Mapping ecosystem services trade-offs and synergies at Natura 2000 sites: a case study from Greece

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ABSTRACT

Mapping of ecosystems and their services has become a dominant framework for the study, research, and management of natural resources in recent decades, contributing to decision-making at local, regional, national, and global levels. At the same time, thematic maps of ecosystems and their services, can be used in relevant training and education programmes with the general objectives of understanding the spatial distribution, structure, and composition of the planet's natural resources, communicating the need for ecosystem conservation and sustainable management. Mapping ecosystems and their services, including the distribution of habitat types, is also a priority of the EU Biodiversity strategy. Within the framework of the LIFE IP 4 Natura project, ecosystem type mapping of a Natura 2000 site was carried out to identify and delineate ecosystem type extent in order to assess the ecosystems services provided, as well astrade-offs and synergies among them. For this purpose, high resolution Earth Observation (EO) satellite and geospatial data at the local level were used. Up-to-date remote sensing techniques such as object-based image analysis, were applied to classify the images and generate the ecosystem type maps. Subsequently, models were developed to estimate and map five ecosystem services namely (i) carbon storage, (ii) water yield, (iii) maximum potential water retention, (iv) soil protection from erosion (avoided erosion) and (v) nutrient delivery. The models were developed through the open-source software InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) and the use of geospatial data. The results of this study are provided through the ppGIS/webGIS LIFE-IP 4 NATURA platform contributing to the management and conservation of the Natura 2000 sites in Greece.

Keywords: Ecosystem functioning, ecosystem type, InVEST, MAES

1. INTRODUCTION

Ecosystem services (ES) offer direct and indirect benefits to human well-being, arising from the inherent structures and functions of ecosystems[1]. Being of critical importance to society and its sustainable development, assessing ecosystems and ES has received increasing attention. An expanding number of studies focus on the analysis of the interdependence between ES provision from ecosystems[2–6] as well as the interactions among multiple ES[7]. The understanding of those relationships is a prerequisite for the sustainable ecosystem management. Often, however, ES are not considered when land use and policy decisions are made because they are difficult to be quantified on a systematic basis[8,9].

As new and more advanced products emerge, Earth Observation (EO) data contribute to research on modelling, mapping, and valuing ecosystem types, and ecosystem services[10]. One of its primary advantages is the ability to conduct synoptic, spatially continuous, and frequent observations, resulting in extensive datasets at various spatial and temporal resolutions.. There are many modelling tools for ES assessment, for example ARIES[12] (Artificial Intelligence for Ecosystem Services), LUCI[13] (Land Utilisation and Capability Indicator) and InVEST[14] (Integrated Valuation of Ecosystem Services and Trade-off) that are used in many studies[11,12]. With the use of appropriate modeling techniques, ES can be quantified, spatially mapped, and occasionally even economically valued. Such maps provide land managers and decision-makers crucial information to assess the possible effects of different management strategies on ES provision[8].

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One of the most widely used ES modelling framework, the InVEST suite, through the use of various geospatial datasets, can provide spatially explicit estimates for a wide range of ES including annual water yield, carbon storage and sequestration, nutrient delivery ratio, sediment delivery ratio, habitat quality among others. These spatial explicit estimates strongly depend on ecosystem type (or land cover) information being a prerequisite input for ES assessment.

Making publicly available and disseminating information related to the ES provided by natural areas can enhance environmental awareness and promoting integrated and sustainable practices. Web mapping platforms have been increasingly used to involve the general public and stakeholders in identifying a variety of ES based on local, site-specific based knowledge rather than relying on proxy data from literature or process modelling. Distributing ES maps through webGIS infrastructures facilitates also the subsequent analysis of the trade-offs and an understanding of the synergies between them [15].

The aim of this work, implemented within the framework of the LIFE IP 4 Natura project, is to provide information about important ecosystems of the Greek territory, as the ones included within the Natura 2000 network and contribute to effective decision making with a view to promoting the protection of the environment and the conservation of biodiversity. To achieve this, we demonstrate a comprehensive methodology which includes ecosystem type mapping within a Natura 2000 site and ES mapping assessment. Subsequently, we identify and analyze their synergistic/trade-off relationships. Our results are publicly available through the web-based Geographic Information System of the LIFE IP 4 Natura project (ppGIS/webGIS LIFE-IP 4 NATURA), giving the capability to a wide range of end users to retrieve scientific geographic data and environmental findings.

2. MATERIALS AND METHODS

2.1 Study Area

The present study focuses on the pilot (case-study) Natura 2000 site, “Dikti: Oropedio Lasithiou, Katharo, Selena, Krasi, Selakano, Chalasmeni Koryfi” (Figure 1), located at the central-eastern part of Crete, in Southern Greece. The site, code-named GR4320002, is a mountainous area, covering 34,007.16 ha with altitudes ranging from 280 to 2148 m. It hosts diverse forests and distinct habitat types, supporting biodiversity and providing essential ES. Most of the area consists of steep mountains and canyons, including a cultivated plateau. Dominant vegetation types include phrygana, pine forests and shrubs, with a small portion of the site covered by vineyards. There is also riparian vegetation with common perennial and annual plants. The study area is of high ecological importance as the flora and fauna include a variety of common species as well as rare and vulnerable endemic species, some of which are found exclusively in the area or in the mountains of Crete[16].

