

Article

Assessment of Green Infrastructure in Riparian Zones Using Copernicus Programme

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Abstract: This article presents an approach to identify Green Infrastructure (GI), its benefits and condition. This information enables environmental agencies to prioritise conservation, management and restoration strategies accordingly. The study focuses on riparian areas due to their potential to supply Ecosystem Services (ES), such as water quality, biodiversity, soil protection and flood or drought risk reduction. Natural Water Retention Measures (NWRM) related to agriculture and forestry are the type of GI considered specifically within these riparian areas. The approach is based on ES condition indicators, defined by the European Environment Agency (EEA) to support the policy targets of the 2020 Biodiversity Strategy. Indicators that can be assessed through remote sensing techniques are used, namely: capacity to provide ecosystem services, proximity to protected areas, greening response and water stress. Specifically, the approach uses and evaluates the potential of freely available products from the Copernicus Land Monitoring Service (CLMS) to monitor GI. Moreover, vegetation and water indices are calculated using data from the Sentinel-2 MSI Level-2A scenes and integrated in the analysis. The approach has been tested in the Italian Po river basin in 2018. Firstly, agriculture and forest NWRM were identified in the riparian areas of the river network. Secondly, the Riparian Zones products from the CLMS local component and the satellite-based indices were linked to the aforementioned ES condition indicators. This led to the development of a pixel-based model that evaluates the identified GI according to: (i) its disposition to provide riparian regulative ES and (ii) its condition in the analysed year. Finally, the model was used to prioritise GI for conservation or restoration initiatives, based on its potential to deliver ES and current condition.

Keywords: green infrastructure; riparian zone; natural water retention measure; ecosystem service; Copernicus; Sentinel-2; vegetation index; water index; downstream service

1. Introduction

In the view of human-induced climate change, ecosystem-based measures for disaster risk reduction (Eco-DRR) and climate change adaptation (CCA) have gained increasing attention [1]. Eco-DRR has been defined as “the sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim to achieve sustainable and resilient development” [2]. Eco-DRR is based on the concept that healthy, diverse and well-managed ecosystems increase the resilience of human societies and the environment to climate change impacts [3].

Taking into account ecosystem management in DRR, as well as within CCA strategies and policies, helps to convert the feedback loop existing between climate change impacts, ecosystem degradation and increased disaster risk [4]. In this context, the possible impacts of climate change on water quantity and quality, agriculture productivity, food security or greenhouse gas emissions have been a major concern [5].

The European Environment Agency (EEA) has the main role in analysing trends and vulnerabilities to assess the progress towards agreed targets and future actions against possible scenarios, both for each Member State of the European Union (MS) and the whole EU [6,7]. Therefore, the EEA has required systematic knowledge that links policy actions to economic, environmental and social trends. This can support the development of relevant, timely, robust and accessible information that helps policy makers and public users to act accordingly [8]. Thus, connecting existing knowledge to wider and deeper analyses, taking advantage of the latest freely available technologies, is a key step for getting efficient, accurate and near-real-time information that can support decisions regarding Eco-DRR and CCA [9].

Consequently, Green Infrastructure (GI) has been appearing more frequently as an effective nature-based spatial planning tool [7]. However, the concept of GI is still under discussion and hence has such a wide range of applications [10]. Thus, despite its increasing relevance in several policy areas, no universally accepted definition exists yet [11]. At a European scale, GI is defined as a concept addressing the connectivity of bionetworks, their protection and provision of ecosystem services (ES), while also contributing to climate change mitigation and adaptation [12–14].

GI operates at different scales and can support several ES. ES are classified as (i) provisioning services, supplying natural resources (e.g., fresh water); (ii) regulatory and maintenance (e.g., climate or flood regulation) or (iii) cultural (e.g., educational or recreational) [15]. In contrast with grey infrastructure (GrI), which usually has a single objective, GI is multifunctional and can thus promote win-win solutions to deliver benefits to several users and stakeholders [16,17]. For instance, floodplains are an important element of river systems to filter and store water, assure natural flood and drought protection [18], sustain biological diversity and provide recreational opportunities [19]. However, around 70–90% of Europe's floodplain area is ecologically degraded [20].

On the contrary, GrI is typically a component of a centralized approach to manage natural related hazards, specifically in the water management sector. It is thus a human-engineered infrastructure, such as levees, reservoirs and water or wastewater treatment plants [17].

However, GI and GrI shall not always be considered as fully replacing the other (e.g., they can complement each other in hybrid approaches) and GI cost-effectiveness is still under discussion: e.g., the US Centre for Sustainable Economy developed the standard Green vs. Gray Analysis (GCA) methodology [21] and the UK Natural Economy Northwest Programme developed the GI Valuation Toolkit [22]; but the published benchmark approach at global scale still needs to be refined at different local scales [23,24].

GI can be divided in several categories: (i) protected areas included in the Natura 2000 network, as defined by the Habitats [25] and Birds Directives [26] and by the 2020 Biodiversity Strategy [27]; (ii) restoration zones; (iii) sustainable use areas (e.g., biosphere reserves); (iv) green urban features; (v) natural and artificial connectivity features (e.g., hedgerows or riparian river vegetation) or (vi) multifunctional zones providing several services, such as access, recreation and biodiversity [14].

Furthermore, GI can include both natural and anthropogenic features, exist both in urban and rural settings and include “blue” spaces, like ponds and stream networks [17]. However, to be considered as a GI component, all its elements need to be part of a larger habitat, green area or network that serves a wider function and that, ideally, has been developed, maintained and enhanced through coordinated interventions [11,12].

Adequately mapping and assessing GI has become a significant task, especially due to its contribution to the management of extreme events, such as floods, droughts or water stress [28–30]. Developing suitable tools to perform this task would ease the mitigation of current and future

risks related to climate change, land cover/land use changes and fluctuations of socio-economic conditions [31].

As pointed out by the European Commission (EC) [13], public authorities have used GrI as a substitute of natural solutions to prevent the degradation of key ecosystem services. GI is instead a successfully tested measure to also provide economic, social and ecological benefits to humans [17].

Therefore, GI's potential as a policy measure to improve the resilience of ecosystems and, as a consequence, of the anthropic structures and activities depending on them and on the ES they deliver, has been increasingly acknowledged by policymakers over the past decades [12,32]. In 2011, the 2020 Biodiversity Strategy [27] explicitly stated the importance of incorporating GI into spatial planning in order to achieve its Target 2 of maintaining and enhancing ES and recovering at least 15% of the degraded ecosystems across Europe.

Later on, the EC formulated a specific strategy on GI [13], aiming to promote it among stakeholders, encouraging investments in, and the development of, trans-European GI networks. The strategy recognized the need to incorporate GI into key policies, such as: (i) the EU Strategy on Adaptation to Climate Change [33]; (ii) upgrading the Natura 2000 Network [25–27]; (iii) the European Forests Strategy [34]; (iv) the Common Agricultural Policy (CAP) objectives [35] or (v) water-related policies, such as the Water Framework [36] or the Floods Directives [37], among others.

Developing new GI and restoring damaged ecosystems that connect natural core areas, reducing bionetwork fragmentation, can tackle both ecosystems' condition and human well-being [38]. Action 5 of the 2020 Biodiversity Strategy [27] called MS to map and assess the condition and pressures on ecosystems and their services in their national territory with the assistance of the EC. The technical report of the 2018 Mapping and Assessment of Ecosystems and their Services (MAES) Initiative [39] presented indeed a core set of suitable ES condition indicators. The set of indicators can act as a basis tool for identifying and prioritising areas for ecosystem restoration and deployment of GI (Target 2 of the 2020 Biodiversity Strategy) [17,19,20,27].

The overall objective of the presented initiatives and strategies is hence to promote GI in Europe to improve the connectivity of Natura 2000 sites [25–27] within and across national borders, linking biodiversity-rich areas where investments for ecosystem protection and restoration are prioritised, so as to enhance the delivery of essential ES throughout the EU territory [27,39]. Specifically, 2018 MAES report [39] states that “the condition indicators for ecosystem attributes are based on the spatial coverage, the configuration and the state of the green space and vegetation. Special attention goes to the share of protected area inside the boundaries. This can be measured by intersecting the area of Natura 2000 sites or of other protected areas”. The proximity to protected areas constitutes indeed a significant indicator to assess GI due to its structural continuity and functional connectivity of semi-natural vegetation, providing favourable corridors for species dispersal and for the improvement of fragmented landscapes [13].

The aim of the presented research is to find a way to: (i) identify GI using Copernicus and Earth Observation, (ii) assess its capacity to deliver benefits to humans, (iii) analyse its condition and (iv) rank its conservation priority accordingly. The case study selected to test the approach is the Po river basin, located in Northern Italy. It is the largest water catchment and a focal point for the economy of the country, with more than 40% of national gross domestic product (GDP) and 35% of agricultural production, which makes climate change effects a major concern [40,41].

The study focuses on riparian areas, which represent transitional areas occurring between land and freshwater ecosystems, characterised by distinctive hydrology, soil and biotic conditions and strongly influenced by the watercourse [42]. Thus, these areas can efficiently serve a wide range of functions related to water quality, flow moderation, soil erosion and biodiversity conservation [16,18–20,28,30,42]. The protection of riparian areas is therefore significant for ES conservation [43,44].

Within these areas, the study focuses on Natural Water Retention Measures (NWRM), which are defined as “multi-functional measures that aim to protect and manage water resources and address water-related challenges by restoring or maintaining ecosystems as well as natural features and

characteristics of water bodies using natural means and processes” [42]. Specifically, the analysis focuses on agriculture and forestry types of NWRM and on regulative ES due to the role of NWRM in regulating extreme events, such as floods or droughts, by storing or slowing runoff, increasing evapotranspiration, increasing groundwater recharge or increasing soil water retention [19,42,43].

