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# Assessment of the Spatial Dynamics and Interactions among Multiple Ecosystem Services to Promote Effective Policy Making across Mediterranean Island Landscapes

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**Abstract:** To manage multiple ecosystem services (ES) effectively, it is essential to understand how the dynamics of ES maintain healthy ecosystems to avoid potential negative impacts on human well-being in the context of sustainable development. In particular, the Ionian Islands in the central Mediterranean are characterized by high natural, ecological, and recreational value; however, the intensification of human activities over time has resulted in the loss of natural ecosystems, which might have negatively impacted ES. Here, we aimed to assess and understand the spatiotemporal dynamics of ES supply and how these components interact across the Ionian Islands to optimize future ES provision and mitigate current trade-offs. We quantified multiple ecosystem services and analyzed their interactions at a temporal scale across the four prefectures of the Ionian Islands. Seven ES were quantified covering all three ES sections (provisioning, regulating and maintenance, and cultural) of the Common International Classification of Ecosystem Services (CICES). ES interactions were investigated by analyzing ES relationships, identifying ES bundles (sets of ES that repeatedly occur together across space and time), and specifying ES occurrence within bundles. The three ES groups exhibited similar patterns on some islands, but differed on islands with areas of high recreation in parallel to low provisioning and regulating ES. Temporal variations showed both stability and changes to the supply of ES, as well as in the interactions among them. Different patterns among the islands were caused by the degree of mixing between natural vegetation and olive orchards. This study identified seven ES bundles that had distinct compositions and magnitudes, with both unique and common bundles being found among the islands. The olive grove bundle delivered the most ES, while the non-vegetated bundle delivered negligible amounts of ES. Spatial and temporal variation in ES appear to be determined by agriculture, land abandonment, and increasing tourism, as well as the occurrence of fires. Knowledge about the spatial dynamics and interactions among ES could provide information for stakeholders and decision-making processes to develop appropriate sustainable management of the ecosystems on the Ionian Islands to secure ecological, social, and economic resilience.

**Keywords:** Mediterranean ecosystems; ecosystem services; mapping; interactions; bundles; spatial dynamics; temporal changes; sustainable management; policy making

## 1. Introduction

The sustainability of economic growth strongly depends on maintaining ecosystem services (ES), a healthy environment, and cohesive societies [1]. Human well-being and sustainable development are dependent on improving the management of natural ecosystems, which secure their long-term sustainable use through conserving them [2,3]. Mapping and assessing ES represent important approaches towards understanding the link between ecosystems and human society, which, in turn, facilitate decision-making and management based on sustainable development strategies [4–6]. A key challenge for ecosystem management is handling multiple ES across landscapes [7], as certain actions enhance the supply of some ES, while inhibiting others [8]. Addressing this challenge requires the identification of synergies and tradeoffs that exist among ES at different scales to promote sustainability in landscape management [9,10]. However, ES interactions are not constant over time, resulting in temporal changes being overlooked in ES-based approaches, which might lead to the misrepresentation of their synergies, leading to future trade-offs [11,12].

Raudsepp-Hearne et al. [10] first introduced the concept of identifying interactions among ES by analyzing the spatial pattern of ES bundles, with this concept being subsequently implemented by many researchers [9,13,14]. An ES bundle refers to a set of interacting (positively or negatively) ES that repeatedly occur across a spatial and temporal scale [8]. Renard [11] used the ES bundle approach to explore the importance of historical dynamics (35-year dataset) in a mixed-use landscape to identify processes and drivers behind the changing relationships among ES. Tomscha and Gergel [12] also demonstrated the importance of monitoring long-term interactions among ES to manage heterogeneous landscapes. In order to avoid future impacts on the provision of benefits to society, it is inevitable to identify possible conflicts among ecosystem services across space and time [11,12,15]. For example, Sutherland et al. [16] showed the utility of monitoring the long-term recovery of ES from timber harvest to maintain multifunctional forests. Furthermore, Koch et al. [17] showed that a lack of information on the temporal and spatial variability of coastal characteristics generates additional management problems when protecting coastal areas. Despite there being a wealth of literature mapping and quantifying the interactions of ES, a recent literature review [18] showed that few studies have investigated the ES bundles of island ecosystems, which is important to identify management practices optimizing or negatively affecting the potential of island landscapes to supply ES.

Mediterranean ecosystems deliver a diverse flow of ES due to the complex relationship between socio-cultural and ecological processes [19,20]. The high diversity of ecosystems in the Mediterranean region is the result of a long history of human activity [21]. However, human populations, along with high consumption levels, have increased rapidly over the last century, resulting in the depletion in the availability of ES [22]. In addition, changes to land use have been recognized as a primary driver affecting ecosystems and their services [23]. These changes are driven by various socio-economic and environmental factors, such as population growth, urban and tourism development, land abandonment or intensification, grazing intensity, and the occurrence of wildfires [22,24–29]; thus, extreme changes could lead to severe losses in the provision of ES.

Especially for Mediterranean islands, which are the number one tourism destination in the world, tourism itself has been one of the most important sectors of the local economies [30–32]. However, space- and time-concentrated tourism may show adverse effects on the environment [33]. In particular, mass-tourism often has severe consequences, due to high demand on accommodation and entertainment facilities [32], resulting in urban and infrastructure development [34]. Consequently, while tourism depends on high natural and cultural values, it is also the main threat to natural ecosystems and to the social wellbeing they support [32,33,35,36]. The islands of the Mediterranean region are also characterized by high natural, ecological, and recreational value, while supporting hotspots of global biodiversity; however the limited resources, area size and remoteness from mainland areas (isolation) are some of the main disadvantages of their physical environment [37]. Given the vulnerability of islands, sustainable management must enhance the ability of ecosystems to recover from either human or environmental disturbance [38]. Through understanding why it is important

to sustain healthy ecosystems, with such high dynamic nature and where increasing tourism and intense land use changes occur, stakeholders and managers might be willing to secure ES provisions that ultimately benefit human wellbeing. This approach might allow stakeholders and managers to maintain or re-design spatial management policies and to meet several important EU initiatives. Such policies include the objectives of Action 5 of the European Union’s Biodiversity Strategy to 2020 and the Sustainable Development Goals (SDGs) of the 2030 Agenda, to halt biodiversity loss and maintain healthy ecosystems under the principals of sustainable development.

In this context, this study focuses on assessing the spatial and temporal dynamics of ES supply and their interactions across the Ionian Islands to optimize future ES provision and to mitigate current trade-offs. Further, we suggest possible implications of our results in policy-making processes that aim to sustain well-functioning ecosystems through providing a diverse set of ES.

## 2. Materials and Methods

### 2.1. Study Area

The study area encompassed the region of the Ionian Islands, which is located in Western Greece (Figure 1). In terms of administrative boundaries, the region consists of four prefectures each of which contain a main Island and some islets. The region covers an area of 2278 km<sup>2</sup>, wherein Corfu, Lefkada, Kefalonia, and Zakynthos cover 640, 355, 878, and 405 km<sup>2</sup>, respectively. These Islands are characterized by high relief landscapes, with elevations reaching up to 1630 m. The local climate is Mediterranean, consisting of mild–humid winters and warm–dry summers. The geology mainly consists of limestone, except for Corfu, which is dominated by Neogene formations and Quaternary deposits [39]. The primary vegetation is characterized by pine forests, olive groves, and other vegetation types, such as transitional and sparse vegetation [40]. The Ionian Islands encompass 14 protected areas under the Natura 2000 Network with natural characteristics and ecological features, such as the presence of nesting habitat for the loggerhead sea turtle *Caretta caretta* [41]. Tourism is one of the most important sectors sustaining the economy of this region [42–45].

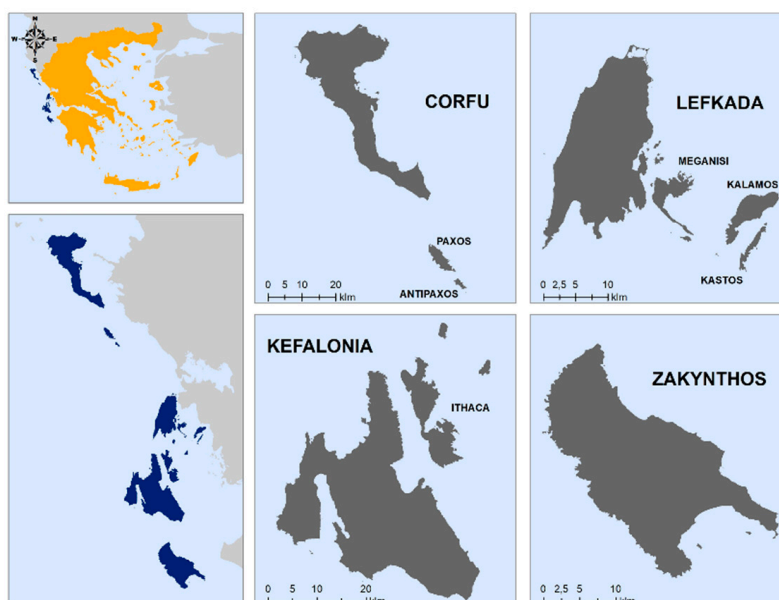


Figure 1. Location of the study area.

### 2.2. Mapping Ecosystem Services

A set of ecosystem services was selected from the Common International Classification of Ecosystem Services—CICES [46,47], based on the value of estimated ES in regional policy-making

processes of the Ionian Islands, as well as data available throughout the entire study region. The list consisted of seven ES and covered all ES sections/groups. Specifically, three ES were selected for Provisioning ES, three for Regulating and Maintenance ES, and one for Cultural ES (Table 1). The CICES framework has been widely adopted by the ES community, as it provides a flexible and hierarchical tool that may be adapted to the specific needs of the different regions [47]. The mapping and quantification of ES was implemented for the 1985–2015 period, with a 10-year time step.

**Table 1.** List of the estimated ecosystem services and their relevant indicators/proxies

ES Section/Group	Ecosystem Services	Indicator/Proxy	Data Sources
Provisioning	Cultivated crops (CC)	Percentage of crop production	1
	Materials from timber (MT)	Presence of forest and agroforest land	1
	Plant-based resources (PR)	Enhanced Vegetation Index (EVI)	2, 3
Regulating and Maintenance	Erosion protection (EP)	Soil Erosion Prevention (SEP)	1, 4, 5, 6
	Climate regulation (CR)	Below and above ground carbon storage	1, 7
	Maintenance of Nursery Populations and Habitats (NS)	Shannon Diversity Index (SHDI)	1
Cultural	Recreation (RC)	Recreation potential	1, 6, 8, 9

Data sources code: (1) Land cover data with spatial resolution 30 m based on Landsat Satellite images [40], (2) Landsat 5 TM satellite images for the years 1985, 1995, and 2005 [48], (3) Landsat 8 OLI satellite image for the year 2015 [48], (4) European Soil Data Center—ESDAC [49], (5) Worldclim—global climate data [50], (6) ASTER GDEM 30 m [51], (7) Carbon Dioxide Information Analysis Center [52], (8) European Ecological Network Natura 2000 [53], (9) Protected area management bodies [53].