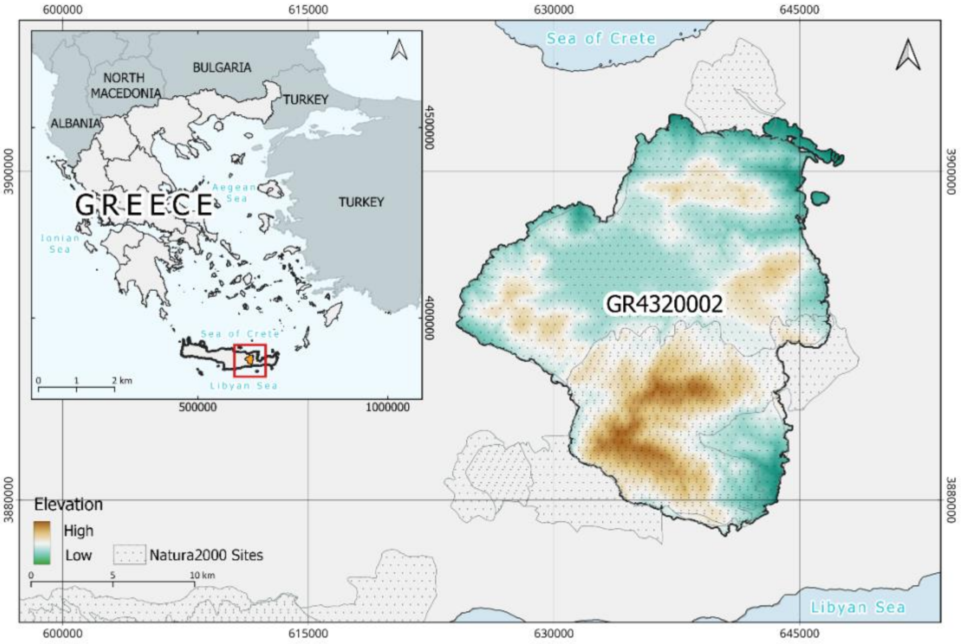

Figure 1. Study area.

2.2 Methodology Outline

To address the aim of our study, we implemented a two-step process as depicted in Figure 2. The first step involved image classification, through object-based image analysis (OBIA) and a machine learning algorithm to generate the ecosystem type map of the study area for the year 2022. The second step involved ES modelling and production of the corresponding ES maps. Subsequently, trade-offs and synergies between paired ES were identified. The outcomes of this study were then integrated into the ppGIS/webGIS LIFE-IP 4 NATURA platform. The methodology employed in this study is illustrated in Figure 2 and further elaborated below.

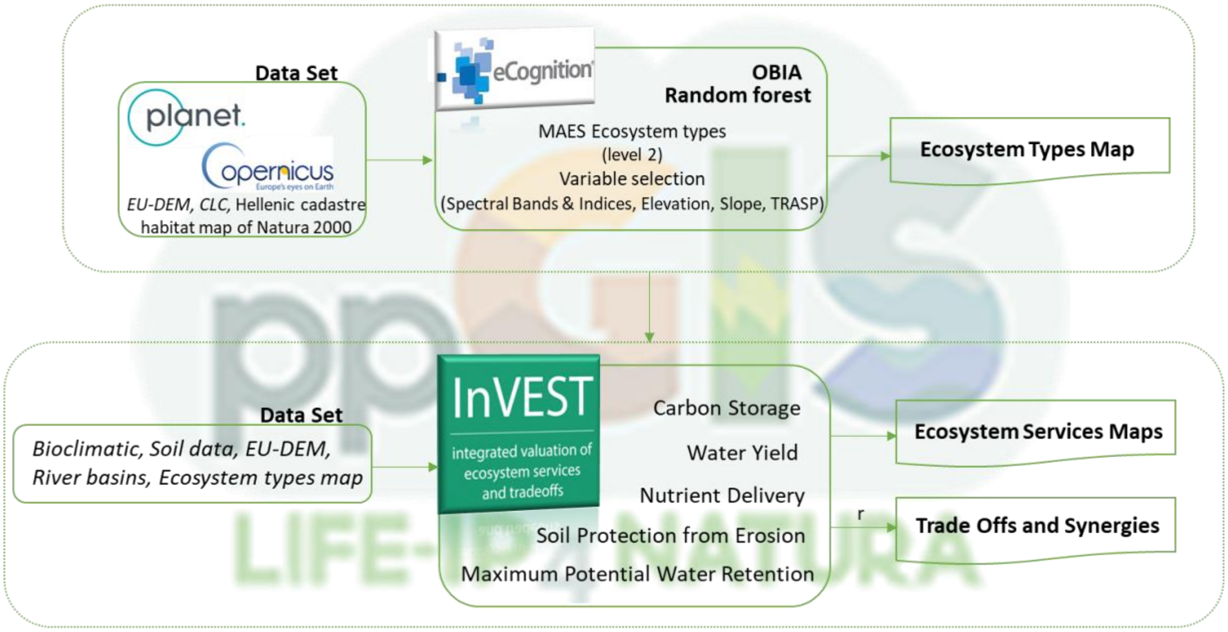

Figure 2. Study workflow.