Lack of recent field data and current availability of open-source satellite-based reliable data with high spatial, temporal and radiometric resolutions makes remote sensing a suitable tool to monitor GI in the case study. Especially due to the full, open and free European Copernicus Land Monitoring Service (CLMS) [45] and after the launch of Sentinel-2 (S2) B in March 2017, increasing its revisit time to just five days [46]. Specifically, the Riparian Zones products from the CLMS local component were used since they provide detailed data on these areas’ land cover/land use class and disposition to deliver riparian ES [47,48]. Moreover, S2 data has been used due to its high spatial resolution to overcome this weakness of the bio-geophysical indices offered in the CLMS [49]. The goal was to determine and evaluate ES condition indicators specified in the reviewed frameworks, such as the greening response and water stress [39], using indices that can be related to vegetation biophysical characteristics, like the Normalized Difference Vegetation Index (NDVI) [50–53].

The approach is an improvement of the current Riparian Zones products [47]. The integration with other datasets (Natura 2000), high-resolution satellite data (S2) and previous research that outlines user requirements [54–56] and sets ES condition indicators [39,57–65], allows the identification of NWRM within the riparian system of a river network and the assessment of their current condition. Furthermore, it overcomes specific limitations mentioned by decision-makers, such as data availability, scalability and possibility to monitor over time [55]. Specifically, it can ease MS tasks [27] by quickly identifying and assessing GI condition and supporting the corresponding management or restoration plans [31].

The article is organized as follows: after introducing the concept of GI and presenting the current policies and initiatives on its deployment and appropriate conservation, Section 2 describes the case study, the input data used and the steps followed for the integration and analysis of the Copernicus products. Section 3 shows illustrations of the identified and assessed GI in the modelled area. Section 4 discusses the results of the analysis, data gaps and future challenges, especially regarding CLMS potential to map and assess GI and, finally, Section 5 summarizes the conclusions derived.

2. Materials and Methods

2.1. Case Study: Po River Basin

Po is the largest Italian basin, covering an area of 74,000 km²; 70,000 km² in Italy and 4000 km² in Switzerland and France. The related river network has a total length of about 6750 km, corresponding 650 km to the main river. The area consists of two regions: Upper Po (75%), characterised by mountainous streams from the Alps [66], and Po Valley (25%) with flat and wide plains [67] (Figure 1).

The hydrological network is therefore characterised by a mixed discharge regime: part Alpine with spring and summer floods and winter droughts and part Apennine with spring and autumn floods and summer droughts [68,69]. The highest streamflow peaks can be observed both in spring and autumn due to precipitation and snow melting, while the Maritime and Liguria Alpine areas are characterised by lower specific discharge and higher evapotranspiration that limits river flow [70,71].

The basin is a strategic area for the Italian economy, produces 40% of gross domestic product (GDP) and has a population of over 16 million [40]. Despite high urbanization, agriculture plays a dominant role in the basin [40,72]. Water uses concern industrial activities, agricultural productions, livestock and inland navigation and, consequently, water extreme events can provoke serious economic damages [41,68].

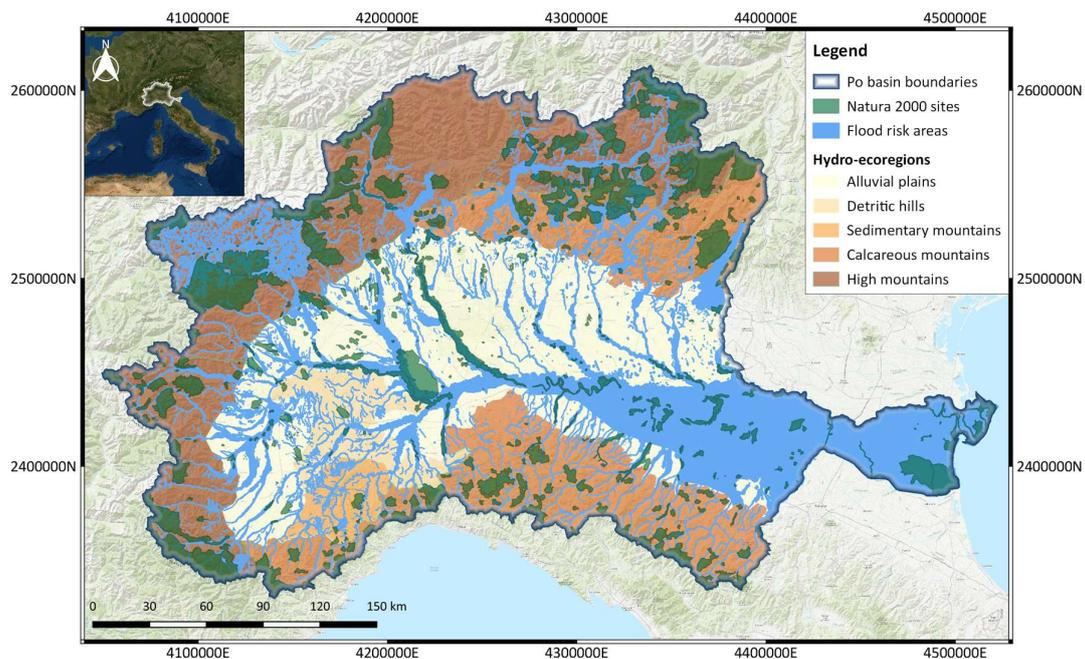


Figure 1. Po hydrographic basin location in Italy: basin boundaries, hydro-ecoregions [73], flood risk area [74] and Natura 2000 sites [75].

Previous scientific research analysed the difference in precipitation, temperature and daily flux of Po river by comparing forecast data (2021–2050) and recorded data (1982–2011). The comparison showed a significant decrease in annual average water availability and a higher frequency and intensity of extreme events [40,41,72]. This makes the region interesting to study GI as a nature-based solution for mitigating water stress effects [70].

Floods and droughts affect the river basin more intensely in its delta area due to higher pressure on water resources [68,72] (Figure 1). Also, Po delta is the largest wetland in Italy and over a third of its surface is protected under the Birds Directive [26] (Figure 1). Therefore, it was selected as the study area to analyse GI condition using data from the Sentinel-2 satellite platform [46].

2.2. Materials

2.2.1. Copernicus Land Monitoring Service: Riparian Zones and Corine Land Cover

CLMS local component focuses on different hotspots, i.e., areas that are prone to specific environmental challenges [49]. The Riparian Zones (RZ) is a local CLMS product that supports the objectives of European legal acts and policy initiatives, such as the Biodiversity Strategy to 2020 [27], the Habitats [25] and Birds Directives [26], the Water Framework [36] and the Floods Directives [37].

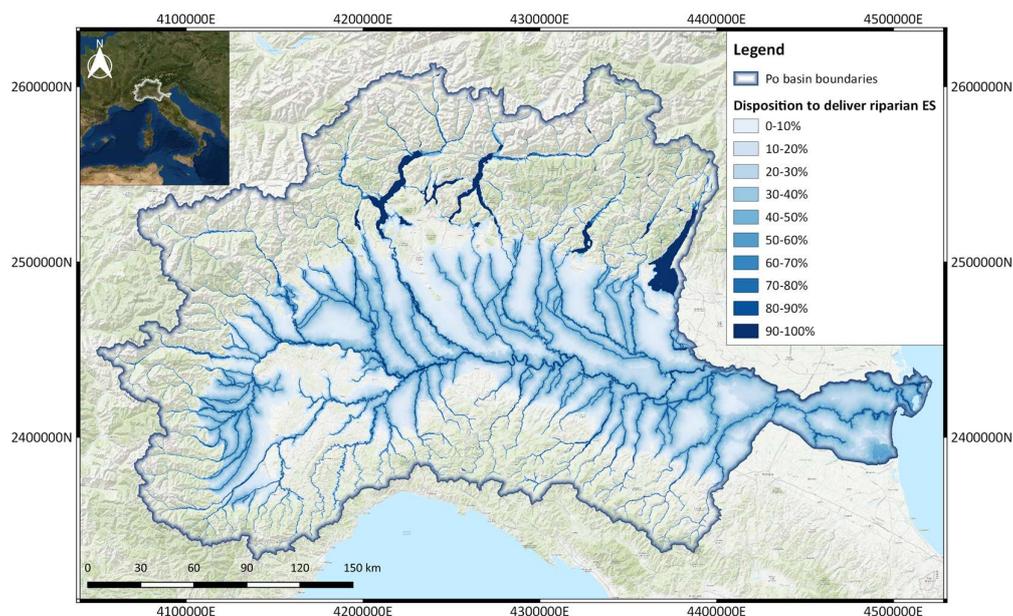
RZ consists of three products: Delineation of Riparian Zones (DRZ), Land Cover/Land Use (RZ LC/LU) and Green Linear Elements (GLE) [47]. Moreover, the DRZ product consists of three components [48] of which the Delineation of Potential Riparian Zones (DRZP) was used. DRZP is derived from weighing hydrological and geomorphological parameters, among other input data (Table 1), to express the likelihood of an area to host riparian features and hence to provide riparian-related benefits.

RZ LC/LU and DRZP (Figure 2) are the main input data used in the approach to identify GI and its potential to provide riparian-related ES respectively, since they provide very detailed information of the riparian environment (LC/LU classes and its characteristics) along large and medium-sized river streams (Table 1).