### 2.2.1. Provisioning Services

Provisioning ES are all nutritional, material, and energetic outputs from living systems [46]. Cultivated crops (CC) represent the production of cultivated plants or agricultural produce for human or animal consumption as food, fiber, or a source of energy [10,54]. Materials from timber (MT) represent the products from trees harvested from natural forests and plantations [54]. Plant-based resources (PR) represent the capacity of ecosystems for energy production, which was estimated using the enhanced vegetation index (EVI) (Equation (1)) from Landsat satellite images. The EVI is used as an indicator of productivity and for vegetation monitoring due to its sensitivity to high biomass [55–57].

$$EVI = G \times \frac{NIR - R}{NIR + C_1 \times R - C_2 \times B + L} \quad (1)$$

where NIR/R/B are atmospherically corrected, or partially atmosphere corrected, surface reflectance in near-infrared, red, and blue bands, respectively. L is the canopy background adjustment. G is a gain factor. C1 and C2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band.

### 2.2.2. Regulating and Maintenance Services

Regulating and Maintenance ES include the ways in which ecosystems control or modify the biotic and abiotic parameters of the environment to improve human well-being [46,58,59]. Erosion prevention (EP) represents the capacity of ecosystems to prevent erosion, and is calculated using the soil erosion prevention framework (Equation (2)) by Guerra et al. [60].

$$Es = Y - \beta e \quad (2)$$

where Es represents the actual ecosystem service provision (tons of soil not eroded), Y represents the structural impact ( $Y = R * LS * K$ ),  $\beta e$  represents the mitigated impact ( $\beta e = Y * a$ , where  $a = C$  and  $Es = 1 - a$ ), R represents the rainfall erosivity, LS represents the topographic factor, K represents the soil erodibility, and C represents the vegetation cover factor.



Climate regulation (CR) represents the carbon storage values [61], which are assigned to each land cover category and are used as a proxy to estimate the capacity of vegetation to contribute towards mitigating climate change. Maintenance of Nursery Population and Habitats (NS) represents the suitable habitats for plant and animal nurseries and reproduction [46,62], which can be estimated with the landscape metric Shannon's diversity index (SHDI) [63], using land cover data and the FRAGSTATS software. FRAGSTATS is a computer software program designed to compute a wide variety of landscape metrics for categorical map patterns.

### 2.2.3. Cultural Services

Recreation (RC) represents the combination of recreation-related indicators that are used to estimate recreation potential. Nature attractiveness for outdoor recreation is mainly affected by naturalness [64,65], relief differencing [66,67], landscape diversity [68,69], and the existence of protected areas [54,70].

Specifically, naturalness is calculated using the naturalness evaluation index (NEI) (Equation (3)) [71,72], in which the land cover data were reclassified into four categories (high natural systems, semi-natural systems, agricultural systems, and artificial systems):

$$NEI = \frac{C_1 + 2 \times C_2 + 3 \times C_3}{3 \times (C_0 + C_1 + C_2 + C_3)} \quad (3)$$

where  $C_0$  is the area covered by artificial systems,  $C_1$  is the area covered by agricultural systems,  $C_2$  is the area covered by semi-natural systems, and  $C_3$  is the area covered by high naturalness systems. NEI ranges from 0 (the landscape reaches a maximum artificial status) to 1 (where the landscape reaches the highest naturalness condition).

Relief differencing was calculated using the geodiversity index (diversity of geomorphological features) proposed by Benito-Calvo et al. [73]. First, 10 different geomorphological features were calculated with an unsupervised classification (ISODATA) based on multi-layer surface variables (elevation, slope, curvature, and roughness) of an ASTER (advanced space-borne thermal emission and reflection radiometer) Global Digital Elevation Model (30 m). The ISODATA classification algorithm refers to an iterative self-organizing data analysis technique and was used to cluster the data elements into different classes [74]. Second, geomorphological features were used to estimate SHDI with FRAGSTATS for measuring the geodiversity index.

These four indicators were normalized and assimilated to estimate the recreation supply. The importance of each indicator was specified using the analytical hierarchy process [75], to estimate specific weights, where naturalness had the highest weight, followed by geodiversity, landscape diversity, and the presence of protected areas.

### 2.3. Quantification of ES Supply and ES Bundles

The values obtained from each ecosystem service were normalized to a scale between 0 and 1, based on the minimum and maximum values (Equation (4)), where 0 indicates low ES supply and 1 high ES supply [76].

$$ES' = \frac{ES - ES_{\min}}{ES_{\max} - ES_{\min}} \quad (4)$$

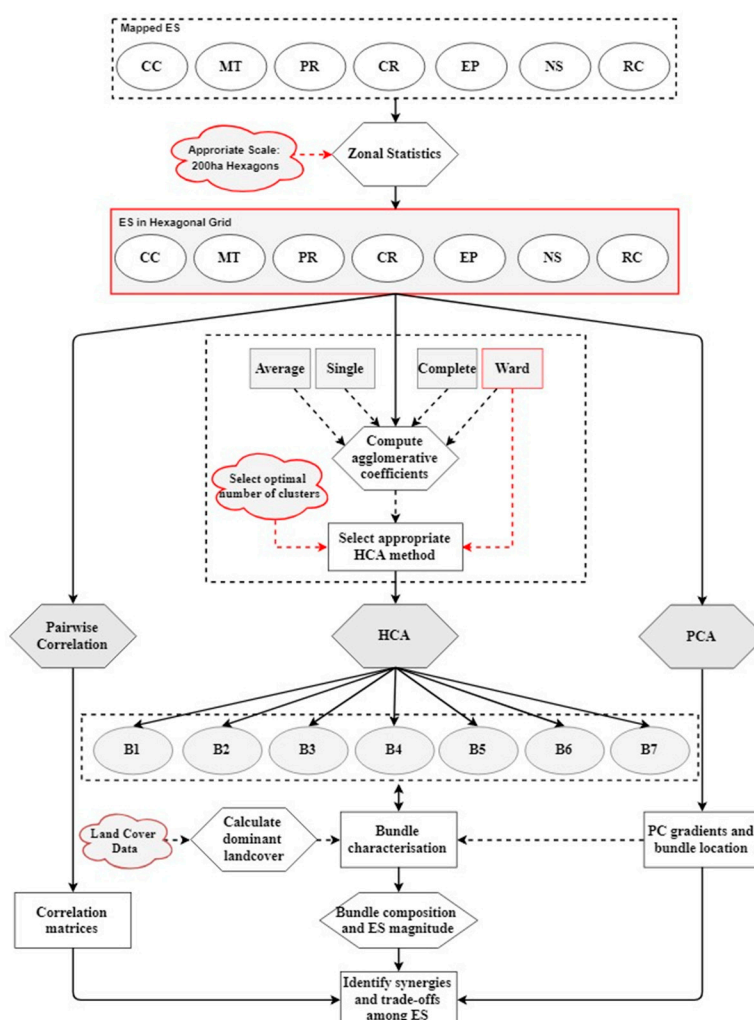
where  $ES'$  is the normalized ES,  $ES_{\max}$  is the maximum value of ES, and  $ES_{\min}$  is the minimum value of ES.

Ecosystem services were averaged to create the Total ES and the three ES sections/groups. Comparison of the supply of ecosystem services over time was displayed with boxplots. In addition, one-way ANOVA along with Games-Howell post hoc tests were used to identify any significant differences between the studied years.

To identify interactions among ecosystem services, an appropriate scale of analysis is required [77–79]. In this study, we tested three different spatial grids (two grids consisting hexagons

of 100 ha and 200 ha, and one grid consisting 267 municipal districts) to select an appropriate scale for assessing ES (Figure 2). The small grid 100 ha represents a local scale where few management practices may occur. The mid-scale grid 200 ha integrates the influence of a diverse landscape in the supply of ecosystem services. The large administrative scale refers to land boundaries where planning and management decisions are likely to be made. A hexagonal grid was preferred over a rectangular grid, because it provided a better representation of spatial connectivity in a complex landscape [80,81]. For each of the three grids, the average values were estimated using zonal statistics. These values were used to calculate Moran's I for measuring the spatial clustering and selecting the best scale. Moran's I is one of the oldest and most common statistics used to examine spatial autocorrelation in spatial data [82] and has been previously used in the ES literature [11,83–85]. Moran's I was used to determine whether ecosystem services are misrepresented as the scale of observation becomes larger [78,86]. It ranges from  $-1$  to  $1$ , where positive values indicate a highly clustered pattern of similar values and negative indicates clustering of dissimilar values.

The framework for analyzing interactions among ecosystem services consisted of three main processes (Figure 2).



**Figure 2.** Methodological flow chart used to identify interactions among ecosystem services (CC: cultivated crops; MT: materials from timber; PR: plant-based resources, CR: climate regulation, EP: erosion prevention; NS: Nursery; RC: recreation; HCA: hierarchical cluster analysis; PCA: principal component analysis; B1–7: ES bundles).

### 1. Pairwise correlation test for analyzing ecosystem service relationships

The Spearman correlation coefficients were calculated for all pairs of variables to investigate the direction (negative or positive) and the strength (weak: 0.10–0.29; moderate: 0.30–0.49; strong: 0.50–1.00; adapted from Renard et al. [11]) of relationships among ecosystem services.

## 2. Cluster analysis for identifying ecosystem service bundles

A method used to create groups with similar characteristics is the agglomerative method hierarchical cluster analysis (HCA) [87]. A variety of agglomerative clustering methods exists from which the single linkage, complete linkage, average linkage, and Ward's hierarchical clustering method are commonly used. Before applying any hierarchical clustering, it is necessary to evaluate the dissimilarity values to specify the agglomeration technique to be used [88]. One objective criterion to compare the clustering structure found by each technique is the agglomeration coefficients, which measure the amount of clustering structure of the ES values; the closer to 1, the stronger the clustering structure [89]. Therefore, we estimated the agglomerative coefficients of the single, complete, average, and Ward method. The most appropriate method was applied to assess the existence of ecosystem services bundles. The cluster dendrogram generated from HCA was classified into a number of classes (bundles) based on the elbow method for selecting the optimal number of classes [90].