2.3 Data and preprocessing

The study utilized the PlanetScope Analytic Ortho Scene Product, sourced from the Planet Labs PBC platform. These products provide orthorectified, calibrated multispectral imagery, facilitating automated extraction of quantitative information. The imagery is processed to remove terrain-induced distortions, ensuring precise spatial representation. The PlanetScope Analytic Ortho Scene is particularly well-suited for processing tasks such as ecosystem type and land cover classifications. Radiometric corrections are also applied to the imagery to address known sensor artifacts and convert the values to at-sensor radiance[17]. The multispectral images used in this study were acquired in August 2022 and cover four spectral bands (blue, green, red and near-infrared) with a spatial resolution of 3 m. The images were also mosaicked to ensure complete coverage of the study area.

Moreover, we used geospatial data including the European Digital Elevation Model (EU-DEM) developed for the Copernicus programme, with a spatial resolution of 25 m[18] and the pan-European database of river networks and catchments developed by the JRC's Catchment Characterisation and Modelling[19]. Furthermore, we employed CHELSA V2.1[20] products including bioclimatic data on precipitation and evapotranspiration, at a resolution of 1 km. Soil data were sourced from the data hub of ISRIC - World Soil Information[21] at a resolution of 250 meters, as well as from the European Soil Data Centre- ESDAC[22].

All ancillary datasets were resampled to standardize their analysis at 25 m and reprojected to the Lambert azimuthal equivalence area (LAEA) projection. This procedure ensured uniformity across all datasets, facilitating their integration and analysis as data uniformity is a prerequisite for their integration into InVEST toolset.

2.4 Ecosystem Types Classification

For the purposes of this study, we produced an ecosystem type map of the study area for the year 2022, utilizing the high resolution PlanetScope imagery. We adopted a seven-class classification scheme according to the "Correspondence between Corine Land Cover classes and ecosystem types" table compiled by MAES (2013)[23], and considering the regional characteristics of the study area (Table 1).

Object-based image analysis (OBIA) was carried out in conjunction with the Random Forest (RF) algorithm to classify the images. In OBIA, objects are created through segmentation representing significant conceptual information. These objects are defined by their spectral attributes, shape, size, and the relationships they exhibit with their environment (adjacency). The combination of these factors is leveraged to ascertain the identity and characteristics of each object[24]. The objects are then classified into distinct classes employing classification algorithms, including machine learning algorithms. Machine learning algorithms are highly effective classifiers of EO data, especially for ecosystem type and land cover classification tasks. Their popularity stems from their ability to achieve high accuracy while imposing minimal demands regarding the statistical properties of the data[25]. Among these algorithms, Random Forest, introduced by Breiman in 2001[26], stands out as an ensemble classifier where multiple decision trees are constructed based on random subsets of training samples and variables[27].

Table 1. Ecosystem type classification used in this study, based on the "Correspondence between Corine Land Cover classes and Ecosystem types" table established according to MAES (2013)[23].

Ecosystem types (Level 2)	**CLC (Level 2)**	**CLC (Level 3)**
Urban (Urb)	1.1. Urban fabric 1.2. Industrial, commercial and transport units 1.3. Mine, dump, and construction sites 1.4. Artificial non-agricultural vegetated areas	
Cropland (Crop)	2.1. Arable land 2.2. Permanent crops 2.4. Heterogeneous agricultural areas	
Grassland (Grass)	2.3. Pastures	
Woodland and Forest (W-F)	3.1. Forests	3.2.4. Transitional woodland and shrub
Grassland (Grass)	3.2. Shrub and/or herbaceous vegetation association	3.2.1. Natural grassland
Heathland and Shrub (H-S)	3.2. Shrub and/or herbaceous vegetation association	3.2.2. Moors and heathland 3.2.3. Sclerophyllous vegetation
Woodland and forest (W-F)	3.2. Shrub and/or herbaceous vegetation association	3.2.4. Transitional woodland and shrub
Sparsely Vegetated Land (SVL)	3.3. Open spaces with little or no vegetation	
Wetlands (Wet)	4.1. Inland wetlands	

The RF classifier was trained through training samples from visual image interpretation and ancillary geospatial datasets,. The spectral information taken into account included the four spectral bands of the original images. Furthermore, in order to improve the classification performance and highlight any discrete coverage within the study area, three spectral indices (NDVI, NDWI, NDSI) were calculated (Table 2). We also included information about the topography of the area derived from the EU-DEM. Elevation, slope, and the Topographic Solar-Radiation Index (TRASP)[29] were incorporated into the analysis process. The classification process was performed using the Trimble eCognition Suite, an advanced image analysis software available for geospatial applications[30].

Table 2. Spectral indices and formulas used in the classification model.

Spectral Index	Index Formula	Reference
Normalized Difference Vegetation Index (NDVI)	$NDVI = \frac{NIR - RED}{NIR + RED}$	[31][Tucker, 1979]
Normalized Difference Water Index (NDWI)	$NDWI = \frac{GREEN - NIR}{GREEN + NIR}$	[32][McFeeters, 1996]
Normalized Difference Soil Index (NDSI)	$NDSI = \frac{RED - BLUE}{RED + BLUE}$	[33][Trimble ECognition Developer, 2018]

2.5 Ecosystem Services Models

To quantify and map the ES of the study area, we developed six ES models using the InVEST toolset. InVEST is a geospatial modeling framework that assesses the impact of land use change on ES and is available at the Natural Capital Project[14]. The ES analysed in this study were (i) carbon storage, (ii) water yield, (iii) maximum potential water retention, (iv) soil protection from erosion (avoided erosion) and (v) nutrient delivery (nitrogen and phosphorous). The ES were selected based on data availability and their relevance to the study area.