Table 1. Main characteristics of the Riparian Zones' (RZ) products from the Copernicus Land Monitoring Service (CLMS) local component used in the approach [47].

Product	Delineation of Potential Riparian Zones	Riparian Zones Land Cover/Land Use
Product short name	DRZP	RZ LC/LU
Product definition	Spatial model which indicates the capacity to host riparian features.	Detailed LC/LU dataset for areas along a buffer zone of selected rivers (Strahler level 3 to 8).
Input data	(1) EU-DEM1 ¹ (2) Water masks ² (3) JRC FHRM ³ (4) HWSD ⁴	(1) DRZA ⁵ (2) Satellite Imagery ⁶ (3) Corine Land Cover 2006/2012 (4) Urban Atlas 2006/2012 (5) Imperviousness degree and tree cover density ⁷ (6) National orthophoto web map services, Google Earth Pro and Bing Maps (7) Numerous additional references and in-situ data sources
Geometric resolution or equivalent scale	Raster: 25 m Vector: 1:50.000	1:10.000
Minimum Mapping Unit	Raster: 625 m ² pixel-based Vector: 50 ha	0.5 ha
Minimum Mapping Width		10 m
Coordinate Reference System	ETRS89/LAEA Europe EPSG: 3035	ETRS89/LAEA Europe EPSG: 3035
Temporal reference	2010–2014	2010–2014
Accuracy	Not-yet-assessed (just by experts)	≥85%
Responsible	European Environment Agency (EEA)	European Environment Agency (EEA)

¹ European Digital Elevation Model, 25 m spatial resolution. ² Water masks from the Riparian Zones Land Cover/Land Use, EU-Hydro 2006, Open Street Map and mask from CORE_03 data for riparian zones gap filling. ³ Flood Hazard Risk Maps by the Joint Research Centre at 20, 50, 100, 200 and 500 years of returned period, 100 m spatial resolution. ⁴ Harmonized World Soil Database. ⁵ Delineation of Actual Riparian Zones. ⁶ Remote sensing satellite data from 1.5 m SPOT-6, 2.0 m Pleiades and 2.5 m SPOT-5. ⁷ Pan-European high-resolution layers from Copernicus initial operations.

**Figure 2.** Disposition to provide regulative ecosystem services (ES) in the Po river basin area, obtained using the Delineation of Potential Riparian Zones (DRZP) product from the CLMS local component [48].

Corine Land Cover (CLC) consists of an inventory of land covers classified in 44 overall classes. It is a pan-European product initiated in 1985 (reference year 1990) and updated every 6 years. The RZ LC/LU product was performed using CLC 2006/2012, among other inputs (Table 1). Thus, CLC 2018 and Corine Land Cover Change (CLCC) 2012/2018 [76] (Table 2) were used for an internal cross-check validation approach of the main input data. The goal was updating the LC/LU classes, avoiding false positives in GI identification due to LC/LU changes between 2012 and 2018, before performing the subsequent spatial and temporal analyses on the vegetation condition. Afterwards, the misclassified GI was photo-interpreted using recent Sentinel-2 satellite images.

Table 2. Main characteristics of the Corine Land Cover (CLC) 2018 and Corine Land Cover Change (CLCC) 2012/2018 [76].

Product	CLC 2018 and CLCC 2012/2018
Satellite data	Sentinel-2 (S2) (and Landsat-8 for gap filling)
Time consistency	2017–2018 (CLC) and 2012–2018 (CLCC)
Geometric accuracy	≤10 m (S2)
Minimum Mapping Unit/Width	25 ha/100 m
Coordinate Reference System	ETRS89/LAEA Europe EPSG: 3035
Change mapping (CLCC)	Boundary displacement min. 100 m All changes ≥5 ha are mapped
Thematic accuracy	≥85%

2.2.2. Ancillary Data: Hydro-Ecoregions, Flood Hazard Risk Maps and Natura 2000 Network

The DRZP layer is not validated yet (by September 2019) due to lack of reference data and characteristics of riparian zones in sufficient detail [48]. To assure that the layer was suitably characterizing riparian areas in the case study area, it was cross-checked with available local ancillary data, i.e., products offered by the Emilia-Romagna region in an open-source catalogue: the hydro-ecoregions (HERs) [73] and the 2013 Flood Hazard Risk Maps (FHRM) [74].

Po HERs have been defined according to the implementation of the Water Framework Directive [36]. Each area is characterized based on: (i) the lithological structure and properties of the rocks (hardness, permeability and influence of water chemistry); (ii) relief (altitude and slope) and (iii) climate, depending on the precipitation and temperature (yearly average and seasonal variation) [73]. On the other hand, the FHRM are defined according to the Floods Directive [37] and delimitate hazard risk areas depending on: (i) scenarios of low, medium or high probability of flood; (ii) return period and (iii) information associated to all the exposed elements [74].

Firstly, these vector and alpha-numeric datasets were interpreted with respect to the aquatic ecosystem functioning and its benefits for the water balance. Subsequently, the outcome was compared with the DRZP buffers and percentage ranges. The correlation is visible in Figures 1 and 2.

The Natura 2000 network, obtained from the same catalogue, defines rich habitats that play a significant role as natural corridors within the wider landscape [75]. It was used to determine its distance to the identified GI. The goal was increasing the conservation priority accordingly [39].

2.2.3. Sentinel-2 Multispectral Imagery

The presented work used also Sentinel-2 (S2) satellite data because it can monitor large surfaces with high spatial, temporal and radiometric resolutions. This may explain its worldwide use as input data for land cover/land use monitoring and decision-making applications [50,51]. Table 3 shows the main characteristics of the optical sensor on-board S2 (the Multispectral Instrument–MSI) and the band set used.

Table 3. Main characteristics of the Sentinel-2 (S2) Multispectral Instrument (MSI) sensor and bands used [77].

Satellite Platform	Sentinel-2 (A & B)
Spatial resolution	10 m ¹ and 20 m ²
Temporal resolution	5 days ³
Time consistency	2015-to date
Radiometric resolution	12 bits
Band set used	Band 2 (Blue): 0.490 μm Band 4 (Red): 0.665 μm Band 8 (NIR): 0.842 μm Band 11 (SWIR ₁): 1.610 μm

¹ Visible and Near-Infrared bands. ² Short-Wave Infra-Red bands. ³ 10 days using one satellite, 5 days using two.

Just 4 bands were needed to calculate the biophysical variables applied to assess GI condition in terms of its vegetative health stage and water content [52]. Vegetation indices are calculated using the spectral bands that capture the Red and Near-Infrared (NIR) reflectance, as this part of the electromagnetic spectrum shows a higher sensitiveness to the leaf chlorophyll content [78,79]. On the other hand, leaf water content largely controls the spectral reflectance in the Short-Wave Infrared (SWIR) interval of the electromagnetic spectrum [80].

2.3. Methodology

The proposed steps to identify the existing NWRM and estimate its disposition and condition for delivering riparian regulative ES (Figure 3) are based on the benchmarks developed for mapping and assessing ecosystems and their services [39,57–65]. This is mainly required by the EEA to fulfil the targets of the 2020 Biodiversity Strategy in this regard [27].

2.3.1. Input Data Acquisition

Specifically, the Delimitation Units DU018A and DU005A, that catch the study area, were downloaded from the Delineation of Potential Riparian Zones (DRZP) and the Riparian Zones Land Cover/Land Use (RZ LC/LU) products in the local CLMS. Then, they were clipped using the basin boundaries.

As for the satellite data used, Sentinel-2 Level 1C (S2 L1C) scenes of the tile T32TQQ that covers Po delta were acquired from the French Sentinel collaborative ground segment PEPS-CNES [81], an operating platform mirroring all Sentinel products provided by the European Space Agency (ESA). Just one S2 tile was analysed in order to observe an area in which the climate conditions, phenology types and development trends could be considered almost the same [51]. 36 scenes for the period of 1st January–30th October 2018, with a cloud cover below 50%, were downloaded and pre-processed. This year was selected to perform an intra-annual assessment of the variability in the phenological trend of the selected GI. Also, it was selected since the scenes were less affected by atmospheric effects and cloud cover.

2.3.2. Pre-Processing

To assure that the main input Copernicus products were suitably characterizing the riparian areas in the case study area in the analysed year, they were cross-checked with auxiliary data, i.e., available local ancillary data and the updated version of CLC 2018. This way, the analysis was based on LC/LU datasets and satellite images of the same period.