## 3. Ordination analysis for specifying ES relationships within bundles

To investigate the relationship among ecosystem services within bundles, a principal component analysis (PCA) was performed to identify the proportions explaining ES variability by the two first axes [82]. PCA also helped to visualize the location of each ES bundle in the PC gradients. Bundles were characterized by examining the dominant land cover of each formed bundle and its position in the gradients of the PCA axes. The composition of each ES bundle was presented using starplots and the magnitude was estimated using the mean value of each ES. Each petal in the starplot is associated with a single ES, where a longer length indicates higher ES supply.

Of note, most processes and data visualization were implemented using the open source software R version 3.5.0 and R Studio Version 1.1.453 and the R packages: cluster [91], corrplot [92], factoextra [93], raster [94], rgdal [95], spatialEco [96], and userfriendlyscience [97]. The hexagonal grids were generated using patch analyst for ArcGIS [98]. Moran's I was calculated with Queen Contiguity using the free and open-source software program GeoDa. The Free and Open Source Geographic Information System 'QGIS' was also used to create maps of the ES supply.

## 3. Results

### 3.1. Mapping and Temporal Changes in ES Supply

The results revealed different intensities and spatial patterns among the individual ecosystem services, as well as among the islands (Table 2 and Figure A1). The cultural service of RC presented the higher intensities across the Ionian Islands, followed by MT, PR, and NS with moderate values, while CC, CR, and EP showed the lower intensities. The higher ES supply was found for RC in Corfu (0.70), while EP in Lefkada and CR in Zakynthos exhibited the lower values (0.19). The low values of CR and EP along with the moderate values of NS resulted in the overall lower intensity of Regulating and Maintenance ES (Table 2). Similarly, the low value of CC and moderate values of MT and PR led to the moderate supply of provisioning supply, resulting in the value of Total ES not exceeding 0.44 in the case of Corfu (<0.38 in the other islands).

Cultivated crops were mostly located in low land areas, showing both dispersed (Corfu and Lefkada) and clustered (Kefalonia and Zakynthos) patterns (Figure A1). Materials from timber and plant-based resources followed a similar pattern where higher values covered areas across the extent of all islands. Climate regulation and erosion prevention were the least intensive services, and mainly covered mountainous and forested regions. Nursery did not show any specific spatial pattern, as this service had higher values throughout the studied areas. Recreation had different patterns of intensity,

with this service being highly evident in the mountainous areas of some islands, while the mountainous areas of other islands had lower recreation supply.

The three ES groups had similar spatial patterns within the extent of each Island. In Corfu, areas with higher values of provisioning and total ES supply were mainly located in the north and south parts, while lower supply was found in the north mountainous and the central regions (Figure 3). In contrast, recreation followed a more evenly distributed pattern, as opposed to the patchier distribution of regulating ES. On Lefkada, provisioning ES was dominant in the lowland areas, while higher regulating and maintenance ES supply was detected in regions where intermediate conditions of provisioning ES occurred. Recreation primarily occurred in the east, north, and south part of Lefkada Island and north of Kalamos Island. As for Total ES, higher values covered mostly the north, northeast, and south part of Lefkada and the north parts of Meganisi and Kalamos (Figure 4). In contrast, lower Total ES supply was found in the central and southwest of Lefkada dominated by mountainous areas. Total ES was evenly distributed across Kefalonia, except in the central part, where lower total ES supply occurred and was divided into two distinct homogeneous regions, with both higher and lower supplies of all ES groups (Figure 5). Most of the areas in this Island with lower provisioning ES supply, had a moderate to high supply of regulating and recreation ES. In addition, higher values of total ES were located in the north and south parts of Ithaca Island. Zakynthos was the only island where provisioning ES had a different spatial distribution to that of regulating and maintenance ES and recreation (Figure 6). Specifically, higher provisioning ES supply occurred in lowland areas, while lower values were located in the mountainous regions. Higher regulating and maintenance ES and recreation were mainly located in mountainous areas, while higher total ES supply occurred both in mountainous and lowland regions. The lowland areas of Zakynthos had a homogeneous distribution of ES, while mountainous areas were characterized by a patchier pattern.

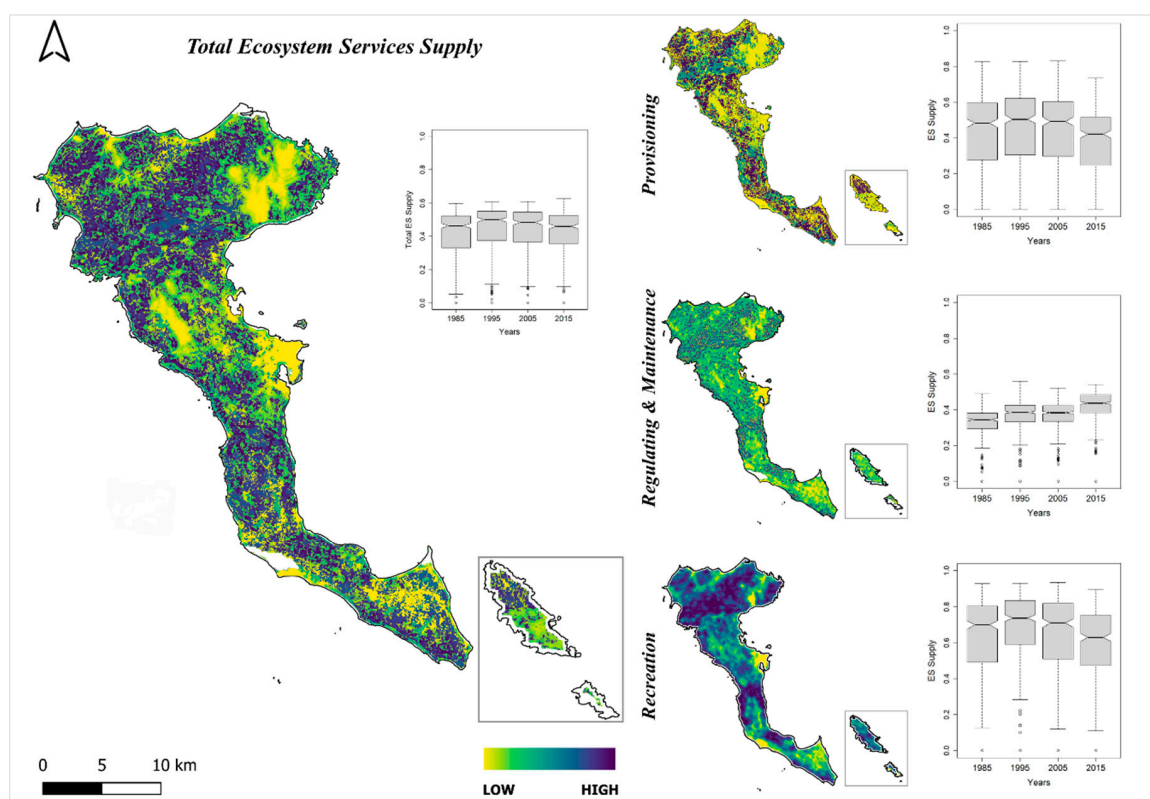
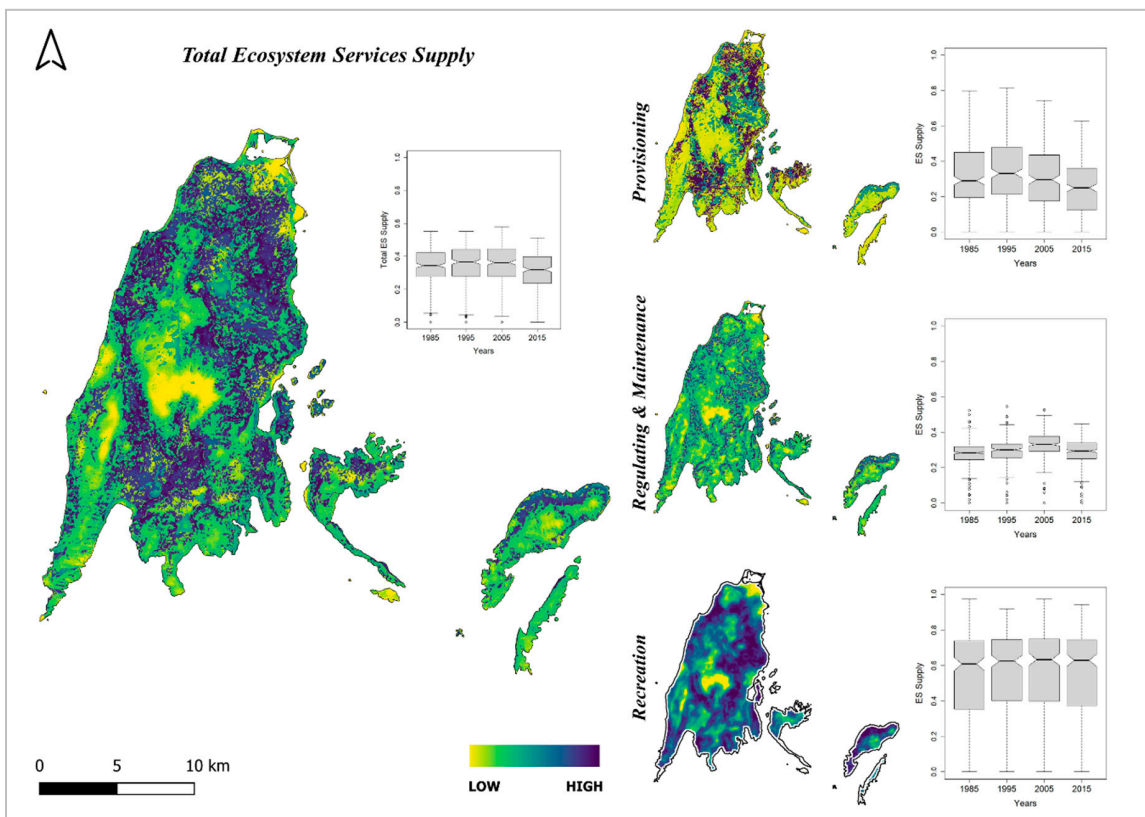
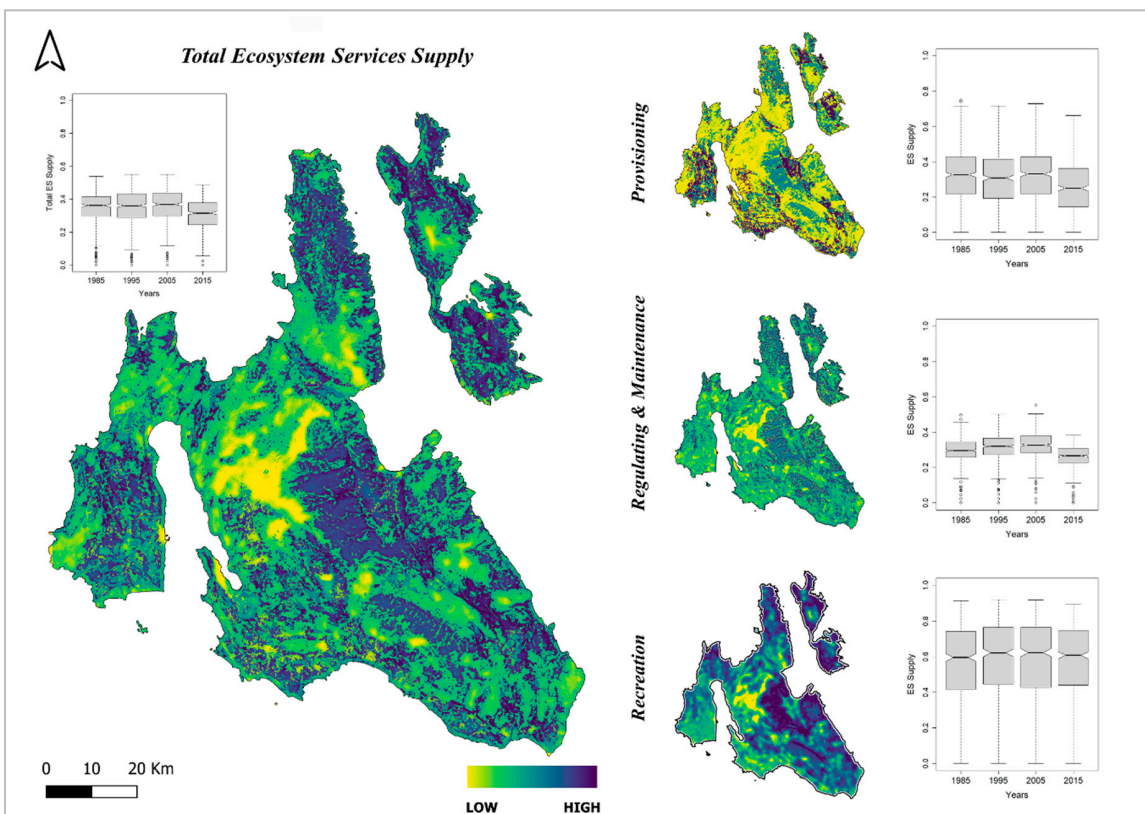


