for Natural Capital Accounting in Italy. *Ecosyst. Serv.* **2020**, *46*, 101207. [CrossRef]
83. Buonocore, E.; Donnarumma, L.; Appolloni, L.; Miccio, A.; Russo, G.F.; Franzese, P.P. Marine Natural Capital and Ecosystem Services: An Environmental Accounting Model. *Ecol. Model.* **2020**, *424*, 109029. [CrossRef]
84. Buonocore, E.; Appolloni, L.; Russo, G.F.; Franzese, P.P. Assessing Natural Capital Value in Marine Ecosystems through an Environmental Accounting Model: A Case Study in Southern Italy. *Ecol. Model.* **2020**, *419*, 108958. [CrossRef]
85. Pacetti, T.; Castelli, G.; Bresci, E.; Caporali, E. Water Values: Participatory Water Ecosystem Services Assessment in the Arno River Basin, Italy. *Water Resour. Manag.* **2020**, *34*, 4527–4544. [CrossRef]
86. Masiero, M.; Biasin, A.; Amato, G.; Malaggi, F.; Pettenella, D.; Nastasio, P.; Anelli, S. Urban Forests and Green Areas as Nature-Based Solutions for Brownfield Redevelopment: A Case Study from Brescia Municipal Area (Italy). *Forests* **2022**, *13*, 444. [CrossRef]
87. Di Pirro, E.; Sallustio, L.; Capotorti, G.; Marchetti, M.; Lasserre, B. A Scenario-Based Approach to Tackle Trade-Offs between Biodiversity Conservation and Land Use Pressure in Central Italy. *Ecol. Model.* **2021**, *448*, 109533. [CrossRef]
88. Zulian, G.; La Notte, A. How to Account for Nature-Based Tourism in Europe. An Operational Proposal. *One Ecosyst.* **2022**, *7*, e89312. [CrossRef]
89. Boschetto, R.G.; Capriolo, A.; Mascolo, R.A.; Arrigotti, J.; Racevich, S.; Bulckaen, A.; Balbi, S.; Villa, F. Analysis of Changes over Time in Four Provisioning Ecosystem Services in Italy. *J. Environ. Account. Manag.* **2023**, *11*, 91–114. [CrossRef]
90. Marino, D.; Barone, A.; Marucci, A.; Pili, S.; Palmieri, M. Impact of Land Use Changes on Ecosystem Services Supply: A Meta Analysis of the Italian Context. *Land* **2023**, *12*, 2173. [CrossRef]
91. Catucci, E.; Buonocore, E.; Franzese, P.P.; Scardi, M. Assessing the Natural Capital Value of *Posidonia oceanica* Meadows in the Italian Seas by Integrating Habitat Suitability and Environmental Accounting Models. *ICES J. Mar. Sci.* **2023**, *80*, 739–750. [CrossRef]
92. Pignatti, S.; Carfora, M.F.; Coluzzi, R.; D'Amato, L.; De Feis, I.; Mora, D.F.; Laneve, G.; Imbrenda, V.; Lanfredi, M.; Mirzaei, S.; et al. Detection of Critical Areas Prone to Land Degradation Using Prisma: The Metaponto Coastal Area in South Italy Test Case. In Proceedings of the IGARSS 2024—2024 IEEE International Geoscience and Remote Sensing Symposium, Athens, Greece, 7–12 July 2024; pp. 1063–1066.
93. Pelorosso, R.; Gobattoni, F.; Geri, F.; Monaco, R.; Leone, A. Evaluation of Ecosystem Services Related to Bio-Energy Landscape Connectivity (BELC) for Land Use Decision Making across Different Planning Scales. *Ecol. Indic.* **2016**, *61*, 114–129. [CrossRef]

94. Schirpke, U.; Scolozzi, R.; Concetti, B.; Comini, B.; Tappeiner, U. Supporting the Management of Ecosystem Services in Protected Areas: Trade-Offs Between Effort and Accuracy in Evaluation. *J. Environ. Assess. Policy Manag.* **2017**, *19*, 1750007. [CrossRef]
95. Appolloni, L.; Sandulli, R.; Vetrano, G.; Russo, G.F. A New Approach to Assess Marine Opportunity Costs and Monetary Values-in-Use for Spatial Planning and Conservation; the Case Study of Gulf of Naples, Mediterranean Sea, Italy. *Ocean Coast. Manag.* **2018**, *152*, 135–144. [CrossRef]
96. Lai, S.; Motroni, A.; Santona, L.; Schirru, M. One Place, Different Communities' Perceptions. Mapping Cultural Ecosystem Services in the Asinara National Park (Italy). In *Computational Science and Its Applications–ICCSA 2021*; Gervasi, O., Murgante, B., Misra, S., Garau, C., Blečić, I., Taniar, D., Apduhan, B.O., Rocha, A.M.A.C., Tarantino, E., Torre, C.M., Eds.; Lecture Notes in Computer Science; Springer International Publishing: Cham, Switzerland, 2021; Volume 12955, pp. 675–691; ISBN 978-3-030-87006-5.