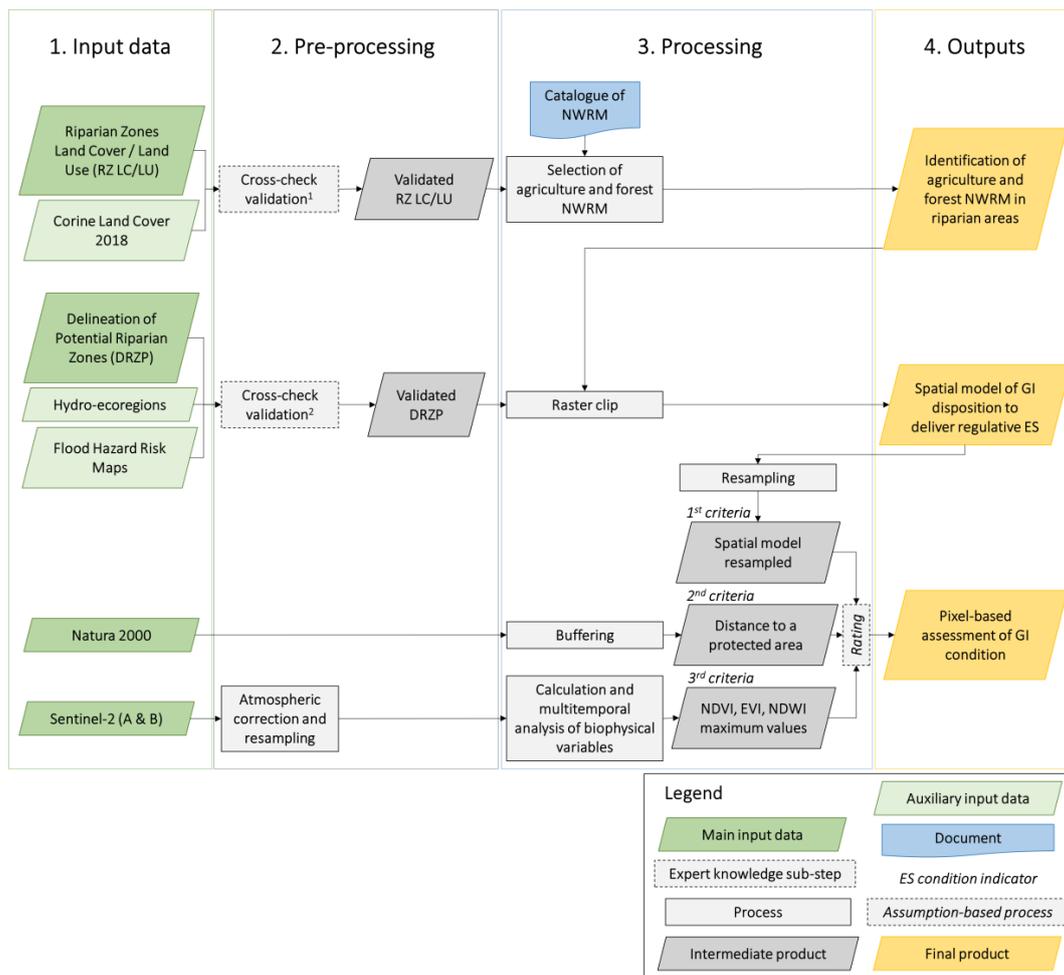


Figure 3. Flowchart of the proposed methodology to identify Natural Water Retention Measures (NWRM) in riparian areas of a river network, its disposition to provide regulative ES and its condition (input data explained in Section 2.2). ¹ Comparison between the land cover/land use classes assigned to the identified GI due to the launch of an updated version of Corine Land Cover in 2018. ² Due to lack of reference data on riparian characteristics in a sufficient level of detail, the authors checked the correlation between the DRZP layer's modelled area in the case study and regional products.

The Maccs-Atcor Joint Algorithm (MAJA) [82] was used right after acquiring the S2 L1C scenes from the PEPS-CNES segment [81]. The selection of this atmospheric correction algorithm was based on its unique method for detecting clouds and shadows using multi-temporal series of data input instead of a single image [82]. This improves the correction of atmospheric, shadows and even slope effects in comparison with SNAP or Sen2Cor-derived S2 L2A [83], which could affect the vegetation and water indices that are calculated afterwards. Thus, time series of the T32TQQ tile were processed together since it did not represent a massive quantity of data.

Afterwards, 7 scenes were selected, one per month from March to September 2018 (Table 4). This selection was made due to their lower cloud cover and hence fewer missing values. Also, since this period of the year catches the most prominent stage of the vegetation development cycle (according to the growing stages specified by the Food and Agriculture Organization of the United Nations, FAO [50,51]). Thus, this period catches the highest values of the analysed bio-geophysical indices if the detected GI is being adequately maintained [78–80].

Table 4. Scenes used of the T32TQQ tile, caught by the S2 MSI sensor, to test the approach; downloaded and pre-processed on the PEPS-CNES collaborative ground segment [81].

Satellite Platform	Date	Cloud Coverage (%)
S2A	30 March 2018	45
S2A	19 April 2018	5
S2A	19 May 2018	31
S2A	28 June 2018	18
S2A	18 July 2018	0
S2A	17 August 2018	2
S2A	26 September 2018	5

Lastly, band 11 (SWIR₁) was resampled from 20 to 10 m using the Semi-Automatic Classification Plugin 6.2.5 [84] in QGIS 3.2.1 in order to calculate the indices with the finest spatial resolution.

2.3.3. Processing and Outputs

A significant phase of the research was finding attributes that allowed to: (i) spatially identify GI sites that serve for water retention (1st output), (ii) recognize their role in the river riparian system (2nd output) and (iii) assign them an importance based on their conservation condition (3rd output) (Table 5). With this aim, assumptions were made by: (i) selecting the common criteria used by the consulted approaches on indicators to detect ecosystems' condition [39,57–65] (1st column) and (ii) linking it to the suitable Copernicus products [47], available ancillary data [75] or the most successfully used bio-geophysical indices to monitor vegetative surfaces [52,78–80] (2nd column).

Table 5. Criteria selected and indicators used to identify riparian NWRM and assess their disposition to deliver regulative ES and their current condition.

Criteria [39,57–65]	Indicators Used	Output Delivered
Capacity to provide ecosystem services	Riparian Zones products [47] from the Copernicus local component:	
	<ul style="list-style-type: none"> - Identification of agriculture and forest riparian GI¹ according to MAES level 4 LC/LU classes². - Disposition to deliver riparian ES according to the DRZP³ product. 	<ol style="list-style-type: none"> 1. Identification of agriculture and forest NWRM in riparian areas 2. Spatial model of GI disposition to deliver regulative ES
Membership in Natura 2000 network	Natural Water Retention Measures catalogue from DG-ENV [42]. Buffers of Natura 2000 areas [75] to calculate the distance to detected GI.	
Indicators of the ecosystem's functional attributes: greening response and water stress	Bio-geophysical indices calculated using Sentinel-2 (S2) ⁴ : <ul style="list-style-type: none"> - NDVI: vegetation vigorousness [78]. - EVI: more sensitive than NDVI in heavily vegetated sites [79]. - NDWI: vegetation water stress [80]. 	3. Pixel-based assessment of GI condition ⁵

¹ Green Infrastructure. ² Mapping and Assessment of Ecosystems and their Services (MAES) level 4 of Land Cover/Land Use classes, consulted in the RZ LC/LU Copernicus local product. ³ Delineation of Potential Riparian Zones product from the Copernicus local component [48]. ⁴ Being NDVI, the Normalized Difference Vegetation Index; EVI, the Enhanced Vegetation Index and NDWI, the Normalized Difference Water Index. ⁵ Using the indicators stated together with output 2.

Identification of Agriculture and Forest NWRM in Riparian Areas

The proposed approach focused first on detecting vegetation and forestry GI sites in the riparian areas of Po river basin. More specifically, nature-based measures for water retention (NWRM). The RZ LC/LU product is the main input used [47]. As it follows the MAES nomenclature (levels 1 to 4) for defining the LC/LU classes, level 4 was consulted due to its higher level of detail.

These LC/LU classes were linked to the type of agriculture and forest NWRM using the catalogues developed by the European Commission Directorate-General Department for Environment Policies (DG-ENV) [42] (Table 6). An area of 4040 km² of agriculture and forest NWRM was detected in the riparian areas of Po river basin, finding a significant appearance of forest riparian buffers (66%), followed by meadows and pastures (20%).

Table 6. Types of agriculture and forest GI for natural water retention (NWRM) identified in the riparian areas of Po river basin and corresponding area extent.

MAES Level 4 LC/LU Classes ¹ [47]	Green Infrastructure [42]	Area (km ²)
Pastures Managed grasslands without trees and scrubs with a Tree Cover Density (TCD) of less than 30% and over or equal 30% Dry, mesic and alpine and subalpine grasslands without trees with a TCD of less than 30% Herbaceous vegetation Heathlands and moorlands Sparsely vegetated areas	Meadows and pastures	775.68
Transitional woodland and scrub Lines of trees and scrub	Buffer strips and hedges	94.10
Annual crops associated with permanent crops Complex cultivation patterns	Crop rotation Strip cropping along contours Intercropping ²	91.46
Land principally occupied by agriculture with significant areas of natural vegetation Agro-forestry with a TCD over 30% and less than 30% Dry, mesic and alpine and subalpine grasslands with trees with a TCD over or equal 30%	Green cover	224.07
Riparian and fluvial broadleaved, coniferous and mixed forest with a TCD over 80%, 50–80%, 30–50% and 10–30% Broadleaved, coniferous and mixed forest swamp with a TCD over 80%, 50–80%, 30–50% and 10–30%	Forest riparian buffers	2688.64
Riverbanks	Riverbanks	133.92
Forest Other natural and semi-natural broadleaved, coniferous and mixed forest with a TCD over 80%, 50–80%, 30–50% and 10–30% Broadleaved evergreen forest with a TCD over 80%, 50–80%, 30–50% and 10–30% Highly artificial broadleaved, coniferous and mixed plantations with a TCD over 80%, 50–80%, 30–50% and 10–30% Other scrub land Sclerophyllous vegetation	Continuous cover forestry	32.26

¹ Mapping and Assessment of Ecosystems and their Services (MAES) level 4 of Land Cover/Land Use classes, consulted in the RZ LC/LU Copernicus local product. ² These GI types have been gathered in the delivered spatial models as crop rotation.

After that, spatial operations were carried out in a model using ArcGIS 10.2 raster calculator algorithms (Figure 3).