Figure 3. Temporal variation in ecosystem service supply and its spatial distribution in 2015 for Corfu.



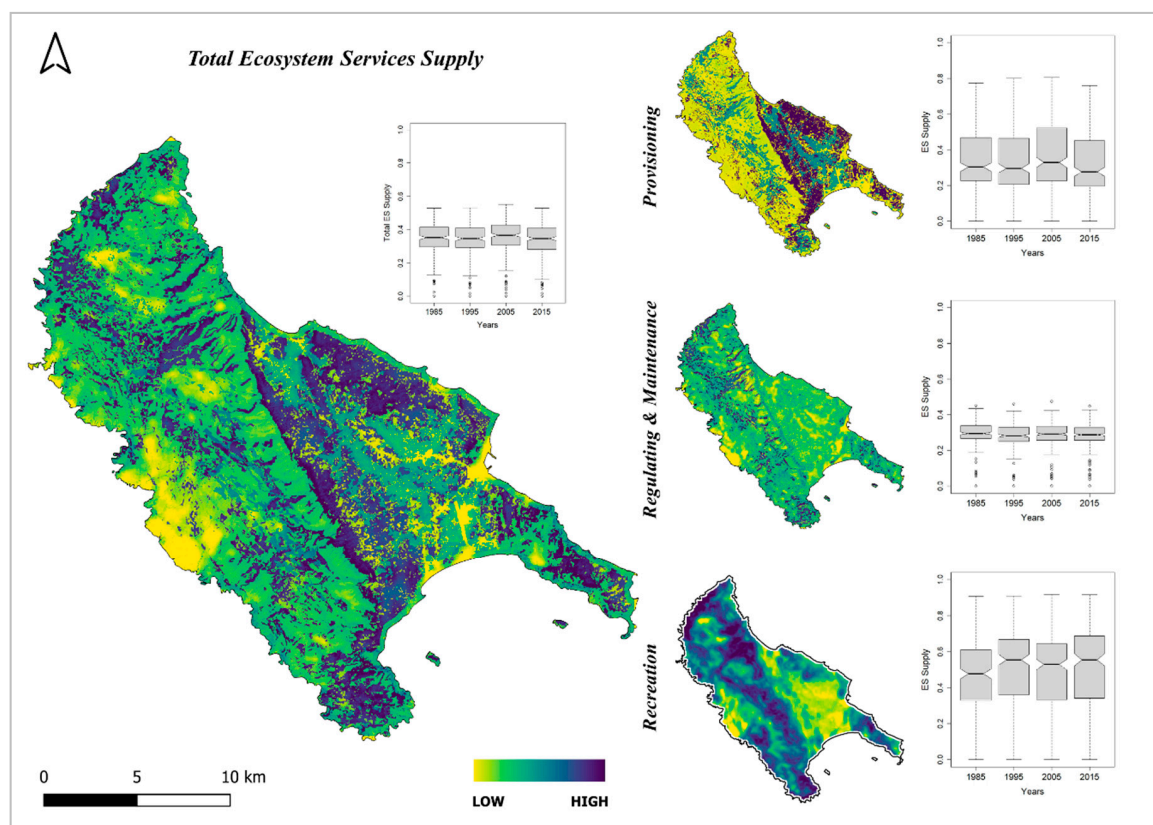


**Figure 4.** Temporal variation in ecosystem service supply and its spatial distribution in 2015 for Lefkada.



**Figure 5.** Temporal variation in ecosystem service supply and its spatial distribution in 2015 for Kefalonia (including Ithaka).





**Figure 6.** Temporal variation in ecosystem service supply and its spatial distribution in 2015 for Zakynthos.

**Table 2.** Average values of ES supply for the 1985–2015 period

ES Supply (Mean of 1985–2015)	Corfu	Lefkada	Kefalonia	Zakynthos
CC	0.38	0.27	0.22	0.35
MT	0.55	0.39	0.35	0.32
PR	0.52	0.43	0.38	0.48
CR	0.33	0.26	0.29	0.19
EP	0.30	0.19	0.23	0.24
NS	0.52	0.57	0.49	0.57
<b>Provisioning</b>	0.50	0.39	0.36	0.39
<b>Regulating &amp; Maintenance</b>	0.29	0.29	0.28	0.26
<b>Cultural (RC)</b>	0.70	0.64	0.62	0.53
<b>Total</b>	0.44	0.38	0.35	0.35

CC: cultivated crops; MT: materials from timber; PR: plant-based resources; CR: climate regulation; EP: erosion prevention; NS: nursery; RC: recreation.

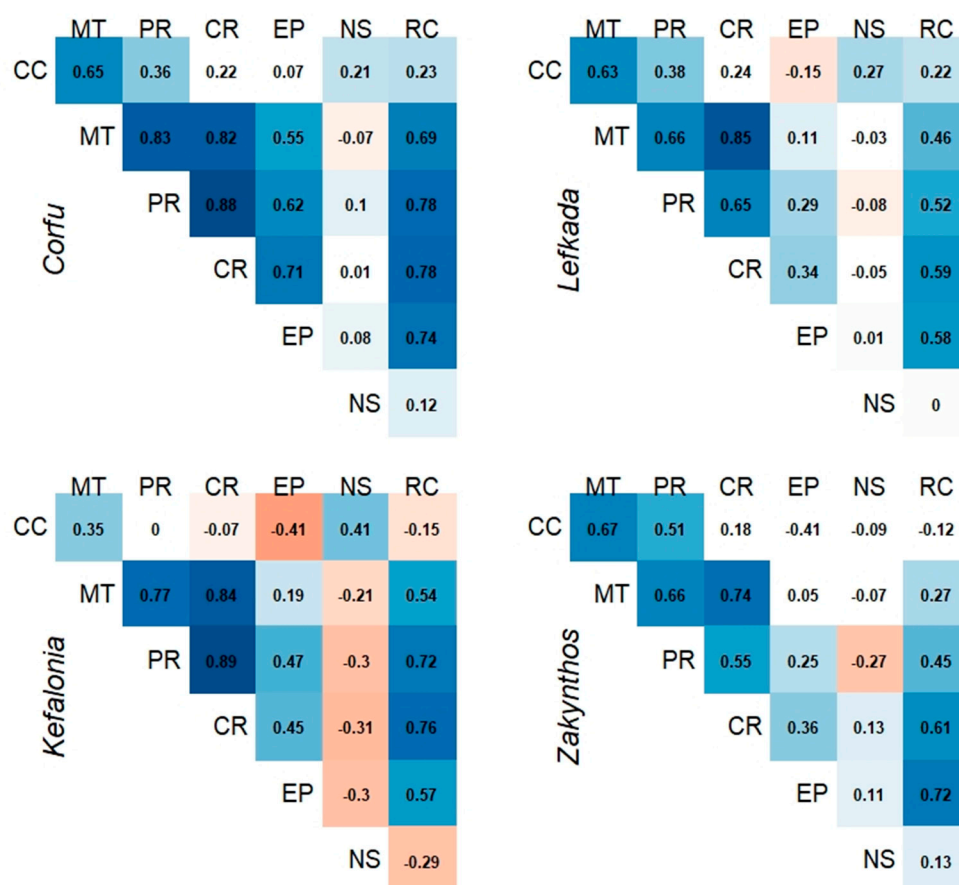
Concerning the temporal variations of ES groups, provisioning ES showed significant differences through the years across the region based on one way ANOVA (Corfu:  $[F(3,1668) = 14.19, p < 0.001]$ , Lefkada:  $[F(3,1092) = 15.77, p < 0.001]$ , Kefalonia:  $[F(3,2280) = 31.34, p < 0.001]$ , Zakynthos:  $[F(3,1036) = 3.37, p = 0.018]$ ). In general, provisioning ES in 2015 significantly decreased from the previous years throughout all Islands. Regulating ES followed two different trends; an overall significant increase over time in Corfu  $[F(3,1668) = 80.41, p < 0.001]$  and in Kefalonia  $[F(3,2280) = 75.06, p < 0.001]$ , and an increase from 1985 to 2005 ( $p < 0.001$ ) followed by a depletion in 2015 ( $p < 0.001$ ) in Lefkada. Significant temporal differences of recreation was found in Corfu Island  $[F(3,1668) = 5.08, p < 0.01]$ , which exhibited higher supply in 1995 compared to 2015 ( $p < 0.01$ ), while there was no significant difference on the other three Islands ( $p > 0.05$ ). Total ES supply showed a significant increase

between 1985 and 1995 in Corfu ( $p < 0.01$ ) and a significant overall decrease between 1995 and 2015 in Lefkada and Kefalonia ( $p < 0.001$ ).

