**Impacts of climate and land-use dynamics on endemic plant distributions in a Mediterranean island hotspot: The case of Evvia (Aegean, Greece)**

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**Abstract:** Anthropogenic climate and land-use change pose major threats to island floras worldwide, yet few studies integrate these drivers in a single vulnerability assessment. Here, we examine the endemic flora of Evvia, the second largest Aegean island in Greece and an important biodiversity hotspot, as a model system to address how these disturbances may reshape biodiversity patterns. We used species distribution models integrating climate projections and dynamic land-use data to forecast potential range shifts, habitat fragmentation, and biodiversity patterns for 74 endemic taxa through 2100. Our findings reveal pronounced projected range contractions and increased habitat fragmentation for all studied taxa, with more severe impacts on single-island endemics. Current biodiversity hotspots, primarily located in mountainous regions, are expected to shift towards lowland areas, probably becoming extinction hotspots. Emerging hotspot analysis identified new biodiversity centres in lowland zones, while high-altitude areas showed sporadic hotspot patterns. Temporal beta diversity analysis indicated higher species turnover of distantly related taxa at higher elevations, with closely related species clustering at lower altitudes. This pattern suggests a homogenisation of plant communities in lowland areas. Assessment of protected area effectiveness revealed that while 94.6% of current biodiversity hotspots are within protected zones, this coverage is projected to decline by 2100. Our analysis identified conservation gaps, highlighting areas requiring urgent protection to preserve future biodiversity. Our study reveals valuable information regarding the vulnerability of island endemic floras to global change, offering a framework applicable to other insular systems. Our findings demonstrate that adaptive conservation strategies should account for projected biodiversity shifts and serve as a warning for other insular biodiversity hotspots, urging immediate actions to maintain the unique evolutionary heritage of islands.

**Keywords:** continental island; environmental management; extinction risk; Mediterranean flora; Natura 2000; species distribution modelling

1. Introduction

Land-use change is currently the primary threat to nature and biodiversity **(Watson et al., 2019)**, but climate change is projected to become the dominant driver in the near future **(Moreira et al., 2023)**. Moreover, these factors can act synergistically, amplifying their negative impacts on biodiversity **(Oliver & Morecroft, 2014)**. This combined effect has altered biodiversity patterns and promoted biotic homogenisation **(Newbold et al., 2020)**, causing range contractions in specialists and expansions in generalists **(Poniatowski et al., 2020)**. The combined effects of climate and land-use change could probably trigger both bottom-up and top-down cascading extinctions **(Kehoe et al., 2021)**. Islands, which often serve as biodiversity and extinction hotspots **(Fernández-Palacios et al., 2021)**, are particularly vulnerable to these threats, due to their isolation and limited area.

The Mediterranean Basin, a global biodiversity hotspot, contains approximately 25,000 plant taxa with high endemism rates **(Médail, 2017)**, particularly in insular and montane areas **(Médail, 2017).** It is also classified as a climate-change hotspot **(Lazoglou et al., 2024)** and an extinction hotspot due to anthropogenic climate change **(Thompson, 2020; Urban, 2024)**. Projections indicate substantial loss of species **(Wiens & Zelinka, 2024)** and wilderness areas in the coming decades, even within protected zones **(Asamoah et al., 2021; Cao, Tseng, et al., 2022)**, rendering it a hotspot for highly threatened taxa **(Médail, 2017)**.

Greece is considered a regional [as defined by **(Cañadas et al., 2014)**] plant diversity hotspot and endemism centre within the Mediterranean Basin **(Médail & Diadema, 2009)** attributed, among others, to its diverse topography and climatic conditions **(Hammoud et al., 2021)**, as well as its numerous mountains and islands (> 8,000). Several biodiversity hotspots and endemism centres exist across the Aegean Islands **(Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al., 2021)**, prominent of which being those occurring in Crete and Evvia, the two largest and richest in terms of single island endemics, Aegean islands **(Panitsa et al., 2018)**, also classified as threatened plant diversity hotspots **(Kougioumoutzis, Kokkoris, Panitsa, Strid, et al., 2021)**.

The challenges faced by the Aegean islands in biodiversity conservation reflect a global pattern observed in island ecosystems worldwide. Biodiversity hotspots in archipelagos are particularly vulnerable to increased threats from climate and land-use changes **(Benavides et al., 2024)**. Examples include the Canary Islands **(Hanz et al., 2023)**, the Hawaiian archipelago **(Fortini et al., 2013),** and New Caledonia **(Pouteau & Birnbaum, 2016)**. These parallels highlight the global significance of studying island endemics' responses to environmental change.

While Aegean biodiversity and biogeographical patterns are relatively well-understood **(Kougioumoutzis et al., 2017)**, climate change vulnerability assessments remain scarce [e.g., **(Kougioumoutzis, Papanikolaou, et al., 2022)**]. These assessments tend to be species-specific or focused on mainland areas **(Pires et al., 2024)**, with only two studies conducted on Aegean islands (Kougioumoutzis et al., 2020; Kougioumoutzis, Kotsakiozi, Stathi, Trigas, et al., 2021) and even then, not dealing with their entire endemic flora. These studies are limited in scope, focusing either on a subset of species or excluding dynamic land-use/land-cover (LULC) data from their analyses. Consequently, they may not fully capture the complex interplay between climate and LULC change that shapes species distributions and extinction risks.

Therefore, elucidating the potential responses of island flora to rapidly changing climatic conditions and identifying current biodiversity hotspots alongside future extinction risk areas may facilitate sophisticated systematic conservation and management planning in Greece.

Despite the growing interest in how Greek endemic plant taxa might adapt to rapid environmental changes **(e.g., Kougioumoutzis et al., 2024)**, no study thus far has focused on the combined effects of climate and land-use change on Greek island endemics. Here, we address this gap by examining the Greek endemic taxa occurring on Evvia, the second largest Aegean island and among the ten largest Mediterranean islands. We chose Evvia as the study area due to its unique position as the second richest Aegean island in terms of single-island endemics after Crete, many of which are obligate serpentine endemics that have undergone recent in situ differentiation **(Trigas & Iatrou, 2006)**. Evvia is a significant biodiversity hotspot and endemism centre within Greece and the Aegean archipelago **(Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al., 2021; Kougioumoutzis, Kokkoris, Panitsa, Strid, et al., 2021)**, as it harbours approximately 30% and 12% of the Greek native and endemic flora, respectively **(Trigas et al., 2008)** in just 2.77% of the country’s area, making it a disproportionately important site for plant conservation. Its diverse topography, geodiversity and climatic conditions, coupled with its relatively large size, make it an ideal model system for studying the impacts of climate and land-use change on island endemics.

To our knowledge, this is only the third study to apply Species Distribution Models (SDMs) to Greek island endemics and the first instance in Greece of incorporating dynamic LULC data into a climate change vulnerability assessment (CCVA) in an insular context, as recommended by **Santos et al. (2021)**. Our approach to modelling the entire endemic flora of Evvia represents a significant advancement in understanding the future of Greek island biodiversity. Moreover, CCVAs that exclude current and projected LULC data risk underestimating species' future extinction risk **(Santos et al., 2021)**. By integrating land-use change data alongside climate projections into our SDMs, this study lays the groundwork for addressing a series of relevant research questions and examines how landscape-level changes in Evvia might influence future biodiversity patterns. This approach enables us to explore important aspects of island endemic species' ecology, including their spatial patterns, susceptibility to environmental changes, and capacity for conservation. Our analysis may deepen our understanding regarding how these unique taxa may adapt to or be impacted by forthcoming ecosystem alterations.

More specifically, this study aims to assess the impacts of climate and land-use change on Greek endemic plant species occurring in Evvia, with a particular focus on single-island endemics. The research objectives are manifold:

1. to evaluate species-specific responses to global change drivers,
2. to identify and project shifts in biodiversity hotspots over time,
3. to provide insights for evidence-based conservation strategies,
4. to evaluate the effectiveness of existing protected areas and identify conservation gaps in Evvia under future climate and land-use change scenarios, and
5. to estimate the current and future extinction risk of the single island endemic species of Evvia

By addressing these objectives, we seek to fill a crucial gap in understanding island endemic vulnerability to environmental changes in the Mediterranean region.

2. Materials and Methods

*2.1. Species Occurrence Data*

Our study focused on the Greek endemic plant taxa and the single island endemics occurring on Evvia (Figure 1) for which occurrence records were available in the Flora Hellenica Database (ongoing; Table S1). The total number of records obtained from the database for these taxa on Evvia was 1,434. All taxa were verified for synonyms based on **Dimopoulos et al. (2013, 2016)** to ensure accuracy. We excluded data points with coordinate uncertainty greater than 1000 m and refined our data using the 'clean\_coordinates' function from the ‘CoordinateCleaner’ 2.0.18 R package **(Zizka et al., 2019)**. The 'elimCellDups' function from the 'enmSdm' 0.5.3.3 R package **(Smith, 2020)** was used to remove duplicate entries. We further thinned the remaining data spatially using the ‘thin’ function from the ‘spThin’ 0.1.0 R package. Our cleaning and spatial thinning procedure followed established protocols **(Aiello-Lammens et al., 2015; Robertson et al., 2016)**. Finally, we included only those taxa with five or more occurrences in our analyses, following **van Proosdij et al., (2016)**, resulting in a final dataset of 716 records for 74 taxa (13 single island endemics and 61 Greek endemic taxa; Table S2).