(i) Carbon storage

The carbon storage module in InVEST employs a simplified carbon cycle to map and quantify the amount of carbon stored and sequestered[34]. The model estimates the current carbon storage in a landscape or the amount of carbon sequestered over time using maps of ecosystem types combined with stocks in four carbon pools (soil, dead organic matter, belowground biomass, and aboveground biomass)[35]. For each LULC type, the model requires an estimation of the carbon amount in at least one of the four fundamental pools mentioned above, given in metric tons per hectare (t/ha). In this study we used the ecosystem type map described in Section 2.4 and the carbon storage was estimated for each ecosystem type considering all the four fundamental terrestrial carbon pools applying literature values[34,36,37] and expert's opinion.

(ii) Water yield

Water yield is the total amount of water in an area that contributes to maintaining the hydrological balance[38] and ecological equilibrium. From an ecosystem perspective, it is defined as the storage of water in rivers, lakes and aquifers and is perhaps one of the services most directly related to human well-being. The InVEST water yield model calculates the annual water yield from a basin, primarily targeted for supporting hydroelectric power generation from reservoirs[35]. Although hydropower constitutes a relatively small portion of Greece's energy sector, the total annual water yield has implications for various potential services, including agricultural irrigation, drinking water provision, hydropower generation, and industrial water extraction. The model is based on the assumption of the water balance equation of the Budyko hydrothermal coupling[39], taking into account the average annual precipitation and the actual evapotranspiration[40]. Therefore, the water yield is calculated as follows:

$$Y_x = \left(1 - \frac{AET_x}{P_x}\right) P_x$$

Where Y_x is the water yield (mm), AET_x is the annual actual evapotranspiration and P_x is the average annual precipitation (mm) in each grid cell x.

The model inputs for this study were the ecosystem types map, the average annual precipitation (P), the Annual Actual Evapotranspiration (AET), the root restricting layer depth, the plant available water content and river basins boundaries. We also used as input the biophysical table containing biophysical parameters such as the plant root depth, crop coefficient (k_c) and information about vegetation for each ecosystem type. Finally, the seasonality factor (Z parameter) was defined setting the value 15 according to literature values[35] and expert's opinion.

(iii) Maximum potential water retention

The maximum potential water retention (S) was calculated using the curve number (CN) approach as:

$$S = \frac{25400}{CN} - 254$$

Where CN is calculated as the following empirical relationship:

$$CN = 6 \times iVEG + 9 \times iPERM + 3 \times iSLOPE + 10$$

Where $iVEG$ represents vegetation class, $iPERM$ represents permeability class, $iSLOPE$ represents drainage capacity class. All indices range from 1 to 5[41].

(iv) Soil protection from erosion (avoided erosion)

For this study the indicator avoided erosion was calculated as:

$$AER_i = RLKS_i - USLE_i$$

where AER_i is the amount of erosion avoided on pixel i, and the difference between $RKLS_i$ and $USLE_i$ represents the benefit of vegetation and good management practices. Sediment retention is computed by finding the difference between potential soil loss (USLE) of the landscape and the maximum potential soil loss (RKLS) which assumes the landscape is bare.

$$USLE_i = R_i \cdot K_i \cdot LS_i \cdot C_i \cdot P_i$$

Where $USLE_i$ is the potential average annual soil loss, R_i (MJ mm ha^{-1} h^{-1} yr^{-1})is the erosivity factor, K_i (t ha h ha^{-1} MJ^{-1} mm^{-1}) is the soil erodibility factor, LS is s the slope length and steepness factor, C_i is the land cover management factor and P_i is the supporting practice factor. The model's inputs includes the ecosystem type map, the EU-DEM, Erosivity (R), Soil Erodibility (K)[43], and the biophysical table including the cover-management factor (C) and the support practice factor (P). The values of C factor were obtained from a literature search according to[44,45]. The P factor was defined as 1 assuming that no erosion-reduction practices are being done[35].

(v) Nutrient delivery (nitrogen and phosphorous)

The model aims to map nutrient sources. It describes the transportation of a mass of nutrition through space using a straightforward mass balancing technique. A map of the types of ecosystems and the corresponding loading rates are used to identify the sources of nutrient burdens. Then, nutrient loads can be separated into parts that are dissolved and those that are linked to sediment. These parts will be carried by surface flow and subsurface flow, respectively, and will cease when they come to a stream. Subsequently, delivery factors are calculated for every pixel by utilizing the characteristics of pixels that are part of the same flow path.

The model's inputs include the ecosystem type map, the EU-DEM, river basins, average annual precipitation (P) and the biophysical table including biophysical parameters (nutrient loading, maximum nutrient retention efficiency, critical length). Values were defined according to literature [46,47]. Threshold for flow accumulation was defined as 1000 after trial and error, and other parameters were set as default[14,35].

2.6 Tradeoffs and synergies

For the trade-offs and synergies identification between paired ES, we performed the Pearson's correlation analysis using R programming language. First, we applied the min-max normalization method to standardize the ecosystem services. The strength of correlation between paired ES was determined by the absolute value of the correlation coefficient. A positive coefficient signifies a synergistic relationship, a negative coefficient indicates a trade-off relationship, and a coefficient of zero denotes no correlation [48].