### 3.2. Temporal Changes in the Correlation among Ecosystem Services

Regarding spatial autocorrelation, our results showed that Moran's I was higher both for the 200 ha hexagonal and the administrative grids (Appendix B). In contrast, the 100 ha hexagonal grid had the lowest Moran's I values. Although, the grid of municipal districts in Kefalonia presented higher spatial clustering in comparison with the other two grids, in Lefkada, the same grid reached an average of 0.19, indicating a low spatial clustering. On the other hand, the 200 ha hexagonal grid in Corfu, Lefkada, and Zakynthos reached the higher values. The latter grid was used as the scale of observation to identify ES interactions.

The pattern of correlations for all islands was relatively similar in all four years (Figure 7 and Appendix C); however, some ES pairs changed through time based on the direction and strength of their relationship. Overall, most ES had a synergistic relationship over time in Corfu, Lefkada, and Zakynthos, while Kefalonia had the most tradeoffs. Kefalonia had the most statistically significant correlations, contrary to Zakynthos, where the most non-significant ( $p > 0.05$ ) relationships were found. The most synergies among regulating ES occurred in Zakynthos, whereas the most tradeoffs occurred in Kefalonia.



**Figure 7.** Spearman pairwise correlations between ES in 2015 (Dark blue indicates strongly positive correlations defined as synergies and dark red indicates strongly negative correlations defined as trade-offs. White squares represent non-significant correlations ( $p > 0.05$ ). CC: cultivated crops; MT: materials from timber; PR: plant-based resources; EP: erosion prevention; CR: climate regulation; NS: nursery; RC: recreation).

Among provisioning ES (CC, MT, and PR), there were mainly strong and moderate positive correlations, especially in Zakynthos where all correlations were higher than 0.50. Only in Kefalonia, certain ES pairs (CC-MT and CC-PR) presented moderate and weak synergies ( $r < 0.35$ ).

The correlations among the regulating and maintenance ES (EP, CR, and NS) showed various results. Specifically, CR and EP demonstrated consistent positive correlations across islands and time, while weak correlations were found between EP and NS. The Nursery service exhibited the most trade-off relationships amongst all ES.

The relationship of provisioning ES with regulating and maintenance ES presented mostly positive correlations across the region, with Kefalonia and Zakynthos exhibiting some trade-offs. The provisioning service of CC with the regulating services of CR and EP showed non-significant correlations through the years; however, a moderate negative correlation between CC and EP was observed in the last period on Kefalonia ( $r = -0.41$ ). Positively strong relationships were identified between MT and CR across all Islands, while between MT and EP, strong synergies were found only in Corfu. The provisioning service of PR was positively correlated with all ES, except NS, where the stronger correlations occurred between PR and CR. The direction of the correlation for PR and NS varied among the islands (Figure 7 and Appendix C). For example, in Corfu, a negative correlation became positive ( $-0.21$  in 1995 to  $0.10$  in 2015), whereas a synergy between PR and NS led to a trade-off relationship in Zakynthos (from  $0.15$  to  $-0.27$ ).

The recreation service showed a strong and moderate synergistic relationship with provisioning ES (MT and PR), as well as with regulating ES (EP and CR) across the Ionian Islands. Particularly in Corfu, RC was significantly positively correlated over time with MT, PR, EP, and CR, reaching coefficient values greater than  $0.61$ ,  $0.58$ ,  $0.67$ , and  $0.73$ , respectively. Among all islands, RC and CC presented both weak synergistic and trade-off relationships. Regarding RC and NS, different correlation patterns were found among the islands. In Corfu, the direction of correlation changed from negative (in 1995) to positive (in 2015). The tradeoff relationship between RC and NS in Kefalonia became stronger, as opposed to Zakynthos, where the synergistic relationship tended to be weaker.

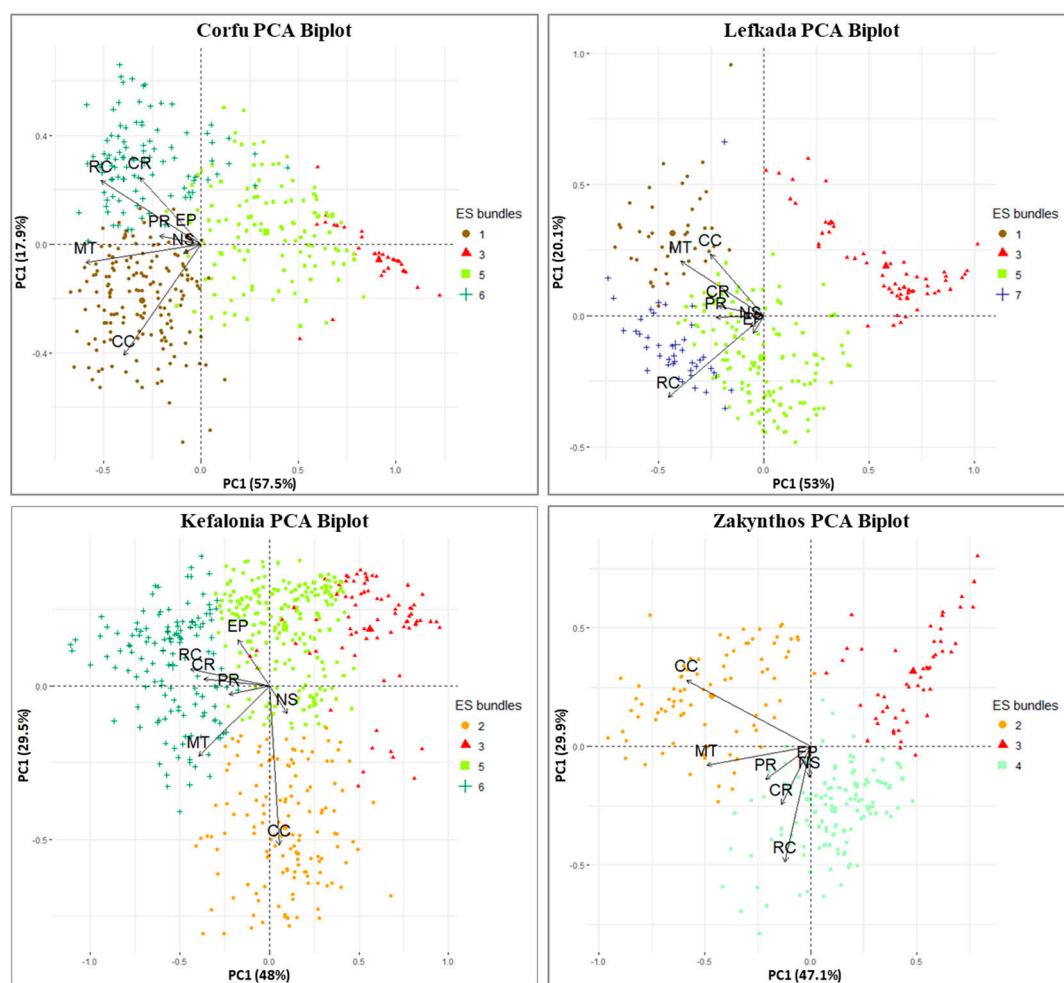
### 3.3. ES Bundle Characterization

Regarding the four agglomerative methods, Ward's method presented the minimum cluster variance for all islands, because it overcame a  $0.98$  agglomerative coefficient followed by the complete method ( $0.94$ ), average method ( $0.91$ ), and single method ( $0.84$ ). Hierarchical cluster analysis formed a total of seven ecosystem service bundles, from which four were identified in Corfu, four in Lefkada, four in Kefalonia, and three in Zakynthos.

The first two PCA axes explained  $75.4\%$  of the ES variability for Corfu,  $73.1\%$  for Lefkada,  $77.5\%$  for Kefalonia, and  $77\%$  for Zakynthos, respectively. The first gradient in Corfu corresponded to an axis that ranged from olives with high recreation supply to low ES supply. The second gradient was identified an axis from cultivated crops to areas with high recreation (Figure 8). The first gradient on Lefkada ranged from mixed olives with high recreation to low ES supply, while the second gradient presented a variation from diverse landscapes of high recreation to olive crop provision. The first axis, identified in Kefalonia, represented a forest recreation to low ES supply gradient, while the second gradient showed an agricultural to erosion prevention gradient. Finally, the gradients identified on Zakynthos were associated with an agricultural to low ES supply (PC axis 1) and recreation to cultivated crops (PC axis 2).

According to their location along the gradients in Figure 8, ES bundles were characterized as olive groves (B1), high agricultural provision (B2), non-vegetated-low supply (B3), mountainous areas (B4), naturally vegetated areas (B5), forest recreation (B6), and high naturalness (B7). Specifically, B1 found in Corfu and Lefkada was located on the gradients where high provision of MT and CC occurs (PCA axis 1) and the dominant land cover was olive crops. The other agricultural bundle (B2) was found on the second axis of Kefalonia and on the first axis of Zakynthos, where areas with various crop provision dominated this bundle. The bundle dominated with urban and open areas (B3) was found on all

islands, and was located on the part of PCA axis 1 where ES were not correlated. In Zakynthos, B4 was characterized by a habitat mosaic (forests, transitional vegetation, shrubs, sparse vegetation, and open areas) that occurred in mountainous areas where recreation was evident. Shrubwoods, transitional vegetation, high-density olives, and forests dominated B5, where, in Corfu, no specific ES occurred. In comparison, in Lefkada and Kefalonia mostly regulating ES took place in B5. The dominant land cover of B6 consisted of forested areas and were located along gradients with high recreation. Finally, B7 was only found in Lefkada, and was placed on the high recreation part of PCA axis 1, where forest, high-density olives, and shrubbery cover were dominant.



**Figure 8.** PCA gradients and bundle location (each point represents a hexagonal unit). CC: cultivated crops; MT: materials from timber; PR: plant-based resources; CR: climate regulation; EP: erosion prevention; NS: nursery; RC: recreation.