*2.2. Environmental Data*

We constructed a high-resolution (1000 metres) monthly climate dataset for 1981-2009, encompassing 19 WorldClim bioclimatic variables (Fick & Hijmans, 2017) and 16 additional environmental variables **(Title & Bemmels, 2018)**. This temporal range matched the collection period of most occurrence records. The dataset incorporated altitude information from the CGIAR Consortium for Spatial Information **(Jarvis et al., 2008)**, with processing carried out via ClimateEU v4.63 and the R packages the "dismo" 1.1.4 **(Hijmans et al., 2017)** and "envirem" 2.2 **(Title & Bemmels, 2018)**, following methods outlined in **Hamann et al. (2013), Marchi et al. (2020) and Wang et al. (2012)**.

We also incorporated soil metrics from SoilGrids **(Hengl et al., 2017)** and dynamic LULC data from **Chen et al. (2022)**, ensuring uniformity in resolution with other environmental metrics. Five critical topographical metrics were quantified: aspect, heat load index, slope, topographic position index, and terrain ruggedness index, using the altitude data previously mentioned and functions from the R packages ‘terra’ 1.7.46 R package **(Hijmans, 2023)** and the “spatialEco” 1.2-0 **(Evans, 2019)**.

The climate projections covered three periods (**Marchi et al., 2020)**:

* 2020s: 2011-2040
* 2050s: 2041-2070
* 2080s: 2071-2100

These projections used three global circulation models (GCMs; i.e., CCSM4, HadGEM2, and an ensemble of 15 global circulation models), two Intergovernmental Panel on Climate Change Representative Concentration Pathways (the less severe RCP45 and the more extreme RCP85; RCPs), in addition to future LULC projections from **Chen et al. (2022)** under three Shared Socioeconomic Pathways (SSPs), namely the SSP1-RCP26, SSP3-RCP70, and SSP5-RCP85 scenarios **(Cao, Wang, et al., 2022)**.

We examined the 60 environmental variables in our analysis, considering the topographical and soil variables to be static over time, while the bioclimatic and LULC variables were dynamic. We utilised a curated set of 22 environmental variables, ensuring that they were carefully chosen to prevent collinearity, which was confirmed through Spearman rank correlation (< 0.7) and variance inflation factors (< 5) **(Dormann et al., 2013)**. The collinearity checks were carried out using the "collinear" 1.1.1 R package **(Benito, 2023)**.

*2.3. Species Distribution Models*

Our analyses included taxa with occurrence-to-predictor ratios below 10:1, and we adhered to guidelines outlined in **Breiner et al. (2015, 2017, 2018)** to accurately model the realised climatic niches of these taxa using the Random Forest algorithm and the "ecospat" 3.1 **(Broennimann et al., 2021)** R package, as outlined in **Valavi et al. (2021, 2022)**.

Taxa were split into two groups: those with ≥10 occurrences and those with 5-9 occurrences **(Jimenez-Valverde, 2021)**. For the first group, we generated pseudo-absences using the 'sample\_pseudoabs' function from the 'flexsdm' 1.3.0 R package **(Velazco et al., 2022)**, applying geographical buffering, environmental constraints and k-means clustering **(Barbet-Massin et al., 2012; Liu et al., 2013; Velazco et al., 2022)**. The second group required random pseudo-absences, following protocols for rare, specialised taxa **(Dubos et al., 2022; Inman et al., 2021)**.

For taxa with 20 or more occurrences, we conducted optimised spatial cross-validation of occurrences and pseudo-absences before model fitting **(Roberts et al., 2017; Santini et al., 2021)**. This was done using the 'part\_sblock' function from the 'flexsdm' 1.3.0 R package **(Velazco et al., 2022)**.

We then evaluated the model's performance against null models **(Raes & ter Steege, 2007)**, using multiple metrics **(Allouche et al., 2006; Fielding & Bell, 1997; Hirzel et al., 2006; Liu et al., 2011; Sofaer et al., 2019)** following the recommendations of **Arenas‐Castro et al. (2022)** and **Konowalik & Nosol (2021)**. This was done using functions available in the ‘CalibratR’ 0.1.2, ‘DescTools’ 0.99.40, ‘ecospat’ 3.2, ‘enmSdm’ 0.5.3.2, ‘Metrics’ 0.1.4, ‘MLmetrics’ 1.1.1 and ‘modEvA’ 2.0 R packages **(Broennimann et al., 2021; Hammer & Frasco, 2018; Márcia Barbosa et al., 2013; Schwarz & Heider, 2019; Signorell et al., 2021; Smith, 2020)**.

We partitioned the occurrences and pseudo-absences for taxa with 5-19 occurrences using the ‘BIOMOD\_CrossValidation’ function from the ‘biomod’ 4.2.4 R package **(Thuiller et al., 2016)**.

We identified potential suitable habitats using models with a minimum TSS score of 0.4. Binary maps for each scenario combination used metrics optimising sensitivity and specificity **(Liu et al., 2005, 2013, 2016)**. As a precaution, we set all non-zero cells in the clamping mask for each taxon to NA to address prediction issues **(Elith et al., 2010)**.

Using the "biomod2" 4.2.4 R package **(Thuiller et al., 2016)**, we analysed future range shifts, assuming minimal dispersal ability for all Greek endemic taxa.

Finally, we calculated fragmentation metrics [patch numbers and effective mesh size **(McGarigal, 2002)**] using the ‘landscapemetrics’ 2.0.0 R package **(Hesselbarth et al., 2019)**.

*2.4. Biodiversity Hotspots Detection*

We analysed species richness (SR), corrected-weighted endemism [CWE; **(Linder, 2001b, 2001a)**] and Phylogenetic Endemism [PE; **(Rosauer et al., 2009)**], following **Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al. (2021)**. Using a time-calibrated phylogenetic tree from **Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al. (2021)**, we processed the plant taxa in our dataset, through the ‘phyloregion’ 1.0.4 **(Daru et al., 2017; Daru, Farooq, et al., 2020; Daru, Karunarathne, et al., 2020)** and the ‘PhyloMeasures’ 2.1 **(Tsirogiannis & Sandel, 2016)** R packages. In line with in **González-Orozco et al. (2016)** and **Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al. (2021)**, we identified biodiversity hotspots based on various taxonomic and phylogenetic biodiversity metrics. These hotspots represent areas with the highest 1% values (termed L1 hotspots) for each metric, identified using functions available in the ‘phyloregion’ 1.0.4 R package **(Daru et al., 2017; Daru, Farooq, et al., 2020; Daru, Karunarathne, et al., 2020)**.

As a complementary analysis, we also identified those cells serving as biodiversity hotspots, based on the Getis-Ord Gi\* **(Getis & Ord, 1992; Ord & Getis, 1995)** metric using functions from the sfdep 0.2.3 **(Parry, 2022)** R package. The Getis-Ord Gi\* metric provides a robust way to locate statistically significant hotspots and coldspots **(Braithwaite & Li, 2007)**, as it determines if a geometric value, specifically a biodiversity metric allocated to an individual grid cell, manifests as either a product of randomness or as part of a discernible non-random aggregation pattern, characterised by clustered patches displaying either predominantly high or low values **(Mitchel, 2005)**. Upon identifying a cluster as a potential hotspot, two statistical measures are computed: a p-value, which quantifies the confidence interval for classifying a cluster as a hotspot, and a z-score, which expresses the deviation of a patch's value within the cluster from the overall mean in standard deviation units. A cluster is regarded as statistically significant, and not merely an outlier, when it meets the criteria of high p-values and z-scores for a patch and its surrounding area **(Getis & Ord, 1992; Mitchel, 2005; Nelson & Boots, 2008; Ord & Getis, 1995)**. This affirmation occurs within a confidence level ranging from 90% to 99%, leading to the rejection of the 'Complete Spatial Randomness' **hypothesis (Getis & Ord, 1992; Mitchel, 2005; Nelson & Boots, 2008; Ord & Getis, 1995)**. In cases where z-scores are positively significant, a larger z-score correlates with more pronounced clustering of high-value patches, denoting distinct hotspots **(Getis & Ord, 1992; Mitchel, 2005; Nelson & Boots, 2008; Ord & Getis, 1995)**. Conversely, significantly negative z-scores indicate more pronounced clustering of low-value patches, forming distinct coldspots **(Getis & Ord, 1992; Mitchel, 2005; Nelson & Boots, 2008; Ord & Getis, 1995)**. This approach allows for a more precise understanding of spatial patterns in biodiversity, moving beyond the assumption of spatial randomness to uncover meaningful ecological insights.