3. RESULTS

3.1 Ecosystem types

Ecosystem type map of GR4320002 is depicted in Figure 3. The natural ecosystem types (Grass, W-F, H-S, SVL, Wet) cover the largest part of the area (29904.88 ha), whereas anthropogenic types (Crop, Urb), including cropland and settlements, cover a smaller area (4983.75 ha) (Table 3).

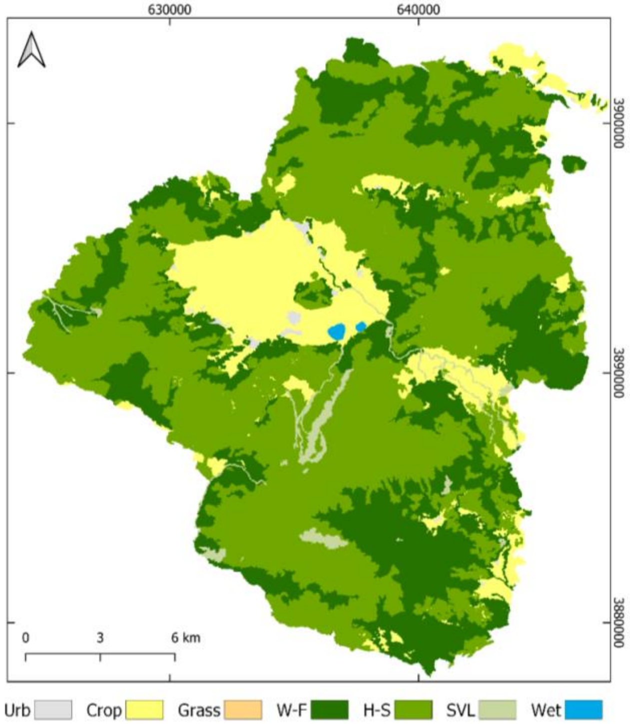

Figure 3. Ecosystem type map of GR4320002 (Urb: Urban, Crop: Cropland, Grass: Grassland, W-F: Woodland and Forest, H-S: Heathland and Shrub, SVL: Sparsely vegetated land, Wet: Wetland).

More specifically, heathlands and shrub is the dominant ecosystem type covering the 53.74% of the study area and woodland and forest cover the 30.19%. Cropland covers the 13.84% and all the other types the 2.23% of the area (Figure 4). Regarding ecosystem types spatial distribution, forest vegetation is distributed throughout the whole area. Crops are distributed at the central and southeast part of the area. Wetlands (Wet) and urban (Urb) ecosystem types are also found in the core area of the site as well.

Table 3. Area (ha) per ecosystem type of GR4320002.

Ecosystem type	**Area (ha)**
Urb	154.44
Crop	4829.31
Grass	1.50
W-F	10532.19
H-S	18749.31
SVL	573.75
Wet	48.13

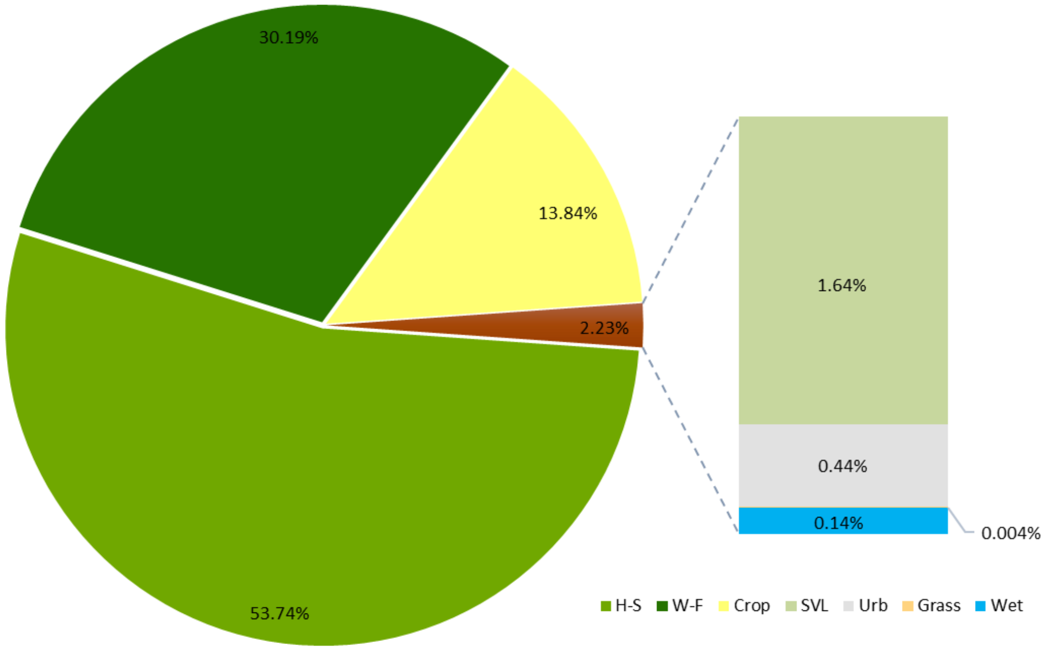

Figure 4. Cover percentages of ecosystem types of GR4320002 (Urb: Urban, Crop: Cropland, Grass: Grassland, W-F: Woodland and forest, H-S: Heathland and shrub, SVL: Sparsely vegetated land, Wet: Wetland).