In Table 3, the spatial changes of ES bundles over time are presented with the area percentage for each studied year. B1 and B2 (crop related bundles) remained stable over time except in Lefkada where the areas covered with olive groves declined 10% with a subsequent increase of B5. B3 decreased in Corfu and Lefkada and increased in Zakynthos, while in Kefalonia remained relatively similar. B4 had a depletion of 5% from its original state in 2015. B6 in Corfu increased throughout all of the studied years, as well as in Kefalonia between 1985–2005. However, in 2015, B6 in Kefalonia decreased by almost 4%. The last bundle (B7) represented areas with high naturalness, due to the existence of forest, shrubbery, and high-density olives, which decreased by 13% between 1985 and 1995, but then increased to 17% in 2015.

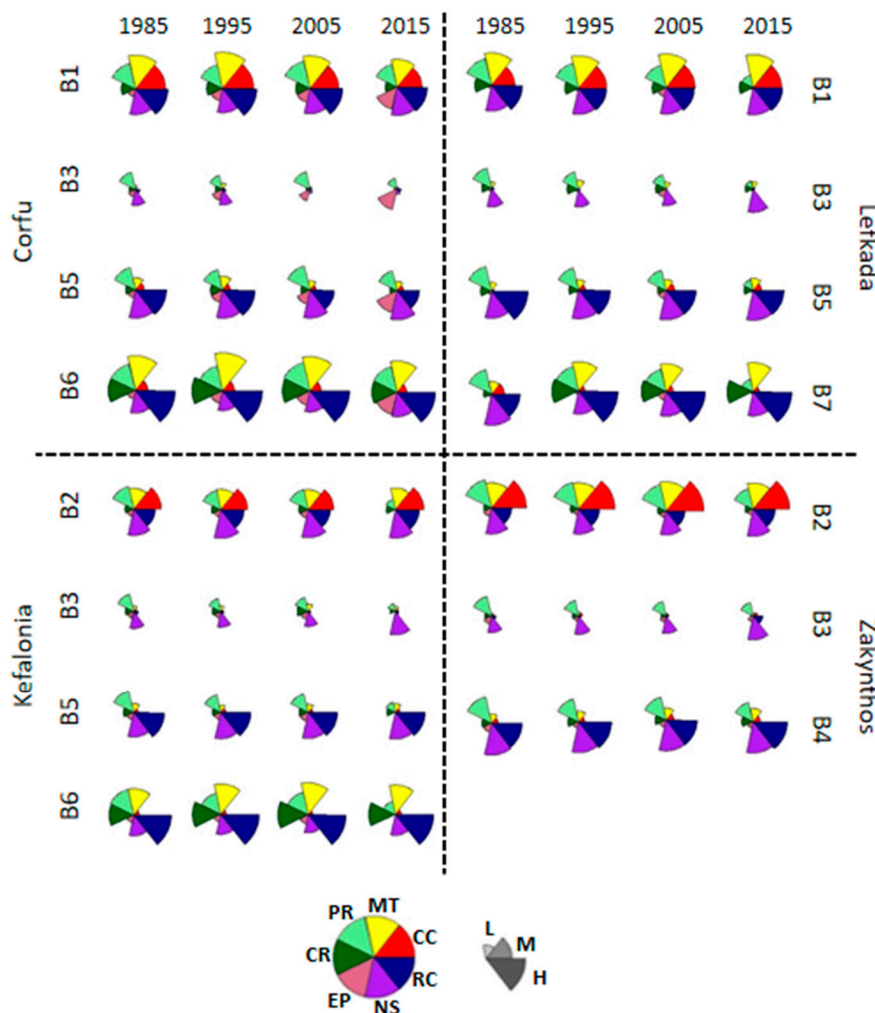
**Table 3.** Changes in the percentage area covered by each ES bundle over time

	Corfu				Lefkada				Kefalonia				Zakynthos			
	1985	1995	2005	2015	1985	1995	2005	2015	1985	1995	2005	2015	1985	1995	2005	2015
<b>B1</b>	45.4	48.1	47.9	45.8	31.7	32.8	22.7	21.7								
<b>B2</b>									27.4	25.8	26.4	26.4	35.8	34.1	36.7	35.7
<b>B3</b>	7.3	3.5	1.9	2.6	7.2	3.9	3.3	4.6	3.5	3.1	3.6	5.2	5.6	2.6	2.0	11.0
<b>B4</b>													58.6	63.3	61.4	53.3
<b>B5</b>	23.7	23.5	26.1	25.7	34.9	49.9	57.2	56.6	41.7	40.5	40.3	42.2				
<b>B6</b>	23.6	24.9	24.2	25.9					23.7	30.0	30.2	26.3				
<b>B7</b>					26.2	13.4	16.8	17.0								

B1: olive groves; B2: high agricultural provision; B3: non-vegetated-low supply; B4: mountainous areas; B5: naturally vegetated areas; B6: forest recreation; B7: high naturalness.

### 3.4. Magnitude and Composition of ES Bundles

Overall, Zakynthos appeared to have the most stable bundle composition and magnitude through time, followed by Kefalonia (Table 3 and Figure 9). Within all ES bundles, there were small variations among years, with the magnitude of few ES changing.



**Figure 9.** Dynamic magnitude of ES bundles. B1: olive groves; B2: high agricultural provision; B3: non-vegetated-low supply; B4: mountainous areas; B5: naturally vegetated areas; B6: forest recreation; B7: high naturalness; CC: cultivated crops; MT: materials from timber; PR: plant-based resources; CR: climate regulation; EP: erosion prevention; NS: nursery; RC: recreation.



In the olive grove bundle (B1), MT, CC, NS, and RC had high provisioning, indicating synergies among them. Within B1 in Corfu, the magnitude of MT decreased over time, while EP increased. In comparison, in Lefkada, PR tended to decline (Figure 9). Agricultural areas (B2) in Kefalonia mainly provided CC and NS with other services also occurring (RC and MT). The high presence of provisioning ES were evident in the agricultural bundle of Zakynthos. In both Zakynthos and Kefalonia, PR in B2 decreased by 2015. As for non-vegetated areas (B3), they presented low ES supply on all islands. The mountainous bundle (B4) was only found in Zakynthos, and had a similar pattern with the naturally vegetated areas (B5) of Lefkada and Kefalonia, where NS and RC were the dominant, while PR decreased through the years. In the B5 of Corfu, the initial intensity and dominance of NS was retained, whereas EP increased and RC decreased. Corfu's forest recreation bundle (B6) presented an increasing magnitude of NS and EP, resulting in the provision of multiple ES in 2015. In the forested areas (B6) of Kefalonia and in the high naturalness bundle (B7) of Lefkada, the supply of PR changed (from high in 1985 to low in 2015) and EP was almost absent. In both B6 and B7, RC had the highest supply, while CC was low or non-existent.

## 4. Discussion

### 4.1. Mapping Ecosystem Services

The spatial distribution of ES in three islands (Corfu, Lefkada, and Kefalonia) followed a similar spatial pattern, where provisioning ES, regulating and maintenance ES, and recreation were spatially co-occurring. This finding contrasted with that of Queiroz et al. [13], who found substantial differences in the distribution of provisioning, regulating, and cultural ES. On Zakynthos only, provisioning ES was distributed differently in relation to the other two ES groups, supporting a study conducted to an Alpine-wide level [99], in which provisioning ES was found to be clustered in different areas to those where regulating and cultural ES occur. All three ES groups exhibited significant differences in their temporal variation over time in Corfu only, whereas provisioning ES and recreation followed a similar decreasing trend and regulating services increased. These results might be due to the loss of forests and high-density olives [40]. As expected, areas of high naturalness provided high ES supply, supporting the results of previous studies [100–103], and contrasted with the lower values obtained in rocky and poorly vegetated areas.

In addition to tourism, agriculture is an important sector of the economy in the Ionian region, which explains the high presence of provisioning ES. Across the study area, olive groves cover most of the agricultural regions, with other crop types (vineyards, arable, and mixed crops) also contributing to the supply of provisioning ES. In addition, areas with a high supply of provisioning ES are characterized by low elevation and flat topography [10,14,99,104], which was more prominent in Zakynthos, as higher elevated areas had a lower supply of provisioning services as opposed to the higher provision of lowland areas.

Regulating and maintenance ES were higher in naturally vegetated and heterogeneous areas. Specifically, forested regions had a higher provision of regulating ES across the Ionian Islands (CR and EP), as shown by other case studies [13,99]. As expected the nursery service (maintenance ES) was found in more diverse landscapes regardless of the type of vegetation. In Kefalonia, damage caused by forest fires 2007 [105], along with a decline in landscape diversity, might have caused the observed decline in regulating and maintenance ES from 2005 to 2015.

The spatial pattern of recreation supply in each of the Islands was dependent on the amount of high-quality vegetation due to the higher weight value given to the degree of naturalness for mapping recreation. In Ionian Islands, a distinct mosaic of forest and olive yards is a characteristic landscape, mainly in Corfu and Lefkada, giving an extra value in the recreational service. Lower values of recreation were found in Zakynthos, due the low coverage of forests and less diverse landscape. These results were consistent with the findings of De Valck et al. [106], where in a mixed landscape including farmlands and forests, diversity was highly appreciated from recreationists.

#### 4.2. Interactions among Ecosystem Services

This study demonstrated that ES relationships may change over time. Similar results were obtained by Renard et al. [11], who showed clear evidence of the ES dynamics. However, the general pattern for the type and strength of the ES relationships was similar among the islands, with some exceptions. Mostly positive correlations were found across the region, with Corfu having the strongest synergies and Kefalonia being subject to the most trade-off interactions. Among provisioning ES there were positive correlations, suggesting a synergistic relationship, such as the one discussed by Turner et al. [14]. Regarding the relationships between provisioning and regulating ES on a diverse landscape, Kong et al. [84] found that crop production had a significantly strong negative correlation with soil retention. However, a similar finding was only evident in Lefkada for one year (2015), where cultivated crops showed a moderate trade-off relationship with erosion prevention. In another study, Swallow et al. [107] found no significant relationship between sediment yield and agricultural production. As for the relationship between provisioning and cultural ES, cultivated crops and recreation presented consistently positive correlations, as in the case of Corfu and Lefkada. This phenomenon might be explained by agricultural land abandonment, since Queiroz et al. [13] connected the absence of strong negative trade-offs between agricultural and cultural services with low intensity agricultural practices. In contrast, in Kefalonia and Zakynthos, cultivated crops and recreation showed an antagonistic relationship, which has also been detected by other studies [10,11,14,54], possibly due to the intensification of agricultural practices. These patterns further enhance the association of mixed olives and forests with the high supply of ES [108,109].