Following this, we employed the 'emerging\_hotspot\_analysis' function, a feature of the sfdep 0.2.3 package **(Parry, 2022)** in R, to discern trends in spatial clustering within biodiversity metrics, considering both spatial and temporal dimensions in Evvia. The Emerging Hot Spot Analysis (EHSA) is designed to analyse spatiotemporal dynamics in biodiversity changes within each grid cell, using a duo of statistical tools: the Getis-Ord Gi\* statistic, as per **Ord & Getis (1995)**, to pinpoint spatial clustering extents and locations of biodiversity changes, and the Mann-Kendall trend test **(Kendall, 1948; Mann, 1945)**, for assessing temporal trends through the time-series. EHSA employs the Getis-Ord Gi\* spatial statistic to ascertain areas where variable values, within a specific location and its surrounding vicinity, significantly diverge (either higher or lower) from the overall regional distribution. This analytical approach is iteratively applied at each time-step, introducing a temporal layer to the spatial analysis **(ESRI, 2024; Hamed, 2009)**. Here, the neighbouring value set for determining hot- or cold-spots encompasses both spatial and temporal dimensions **(ESRI, 2024; Hamed, 2009)**. The EHSA methodology utilises a 'space-time cube' framework, where value sums or point counts are tabulated across bins defined along two spatial axes and one temporal axis **(ESRI, 2024; Hamed, 2009)**. The resultant EHSA output is a two-dimensional grid, categorizing cells based on clustering patterns over time **(ESRI, 2024; Hamed, 2009)**. This categorisation employs descriptors like 'new', 'consecutive', 'persistent', 'intensifying', 'sporadic', 'oscillating', and 'historical' to articulate the timing, trends, and temporal consistency of various degrees of deforestation at each location **(ESRI, 2024; Hamed, 2009)**. This categorisation framework evaluates each grid cell through four criteria: the presence of a hotspot in the final time step, if more than 90% of time steps are classified as hotspots, the degree of temporal change in the intensity of a hotspot, and any historical instances of a coldspot **(ESRI, 2024)**. It is important to note that this logic is equally applicable to coldspots, and not every factor may be pertinent for each category of spot definition.

Additionally, Priority Hotspots were determined as per **Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al. (2021)**, emphasising the overlap between CWE and PE metrics. In this context, biodiversity hotspots are defined and referred to as local biodiversity hotspots, which are situated within broader regional biodiversity hotspots **(Cañadas et al., 2014)**. These analyses were replicated across all GCMs, RCPs, SSPs, and periods for both Greek endemic and single island endemic taxa.

Furthermore, we delineated Anthropocene refugia in our study area. These refugia comprise cells that currently function as and will persist as Priority Hotspots across all combinations of GCMs, RCPs, SSPs, and periods, determined by a strict consensus approach. The area and altitude of these Anthropocene refugia were calculated for all Greek endemic taxa and single-island endemics included in our analysis.

*2.5. Temporal Beta Diversity*

The estimation of temporal taxonomic and phylogenetic beta diversity, along with its constituent elements [replacement and richness differences as per **Baselga, (2010), Carvalho et al. (2012)** and **Magurran (2021),** for both the present and all projected future scenarios, was conducted using the ‘divraster’ 1.0.3 R package **(Cardoso et al., 2015; Mota et al., 2023)**. Taxonomic beta diversity captures changes in species composition, while phylogenetic beta diversity accounts for the evolutionary relationships among species. By considering both aspects, we can reveal patterns not only for the turnover of species but also for the turnover of evolutionary history across time. Furthermore, we pinpointed the L1 hotspots of temporal taxonomic and phylogenetic beta diversity within the framework described above and determined the degree of their overlap.

*2.6. Assessment of Protected Area Effectiveness and Conservation Gaps in Evvia*

Our overlap analysis was confined to terrestrial Evvia and the Special Areas of Conservation (which also includes Special Areas of Conservation that are Special Protection Areas) within the Natura 2000 network of protected areas in Evvia. To evaluate the efficacy of the existing protected areas network in Evvia, we initially gathered data from the World Database on Protected Areas using the "wdpar" 1.0.0 R package **(Hanson, 2020)**. Subsequently, we superimposed current and future L1 hotspots for the weighted biodiversity metrics onto the Greek protected areas network in Evvia using the "sf" 0.8.0 R package **(Pebesma, 2018)**. We thus concentrated on the Priority Hotspots as classified by **Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al. (2021)**, to pinpoint conservation gaps as per **Noroozi et al. (2019)**. Cells identified as Priority Hotspots in the 99% quantile (L1) in our analyses, either not covered by Special Areas of Conservation or had less than 10% coverage **(Xu et al., 2017)**, were designated as Priority conservation gaps in accordance with **Noroozi et al. (2019)**. These analyses were also applied to all Greek endemic taxa and single-island endemics included in our study. Additionally, we replicated these analyses for biodiversity hotspots as identified by the Getis-Ord Gi\* metric and the results from the Emerging Hot Spot Analysis.

*2.7. Land Use and Land Cover Changes*

The dynamics of LULC, along with their alterations, are subject to ongoing surveillance due to a significant uptick in land use and cover changes in recent decades **(Exavier & Zeilhofer, 2020)**. For this analysis, we used the OpenLand 1.0.2 package in R, which offers a robust and integrated approach for probing into LULC alterations **(Exavier & Zeilhofer, 2020)**. This package enabled a systematic assessment of LULC transitions in our study area, including their temporal patterns and spatial distribution. We conducted an intensity analysis of the available LULC data to quantify both the rate of change and the underlying transition patterns between different land cover types.

*2.8. Preliminary IUCN Extinction Risk Assessment*

Five of the 13 single-island endemics in our SDM analyses possessed current IUCN Red List assessments. Two species' assessments (*Campanula constantinii* and *Campanula cymaea*) were obtained from the IUCN Red List online database (IUCN, 2024), while three additional species' assessments (*Onosma* *euboica*, *Scutellaria* *goulimyi*, *Sideritis* *euboea*) were provided by the Hellenic Botanical Society ahead of their publication on the IUCN Red List platform (Hellenic Botanical Society, unpublished data 2024, personal communication). Although these formal assessments were based on occurrence records, we conducted independent SDM-based threat evaluations for all studied single-island endemics to maintain methodological consistency and facilitate temporal projections of extinction risk. This re-assessment served two main purposes. First, it allowed us to compare our SDM-based assessments with the formal IUCN assessments, thereby enabling us to evaluate the accuracy of our models. Second, it established a consistent methodological framework for assessing extinction risks under both current and future conditions for all the single-island endemics in our analyses, including those without formal assessments. For the baseline period and each combination of GCM, RCP, SSP, and period, we allocated preliminary IUCN threat categories to all single-island endemic taxa examined in our study. We based this classification on their distribution within Evvia and employed our models' projections and binary transformations under IUCN Criteria A and B. We implemented this process using the "ConR" 1.1.1 R package **(Dauby et al., 2017)**, along with the R code from **Stévart et al. (2019)**, adopting the framework previously developed by **Kougioumoutzis, Kokkoris, Panitsa, Strid, et al. (2021)** for a broader geographical scope in Greece.

*2.9. Estimation of the Evolutionary Distinct and Globally Endangered (EDGE) Index – Current and Future EDGE Spatial Patterns*

Evolutionary distinctiveness (ED) was calculated for Greek endemic species present in Evvia using the time-calibrated phylogenetic tree from **Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al. (2021)**, which was pruned to include only the relevant taxa. The 'phyloregion' 1.0.4 R package **(Daru et al., 2017; Daru, Farooq, et al., 2020; Daru, Karunarathne, et al., 2020)** facilitated the ED computation. EDGE scores, representing the anticipated loss of evolutionary history for each taxon on a logarithmic scale, were derived using the following equation **(Isaac et al., 2007)**:

EDGE = ln(1 + ED) + GE × ln(2) (1)

In this formula, ED represents the evolutionary distinctiveness value obtained from 'phyloregion', while GE denotes the weighted IUCN threat category [LC = 0; NT = 1; VU = 2; EN = 3; CR = 4]. Each increment in the Red List category corresponds to a two-fold increase in extinction risk **(Dauby et al., 2017)**.

For each grid cell, mean EDGE values were calculated for the Greek endemics occurring in Evvia under all combinations of GCM/RCP/SSP and period. The baseline mean EDGE value was then subtracted from each future GCM/RCP/SSP and period combination to determine the mean delta EDGE (ΔEDGE) for the 2020s, 2050s, and 2080s. Negative ΔEDGE values indicate probable extinction hotspots, while positive values signify probable extinction coldspots. The ΔEDGE index serves as a proxy for conservation prioritisation, highlighting areas where evolutionarily distinct and highly threatened species may face extinction due to climate and land-use change. Increasingly negative ΔEDGE values underline the urgency for immediate conservation actions in a given grid cell, as they suggest for example, that Critically Endangered species with high ED values are at risk of being lost. The more negative the ΔEDGE index, the more pressing the need for swift conservation measures to be implemented.

3. Results

*3.1. Species Distribution Models*

All the models showed strong predictive capabilities (Table S2; Figure S1) and outperformed random expectations to a statistically significant degree (p < 0.01). Depending on the taxon category, different environmental factors were identified as the most important predictors for most of the taxa analysed (Table S3):

1. Thornthwaite’s aridity index, count of the number of months with mean temp greater than 10℃ and the volumetric fraction of coarse fragments for the Greek endemics (Table S3; Figure S2), likely reflecting their adaptation to the dry, rocky habitats and temperature extremes characteristic of the Mediterranean climate and
2. Temperature annual range, heat load index and Thornthwaite’s aridity index for the single island endemics (Table S3; Figure S3), likely reflecting their sensitivity to temperature fluctuations and heat stress in their restricted island ranges

Temporally static factors predominantly drive the distribution of Greek endemic species, while dynamic factors primarily influence the distribution of single-island endemics on Evvia (Table S3; Figures S2-3).

We primarily concentrate on the CCSM4 GCM RCP 85 SSP5-RCP85 scenario for the 2080s, as it depicts the most severe scenario regarding expected range alterations (Table S4), allowing us to assess the probable worst-case impacts on the endemic flora.