3.2 Ecosystem services

Table 4 illustrates the ES values for each ecosystem type. Carbon storage is 4443.905 10^3t, soil protection from erosion is 7701.046 10^3t, water yield and maximum potential water retention are 579.236 10^6 mm and 158.296 10^6 mm respectively and nutrient delivery is 25.624 10^3 kgr for nitrogen and 3741.231 10^3 kgr for phosphorus. The main sources of ES are the H-S, W-F and Crop ecosystem types. More specifically the H-S and W-F are the main pools of carbon storage and maximum potential water retention with their combined contribution being 92.56% and 92.35% respectively. Regarding the ecosystem service protection from soil erosion crop show the lowest values. Forests exhibit the highest values for these three ES. Conversely, cropland covered areas present higher values regarding nutrient delivery and water yield accounting for 60.09% for nitrogen, 75.13% for phosphorus and 26,03% for water yield (Figure 5).

In terms of their spatial distribution, carbon storage and maximum potential water retention exhibit similar patterns, with lower values distributed in the central and southeastern parts and higher values distributed throughout the area, especially in the south. In contrast, water yield and nutrient delivery show opposite patterns, with higher values concentrated in the central area. Soil protection from erosion display high pattern variation, with the lowest values observed at the central part of the area where the core of the cultivated land is located. (Figure 6).

Table 4. Ecosystem services per ecosystem type of GR4320002.

Ecosystem types	**Ecosystem Services**					
	Carbon Storage (10^3 t)	**Water Yield (10^6 mm)**	**Max. Potential Water Retention (10^6 mm)**	**Soil Protection from Erosion (10^3 t)**	**Nutrient Delivery-Nitrogen (10^3 kgr)**	**Nutrient Delivery-Phosphorus (10^3 kgr)**
Urb	0	7.675	0.174	16.320	0.213	23.055
Crop	328.393	150.782	10.740	563.540	15.398	2810.681
Grass	0.146	0.044	0.002	0.222	0.001	0.060
W-F	1769.408	140.174	59.295	2399.848	2. 255	325.344
H-S	2343.664	257.867	86.891	3678.217	7.620	564.472
SVL	2.295	22.694	1.128	1041.377	0.137	17.619
Wet	0	0	0.066	1.521	0	0
Total	**4443.905**	**579.236**	**158.296**	**7701.046**	**25.624**	**3741.231**

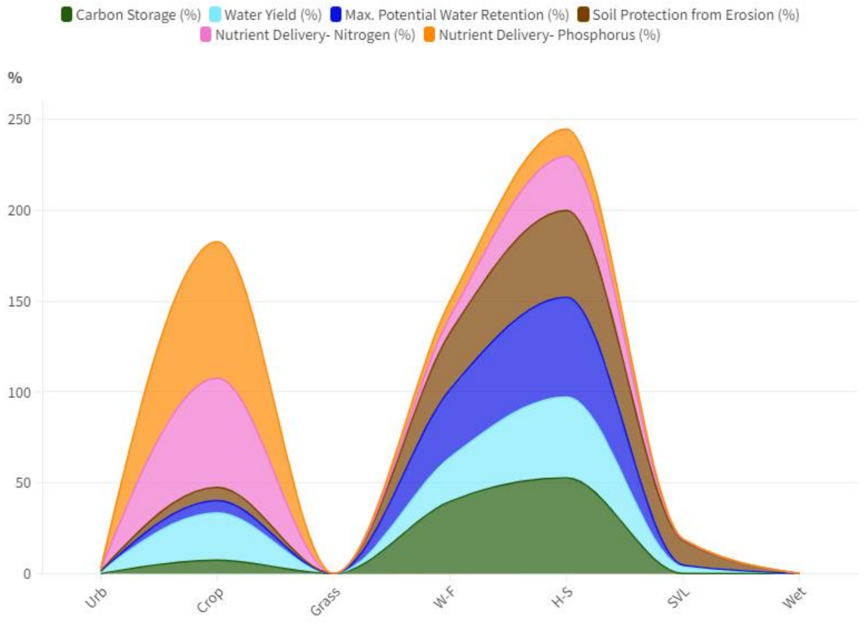

Figure 5. Ecosystem services provision (%) per ecosystem type.