The ES assessment followed in this study, presented various correlations and facilitated the formation of ES bundles. In total, seven ES bundles were formed in the Ionian Islands, from which agricultural and forested bundles were also identified in most studies, indicating that there is a general pattern in the formation of ES bundles. Each Ionian Island formed one bundle of agricultural use (B1 in Corfu and Lefkada, and B2 in Kefalonia and Zakynthos), supporting the results of other studies [14,104,110]. In comparison, other studies identified two crop-related bundles in a single study area [10,11,13]. Most of these existing studies recognized agricultural cover as the dominant bundle, which was only the case for the olive grove bundle (B1) in Corfu. However, the agricultural bundles still covered a large amount of land in the Mediterranean ecosystems of the Ionian Islands. In addition, this bundle in Corfu provided a set of multiple ES (incl. all ES groups) through the years, which contrasted with other agricultural bundles [10,11,84]. In Zakynthos, despite the increase in the tourism industry and population density [40], the agricultural bundle varied across years, but retained a stable extent and supply of Provisioning ES. However, in the case of another Greek Mediterranean Island, declines in the agricultural sector were linked to increasing tourism [111]. Kefalonia presented an interesting result, not found in other studies, where the agricultural bundle provided a similar and higher magnitude of recreation than provisioning ES. Seasonal variations might occur in the agricultural bundles, since different crop types are harvested in specific times of the year (i.e., vineyards are harvested in the summer season, while olive groves in the fall or winter season).

The developed bundle covered mainly by rocky, open, and urban areas (B3) occupied the smallest extent in all islands and provided a negligible amount of ES over the studied years, with similar results being obtained for other urban bundles [112]. However, these findings also contrasted with other studies, in which urban bundles provided a set of ES related to provisioning and regulating ES and, in some cases, cultural ES [10,13]. The stable composition and magnitude of the B3 bundle in Zakynthos and Kefalonia might be due to their supporting similar livestock densities, as discussed by Kefalas et al. [40].

The mountainous bundle found only in Zakynthos was characterized by a diversity of forest, transitional vegetation, shrubs, sparse vegetation, and, even, rocky and open areas, explaining the high supply of nursery and recreation. This result was obtained because the diversity of landscapes was a key indicator for these two services. Similarly, in the mountainous bundle obtained by Yang et al. [113], forest recreation had a high supply. However, in this previous study, regulating services were also

highly evident in mountainous areas, as opposed to the low regulating ES supply in Zakynthos. Similar to B3 in Zakynthos, the maintenance of livestock densities resulted in the stable composition and ES magnitude of the mountainous bundle.

It is clear that, within a region, and especially an Island complex, different ES patterns occur, both among islands and at a temporal scale. For example, in Kefalonia, between 1985 and 1995, the agricultural bundle and the naturally vegetated bundle decreased in size, while forest areas increased, suggesting a lack of disturbance. In comparison, a different profile appeared between 2005 and 2015, where a depletion of forest ecosystems (decrease of B6) and gain in rocky and open areas might have been caused by forest fires [105]. Also, on Zakynthos, transitions between the non-vegetated bundles and the mountainous ecosystems might be explained by impacts from forest fires [114]. The progressive decrease in the non-vegetated bundle in Corfu with a subsequent increase in the olive grove bundle and the forest bundle might be explained by land abandonment in some areas and agricultural transition in others. Renard et al. [11] found similar contrasting trajectories in a single study area (field abandonment and agricultural specialization), contributing to the changes to ecosystem service bundles. Fire regeneration could also be suggested as a driver in the observed patterns of Corfu; however, fire events were concentrated in the north mountainous areas, where only low density vegetation was evident [40].

#### 4.3. Implications for Policy Making

Decision makers and land managers often question how to implement ES assessments into current and future strategies [115,116].

For example, abandoning all agricultural practices, instead of maintaining a well-balanced agricultural and natural landscape, might fail to support nursery populations, in parallel to losing traditional Mediterranean landscapes [117–120]. In our case, we found that while the ‘forest recreation’ and ‘high naturalness’ bundles provide highly supplied ES, ‘olive groves’ seem to supply a variety of provisioning, regulating and cultural ES over the years. This pattern indicates that a mixed-use landscape has higher potential to provide multiple ES, as opposed to a fully abandoned and homogeneous landscape.

On the other hand, agricultural intensification might alter natural characteristics and could create more intense trade-offs with other services, such as water quality, erosion prevention, and recreation opportunity [11,121–123]. Conflicts between provisioning and other ES found in lowland areas of Zakynthos, suggest that there might be potential for more regulating and cultural services in these areas to avoid further increase in trade-offs among ES. By incorporating various crop types mixed with natural zones, instead of specializing on specific types, throughout an agricultural–natural ecosystem can create a more diverse landscape and other services could be enhanced without decreasing essential ES [124].

The increase in tourism requires more space for facilities and activities, with a subsequent loss of natural ecosystems and their services, which is the case for Corfu and Zakynthos [30]. While investing in more accommodation and entertainment facilities seems profitable, it is a temporary decision leading to long-term consequences, as tourism depends on the highly natural and cultural value of the Ionian Islands. If decisions on land modification are not properly managed or not carefully planned, severe impacts both on the environment and tourism might occur in the near future. Despite the negative impact of mass-tourism on natural ecosystems, the preservation of cultural landscapes providing local products and touristic opportunities could contribute to a more sustainable tourism [30,40].

Regarding recreation, which is of high importance in the Ionian Islands, attention is needed due to an increasing focus on nature tourism (also known as eco-tourism). Lacitignola et al. [32] define eco-tourism as “responsible travel to areas with relatively high degree of natural values”. However, like any other resource exploitation activity, nature-based tourism requires management and control [33]. Specifically, recreation and nature tourism consist of activities that have both economic and environmental implications, such as disturbance frequency, development of facilities, unorganized

visits, and a lack of knowledge and information [33,125]. Therefore, detailed information is required on the possible impacts of all activities, even those dependent on the quality of the environment more than any other form of tourism. Nonetheless, the synergistic relationship of recreation with other ES revealed the potential of Mediterranean ecosystems to support multiple ES.

Such management actions, which aim to increase specific ES rather than multiple ES, should be well planned, designed, and implemented to maintain equilibrium between human-wellbeing and healthy ecosystems. Knowledge on the interactions among ES might prevent future impacts from resource management policies [126,127], especially when managing heterogeneous landscapes [128], such as those in the Ionian Islands.

## 5. Conclusions

To manage ecosystems sustainably, knowledge about how ES vary at spatial and temporal scales is required. This study showed the similarities and differences in the distribution and interactions of ES among the Ionian Islands. Provisioning, regulating, and recreation ES present spatial congruence in some islands, as opposed to others, where provisioning ES followed different pattern in relation to regulating ES and recreation. In addition, the mountainous areas of Lefkada were occupied by lower Total ES supply due to the absence of natural vegetation, whereas the mountainous regions of Kefalonia had moderate to higher Total ES values. The contribution of mixed olive trees with natural vegetation played a key role in these patterns. Overall, recreation was dominant in relation to provisioning and regulating ES, as the islands are characterized by high natural and diverse ecosystems. This study also demonstrated that interactions among ecosystem services were not static and changed over time, probably as a result of changing spatial policies directly affecting land cover. Agricultural production, land abandonment, increasing tourism, and forest fires might represent the main factors driving trajectories in ES relationships and among ES bundles. The formed ES bundles had distinct compositions and magnitudes, but these were highly dependent on the selected ES and mapping methods. However, similar results were observed in other study areas, indicating the formation of key ES bundles across different landscapes. Areas dominated by olive groves delivered the most ES with high magnitude, showing high synergies within these regions, due to the complex ecological processes that are needed to maintain such ecosystems. This study's findings provide useful information on the dynamic nature of ES in Mediterranean island ecosystems, which can be used by stakeholders, decision- and policy-makers for promoting sustainable resource management and planning. Knowledge on the spatial and temporal changes of ES supply and interactions can improve the understanding of underlying processes affecting these changes and optimize the provisioning of multiple ES.

Further research could focus on how socioeconomic factors influence the provisioning of ES and ES bundles, as well as the impacts of possible management policies (for example, with the Common Agricultural Policy) on ES. This approach would facilitate the adjustment of current management plans and the design future strategies to ensure a constant supply of ecosystem services is maintained.

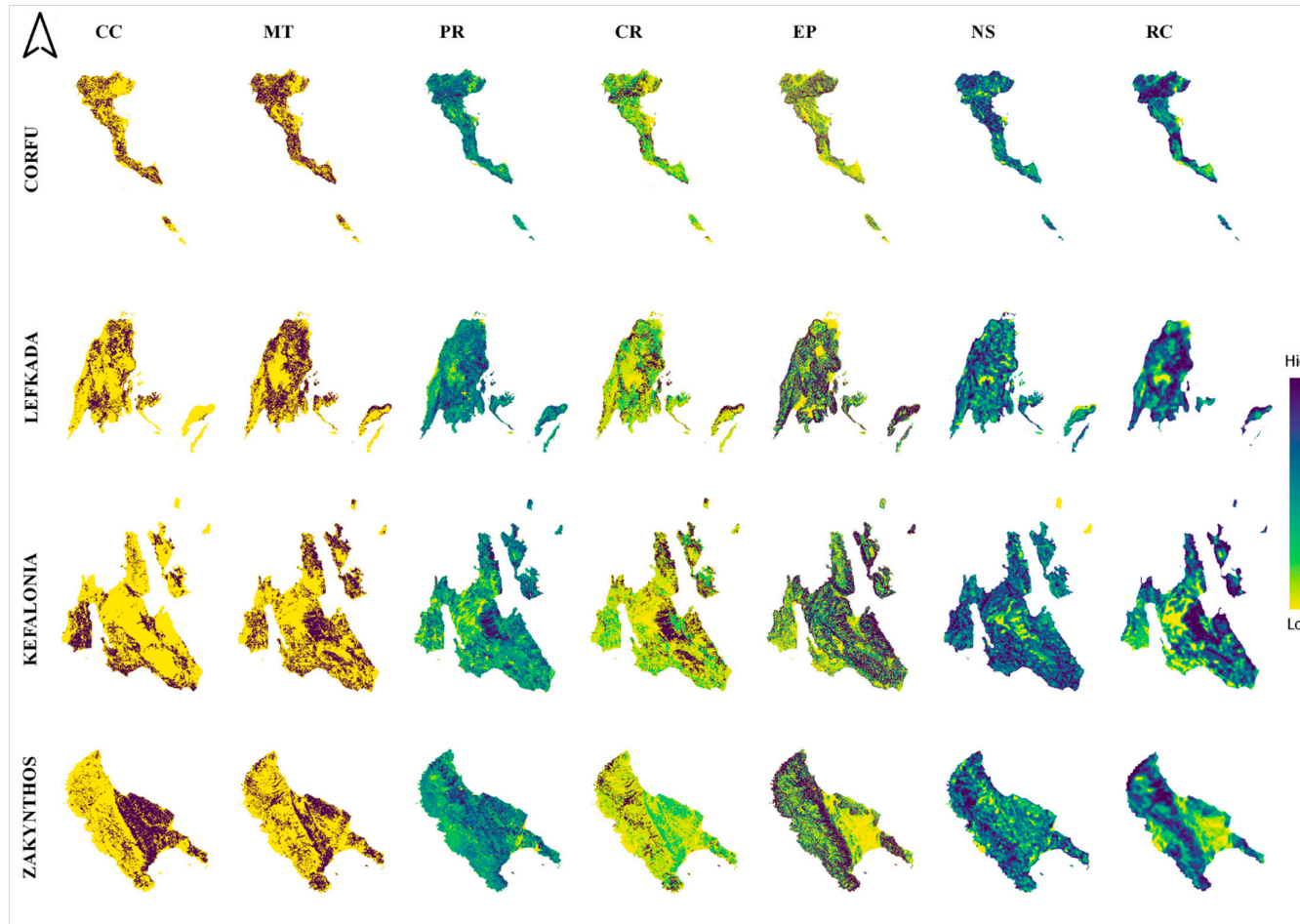
**Author Contributions:** Conceptualization and methodology: R.S.L. and K.P.; Data analysis: R.S.L.; Writing—original draft manuscript: R.S.L. and K.P.; and Writing—review and editing: K.P., S.K., V.D., and A.M.