*3.2. Habitat Suitability Range Change*

We observed marked variations among species concerning all identified sources of uncertainty, encompassing both the magnitude and direction of predicted range shifts (Table S4; Figures S4-5). All taxa are projected to undergo range reductions, becoming increasingly pronounced over time (the median range reduction is projected at -58.7%; Table S4; Figures S4-5). Single-island endemics are projected to experience significantly greater range reductions compared to Greek endemics in Evvia across all periods, since the median reduction of the single-island endemics is -63.2% (95% CI: -57.7% to -68.6%; Tables S5-6; Figure 2) and that of the Greek endemics is -51.4% (95% CI: -48.9% to -53.9%; Tables S5-6; Figure 2). Among single-island endemics, two species, namely *Alyssum densistellatum* and *Viola dirphya*, are projected to lose their entire suitable habitat (100% median area loss across all periods; Table S5). In comparison, only one single island endemic taxon, *Alyssum euboeum,* is projected to maintain its current range without any loss (Table S5), meaning that there is high interspecific variation even within the two taxon categories (i.e., Greek endemics and single island endemics), not just among them.

Additionally, for all taxa, future projections indicate lower scores on both fragmentation metrics than current values (Figure S6). Single island endemics have statistically significantly lower mesh size than Greek endemics across all periods, meaning they occupy much more fragmented patches. These findings highlight the vulnerability of Evvia's endemic flora to climate and land-use change, with substantial habitat losses and fragmentation expected over the coming decades.

*3.3. Biodiversity Hotspots*

The highest values for all biodiversity metrics are found on Mt. Dirphys for Greek endemic taxa (Figures S7-10) and on Mt. Prionas and Mt. Telethrio for single-island endemics (see Figures S11-14). However, areas currently exhibiting the largest values for both taxon categories, according to traditional, non-weighted biodiversity metrics (i.e., species richness and phylogenetic diversity), are projected to lose this status in the future (Figures 3 & S15-17). These areas will likely become severe biodiversity depletion zones—regions characterised by exceptional species and genetic diversity loss—and extinction hotspots where local extinctions will be concentrated, as numerous taxa are expected to become extinct, be locally extirpated, or undergo altitudinal range shifts (Table S4; Figures 3 & S15-21). Interestingly, the areas richest in species are predicted to broadly overlap between Greek and single island endemics, contrasting the current situation (Figures S7, S11, S16 & S18). This trend is emphasized by geographically weighted metrics (Figures S22-25). Over time, areas with high CWE and PE values are projected to be coastal cliffs in north-eastern and central Evvia (Figures S22-25).

Currently, L1 and Getis-Ord Gi\* CWE-PE hotspots for Greek endemics are primarily located in the mountainous areas of central (Mts. Dirphys, Kandilio, Pixiaras) and southern (Mt. Ochi) Evvia (Figures 4-5). The same applies to single island endemics, except that Mt. Telethrio in northern Evvia also constitutes a hotspot (Figure S26-27). Coldspots are mainly situated in the lowland areas of northern and central Evvia, a trend expected to extend into southern Evvia over time (Figures 5 & S27). While this pattern holds for all biodiversity metrics, phylogenetic diversity is an exception, with Getis-Ord Gi\* hotspots primarily in central and northern Evvia and coldspots in central and southern Evvia (Figure S28).

Regarding the emerging hotspots analysis, various lowland and coastal areas emerged as new (first time classified as hotspot) and consecutive (classified as hotspot in > 90% of time steps) hotspots for the weighted biodiversity metrics (Figures 6 & S29). In contrast, several high-altitude areas appear as sporadic (classified as hotspot in <50% of time steps) and oscillating (classified as hotspot in 50-90% of time steps) hotspots (Figures 6 & S29). These EHSA results suggest a future shift of endemic diversity towards lower elevations. On the other hand, coldspot areas are projected to expand their range to higher altitudes, mainly in northern and central Evvia (Figures 6 & S29). Both these phenomena can be attributed to the fact that a wide range of plant taxa will be facing extinction, local extirpation, or changes in their altitude distribution (Table S4; Figures 3 & S15-21).

According to the combined CWE-PE metric, none of the currently identified Priority Hotspots (L1 CWE-PE) are projected to persist for either taxon category. The current Priority Hotspots cover 30.1-40.7 km2, occurring at 951-976 m a.s.l. (Table S7), with those attributed to single island endemics being larger and occurring at higher altitudes. In all cases, the Priority Hotspots will undergo significant altitudinal contractions (-91.5 to -93.4%; Table S7) and range changes (Table S7).

*3.4. Temporal Beta Diversity*

The temporal taxonomic and phylogenetic beta diversity of both Greek endemics and single island endemics was mainly driven by the turnover of species with low phylogenetic relatedness at higher elevations (indicated by values greater than 0.5 in the Replacement/Total temporal beta diversity in Figures S30-31). In contrast, more closely related species tended to cluster at lower elevations (Figures S30-31). This trend was especially marked in the high-altitude areas of Evvia (Figures 7 & S31-33), suggesting that climate and land-use change will likely drive the loss of distinct evolutionary lineages in mountainous areas while promoting the persistence of closely related taxa in the lowlands. Furthermore, we observed that the central lowland areas of Evvia predominantly featured the highest values (namely, the L1 hotspots) for both types of beta diversity (Figure S33), indicating that these regions may experience the greatest taxonomic and phylogenetic turnover over time. The L1 hotspots for temporal taxonomic beta diversity were primarily found in the northern part of Evvia. In contrast, those for phylogenetic beta diversity were more common in the southern part (Figure S33). These areas do not overlap with the L1-L3 CWE-PE hotspots, implying a potential mismatch between areas of high endemic diversity and those prone to high compositional change.

*3.5. Assessment of Protected Area Effectiveness and Conservation Gaps in Evvia*

Currently, 94.6% and 98.0% of the CWE-PE L1 hotspots for the Greek endemics and the single island endemics, respectively are encompassed within the Greek protected areas network in Evvia (Table S9). However, this percentage is anticipated to decline markedly over time. The future overlap is projected to range between 48.1% at its highest and 20.9% at its lowest (Table S9) for the Greek endemics, while for the single island endemics this range lies between 8.8% and 14.9% (Table S9). Regarding the biodiversity hotspots identified through the Getis-Ord Gi\* metric for the Greek endemics, 54.9% (median estimate based on all four biodiversity metrics) currently fall within the designated Greek protected areas in Evvia (Table S10). The median estimate for the single island endemics is 43.6% (Table S10). Conversely, a mere 2.08% of the identified coldspots and 17.6% of regions not classified as either hotspots or coldspots are encompassed within these protected areas for the Greek endemics (Table S10). Regarding the single island endemics, 4.06% of the identified coldspots and 21.9% of regions not classified as either hotspots or coldspots lie within these protected areas (Table S10). Future projections suggest a divergent trend for the Greek endemics: a decrease in the proportion of protected hotspots, an increase in areas deemed statistically insignificant, and relative stability in the coverage of coldspots within these protected areas (Table S10).

Concerning the EHSA outcomes for the CWE-PE metric, the inclusion of these hotspots in the Greek protected areas network in Evvia ranges from 0.00% to 68.1% for the Greek endemics and from 0.00% to 100.0% for the single island endemics (Table S11). This variance is attributed to oscillating hotspots (or new hotspots for the single island endemics) at the lower end of this range and sporadic hotspots (or oscillating coldspots for the single island endemics) at the higher end (Table S11). Thus, the Priority conservation gaps in Evvia thus range from 5.4% to 100% depending on the method used to determine the Priority Hotspots (Tables S9-11), highlighting the need for a re-evaluation of the current protected area network.

*3.6. Land Use and Land Cover Changes*

In Evvia, projections indicate an upward trend in the coverage by broadleaf deciduous temperate, evergreen shrubs and needleleaf evergreen temperate trees, anticipated to persist through to the year 2100 (Figures S34-37). Conversely, a more substantial increase is forecasted for crop abandonment (Figures S34-37), which could provide opportunities for endemic species to colonise these areas but may also facilitate invasions by non-native species. Furthermore, a distinct shift is projected in C3 grasslands, transitioning predominantly to shrublands. This transition is characterised by a significantly higher relative loss rate than the average loss rate observed across other LULC classes (Figures S34–S37), likely impacting endemic species dependent on grassland habitats. Finally, most areas expected to experience 1–3 LULC transition steps are predominantly situated in central and southern Evvia (Figure S38).

*3.7. IUCN Extinction Risk Assessment*

Our SDM-based extinction risk assessments for the baseline period matched perfectly with the formal IUCN assessments for the five single island endemics with existing evaluations. More specifically, the threat categories assigned based on our SDM projections corresponded with those determined by the IUCN for all five taxa (Table S12). This validation of our methodology against independent expert assessments strengthens the reliability of our projected future extinction risks under climate and land-use change scenarios and indicates that our models effectively reflect the current distributions and extinction risks of these species.

Our analysis of Evvia's single-island endemic species under IUCN Criterion A reveals that currently, 23.1% are classified as Least Concern (LC) or Near Threatened (NT; Table S13; Figure 8). This proportion remains consistent through to the 2080s (Table S13; Figure 8), indicating that these taxa may exhibit resilience in population size despite projected environmental changes. However, the percentage of species classified as Critically Endangered (CR) increases significantly, rising from 7.7% at present to 53.8% by the 2080s (Table S13; Figure 8). This sharp escalation suggests that many species are expected to experience severe population declines.