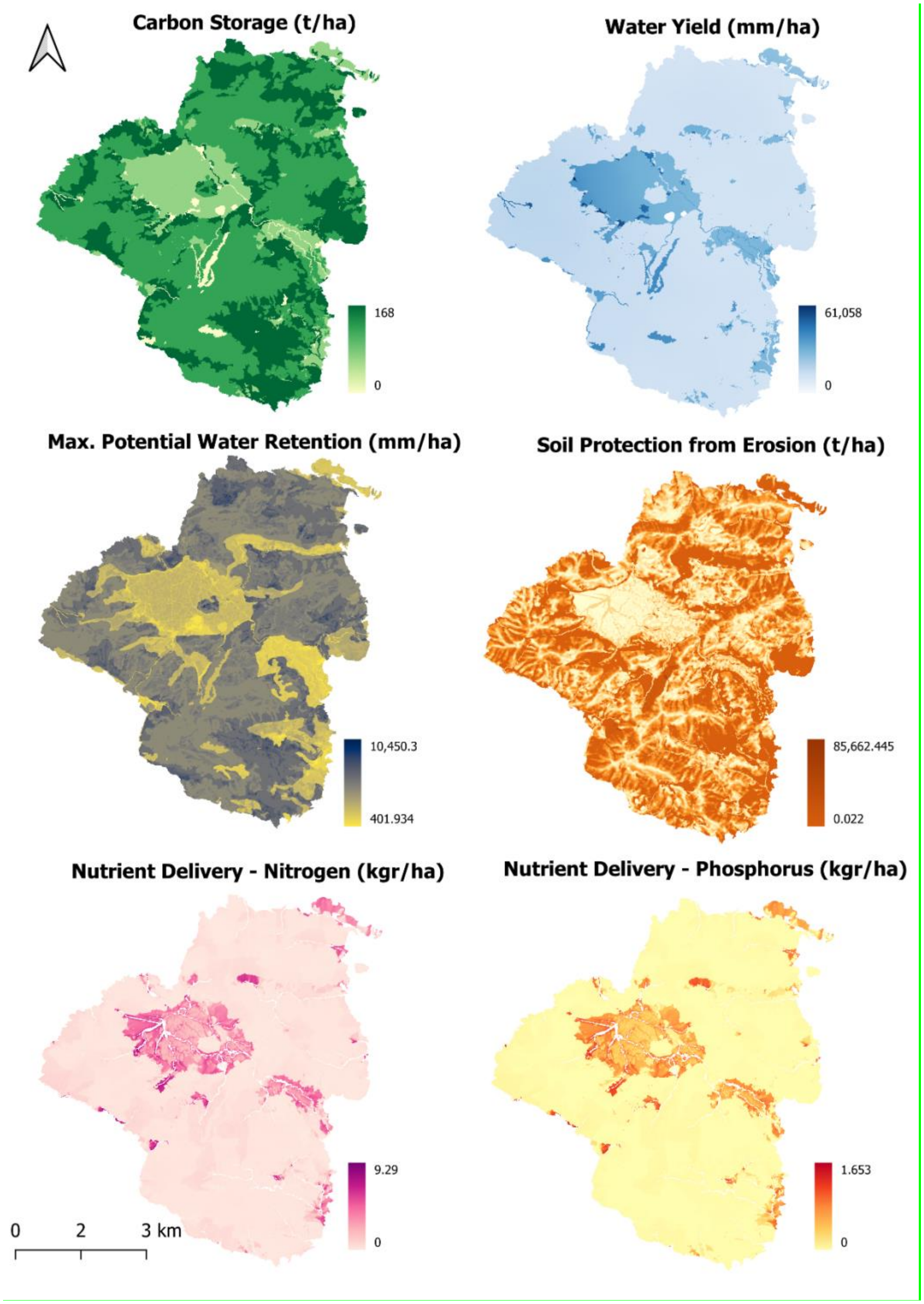

Figure 6. Spatial distribution of ES at GR4320002, **(a)** Carbon storage, **(b)** Water yield, **(c)** Maximum potential water retention, **(d)** Soil protection from erosion, **(e)** Nutrient delivery- nitrogen, **(f)** Nutrient delivery- phosphorus.

3.3 Trade-offs and synergies

The trade-offs and synergies of 15 paired ES are depicted in Figure 7. More specifically, 10 ES pairs display a trade-off relationship, whereas 5 pairs display a synergistic relationship. Regarding trade-offs, CS/WY (-0.878) show the highest degree of trade-off followed by CS/ND-N (-0.640) and CS/ND-P (-0.633). The paired ES MPWR/WY, MPWR/ND-N and MPWR/ND-P show high degree of trade-off relationship as well (r > |0.5|). All the other pairs indicate a low degree of trade-off (r < |0.1|). Concerning synergies, the highest degree is observed for ND-P/ND-N (0.978) followed by CS/MPWR (0.659) and WY/ND-N and WY/ND-N (r > |0.5|). Low degree of synergy shows the pair WY/SPER (r < |0.1|). Compared with other ESs, soil protection from erosion (SPER) showed the lowest degree of trade-offs and synergies with the other ES whereas CS showed the strongest.