97. Gebre, T.; Gebremedhin, B. The Mutual Benefits of Promoting Rural-Urban Interdependence through Linked Ecosystem Services. *Glob. Ecol. Conserv.* **2019**, *20*, e00707. [CrossRef]
98. Schirpke, U.; Scolozzi, R.; De Marco, C. *Modello Dimostrativo di Valutazione Qualitativa e Quantitativa dei Servizi Ecosistemici nei siti Pilota*; EURAC Research: Bolzano, Italy, 2014; p. 75.
99. Regione Lombardia. Strategic Environmental Assessment of PTR 2021. 2021. Available online: https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioPubblicazione/servizi-e-informazioni/Enti-e-Operatori/territorio/pianificazione-regionale/conferenza-vas-revisione-ptr-pvp/conferenza-vas-revisione-ptr-pvp (accessed on 18 January 2025).
100. Arcidiacono, A.; Ronchi, S.; Salata, S. Ecosystem Services Assessment Using InVEST as a Tool to Support Decision Making Process: Critical Issues and Opportunities. In *Computational Science and Its Applications–ICCSA 2015*; Gervasi, O., Murgante, B., Misra, S., Gavrilova, M.L., Rocha, A.M.A.C., Torre, C., Taniar, D., Apduhan, B.O., Eds.; Lecture Notes in Computer Science; Springer International Publishing: Cham, Switzerland, 2015; Volume 9158, pp. 35–49; ISBN 978-3-319-21409-2.
101. Gaglioppa, P.; Guadagno, R.; Marino, D.; Marucci, A.; Palmieri, M.; Pellegrino, D.; Schirpke, U.; Caracausi, C. Forest management based on ecosystem services and payments for ecosystem services: Considerations after the project LIFE+ Making Good Natura. *Forest@* **2017**, *14*, 99–106. [CrossRef]
102. Leonhardt, S.D.; Gallai, N.; Garibaldi, L.A.; Kuhlmann, M.; Klein, A.-M. Economic Gain, Stability of Pollination and Bee Diversity Decrease from Southern to Northern Europe. *Basic Appl. Ecol.* **2013**, *14*, 461–471. [CrossRef]
103. Alias, C.; Benassi, L.; Bertazzi, L.; Sorlini, S.; Volta, M.; Gelatti, U. Environmental Exposure and Health Effects in a Highly Polluted Area of Northern Italy: A Narrative Review. *Environ. Sci. Pollut. Res.* **2019**, *26*, 4555–4569. [CrossRef]
104. Pezzagno, M.; Richiedei, A.; Tira, M. Spatial Planning Policy for Sustainability: Analysis Connecting Land Use and GHG Emission in Rural Areas. *Sustainability* **2020**, *12*, 947. [CrossRef]
105. Richiedei, A.; Giuliani, M.; Pezzagno, M. Unveiling the Soil beyond Definitions: A Holistic Framework for Sub-Regional Soil Quality Assessment and Spatial Planning. *Sustainability* **2024**, *16*, 6075. [CrossRef]
106. *Climate Change 2007: The Physical Science Basis*; Intergouvernemental Panel on Climate Change, Ed.; Cambridge University Press: Cambridge, UK, 2007; ISBN 978-0-521-88009-1.
107. Eggleston, H.S.; Buendia, L.; Miwa, K.; Ngara, T.; Tanabe, K. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*; IPCC: Geneva, Switzerland, 2006.