Under Criterion B, which assesses geographic range size, our projections show a concerning trend. The proportion of species deemed Extinct (EX) rises from zero currently to 15.4% by the 2020s and remains at this level thereafter (Table S13; Figure 8). This early increase indicates an immediate extinction risk for certain species within the next few years.

When we combine both Criteria A and B, the deterioration in conservation status becomes more pronounced. The percentage of species classified as CR or EX increases markedly from 7.7% at present to 53.9% by the 2080s (Table S13; Figure 8). Conversely, the proportion of species assessed as LC or NT decreases from 23.1% to 15.4% over the same period. These trends suggest a progressive decline in the overall conservation status of the single island endemics in Evvia in the coming decades. *Alyssum densistellatum* and *Viola dirphya* are expected to become extinct under any GCM/RCP/SSP and period combination (Table S13).

*3.8 Estimation of the Evolutionary Distinct and Globally Endangered (EDGE) Index – Current and Future EDGE Spatial Patterns*

Based on Criteria A and B, the EDGE scores for single-island endemics range from 4.07 to 5.48, with a median of 4.48 (Tables S13-14). Only two taxa, namely *Asperula* *suffruticosa* and *Viola* *dirphya*, exhibit EDGE scores surpassing 5.0, with *Viola dirphya* being the sole species classified as CR.

The projected spatial patterns of the ΔEDGE index for the 2080s reveal a heterogeneous distribution of probable extinction hotspots and coldspots across Evvia, with these patterns being similar across periods (Sperman’s rho: 95.6 – 97.4%; Figures 9 & S39-40). Most grid cells with negative ΔEDGE values are concentrated in the south, central and north mountain regions of Evvia, indicating areas where evolutionarily distinct and threatened single island endemics are at higher risk of extinction due to climate and land-use change (Figures 9 & S39-40). These probable extinction hotspots are especially evident in Mts. Dirphys and Telethrio, where they coincide with 14% of the CWE-PE L1 hotspots for single-island endemics (Figure 10), covering an area of 4.63 km2. Among these overlapping grid cells, one located in Mt. Telethrio lies outside the Greek protected areas network in Evvia, representing a significant conservation gap as it constitutes both a hotspot of probable extinction for evolutionarily distinct and threatened single-island endemics and a L1 CWE-PE hotspot (Figure 10). Furthermore, numerous other grid cells with highly negative ΔEDGE values in northern and central Evia fall outside the Greek protected areas network (Figure 9). The spatial patterns accent the need for targeted conservation efforts in the identified extinction hotspots to reduce the impact of climate and land-use change on evolutionarily distinct and threatened taxa in these regions.

4. Discussion

Our study uncovers how climate and land-use change may affect the endemic flora of Evvia, using a robust species distribution modelling approach that integrates both climate and land-use change projections. We analysed a thorough set of environmental variables, including bioclimatic, topographical, soil, and land-use data, to model the realised climatic niches of 74 endemic plant taxa (Table S2). Land-use change projections were incorporated into the models by using dynamic land-use data for both current and future scenarios. This integration of land-use change alongside climate change projections strengthens the reliability and applicability of our findings.

Our results point out the vulnerability of Evvia's endemic flora to climate change projecting substantial range contractions, increased habitat fragmentation, and altitudinal shifts. Biodiversity hotspots are projected to shift from mountainous areas to lowland regions, while coldspots expand to higher elevations. Temporal beta diversity patterns suggest a future loss of distinct evolutionary lineages at higher altitudes and increased turnover in lowland areas.

The magnitude and direction of these changes, however, vary considerably among taxa and are subject to multiple sources of uncertainty, including possible interactions with invasive species, pollinator dynamics, and microhabitat processes not fully captured in our models. Nonetheless, it is important to note that unmodeled biotic interactions could alter these outcomes.

*4. 1. Species Specific Responses to Global Change Drivers*

Our findings indicate that all examined taxa are projected to experience range reductions, with median losses of 58.7% by the 2080s under the most severe climate scenario (CCSM4 GCM RCP 8.5 SSP5). Single-island endemics are particularly vulnerable, with a median projected range reduction of 63.2%, compared to 51.4% for Greek endemics (Tables S4-6; Figures 2 & S4-5). More specifically, *Alyssum densistellatum* and *Viola dirphya* are expected to lose their entire suitable habitat, while *Alyssum euboeum* may maintain its current range (Tables S5-6; Figure 2). These projections highlight the heightened sensitivity of narrowly distributed species to climate and land-use changes (Manes et al., 2021).

The differential responses between Greek endemics and single-island endemics can be attributed to the distinct environmental factors influencing their distributions (Table S3; Figure S3). Greek endemics occurring in Evvia are primarily affected by soil characteristics, as well as Thornthwaite’s aridity index (Table S3; Figure S3), reflecting their adaptation to stable, dry, and rocky Mediterranean habitats (Georghiou & Delipetrou, 2010; Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al., 2021). Single-island endemics are more influenced by temperature/aridity-related factors and heat load index (Table S3; Figure S3), indicating a greater sensitivity to temperature fluctuations and heat stress, since most neo-endemics in Evvia occur in relatively arid areas with low climate change velocity (Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al., 2021).

The marked variation in projected range changes among both single-island endemics and Greek endemics on Evvia is also linked to the species-specific associations with different land-use types. Taxa restricted to areas classified as barren land—which are forecasted to contract considerably in the coming decades (Figures S34-37)—face more severe range contractions (e.g., *Alyssum densistellatum*, *Viola dirphya*) compared to taxa occurring in other land-use types as well (e.g., *Cerastium candidissimum*, *Fritillaria euboeica*). In contrast, species inhabiting land-use types projected to remain stable or expand, such as forested areas or shrublands, show greater resilience, with some maintaining their current distributions or experiencing only minor range reductions (e.g., *Abies cephalonica* or *Paeonia mascula* subsp. *hellenica*). Local afforestation and woody vegetation encroachment account for most of the observed net positive land-use effects by enlarging forested and shrub-dominated habitats. These processes favour species reliant on understorey microhabitats or those requiring thorny shrub barriers to limit herbivory. Moreover, ongoing agricultural abandonment in parts of Evvia is expected to facilitate the conversion of croplands into woody vegetation formations (Chen et al., 2022). This expansion partially offsets adverse climatic impacts by increasing the availability of suitable habitats for endemic taxa adapted to these vegetation types. This distinction underscores the importance of considering species-specific ecological requirements when assessing vulnerability to global change drivers and the interplay of ecological, evolutionary, and anthropogenic forces in shaping species distributions (Sweeney & Jarzyna, 2022).

Our projections indicate increased habitat fragmentation and reduced connectivity for all taxa (Figure S6). Future fragmentation metrics show lower scores than current values, suggesting that the combined effects of climate and land-use changes will exacerbate habitat isolation, consistent with the data reported for other rare Greek endemics occurring in mainland Greece (Kougioumoutzis et al., 2024; Pires et al., 2024). This fragmentation poses additional challenges for species dispersal and gene flow, particularly for endemics with limited dispersal ability.

Habitat fragmentation, a major driver of biodiversity decline, may lead to increased extinction risk for numerous taxa by reducing habitat connectivity and increasing isolation (Haddad et al., 2015). This threat, according to a meta-analysis, is more pronounced in habitat specialists compared to generalists, since they might experience up to 35% higher extinction rates in fragmented landscapes (Keinath et al., 2017) and, as a result, become even more susceptible to additional habitat degradation.

*4.1.2 Comparative analysis with other island systems*

Our analyses reveal broadly consistent patterns with those documented in various island systems (Table S15), demonstrating increased extinction risks for endemic species under climate change scenarios. Climate change models for Crete project a 98.3% range reduction for 172 single-island endemics, with up to 90% facing potential extinction within decades (Kougioumoutzis et al., 2020). The lower magnitude of projected range reductions on Evvia, compared to Crete, likely reflects both reduced anthropogenic pressure—characterised by lower rates of urban expansion and tourism development—and our incorporation of land-use change variables. This methodological approach typically yields more conservative range decline and extinction risk projections, as evidenced across diverse taxa: Greek mainland endemics in the Peloponnese (Pires et al., 2024) or the entire Madagascar endemic flora (Brown et al., 2015).

This methodological distinction is exemplified by *Nepeta argolica* subsp. *dirphya*, where climate-only models once projected a 75.4% range contraction on Evvia (Kougioumoutzis, Papanikolaou, et al., 2022), while our integrated assessment (factoring both climate and land-use change) projects a much smaller, 6% reduction. Such marked differences accentuate the value of evaluating multiple global change drivers simultaneously, revealing how land-use alterations can modulate or, in some cases, exacerbate climate change impacts (Brown et al., 2015; Montràs-Janer et al., 2024; Pires et al., 2024; Santos et al., 2021).

The vulnerability of island plants to global change extends far beyond the Mediterranean Basin. Studies across diverse island systems, such as the Canary Islands (Hanz et al., 2023), Cabo Verde (Varela et al., 2022), Japan (Ogawa-Onishi et al., 2010), Socotra (La Montagna et al., 2023), Madagascar (Brown et al., 2015) and the Falkland Islands (Upson et al., 2016), demonstrate consistent patterns of projected range reductions and potential extinctions for endemic plant taxa (Table S15). In particular, climate change models project range reductions of 38% for 228 single-island endemics in the Canary Islands and 74% for 469 single-island endemics in New Caledonia (Hanz et al., 2023; Pouteau & Birnbaum, 2016). However, important differences in topography, land-use intensity, and evolutionary histories may limit straightforward comparisons.