Spatial Model of GI Disposition to Deliver Regulative ES

Clipping the identified NWRM (1st output) by the DRZP model [47] allows to detect the disposition of each site to deliver the associated regulative ES in the riparian system [42]. This disposition can be expressed by weighing different hydrological and geomorphological parameters that affect the

appropriate functioning of riparian ecosystems, especially during extreme events, such as floods or droughts [28,30,42,72–74], and that the DRZP product takes into account (Table 1): (i) distance to water bodies, (ii) slope, (iii) flood hazard risk areas and their return period and (iv) soil type (i.e., erosion and permeability features) [47,48].

As a result, a spatial model of the identified agriculture and forest GI shows its disposition to deliver NWRM-related regulative ES (2nd output), measured from 0% to 100% and with a spatial resolution (SR) of 100 m due to the SR of the Copernicus product [47].

Pixel-based Assessment of GI Condition

- Buffering of the Natura 2000 network

The Natura 2000 areas of the river basin [75] were buffered every 10 m until 100 m [39,85]. Then, the identified GI was classified according to 10 distance ranges. This parameter was used to prioritise adequate management and conservation of those GI sites that belong or are close to Natura 2000 areas due to their contribution to the ecosystem's appropriate functioning, being hence significantly vulnerable items to changing climate consequences [39,57–65].

- Calculation and multitemporal analysis of biophysical variables

Vegetation and water indices were calculated for the period of March–September 2018 using the spectral bands from the 7 selected S2 images, once corrected from the atmospheric effect and resampled. Also, a filter of GI with a surface of less than 0.1 ha was applied due to S2 spatial resolution.

Several indices were analysed complementarily to obtain a more accurate and reliable characterization of the environment [52]. These spectral indices (Table 5) were selected for being the most significantly used in vegetation and forestry studies, achieving representative and accurate results in previous experiences [52,86,87].

The Normalized Difference Vegetation Index (NDVI), as well as the Enhanced Vegetation Index (EVI), have been the most successful in studying the development stage, healthiness and vigorousness of vegetation [50,51,86]. On the other hand, the Normalized Difference Water Index (NDWI), also called Normalized Difference Moisture Index (NDMI) in some studies, has been used to detect wetness and water content in vegetation [87].

NDVI is calculated using the reflectance from the Red channel (R) and the Near-Infrared (NIR) (Equation (1)) [78]. EVI was selected since it complements the information derived from NDVI, being more sensitive to differences in heavily vegetated areas and less affected by atmospheric noise [79,86]. It is calculated similarly to NDVI, but also considering the reflectance in the Blue channel (B) (Equation (2)) [79].

$$\text{NDVI} = \frac{\text{NIR} - \text{R}}{\text{NIR} + \text{R}} \quad (1)$$

$$\text{EVI} = 2.5 \frac{\text{NIR} - \text{R}}{\text{NIR} + (6 \text{R} - 7.5 \text{B}) + 1} \quad (2)$$

However, vegetation indices have a limited capability for retrieving vegetation water content due to uniquely providing information on vegetation greenness (chlorophyll), which is not directly nor uniformly related to the quantity of water in vegetation [80,87]. Thus, NDWI was also calculated.

This index is defined using NIR and SWIR reflectance (Equation (3)) and, as NDVI and EVI, shows values in the range of -1 to $+1$, with higher values corresponding to higher leaf water content and vegetation cover [80]. The main reason for choosing this index was the easier observable monitoring of vegetative and forestry stages when observing their reflectance in the SWIR bands, as well as to identify water stress [52,87].

$$\text{NDWI} = \frac{\text{NIR} - \text{SWIR}_1}{\text{NIR} + \text{SWIR}_1} \quad (3)$$

Finally, a statistical analysis was performed to evaluate the yearly maximum value (and hence the healthiest and most vigorous vegetation stage) per index, pixel and GI type. This is since each vegetation surface displays its specific multitemporal variation of biophysical characteristics. Thus, each surface is defined according to a specific variation pattern during its annual development cycle [50,51].

- Rating of the ES condition indicators

The value of the indicators selected to assess GI condition (3rd output) was weighed using the following expressions as assumptions based on the existing theoretical approaches (Table 5) to allow their interpretation through a remote-sensing based approach:

$$\text{Capacity to provide ecosystem services} \quad D_i = D/10; [0, 10], \quad (4)$$

$$\text{Membership in Natura 2000 network} \quad N_i = N/10; [0, 10], \quad (5)$$

$$V_i = NDVI(BOA)_{\max i} \cdot 10; [0, 10], \quad (6)$$

$$\text{Greenness response and water stress} \quad E_i = EVI(BOA)_{\max i} \cdot 10; [0, 10], \quad (7)$$

$$W_i = NDWI(BOA)_{\max i} \cdot 10; [0, 10], \quad (8)$$

Representing i , the data extracted per pixel (10×10 m); D , the disposition to deliver the associated regulative ES, resampled to 10 m SR and expressed in percentages; N , the distance range from a GI to the Natura 2000 network; $NDVI(BOA)_{\max i}$, $EVI(BOA)_{\max i}$ and $NDWI(BOA)_{\max i}$, the maximum value per pixel for the analysed period (March–September 2018) of the bio-geophysical indices. All the indicators were analysed as integers and expressed in values from 0 to 10. Moreover, if in a pixel no data existed for a parameter, a null value was assigned to that indicator.

The conservation condition, C , (Equation (9)) was obtained per-pixel and per type of NWRM (V_j). Then, it was dissolved to obtain one single modelled area indicating GI condition in the case study. The condition index was obtained summing the selected indicators, equally scaled, to allow the easy integration of new condition indicators in future assessments. All the evaluated parameters were considered equally significant since the consulted literature did not mention any distinction of priorities in that regard.

$$\text{Conservation condition, } C_i = D_i + N_i + V_i + E_i + W_i; \forall j, [0, 50], \quad (9)$$

Finally, the integer values obtained with Equation (9), from 0 to 50, with higher values representing a better condition, were translated into a ramp colour legend. This eases the interpretation of the spatial model, quickly locating GI playing a major role in the delivery of ES but that, given their compromised condition, would require management interventions.

The developed model assesses GI actual status based on the maximum value of the vegetation and water indices achieved per type of GI in its intra-annual development trend, among other condition indicators. Neither intra-seasonal nor inter-annual changes are assessed.

3. Results

Appropriately assessing ecosystems' condition must concern individual ecosystems, but also their territorial context [12,27,39]. Thus, the assumptions made and indicators used in the approach, based on the frameworks developed to map and assess ecosystems' conditions and their services (Table 5), include: (i) disposition of the identified NWRM to provide regulative ES in the riparian system, (ii) proximity to protected areas included in Natura 2000 and (iii) remotely-sensed greenness and water stress response as means of the ecosystem's functional attributes.

Figure 4 shows the inputs used (1st and 2nd columns) and outputs delivered (3rd column) for the same area extent. The area is part of the Po delta. It mainly consists of lines of trees and scrub, natural and semi-natural broadleaved forests and alpine and sub-alpine natural grassland (Figure 4a). According to the NWRM catalogue [42], these LC/LU classes were translated into "green cover", "forest riparian buffers" and "buffer strips and hedges" (Table 6) (Figure 4g). Those NWRM located closer to the river streams present a higher disposition to deliver regulative ES (Figure 4h), based on the DRZP

dataset (Figure 4b), and a higher proximity to protected areas in Natura 2000 (Figure 4c). These two condition indicators and the analysis of biophysical variables (2nd column of Figure 4) allowed to detect GI in moderate condition (Figure 4i).