108. *Natural Capital Committee Annual Report 2018*; England's Economic Affairs Committee: London, UK, 2018.
109. Sallustio, L.; Quatrini, V.; Geneletti, D.; Corona, P.; Marchetti, M. Assessing Land Take by Urban Development and Its Impact on Carbon Storage: Findings from Two Case Studies in Italy. *Environ. Impact Assess. Rev.* **2015**, *54*, 80–90. [CrossRef]
110. IPCC. *Good Practice Guidance for Land Use, Land-Use Change and Forestry*; Penman, J., Ed.; The Intergovernmental Panel on Climate Change: Hayama, Japan, 2003; ISBN 978-4-88788-003-0.
111. Marchetti, M.; Sallustio, L.; Ottaviano, M.; Barbati, A.; Corona, P.; Tognetti, R.; Zavattero, L.; Capotorti, G. Carbon Sequestration by Forests in the National Parks of Italy. *Plant Biosyst.-Int. J. Deal. All Asp. Plant Biol.* **2012**, *146*, 1001–1011. [CrossRef]
112. Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*; United States Government: Washington, DC, USA, 2016.
113. Maluccio, S.; Grassi, T.; Romano, R. *Progetti Forestali di Sostenibilità in Italia 2021–2022*; Nucleo Monitoraggio del Carbonio, CREA: Roma, Italy, 2024.
114. *Guidelines on Best Practice to Limit, Mitigate or Compensate Soil Sealing*; European Commission, Ed.; Publications Office: Luxembourg, 2012; ISBN 978-92-79-26210-4.
115. Provincia di Brescia. *Documento di Scoping del Piano Territoriale di Coordinamento Provinciale della Provincia di Brescia*, Versione 2.0. 2013. Available online: https://territorioweb.provincia.brescia.it/ptcp-luglio-2016/05_Rapporto%20ambientale%20e%20studio%20di%20incidenza/Documento%20di%20Scoping.pdf (accessed on 18 January 2025).
116. Terrado, M.; Sabater, S.; Chaplin-Kramer, B.; Mandle, L.; Ziv, G.; Acuña, V. Model Development for the Assessment of Terrestrial and Aquatic Habitat Quality in Conservation Planning. *Sci. Total Environ.* **2016**, *540*, 63–70. [CrossRef] [PubMed]

117. Sallustio, L.; De Toni, A.; Strollo, A.; Di Febbraro, M.; Gissi, E.; Casella, L.; Geneletti, D.; Munafò, M.; Vizzarri, M.; Marchetti, M. Assessing Habitat Quality in Relation to the Spatial Distribution of Protected Areas in Italy. *J. Environ. Manag.* **2017**, *201*, 129–137. [CrossRef] [PubMed]
118. Nieto, A.; Roberts, S.P.M.; Kemp, J.; Rasmont, P.; Kuhlmann, M.; García Criado, M.; Biesmeijer, J.C. *European Red List of Bees*; Publications Office of the European Union: Luxembourg, 2014; ISBN 978-92-79-44512-5.
119. *ESTIMAP: Ecosystem Services Mapping at European Scale*; Zulian, G., Paracchini, M.L., Maes, J., Liquete, C., European Commission, Eds.; Publications Office: Luxembourg, 2013; ISBN 978-92-79-35274-4.
120. Klein, A.-M.; Vaissière, B.E.; Cane, J.H.; Steffan-Dewenter, I.; Cunningham, S.A.; Kremen, C.; Tscharntke, T. Importance of Pollinators in Changing Landscapes for World Crops. *Proc. R. Soc. B* **2007**, *274*, 303–313. [CrossRef]
121. European Environment Agency. *Costs of Air Pollution from European Industrial Facilities 2008–2012: An Updated Assessment*; Publications Office: Luxembourg, 2014.
122. *Air Quality in Europe: 2015 Report*; Guerreiro, C., de Leeuw, F., Foltescu, V., González Ortiz, A., Horálek, J., European Environment Agency, Eds.; Publications Office: Luxembourg, 2015; ISBN 978-92-9213-701-4.