Our findings reveal substantial vulnerability of Evvia's endemic flora to climate and land-use change, with projected habitat losses and fragmentation over the coming decades reflecting their demonstrated sensitivity to temperature fluctuations and heat stress (Table S3; Figure S3). These comparisons highlight a consistent trend of significant range contractions and extinction risks for endemic plant taxa across various Mediterranean and island ecosystems. The similar magnitudes of projected area loss and extinction rates emphasize that the challenges faced in Evvia are part of a broader global issue requiring coordinated conservation efforts, but regional-scale incentives and stakeholder engagement will shape practical outcomes.

This vulnerability is particularly acute in island ecosystems like Evvia, which function as extinction hotspots (Fernández-Palacios et al., 2021) where endemic species face disproportionate extinction risks (Schrader et al., 2024). While our projected extinction rates correspond with global estimates (Wiens & Zelinka, 2024), we posit that these projections are conservative. This assessment is based on three key factors. First, SDMs incorporating dynamic land-use variables typically underestimate local extirpations (Auffret et al., 2024). Second, potential extinction debts remain unaccounted for, arising from plants' lagged responses to environmental change, extended life histories, and persistence in soil seed banks (Corlett, 2024; Cronk, 2016; Plue et al., 2021). Third, our models exclude biotic interactions, particularly the cascading effects of pollinator network collapse (Mendes et al., 2024) and consequent reproductive failure (Artamendi et al., 2024), factors especially pertinent in Evvia's highlands, where pollinator Wallacean shortfalls exceed those of other Aegean islands and multiple pollinator extinctions are projected by the end of the century (Kougioumoutzis, Kaloveloni, et al., 2022).

*4.2. Extinction Risk Assessment*

Our SDM-based extinction risk assessments for the baseline period showed complete concordance with formal IUCN assessments for the five previously evaluated single-island endemics (Table S12), validating our projections of future extinction risks under combined climate and land-use change scenarios.

*4.2.1 Projected changes in threat categories*

Threat assessment projections reveal critical trajectories for Evvia's single-island endemics under all GCM/RCP/SSP and period combinations. Currently, while 23.1% of species are classified LC or NT under both Criteria A and B, this percentage will drop slightly, as the extinction risk status for at least two taxa (*Campanula cymaea* and *Centaurea mantoudii*) is projected to improve under all GCM/RCP/SSP and period combinations (Table S13). However, the proportion of CR species shows a dramatic increase from 7.7% at present to 38.5% by the 2080s under both Criteria, suggesting severe projected population declines and range contractions. Our results are in line with Lughadha et al. (2020) and Bachman et al. (2024) who stated that up to 39-45.1% of all vascular plant species are threatened with extinction over the coming decades, as well as with Attorre et al. (2018) who found that range contractions could lead to a deterioration of the threat assessment of some Italian plants.

Our findings parallel those of Román-Palacios & Wiens (2020), who project 16-70% species extinction rates even with niche shifting capacity—a particularly challenging prospect for Evvia's endemic perennial (sub-)shrubs. At least five single island endemics, namely *Asperula suffruticosa*, *Campanula constantinii*, *Quercus trojana* subsp. *euboica*, *Sideritis euboea* and *Silene oligacantha* subsp. *pseudoradicosa* are projected to become classified as CR within the current decade (Table S13), necessitating immediate conservation intervention. This is especially worrying for *Sideritis euboea*, whose Mt. Ochi subpopulations already exhibit genetic depletion under intense anthropogenic pressure (Sarrou et al., 2022).

Furthermore, the proportion of Extinct species rises from zero at present to 15.4% by the 2020s under Criterion B and remains stable thereafter, indicating that some species (i.e., *Alyssum densistellatum* and *Viola dirphya*) may face imminent extinction within the next few years. Such a prospect is particularly alarming given that Criterion B evaluates geographic range size, a key consideration for island endemics with naturally restricted distributions.

*4.2.2 Comparative analyses with other island endemics and island systems*

Overall, our results indicate a progressive deterioration of conservation status over time, with CR or EX categories soaring from 7.7% to 53.9% by the 2080s and LC/NT species diminishing from 23.1% to 15.4%. Our findings parallel projections from Crete, the hottest Mediterranean island biodiversity hotspot (Médail, 2017), where up to 19 single island endemics are projected to become extinct by the end of the century (Kougioumoutzis et al., 2020). Similar extinction trajectories are projected for genetically depauperate single island endemic taxa, such as *Allium iatrouinum* and *Aethionema retsina* (Kougioumoutzis, Kotsakiozi, Stathi, Trigas, et al., 2021) and even specialised coastal cliff Greek endemics with relative reproductive success, such as *Limonium zacynthium* or *Asperula naufraga* (Valli et al., 2021, 2024).

More specifically, Evvia exhibits higher extinction risks compared to two global island biodiversity hotspots (Table S15; Figure 8): the Canary Islands (4.39% extinction risk for 228 single-island endemics; Hanz et al., 2023) and New Caledonia (15% extinction risk for 469 single-island endemics; Pouteau & Birnbaum, 2016). Considering that both fragmentation metrics included in our analyses are expected to increase in the future, this fact stress the vulnerability of Evvia's endemic flora to climate and land-use change, with substantial habitat losses and fragmentation expected over the coming decades, which reflects the Evvian single island endemics’ sensitivity to temperature fluctuations and heat stress (Table S3; Figure S3).

These changes may accelerate genetic diversity erosion, particularly concerning given the already low genetic diversity and increased extinction risk among many Greek endemics (Augustinos et al., 2014; Kougioumoutzis, Kotsakiozi, et al., 2021; Liveri et al., 2024; Valli et al., 2021, 2024). Our findings support Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al.'s (2021) hypothesis that increased extinction rates in Greece may reflect Greek endemics' inability to track their realised niche shifts under changing climatic conditions.

The results of this study have immediate implications for conservation planning in Evvia. The projected rapid decline in species' conservation status suggests that proactive conservation measures are needed rather than reactive management approaches. The stability in some threat categories after the 2020s might indicate the existence of potential climatic microrefugia in coastal precipitous cliffs that could serve as priority areas for conservation efforts.

Finally, it is possible our model-based projections underestimate local extirpations if species experience lagged responses or if negative interactions (e.g., invasive species, pollinator declines) accelerate population declines. Further field-based research would help elucidate whether these worst-case scenarios unfold in the coming years.

*4.3. Shifts in Biodiversity Hotspots*

Our analyses identified a significant concentration of endemic taxa in mountainous regions on Evvia (Figures S7-14) —a trend that has also been reported across other areas (Rahbek et al., 2019). This clustering is often tied to the increased isolation and diverse range of habitats found in these rugged landscapes (Steinbauer et al., 2016), as mountain systems function as both historical refugia and centres of speciation, with their topographical complexity creating distinct microclimates and ecological niches that promote species diversification (Antonelli et al., 2018). Mediterranean mountain ranges typically exhibit higher endemism rates compared to lowland areas, partly due to their role as climatic buffers during past environmental fluctuations (Médail & Diadema, 2009) and their capacity to maintain isolated populations through topographic barriers (Perrigo et al., 2020). Greek endemics occurring in Evvia are distinguished by their limited distribution ranges and specialised habitat requirements (Trigas et al., 2008; Trigas & Iatrou, 2006), with many occurring exclusively in challenging environments such as cliffs and screes (Kontopanou & Panitsa, 2020; Panitsa et al., 2021; Panitsa & Kontopanou, 2017).

*4.3.1 Projected spatial and altitudinal redistributions*

The results of this study reveal substantial spatial and altitudinal redistributions of the Greek endemic plants occurring in Evvia. Currently identified Priority Hotspots face significant altitudinal contractions, with projected area losses of 91.5-93.4% affecting 37.9% of their extent (Table S7; Figures 3 & S15, S20-21). Such drastic reductions threaten irreplaceable plant genetic repositories, calling for urgent, proactive management actions (Kokkoris, Skuras, et al., 2023; Médail & Baumel, 2018).

Currently established mountainous hotspots (Figures 3-5 & S15, S26-27), including Mt. Dirphys, are projected to lose their conservation significance, while new hotspots emerge in lowland and coastal regions (Figures 4 & S26). This trend rather than reflecting a genuine surge in endemism at lower altitude, it more likely signifies a redistribution sparked by differential taxonomic loss across elevational gradients. Most Greek endemics occurring in Evvia and all the single island endemics are projected to lose a significant portion of their altitudinal range (Figures S20-21), conforming to the documented patterns of altitudinal range contractions (Rubenstein et al., 2023). Only a few might be able to track their niche upwards as a response to increasing aridity (Lamprecht et al., 2021), probably due to the escalator to extinction effect (Urban, 2018), since mountainous island species are especially vulnerable to global change drivers due to their limited dispersal capacity and the finite nature of upslope habitat (Steinbauer et al., 2018). Any projected downslope range shifts may be attributable to competitive release, habitat modification or the combination of both processes (Lenoir et al., 2010).

*4.3.2 Evolutionary implications and future refugia*

Maximum taxonomic and phylogenetic temporal turnover is projected for lowland regions (Figures 7 & S32), indicating substantial restructuring of species compositions and evolutionary histories. Climate and land-use changes are likewise expected to drive lineage loss in mountainous areas while favouring more stress-tolerant or generalist taxa in lowlands. The EHSA analyses supports this trend, as various lowland and coastal areas emerged as new hotspots, while several high-altitude areas appear as sporadic hotspots (Figures 6 & S29).