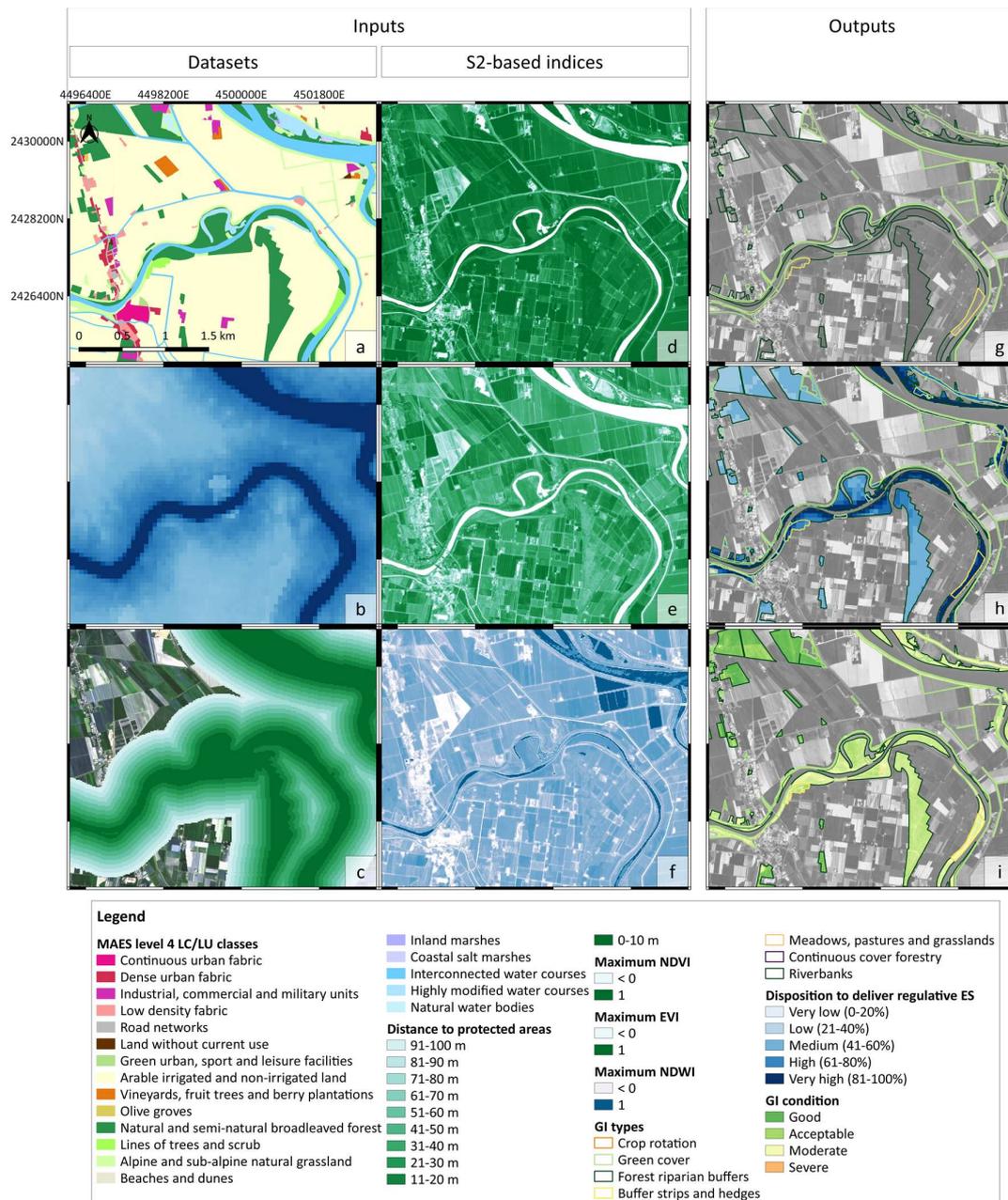


Figure 4. Riparian NWRM in an area of Po delta: (a) MAES level 4 LC/LU classes (from RZ LC/LU). (b) Disposition to deliver riparian ES (from DRZP). (c) Distance to protected areas in Natura 2000. (d) Maximum NDVI in 2018. (e) Maximum EVI in 2018. (f) Maximum NDWI in 2018. (g) 1st output: Identification of agriculture and forest NWRM in riparian areas. (h) 2nd output: Spatial model of GI disposition to deliver regulative ES. (i) 3rd output: Pixel-based assessment of GI condition.

3.1. Spatial Model of GI Disposition to Deliver Regulative ES

A spatial model weighing the capacity of the identified GI to deliver NWRM-related ES, such as protection against flood events, was obtained for the entire river basin. This disposition is measured in

percentages from 0% to 100% and translated into a colour ramp from light to dark blue, following the labels of very low, low, medium, high and very high capacity to ease its interpretation (Figure 5).

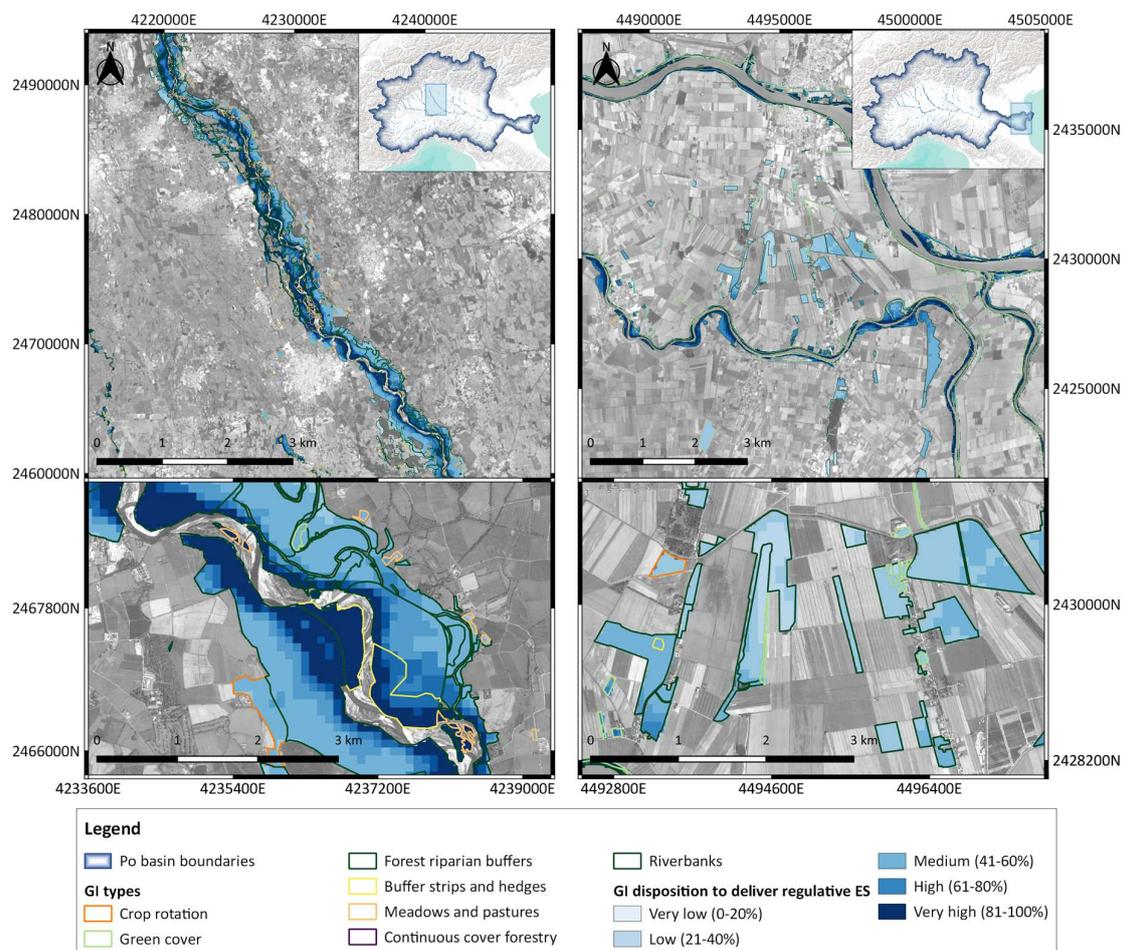


Figure 5. Spatial model representing the disposition of the identified agriculture and forest NWRM for providing the associated regulative ES in the river network of Po basin: Po hills in the central part of the basin (left) and Po delta (right).

The highest capacity to deliver the related regulative ES was found in NWRM located closer to the river flows (dark blue). Moreover, the riparian buffers located closer to the river courses were wider in the central part of the basin than in the delta area (Figure 5).

3.2. Pixel-Based Assessment of GI Condition

A model representing riparian GI condition in 2018 was obtained in Po delta (Figure 6). GI condition is illustrated according to a colour ramp from green to red, following the labels of good, acceptable, moderate, severe or critical, depending on the indicators' values (Table 5), assessed through Equations (4)–(9).

The assessment model delivered might serve as an early warning tool for that GI holding a major ecological role (highly weighed capacity to deliver regulative ES and proximity to Natura 2000 sites), but not suitably conserved (showing low vegetation healthiness and exposure to water pressures according to the bio-geophysical indices' values).

Figure 6 shows the identified riparian GI condition in two different areas of Po delta: (i) GI buffers closer to the river flow (left), mainly identified as “forest riparian buffers” and “green cover” (Table 6), and (ii) fields located between river flows (right), identified as “forest riparian buffers” and “crop rotation” (Table 6), whose disposition to deliver regulative ES is shown in Figure 5 (right).

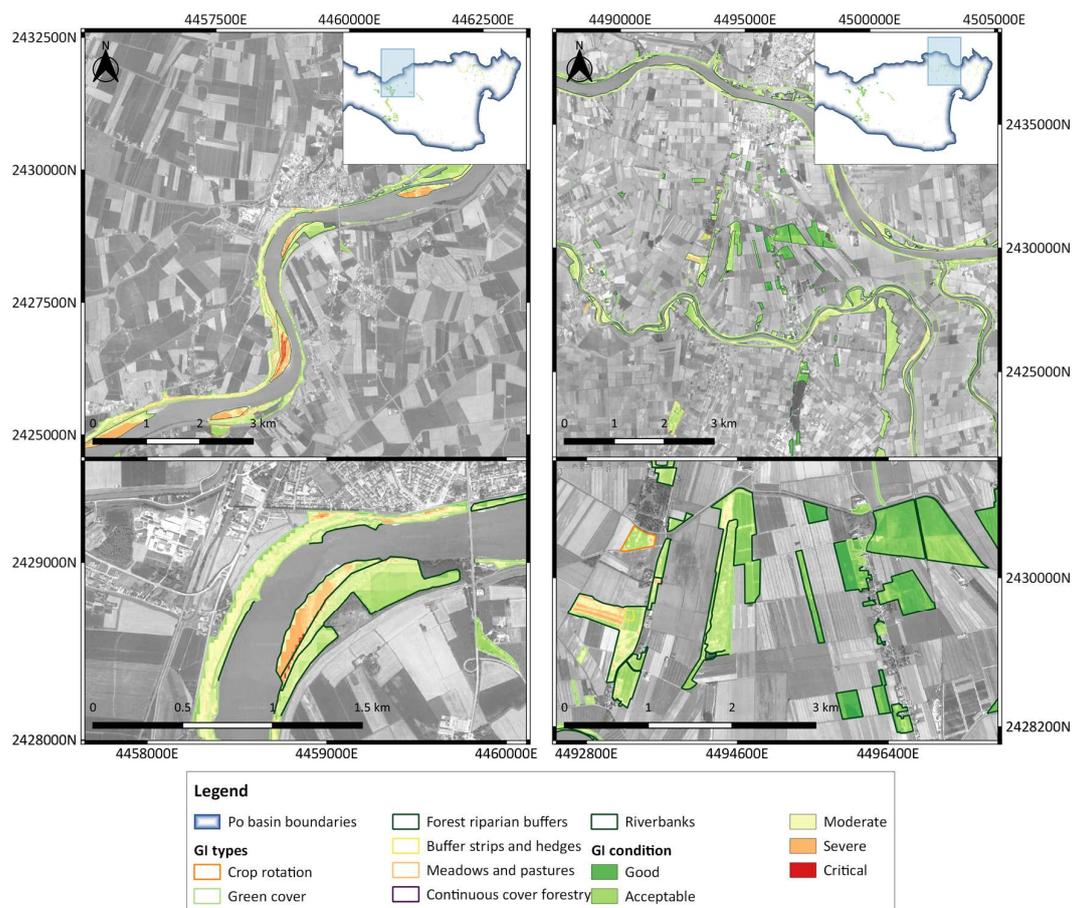


Figure 6. Assessment of the condition of the identified GI sites in the riparian areas of Po delta in 2018: GI buffers next to a river flow (**left**) and complex agricultural patterns (**right**).