123. Nedkov, S.; Burkhard, B. Flood Regulating Ecosystem Services—Mapping Supply and Demand, in the Etropole Municipality, Bulgaria. *Ecol. Indic.* **2012**, *21*, 67–79. [CrossRef]
124. Tate, K.W. Interception on Rangeland Watersheds. *Rangel. Watershed Program Fact Sheet* **1995**, *36*, 1–4. Available online: http://ucanr.edu/sites/UCCE_LR/files/180588.pdf (accessed on 18 January 2025).
125. De Groot, R.; Brander, L.; Van Der Ploeg, S.; Costanza, R.; Bernard, F.; Braat, L.; Christie, M.; Crossman, N.; Ghermandi, A.; Hein, L.; et al. Global Estimates of the Value of Ecosystems and Their Services in Monetary Units. *Ecosyst. Serv.* **2012**, *1*, 50–61. [CrossRef]
126. Stoker, G. Public Value Management: A New Narrative for Networked Governance? *Am. Rev. Public Adm.* **2006**, *36*, 41–57. [CrossRef]
127. Bagstad, K.J.; Villa, F.; Batker, D.; Harrison-Cox, J.; Voigt, B.; Johnson, G.W. From Theoretical to Actual Ecosystem Services: Mapping Beneficiaries and Spatial Flows in Ecosystem Service Assessments. *Ecol. Soc.* **2014**, *19*, art64. [CrossRef]
128. Aryal, K.; Maraseni, T.; Apan, A. How Much Do We Know about Trade-Offs in Ecosystem Services? A Systematic Review of Empirical Research Observations. *Sci. Total Environ.* **2022**, *806*, 151229. [CrossRef] [PubMed]
129. Burkhard, B.; Kandziora, M.; Hou, Y.; Müller, F. Ecosystem Service Potentials, Flows and Demands-Concepts for Spatial Localisation, Indication and Quantification. *Landsc. Online* **2014**, *34*, 1–32. [CrossRef]
130. Tao, Y.; Wang, H.; Ou, W.; Guo, J. A Land-Cover-Based Approach to Assessing Ecosystem Services Supply and Demand Dynamics in the Rapidly Urbanizing Yangtze River Delta Region. *Land Use Policy* **2018**, *72*, 250–258. [CrossRef]
131. Stoll, S.; Frenzel, M.; Burkhard, B.; Loke, R. Assessment of Ecosystem Integrity and Service Gradients across Europe Using the LTER Europe Network. *Ecol. Model.* **2015**, *295*, 75–87. [CrossRef]
132. Cai, W.; Gibbs, D.; Zhang, L.; Ferrier, G.; Cai, Y. Identifying Hotspots and Management of Critical Ecosystem Services in Rapidly Urbanizing Yangtze River Delta Region, China. *J. Environ. Manag.* **2017**, *191*, 258–267. [CrossRef]
133. Hou, Y.; Burkhard, B.; Müller, F. Uncertainties in Landscape Analysis and Ecosystem Service Assessment. *J. Environ. Manag.* **2013**, *127*, S117–S131. [CrossRef]
134. Ruhl, J.B.; Kraft, S.E.; Lant, C.L. *The Law and Policy of Ecosystem Services*; Island Press: Washington, DC, USA, 2007; ISBN 978-1-55963-094-8.
135. Tallis, H.; Kareiva, P.; Marvier, M.; Chang, A. An Ecosystem Services Framework to Support Both Practical Conservation and Economic Development. *Proc. Natl. Acad. Sci. USA* **2008**, *105*, 9457–9464. [CrossRef] [PubMed]
136. Fisher, B.; Turner, R.K.; Morling, P. Defining and Classifying Ecosystem Services for Decision Making. *Ecol. Econ.* **2009**, *68*, 643–653. [CrossRef]
137. Johnson, G.W.; Bagstad, K.J.; Snapp, R.R.; Villa, F. Service Path Attribution Networks (SPANs): A Network Flow Approach to Ecosystem Service Assessment. *Int. J. Agric. Environ. Inf. Syst.* **2012**, *3*, 54–71. [CrossRef]
138. Bagstad, K.J.; Johnson, G.W.; Voigt, B.; Villa, F. Spatial Dynamics of Ecosystem Service Flows: A Comprehensive Approach to Quantifying Actual Services. *Ecosyst. Serv.* **2013**, *4*, 117–125. [CrossRef]


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