This dynamic reorganisation of species and communities may foster biotic homogenisation (Daru et al., 2021), challenging the spatial stability of biodiversity hotspots in the Anthropocene (Myers et al., 2000). Future refinements in community-level models should also account for complex species interactions that may modulate or exacerbate these transitions. Our findings demonstrate that climate and land-use change may fundamentally reshape biogeographic patterns at local scales, consistent with observations across multiple biodiversity hotspots and taxa (González-Orozco et al., 2016; Guo et al., 2023; Kougioumoutzis et al., 2020, 2024; Kougioumoutzis, Kaloveloni, et al., 2022; Minev-Benzecry & Daru, 2024).

These apparent shifts in biodiversity hotspot distribution do not necessarily imply that new areas are gaining endemic species. More likely, it reflects a decline in endemic taxa within existing hotspots, which subsequently creates a proportional increase in other regions. Because CWE and PE (measures that emphasize rarer and evolutionary distinct taxa) are especially sensitive to the loss of evolutionary distinct taxa with limited ranges, the disappearance of these taxa in certain hotspots can artificially raise CWE and PE values in areas where at least some of those taxa remain. If generalist, closely related taxa prove more resilient to changing conditions, the overall result can be higher CWE and PE values—even in the face of declining total biodiversity.

Future hotspot convergence for Greek endemic taxa and Evvian single-island endemics—despite current distributional differences (Figures S7, S11, S16 & S18, S22-25)—suggests potential shared refugia for resilient taxa (e.g., *Alyssum euboeum*), particularly in northeastern and central Evvian coastal cliffs. Many Greek endemics occurring in Evvia possess stress-tolerance strategies (Trigas et al., 2008) and are either obligate or facultative cliff endemic chasmophytes (Kontopanou & Panitsa, 2020; Panitsa & Kontopanou, 2017).

Chasmophytic cliff endemics exhibit higher survival rates which may be attributed to their physiological adaptations, the higher expression of genes regulating oxidative phosphorylation, their life-history traits, as cliff endemics are high-stress tolerant plants (Múgica et al., 2024; Snogerup, 1971; Thompson, 2020). In the Aegean, precipitous coastal cliffs harbour a highly specialised and often relictual endemic flora (ca. 21% of the Greek endemics; Kontopanou & Panitsa, 2020; Panitsa & Kontopanou, 2017) of Messinian origin (Greuter, 1972; Greuter, 1979). These taxa have persisted through random genetic drift and microclimatic buffering despite progressive climatic deterioration over the last 5 My (Greuter, 1972; Greuter, 1979). Thus, the coastal cliff areas where future biodiversity may lie could host the more stress-tolerant endemic taxa, those who might be able to withstand the intense climate and land-use change impacts due to their innate resilience.

This potential for shared refugia has significant implications for conservation planning, as it necessitates the development of strategies that can accommodate multiple taxa with likely divergent ecological requirements. However, we have to note that we did not explicitly consider the adaptive capacities of endemic species (Aguirre-Liguori et al., 2021), which may influence their long-term responses to global change. While there is evidence of rapid evolution and phenotypic plasticity in some island plants (Bothmer, 1974; Jaros et al., 2018; Strid, 1970), empirical data on the adaptive potential of Evvia's endemic flora is currently lacking. Uncertainties concerning pollinator availability, seed bank persistence, and propensity for dispersal further compound the predictive limitations. Future research should investigate the genetic diversity and adaptive capacities of these species through field studies, common garden experiments, and genetic analyses to refine our understanding of their vulnerability to climate and land-use change (Augustinos et al., 2014; Kougioumoutzis, Kotsakiozi, Stathi, Trigas, et al., 2021).

*4.3.3 Conservation priorities*

The high-altitude regions, despite functioning as current diversity and conservation hotspots with increased EDGE scores (Figures 9, S39–40), risk transitioning into extinction hotspots, as indicated by their low ΔEDGE scores (Figures 9–10). This worrisome pattern, also noted in Crete (Kougioumoutzis et al., 2020), appears especially pronounced in Mts. Dirphys and Telethrio, where these potential extinction hotspots overlap with 14% of the CWE-PE L1 hotspots identified for single-island endemic species (Figure 10). Additional areas exhibiting very low ΔEDGE scores are in northern and central Evvia, falling outside the established protected areas network (Figure 10).

These vulnerable regions warrant urgent prioritisation in conservation initiatives. The imperative to identify conservation priorities and implement efficient measures grows increasingly pressing as human activities and land use exert unrelenting pressure on natural habitats, precipitating severe alterations in biodiversity (Montràs-Janer et al., 2024; Oliver & Morecroft, 2014). The strategic identification of areas characterised by high EDGE and low ΔEDGE scores offers a robust, data-driven approach for prioritizing regions of high conservation and evolutionary significance that face increased extinction risk, as demonstrated in Crete (Kougioumoutzis et al., 2020). Adopting this approach can inform the development of targeted, evidence-based conservation strategies to protect biodiversity in the face of unprecedented anthropogenic pressures. Given Evvia’s exposure to repeated wildfires and infrastructure expansion (e.g., wind farms), further habitat degradation could amplify extinction risks unless integrated management plans are implemented.

*4.4. Effectiveness of Protected Areas and Conservation Gaps*

The Natura 2000 protected area network in Evvia is projected to become less effective at preserving shifting patterns of endemic diversity, which compels a re-evaluation of current conservation priorities. Concurrent LULC changes, such as the expansion of shrublands and forests and the abandonment of croplands, may present both opportunities and challenges for the endemic taxa. While presently a high percentage of hotspots are within NATURA 2000 sites, this coverage is projected to decline over time—to as low as 20.9% for Greek endemics and 8.8% for single-island endemics (Tables S9–S11), being in line with previous studies from Greece and other regions across the globe (Braz Pires et al., 2024; Cui et al., 2024; Dobrowski et al., 2021; Kougioumoutzis et al., 2020a; Kougioumoutzis, Kaloveloni, et al., 2022; Pires et al., 2024; Wang et al., 2022). These patterns are further exemplified by the spatial variability identified through the Emerging Hot Spot Analysis, which highlights dynamic shifts in hotspots across time, including areas with inconsistent or sporadic protection (Tables S9–S11).

Such coverage losses expose critical conservation gaps, emphasising that static protected-area boundaries may fail to capture rapidly shifting biodiversity patterns (Reside et al., 2018). The projected decline in the coverage of current Priority Hotspots by protected areas (Tables S7, S10-11) indicates that conservation strategies should be adaptive and regularly updated to accommodate changing species distributions. More specifically, while current conservation efforts in Evvia may appear sufficient based on present species distributions, the anticipated future shortfalls—ranging from moderate declines in coverage to near-complete gaps—highlight the urgent need to reevaluate the design and management of protected areas (Reside et al., 2018), as suggested in previous studies (Kougioumoutzis, Kokkoris, Panitsa, Kallimanis, et al., 2021; Kougioumoutzis, Kokkoris, Panitsa, Strid, et al., 2021; Kougioumoutzis, Kaloveloni, et al., 2022; Spiliopoulou et al., 2021, 2023). This could involve the implementation of flexible protected area networks or the prioritisation of future biodiversity hotspots in land-use planning. Specifically, we recommend the following actions for Evvia, in line with the EU Biodiversity Strategy for 2030 and the post-2020 global biodiversity framework:

* + - 1. Identify and prioritise areas projected to serve as future biodiversity hotspots for legal protection and conservation management, contributing to the EU's target of protecting 30% of land and sea by 2030
      2. Develop iterative conservation plans that can accommodate shifts in species distributions and ecological requirements over time, ensuring the long-term effectiveness of protected areas
      3. Engage local communities and stakeholders in conservation planning efforts to ensure socio-economic considerations are addressed, promoting the integration of biodiversity values into local planning and development processes
      4. Strengthen monitoring programs to track changes in species abundances and distributions, informing adaptive management strategies and contributing to the EU's goal of improving knowledge, the science base, and technologies relating to biodiversity

Implementing these recommendations will require close collaboration among researchers, conservation practitioners, policymakers, and local communities. The possible socio-economic impacts of the projected biodiversity changes, such as the loss of ecosystem services or the need for sustainable land-use practices, should be carefully considered in conservation planning efforts. By linking conservation goals with sustainable development objectives, such as the UN Sustainable Development Goals, Evvia can serve as a model for integrating biodiversity conservation into broader societal goals.

It is important to acknowledge that our study focused primarily on the direct impacts of climate and land-use change on endemic plant distributions. However, other anthropogenic stressors, such as pollution, invasive species, and habitat fragmentation, may also interact with these drivers to shape future biodiversity patterns. For example, the increasing frequency and intensity of wildfires on Evvia, exacerbated by climate change and land-use practices, could accelerate habitat loss and fragmentation for endemic species. Similarly, the expansion of invasive plant species, facilitated by climate change and human activities, could increase competition and further restrict the suitable habitat for endemic taxa. Future research should aim to integrate these additional stressors into species distribution models and conservation planning efforts to provide an in-depth understanding of the threats facing Evvia's biodiversity.