The developed model allows to find GI in severe and critical conditions (orange to red colours) in both locations. In the first case, it corresponds to areas that suffer from water stress events (floods and droughts) due to influence of the river flow and, in the second, to stressed vegetation. These results are estimated from very low values of the bio-geophysical indices (which characterise bare soil and water masses) combined with a high capacity of the NWRM to deliver regulative ES and the proximity to, or inclusion in, protected habitats.

3.3. Results Per GI Class

3.3.1. Disposition to Deliver Regulative ES

The capacity to provide regulative ES (Figure 5) was evaluated in an area of 3077 km² of the detected NWRM in Po basin, of which over 40% presented high or very high ranges (Figure 7).

“Forest riparian buffers” represented the greater GI area showing a very high disposition to deliver regulative ES, followed by “meadows and pastures” (Figure 8). This outcome could be expected since these classes represent the major riparian GI surface in the basin. However, it seems remarkable that nearly all the surface occupied by natural “riverbanks” presented a very high disposition to deliver regulative ES. This fact might be related to their proximity to the river streams and hence their important role in flood scenarios.

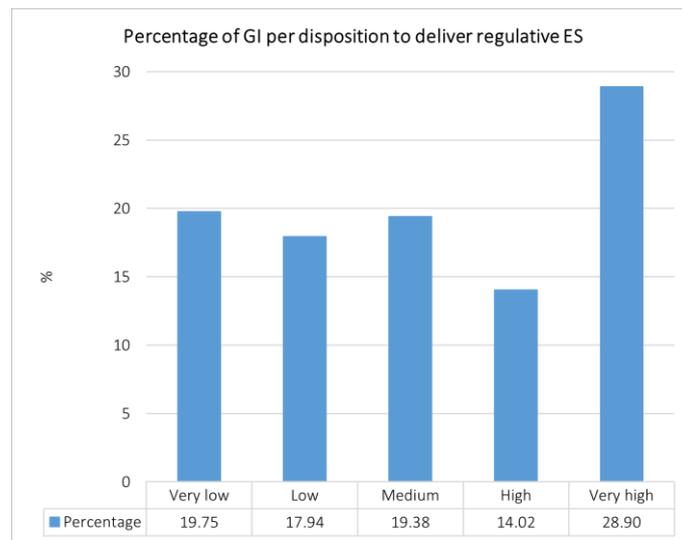


Figure 7. Percentage of GI per disposition to deliver regulative ES.

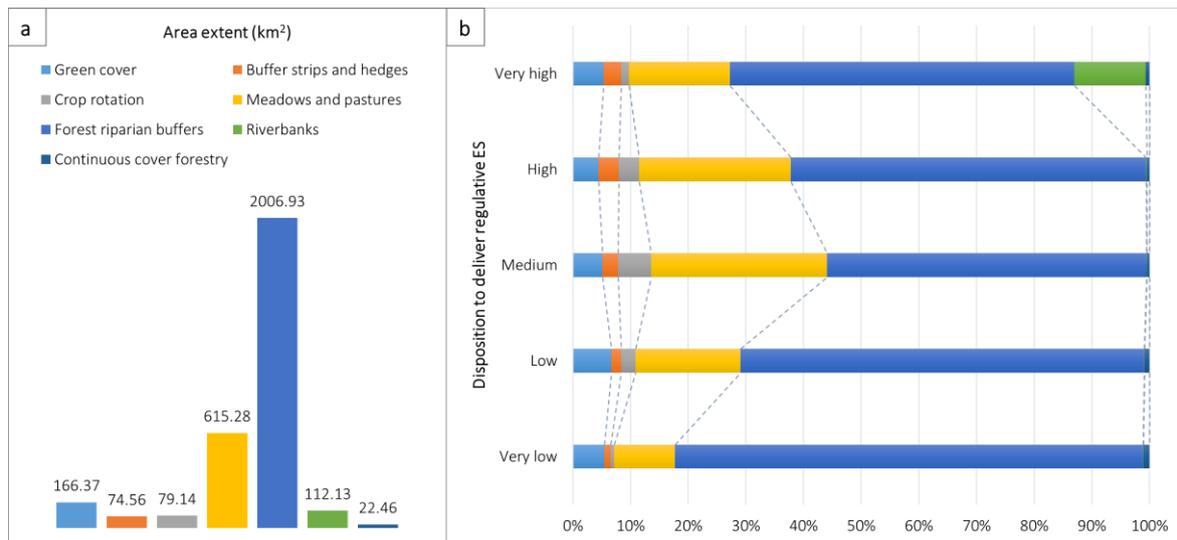


Figure 8. Assessment of GI disposition to deliver regulative ES in Po basin: (a) Area extent of each GI type that could be assessed using the DRZP Copernicus product. (b) Distribution of GI capacity to provide regulative ES depending on the type.

3.3.2. Condition Assessment in 2018 in Po Delta

The current condition was assessed (Figure 6) in an area of 102.5 km², which represents the agriculture and forest riparian NWRM in the Po delta. Over 80% was evaluated as presenting either an acceptable or moderate condition in 2018 following the presented approach, 5% showed a good condition and about 12% presented a severe or critical status (Figure 9).

“Crop rotation” stood out as the riparian NWRM most affected by a critical condition, followed by “forest riparian buffers” and natural “riverbanks” (Figure 10). This might be due to high exposure to vegetation stress and water pressures, but it must be considered that natural “riverbanks” also represented a very high capacity to deliver regulative ES (Figure 8). Therefore, this GI should be managed accordingly. Also, “green cover” was the main GI facing a severe condition (Figure 10).

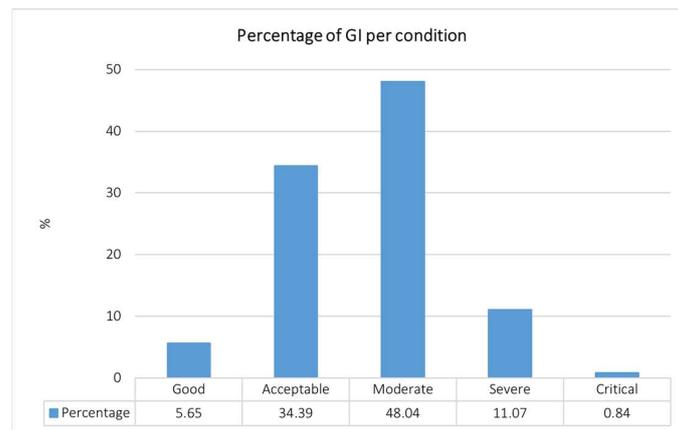


Figure 9. Percentage of GI per condition in 2018 in Po delta.

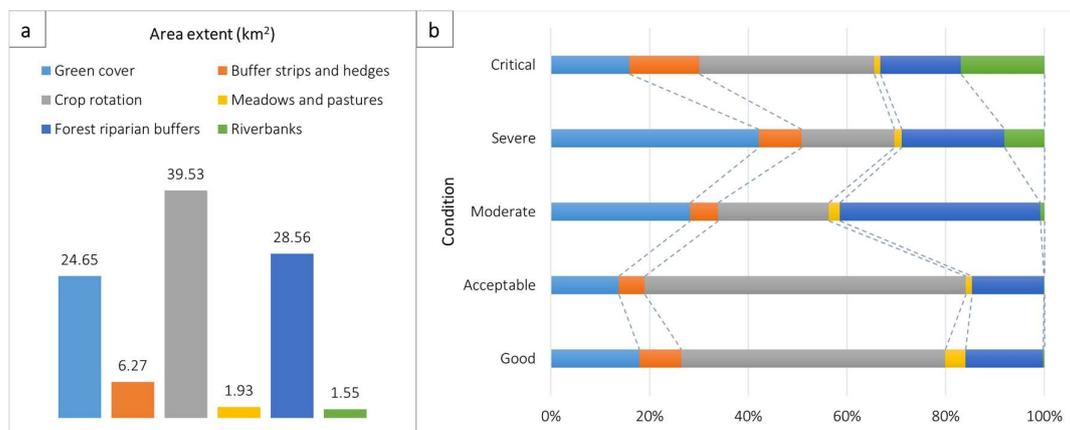


Figure 10. Assessment of GI condition in Po delta: (a) Area extent of each GI type. (b) Distribution of GI condition in 2018 depending on the type.