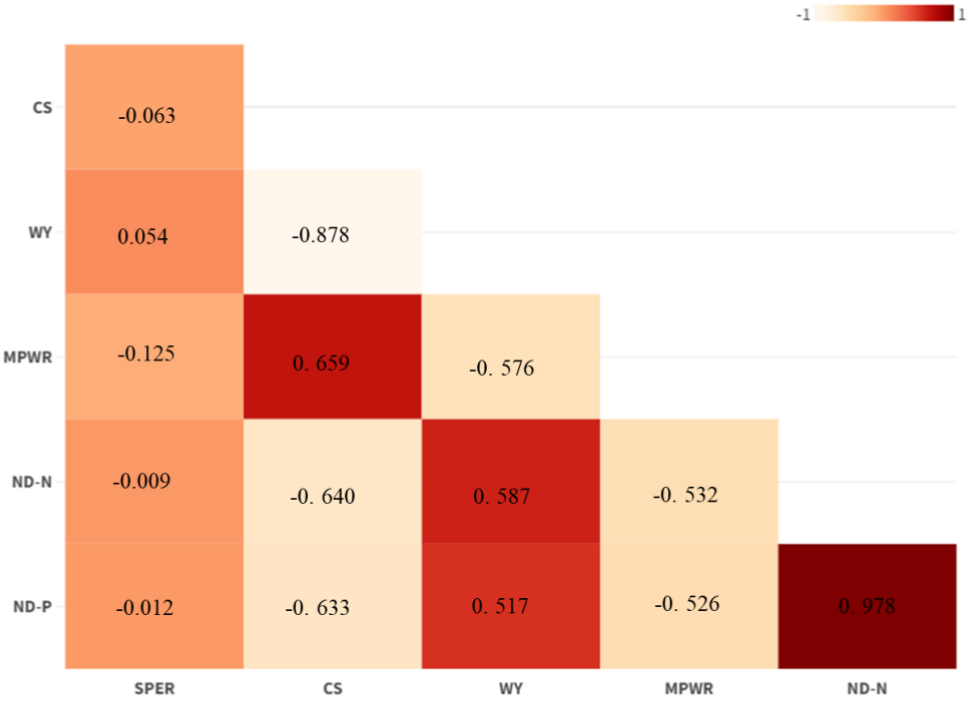

Figure 7. Pearson Correlation coefficients of paired ES. (CS: Carbon storage, WY: Water yield, MPWR: Maximum potential water retention, SPER: Soil protection from erosion, ND-N: Nutrient delivery- nitrogen, ND-P: Nutrient delivery- phosphorus).

4. DISCUSSION AND CONCLUSIONS

In this study, we applied a comprehensive analysis framework to generate ecosystem type and ES maps at the local scale within a Natura 2000 protected area in Greece. To achieve this, we employed EO data, remote sensing techniques and the open-source software InVEST. By assessing and quantifying ecosystem types and ES we analysed their distribution and relationships, including trade-offs and synergies, aiming to provide valuable information for land planning and management.

The largest part of the study area is covered by different types of vegetation, primarily shrubs and secondarily forests with notable altitudinal variations. In the centre of the study area, at lower elevations, anthropogenic ecosystem types (Crop and Urb) are found, adding diversity to the landscape. More specifically, the dominant ecosystem type is H-S, covering almost the half region and followed by W-F and Crop. Besides Crop and Urb, natural ecosystem types are present and cover the majority of the study area. The largest area of cultivated land is located in the centre and east, where small settlements are found. The forest vegetation, characterizing the W-F and H-S ecosystem types, is found at higher elevations and surrounds the Crop ecosystem type.

Ecosystem types and their changes have a profound impact on ES as many studies[49–51] state, complying with our results. The main sources of carbon storage considering ecosystem types in our case study, are H-S, W-F and Crop. Forested areas exhibit the highest levels of carbon storage, highlighting their critical role as a carbon pool, while Urb and Crop demonstrate significantly lower levels of carbon storage. Intensive agricultural practices, such as soil decomposition, biomass removal during harvesting, and soil erosion, contribute to carbon loss. In addition, converting forest land to agriculture, exacerbates carbon decomposition and reduces carbon storage[52]. Determining the relationship between different ecosystem types and their impact on carbon balance is crucial for developing policies that conserve and enhance carbon storage[16].

However, it should be noted that urban ecosystems, and secondarily croplands, exhibited the highest levels of water yield. Built-up areas are usually covered by concrete, asphalt, or impervious materials, which reduce water infiltration and concentration time[6]. Moreover, urbanization could change local climatic processes and precipitation patterns[53]; thus, built-up land leads to high water yield levels[54]. According to Zhang X. et al[53], the influence of landscape configuration on water yield was found less significant compared to precipitation. Nevertheless, its importance lies in its relative controllability and widespread applicability in regional planning, distinguishing it from other land covers[53]. The maximum potential water retention is mainly provided by forest vegetation according to our results. The water retention capacity of soil is mainly determined by its texture, density, and organic matter content. Also, the flatter the slope, the higher the overall water retention capacity, while the steeper the slope, the faster the water flow and the less time the water has to infiltrate[55].

Cropland provide lower soil protection from erosion. These areas exhibit high levels of soil loss because much of the land lacks natural vegetation and is therefore the main source of erosion and sediment production[56]. As expected, the spatial variation in soil protection follows the spatial pattern of natural vegetation; the greatest protection is observed where natural vegetation dominates. Plant roots stabilize the soil and stems and leaves slow down water so that it has time to infiltrate through the soil profile. The assessment and mapping of this ES can be used to identify places in the landscape where soil is vulnerable to loss, erosion, or other problematic situations and provide useful information for the management and protection of soil resources[16].

In contrast, cropland showed the highest levels of nutrient delivery both for nitrogen and phosphorus. Our findings confirm earlier studies'[57], that indicate high delivery of nutrients from this type of ecosystem. In cropland, because of the soil exposure for a long period (late autumn, winter, early spring), the magnitude of the phosphorus and nitrogen load released from the basin is affected. Ecosystem types, precipitation and soil structure are key factors for nutrient delivery[58]. The nutrient delivery and retention from woodland and forest and from heathland and shrub depends on factors such as forest species, soil type, vegetation status and climatic conditions.

Understanding the trade-offs and synergies among ES is crucial for managing multifunctional ecosystems effectively and minimizing costly compromises[59]. Identifying these synergies and trade-offs, along with the land use types that contribute to ES provision, allows policymakers to better comprehend the hidden consequences of prioritizing one ES over another. This understanding aids in the prioritization of management strategies and supports the creation of landscapes that balance conservation with production. Consequently, it promotes ecological, social, and economic resilience[60].

Within the framework of the LIFE IP 4 Natura project, we developed the ppGIS/webGIS LIFE-IP 4 NATURA, a platform that integrates the results of our study, providing access to a range of end users, from government officials to the general public. This initiative can contribute to an effective spatial planning and promote awareness on climate change and environmental conservation at the Natura 2000 sites in Greece.

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