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## Appendix A



**Figure A1.** Maps of individual ES for 2015. CC: cultivated crops; MT: materials from timber; PR: plant-based resources; CR: climate regulation; EP: erosion prevention; NS: nursery; RC: recreation.



## Appendix B

Table A1. Moran's I (M.I.) spatial autocorrelation results for Corfu

Corfu	Hexagonal 100 ha			Hexagonal Grid 200 ha			Municipal. Grid		
	M.I.	z-Value	p-Value	M.I.	z-Value	p-Value	M.I.	z-Value	p-Value
1985	0.3517	15.1191	0.001	0.5010	16.4085	0.001	0.4353	6.6289	0.001
1995	0.3009	13.1178	0.001	0.4730	15.6784	0.001	0.4132	6.3022	0.001
2005	0.3227	13.9348	0.001	0.5167	16.7924	0.001	0.4367	6.5128	0.001
2015	0.3097	13.5481	0.001	0.4886	15.8971	0.001	0.4037	5.9502	0.001

Randomization: 999 Permutations.

Table A2. Moran's I (M.I.) spatial autocorrelation results for Lefkada

Lefkada	Hexagonal 100 ha			Hexagonal Grid 200 ha			Municipal. Grid		
	M.I.	z-Value	p-Value	M.I.	z-Value	p-Value	M.I.	z-Value	p-Value
1985	0.3809	12.9064	0.001	0.4394	10.3041	0.001	0.2615	2.6396	0.006
1995	0.3798	12.7979	0.001	0.4442	10.4601	0.001	0.2099	2.1799	0.024
2005	0.4142	13.6465	0.001	0.4483	10.6174	0.001	0.1891	1.9680	0.036
2015	0.3955	13.1485	0.001	0.5005	11.7509	0.001	0.1176	1.3183	0.112

Randomization: 999 Permutations.

Table A3. Moran's I (M.I.) spatial autocorrelation results for Kefalonia

Kefalonia	Hexagonal 100 ha			Hexagonal Grid 200 ha			Municipal. Grid		
	M.I.	z-Value	p-Value	M.I.	z-Value	p-Value	M.I.	z-Value	p-Value
1985	0.1983	10.0153	0.001	0.3429	12.5241	0.001	0.4295	6.7134	0.001
1995	0.2406	12.0775	0.001	0.4069	14.8225	0.001	0.4982	7.8021	0.001
2005	0.2169	10.8401	0.001	0.4083	15.0074	0.001	0.5063	8.0189	0.001
2015	0.2675	13.1031	0.001	0.4222	15.4819	0.001	0.4531	7.1961	0.001

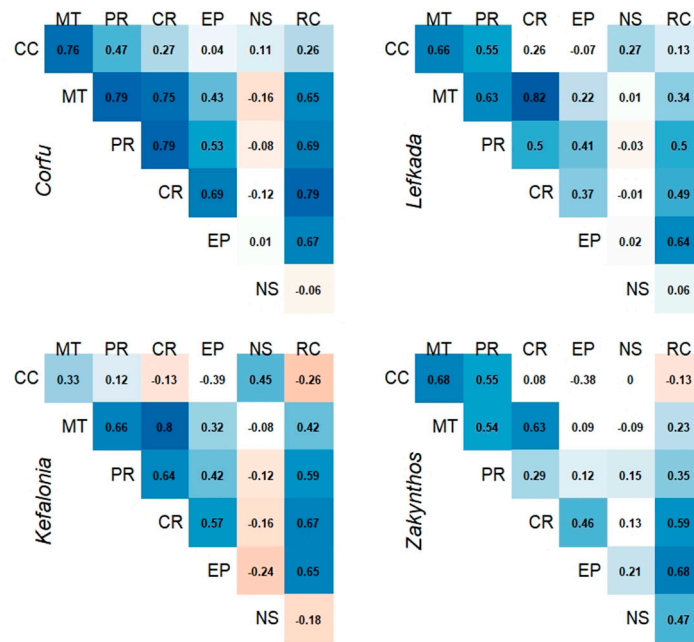
Randomization: 999 Permutations.

Table A4. Moran's I (M.I.) spatial autocorrelation results for Zakynthos

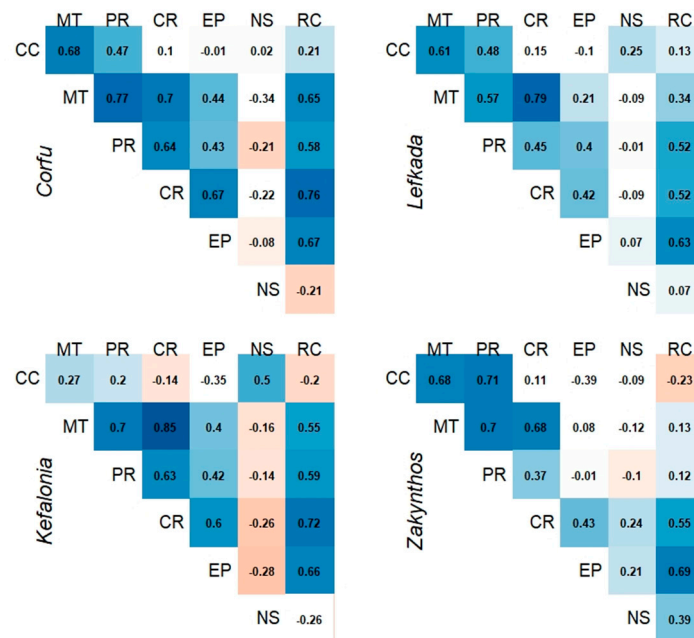
Zakynthos	Hexagonal 100 ha			Hexagonal Grid 200 ha			Municipal. Grid		
	M.I.	z-Value	p-Value	M.I.	z-Value	p-Value	M.I.	z-Value	p-Value
1985	0.3193	11.6542	0.001	0.3681	8.8311	0.001	0.3086	3.4895	0.003
1995	0.3246	11.8395	0.001	0.3723	9.1376	0.001	0.3625	4.1015	0.001
2005	0.3000	10.7004	0.001	0.3267	8.0560	0.001	0.3368	3.7379	0.001
2015	0.3175	11.3667	0.001	0.4235	10.1869	0.001	0.3304	3.7096	0.001

Randomization: 999 Permutations.

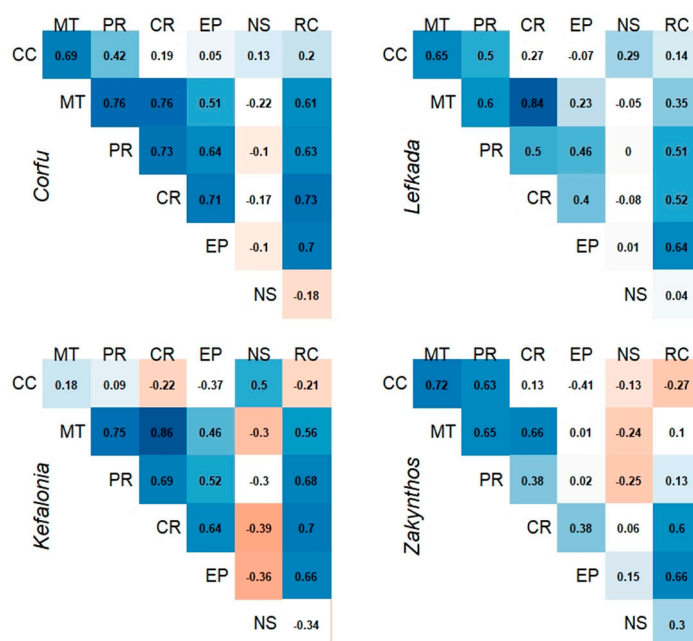
Appendix C



**Figure A2.** Pairwise correlations among ES for 1985. Dark blue indicates strongly positive correlations defined as synergies and dark red indicates strongly negative correlations defined as trade-offs. White squares represent non-significant correlations ( $p > 0.05$ ); CC: cultivated crops; MT: materials from timber; PR: plant-based resources; CR: climate regulation; EP: erosion prevention; NS: nursery; RC: recreation.



**Figure A3.** Pairwise correlations among ES for 1995. Dark blue indicates strongly positive correlations defined as synergies and dark red indicates strongly negative correlations defined as trade-offs. White squares represent non-significant correlations ( $p > 0.05$ ); CC: cultivated crops; MT: materials from timber; PR: plant-based resources; CR: climate regulation; EP: erosion prevention; NS: nursery; RC: recreation.



**Figure A4.** Pairwise correlations among ES for 2005. Dark blue indicates strongly positive correlations defined as synergies and dark red indicates strongly negative correlations defined as trade-offs. White squares represent non-significant correlations ( $p > 0.05$ ); CC: cultivated crops; MT: materials from timber; PR: plant-based resources; CR: climate regulation; EP: erosion prevention; NS: nursery; RC: recreation.

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