On the other hand, a high percentage of agricultural fields holding crop rotation, intercropping or other complex crop patterns (gathered as a sole GI class named “crop rotation”) (Table 6) showed a good or acceptable condition (Figure 10). As for the GI class “continuous cover forestry”, it was the only one not found in Po delta, which could be assumed since it did not represent a significant area in the basin.

4. Discussion

Decision-makers have mentioned the need for a practical tool that shows values or thresholds characterizing ES supply and condition, facilitating the accomplishment of policy objectives [88,89]. The presented approach can serve as a baseline, helping in understanding the indicator frameworks [55]. It specifically focuses on easing the tasks of Member States (MS) on the Mapping and Assessment of Ecosystems and their Services (MAES) (Action 5 of the 2020 Biodiversity Strategy [27]).

With the aim to overcome previous tools’ weaknesses on scalability, data availability and possibility to monitor over time [55,58,89,90], the theoretical indicator frameworks [39,57–65] are linked to the freely-available sources of remotely-sensed data that are suitable to monitor them (Table 5): (i) products offered in the Copernicus Land Monitoring Service (CLMS) [49] and (ii) satellite-based bio-geophysical indices to monitor vegetated surfaces [52,78–80].

The approach focuses on riparian zones since the potential to positively contribute to the socio-economic and environmental resilience of their area of influence has been proven [19,20,28,30,42] based on the following effects: improved water quality, positive trend of new natural riparian

functionalities, enhanced environmental and morphological quality and increased awareness of stakeholders and citizens.

Specifically, the Riparian Zones dataset was used as the main input of the approach. Very few scientific experiences exist that refer to it [48,91]. In fact, the main product used, DRZP, is not validated by September 2019 due to lack of appropriate validation data comparable to it [48]. Thus, the developed approach contributes to increase the applicability of this dataset, not generally to riparian areas, but specifically to map and assess NWRM, which are important elements for the water sector, especially for regulating extreme events, such as floods or droughts. The method identifies NWRM in riparian regions, evaluates its capacity to deliver regulative ES and assesses its current preservation condition. The approach considered innovative elements to assess GI and allowed to find weaknesses that should be solved in existing datasets.

GI condition was assessed according to the following criteria (selected from the aforementioned indicator frameworks): (i) capacity to provide ES, (ii) membership or proximity to the Natura 2000 network and (iii) indicators of the ecosystem's functional attributes: greening response and water stress (Table 5). Obtaining the condition index by summing the indicators' values, equally scaled, allows its scalability in terms of integrating indicators from future frameworks. Considering the distance of GI to protected areas included in Natura 2000 is a significant and novel element of the approach. These areas play a distinct role in the natural ecosystem's functioning [27]. Therefore, the appropriate conservation of GI connected to these areas must be prioritised accordingly [39].

Firstly, the NWRM catalogue developed by DG-ENV [42] was used to identify GI as to ensure consistency with already existing and validated definitions. However, it shows weaknesses in the NWRM class definition (e.g., not including wetland riparian vegetation in the hydro-morphological sector). Also, it is challenging to translate some classes into specific LC/LU (e.g., green cover). Therefore, the process for identifying GI should remain more autonomous to increase the usability of the approach.

The analysis focused on vegetation riparian GI. Hydro-morphological types of GI (e.g., wetlands, saltmarshes or reeds) are also important for flood and drought regulation [42], but the interpretation of biophysical variables differ for "green" and "blue" GI, i.e., the reflectance values, annual developing trends and hence the meaning of the indices [50,51,78–80]. Therefore, appropriate indices to monitor this GI must be thoroughly selected and understood before this GI's assessment could be integrated in the approach. Annual trends also vary between different vegetation GI. Thus, the indices' values were rated per type of GI.

The approach used S2 data to calculate the biophysical variables with a high spatial resolution (10 m) [46] and thereby overcome the weakness of the CLMS [49]. Just Copernicus' global component provides bio-geophysical indices products, by September 2019. These products present 300 m/1 km spatial resolutions, not fulfilling the needs at local scales [52,54].

However, clouds and shadows remain a major inconvenience when processing and interpreting bio-geophysical indices, even after correcting the images from the atmospheric effect [51,92]. Therefore, the indices can sometimes show low or even negative values that do not correspond to the vegetation features.

This was solved by analysing the maximum values of the indices in the period of March–September 2018. Thus, the analysis considers the most vigorous, healthiest and highest leaf water content response of each GI development cycle in the analysed year [50,51]. However, the possibility of having evaluated values that represent a cloud or shadow instead of the natural surface condition must be considered.

Analysing the outcomes, the representativeness of each NWRM, as well as the capacity to provide regulative ES, can be quickly interpreted in the modelled area. In Po river basin, "forest riparian buffers", followed by "meadows and pastures", popped up as the greater GI areas (Table 6). Moreover, most of this surface presented a high or very high capacity to deliver regulative ES (Figure 8). Instead, "continuous cover forestry" was the less presented GI (Table 6).

Also, the delivered model shows GI condition. 12% of the riparian GI area in Po delta presented a high conservation priority (severe or critical condition) in the analysed year (Figure 9). Most of this GI

was also closer to river streams (Figure 6). Thus, the condition index may result due to stressed or saturated vegetation conditions (i.e., very low values of the bio-geophysical indices) merged with a high capacity to supply regulative ES (Figure 5) and proximity to protected areas.

“Riverbanks” represent a frequently used nature-based measure for flood protection. This NWRM face severe and critical conditions in Po delta (Figure 10), while having a very high capacity for delivering regulative ES (Figure 8). However, it must be considered that riverbanks sometimes represent fully functional sparsely vegetated areas [42].

Alongside the regulation of water stress events, such as floods or droughts, riparian areas can provide other significant benefits to the environment and society [19,20,28,42]. Therefore, having open access to a tool that quickly highlights GI facing severe or critical conditions, hence not appropriately conserved, should raise awareness, help and motivate decision-makers to take action, supporting restoration and management strategies that improve the environmental quality of that area (e.g., revegetation measures) [23,31,43].

To this end, the interpretation of the model shall be supported by degradation assessments and analyses of the impact of GI presence or absence [93]. Also, inter-annual analyses would allow to interpret the GI condition index depending on previous trends (i.e., considering each GI likelihood to achieve different indices’ maximum values). However, the required datasets do not perfectly fit inter-annual analyses, with the consequent impact on the results of using LC/LU datasets from other periods. In this regard, the upcoming Copernicus product CLC+ will ease a more analytic mapping of the Earth’s surface and a more flexible combination with other datasets [94].

Finally, the decision of motivating either conservation initiatives on GI in a good condition or recovering strategies on damaged GI will depend on regional policy objectives and cost-effectiveness of the measures [93]. This decision could be further substantiated by applying an ES valuation exercise, supplementing the information derived from the condition indicators. However, this approach remains challenging due to the complexity of standardising ES values, which are strongly dependent on context specific circumstances that would require detailed local datasets [95].

5. Conclusions

There is a growing demand for GI and ES assessments due to their significant role in natural hazards mitigation and climate change adaptation. However, information on the condition of, and changes in, Europe’s ecosystems dominated by vegetation is still limited. The presented approach represents a new method to overcome the current lack of data on riparian characteristics. The integration of highly detailed products from the CLMS (Riparian Zones) with other datasets (protected areas in Natura 2000) and high-resolution satellite data (S2) demonstrates, through the followed approach, their potential to: (i) identify GI in the riparian areas of a river network, specifically agriculture and forestry measures that serve for natural water retention; (ii) assess its disposition to deliver the related regulative ES; (iii) analyse its condition according to the existing indicator frameworks, such as the 2018 MAES report and (iv) rank its conservation priority. Policy-related factors, such as the latest initiatives of each region to either conserve GI in good condition or recover degraded GI, should be taken into account in the latter case.

GI sites are currently subjected to many pressures caused by both natural and anthropogenic actions, which decrease its capacity for delivering ES. Thus, Copernicus evolution depends on meeting the needs for ecosystems’ monitoring and management coming from environmental and socio-economic policies and strategies at global, European and local scales. In this regard, the presented research highlights once more [52] the products’ spatial resolution as a significant handicap, by September 2019. On one hand, having full access to bio-geophysical indices based on already processed data from S2 would ease the tasks of downloading and processing this data, as well as dealing with missing values. On the other hand, it would highly increase the spatial resolution of the products to 10 m, fulfilling users’ needs for studies at local scales [54]. Then, these indices could be used to develop new products

or improve the existing ones in the frame of mapping and assessing green areas. The upcoming CLMS High Resolution Vegetation Phenology and Productivity will help in this sense [96].

In conclusion, the approach allows to:

- Provide a scalable tool based on open-source data, mainly from the CLMS, to support environmental and sustainability policies and strategies in the field of mapping GI and monitoring its condition and pressures in riparian areas.
- Provide a design to account for the constitutive elements of nature-based solutions, such as GI, including its multifunctionality and a simultaneous delivery of environmental and social benefits, based on a multi-stakeholder engagement.

Finally, it can be concluded that it is possible to conjugate environmental protection and territorial development through the coordination of monitoring activities. Prioritising GI's need of restoration depending on its role in the river system, proximity to protected areas and current condition can help raising awareness and implementing actual needs in regional coordination actions. This determines the need of communication with the public and decision-makers to highlight the potential of Copernicus as an upstream service to collect, share, organize and elaborate data on natural resources management, both in real time and historical studies. In the future, a closer collaboration with policy and decision-makers could help in Copernicus uptake at local scale, creating services that suit their needs and requirements and making it a more real-world tool that facilitates the use of remotely-sensed information in policy.

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