*4.5. Management implications*

In this study we documented the climate and land use change impact on the endemic flora of Evvia, an impact that acts incrementally with changes occurred by wildfires and the development of wind farms, due to habitat loss, degradation, alteration and possible ecological disruption. The construction and operation of wind farms can lead to habitat fragmentation, which may adversely affect the narrowly distributed species like those found on the higher altitudes of Evvia’s mountains. Additionally, fires (like the 2021 Evvia megafire), whether natural or anthropogenic, can further exacerbate these threats by altering the delicate balance of these ecosystems, likely leading to the loss of endemic species that are not adapted to frequent fire disturbances. While the development of wind farms on Evvia could contribute to sustainable energy goals, it is imperative to balance these developments with the conservation of the island's unique endemic flora, considering the present study’s findings on climate – land use change impact. The provisions of the EU Green Deal and the recently adopted EU Nature Restoration Law should guide future actions and draft a prioritisation scheme for the different ecosystems and habitat types, towards resilience in future conditions.

By this, to protect the local endemic plant taxa from climate change, land use alteration and the possibility of repetitive forest fires, a multifaceted approach is necessary, integrating habitat management, conservation genetics, and fire management strategies.

Firstly, understanding the potential impacts of climate change on habitat suitability is vital. SDMs have shown that many Greek tree species may experience habitat shrinkage under future climate scenarios, particularly at higher elevations. However, some species, such as *Abies cephalonica*, may maintain their distribution under certain scenarios, suggesting that targeted conservation efforts could reduce some impacts of climate change **(Fyllas et al., 2022)**. For endemic medicinal and aromatic plants, such as those in the genus *Nepeta*, SDMs predict severe range retractions due to climate change, driven by soil and aridity variables. Conservation efforts should focus on identifying and protecting current and future species richness hotspots, which are expected to shift geographically over time **(Kougioumoutzis, Papanikolaou, et al., 2022)**.

Fire management is another critical component. High altitude coniferous forests, including those dominated by Greek fir (*Abies cephalonica*) and black pine (*Pinus nigra*), are increasingly affected by fires, which these species are not adapted to regenerate from naturally. Active reforestation and careful management of fire-prone regions are necessary to aid tree recovery and maintain ecosystem integrity **(Arianoutsou et al., 2010)**, as well as for in situ and ex situ conservation actions. Additionally, conservation genetics can play a vital role. For CR Greek endemics, genetic diversity assessments reveal moderate diversity levels, indicating possible resilience to environmental changes. However, climate change is expected to significantly impact their range sizes. In-situ measures, such as population reinforcement, and ex-situ strategies, like seed bank conservation, are recommended to preserve genetic diversity and ensure long-term survival **(Kougioumoutzis, Kotsakiozi, Stathi, Trigas, et al., 2021)**.

5. Conclusions

Our study assesses the potential impacts of climate and land-use change on the endemic flora of Evvia, revealing complex patterns of range shifts, biodiversity hotspot reorganisation, and challenges to current conservation strategies. As global change accelerates, such integrated assessments—incorporating land-use patterns, climate projections, and future adaptive responses—are necessary to devise robust, forward-looking conservation measures.

The observed hotspot shift from mountainous to lowland areas demonstrates that island conservation approaches require fundamental restructuring. By embracing dynamic, adaptive approaches and considering the complex interactions between multiple global change drivers, we can improve our ability to preserve the unique and irreplaceable biodiversity of island ecosystems in the face of unprecedented environmental change.

Future research should focus on:

* + - 1. Incorporating biotic interactions and species' adaptive capacities into modelling efforts
      2. Investigating the possibility for rapid evolution in island endemic plants in response to climate change
      3. Testing adaptive, long-term conservation strategies, such flexible protected area designs and adaptive management approaches
      4. Assessing the implications of changing endemic plant distributions on ecosystem services

The current state of global biodiversity places island-endemic species at risk, with those on Evvia exemplifying broader challenges faced by other island ecosystems. Research findings should now translate into immediate, practical conservation measures to protect these irreplaceable island taxa and their habitats.

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**Data Availability Statement:** All data underpinning this study's findings are available in the manuscript and supplementary materials. The study integrated multiple open-access datasets. The bioclimatic variables were created with the ClimateEU v4.63 software [Hamann et al. (2013), Marchi et al. (2020); Wang et al. (2012)] available from <https://sites.ualberta.ca/~ahamann/data/climateeu.html>. We retrieved altitudinal data from the CGIAR Consortium for Spatial Information available from <https://csidotinfo.wordpress.com/data/srtm-90m-digital-elevation-database-v4-1/>. We obtained soil data from SoilGrids available from <https://soilgrids.org/>. Land-use/land-cover projections came from the 1-km resolution SSP-RCP scenarios dataset (Chen et al., 2022; <https://doi.org/10.5281/zenodo.4584775>). Publicly available species extinction risk assessments were retrieved from the IUCN Red List database ([www.iucnredlist.org](http://www.iucnredlist.org)) on 18 December 2024, filtering for Tracheophyta in Greece. Three assessments (*Onosma* *euboica*, *Scutellaria* *goulimyi*, *Sideritis* *euboea*), pending upload to the IUCN website, were provided by the Board of the Hellenic Botanical Society and can be obtained upon request from the Board. Any requests pertaining the species occurrence data should be addressed to Prof. Panayotis Dimopoulos and Prof. Em. Arne Strid, as these species are rare and threatened Greek or single island endemics.

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**Figure legends**

**Figure 1.** Topography of Evvia, Greece. Main panel: Detailed topographical map of Evvia and adjacent mainland, with key mountain peaks that appear in the main text, labelled. Solid black lines denote the NATURA 2000 protected areas network in Evvia. Insets: (top right) Global location of Greece highlighted in red; (bottom right) Greece with broader study area indicated by red rectangle.

**Figure 2**. Projected area range loss (%) for Greek endemic plants and single island endemics (SIE) occurring in Evvia and included in our analyses for the 2020s, 2050s, and 2080s. Data points represent mean values, connected lines show temporal trends, and shaded areas indicate 95% confidence intervals.

**Figure 3.** Mean difference in species richness: This figure illustrates the projected average variation in species richness for Greek endemics in Evvia, comparing future scenarios to the baseline period. The methodology entails calculating the difference in species richness for each combination of the GCMs, RCPs and SSPs concerning the current species richness. These calculations are performed for three distinct future intervals: the 2020s, 2050s, and 2080s. Here we present the results for the 2080s. The average of these differences is then computed to represent the overall mean shift in species richness for all species considered in the analyses.

**Figure 4.** From left to right: L1 (top 1%) corrected-weighted – phylogenetic endemism (CWE-PE) hotspots, also known as Priority Hotspots (marked with red cells), for both (A) the baseline period and (B) the future under the strict consensus rule, meaning we only considered cells projected to serve as Priority Hotspots across every combination of GCM, RCP, SSP, and period for the Greek endemics.

**Figure 5.** This figure displays for the Greek endemics occurring in Evvia, the Getis-Ord Gi\* corrected-weighted – phylogenetic endemism (CWE-PE) hotspots, also known as Priority Hotspots, and CWE-PE coldspots. From left to right, panel (A) shows the baseline period with Priority Hotspots marked in dark green cells. Panel (B) illustrates the future scenario under the CCSM4 RCP 85 SSP5-RCP85 combination in the 2080s, also highlighting Priority Hotspots. Panel (C) depicts the Anthropocene refugia. Throughout, CWE-PE coldspots are indicated with blue cells.

**Figure 6.** Classification of hotspots and coldspots in emerging hotspot analysis for selected biodiversity metrics for the Greek endemics occurring in Evvia. Displayed in a clockwise arrangement from the upper left to the bottom right, the figure illustrates the following categories: Species Richness (SR), Phylogenetic Diversity (PD), Corrected Weighted Endemism (CWE), and Phylogenetic Endemism (PE), each with their respective hotspots and coldspots.

**Figure 7.** Temporal **(A)** taxonomic and **(B)** phylogenetic beta diversity between the baseline period and the CCSM4 RCP 85 SSP5-RCP85 combination in the 2080s for the Greek endemics occurring in Evvia.

**Figure 8.** Assessment of Evvia's single-island endemic species under IUCN threat categories. The figure presents the proportion of species in each category for current conditions, based on IUCN Criterion A and B. Future projections for the 2020s, 2050s, and 2080s are also displayed, derived from the CCSM4 General Circulation Model using the Representative Concentration Pathway 85 and Shared Socioeconomic Pathway 5-RCP85, representing the most extreme scenario for projected range shifts. CR: Critically Endangered; EN: Endangered; EX: Extinct; LC or NT: Least Concern or Near Threatened; VU: Vulnerable.

**Figure 9.** Spatial patterns of the ΔEDGE index for the 2080s across Evvia. The map depicts the projected change in the mean EDGE values for each grid cell, calculated by subtracting the baseline mean EDGE value from the future median EDGE value under all GCM/RCP/SSP combinations for the 2080s. Green cells indicate negative ΔEDGE values, representing probable extinction hotspots where evolutionarily distinct and threatened endemic species are at higher risk of extinction due to climate and land-use change. Red cells denote positive ΔEDGE values, suggesting probable extinction coldspots where the anticipated loss of evolutionary history is lower. The solid black lines outline the terrestrial Natura 2000 network of protected areas in Evvia.

**Figure 10.** Cells representing probable extinction hotspots in Evvia according to the ΔEDGE index calculated by subtracting the baseline mean EDGE value from the future median EDGE value under all GCM/RCP/SSP combinations for the 2080s, where evolutionarily distinct and threatened endemic species are at higher risk of extinction due to climate and land-use change. The solid black lines outline the terrestrial Natura 2000 network of protected areas in Evvia.