The conservation status of the Cretan Endemic Arthropods under Natura 2000 network

Authors

Giannis Bolanakis[1,2,т,*]ID, Savvas Paragkamian[1,3,т]ID, Maria Chatzaki[4] ID, Nefeli Kotitsa[2,5], Liubitsa Kardaki[2] and Apostolos Trichas[2] ID

[1] Department of Biology, University of Crete, Heraklion, Crete, Greece
[2] Natural History Museum of Crete, University of Crete, Heraklion, Crete, Greece
[3] Institute of Marine Biology, Biotechnology and Aquaculture (IMBBC), Hellenic Centre for Marine Research (HCMR), Heraklion, Crete, Greece
[4] Department of Molecular Biology and Genetics, Democritus University of Thrace, Dragana, 68100 Alexandroupolis, Greece
[5] Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Sofia, Bulgaria

[т] these authors contributed equally to this work

[*] **Corresponding author**

Abstract

Arthropod decline has been globally and locally documented, yet they are still not sufficiently protected. Crete (Greece), a Mediterranean biodiversity hotspot, is a continental island renowned for its diverse geology, ecosystems and endemicity of flora and fauna, with continuous research on its Arthropod fauna dating back to the 19th century. Here we investigate the conservation status of the Cretan Arthropods using Preliminary Automated Conservation Assessments (PACA) and the overlap of Cretan Arthropod distributions with the Natura 2000 protected areas. Moreover, we investigate their endemicity hotspots and propose candidate Key Biodiversity Areas. In order to perform these analyses, we assembled occurrences of the endemic Arthropods in Crete located in the collections of the Natural History Museum of Crete together with literature data. These assessments resulted in 75% of endemic Arthropods as potentially or likely threatened. The hotspots of endemic taxa and the candidate Key Biodiversity Areas are distributed mostly on the mountainous areas where the Natura 2000 protected areas have great coverage. Yet human activities have significant impact even in those areas, while some taxa are not sufficiently covered by Natura 2000. These findings call for countermeasures and conservation actions to protect these insular environments, especially mountain species that lack the space to further escape from threats affecting their habitat

Keywords

Biodiversity Hotspots, Protected areas, Island conservation, Insects, Spiders, Myriapoda, Scorpiones

1. Introduction

In the Anthropocene, the need to tackle biodiversity loss is urgent (Johnson et al. 2017; Meng et al. 2021). Arthropods include more than 78% of the described animal taxa (Zhang 2013) numbering approximately 7 million terrestrial species (Stork 2018). Many recent studies highlight the decline of Insect (Cardoso et al. 2020; Wagner 2020; Raven and Wagner 2021), Spider (Potapov et al. 2019; Branco and Cardoso 2020) and Myriapod biodiversity (Karam-Gamael et al. 2018; Iniesta et al. 2023). For instance, Hallmann et al. (2017) estimate a 75% reduction of flying Insect biomass in Germany in the last 27 years. Klink et al. (2020) yielded a 9% per decade decline in Insect abundance. Sánchez-Bayo and Wyckhuys (2019) estimate the possible extinction of 40% of Insect species in the near future (but see Wagner (2019) for a critique). Yet, the actions taken for their conservation are deemed as insufficient in global and local scale (Cardoso et al. 2012; D’Amen et al. 2013; Chowdhury et al. 2023).

Numbering approximately 7,000 species [extrapolated from Fauna Europaea (Jong et al. 2014) and Legakis et al. (2018)], the Arthropods of Crete, Greece, have been studied for almost two centuries (Anastasiou et al. 2018). Only 135 (27 endemic) of these species (1.9%) have been assessed in IUCN Red List as of this publication, making Arthropods the third most evaluated group of the island, behind vascular plants (291) and land mollusks (165). The low evaluation percentage is a common motif for Arthropods, hindered by the lack of data (Cardoso et al. 2011a, b; Cardoso et al. 2012; Wagner et al. 2021) and charisma of the Arthropods themselves (Cardoso 2012; Wang et al. 2021), leading to knowledge shortfalls (see Hortal et al. 2015).

Crete is located between three continents (Europe, Africa, Asia), in a well-established global biodiversity hotspot (Myers et al. 2000) of the Mediterranean basin. Isolated from the rest of the Aegean and the continental Greece for more than 5 million years (Fassoulas 2018), with a complex geological and climatic history and long-term human presence (Rackham and Moody 1996), Crete has developed a species rich biodiversity with high endemism (Médail and Quézel 1997; Chatzaki et al. 2015; Sfenthourakis and Schmalfuss 2018; Vardinoyannis et al. 2018). It is a special biogeographical entity for various taxonomic groups: Buprestidae (Mühle et al. 2000), Tenebrionidae (Fattorini 2006a, 2008), Cerambycidae (Vitali and Schmitt 2017), Orthoptera (Willemse et al. 2023), Vascular Plants (Kougioumoutzis et al. 2017) and snails (Vardinoyannis et al. 2018). Moreover, Crete presents the highest percentage of threatened species of the IUCN assessed Greek fauna and flora (12%) (Spiliopoulou et al. 2021) and is the hottest Mediterranean island for plant endemism (Médail 2017). The biogeographical and conservational significance of Crete thus becomes apparent.

Arthropod decline is the result of multiple - synergistically acting - causes (Cardoso et al. 2020; Wagner 2020; Wagner et al. 2021). Habitat loss (Cardoso et al. 2020; Wagner 2020; Wagner et al. 2021), agricultural intensification (Habel et al. 2019; Raven and Wagner 2021), urbanization (Wagner et al. 2021), pollution/pesticides (Brühl and Zaller 2019; Cardoso et al. 2020) and climate change (Cardoso et al. 2020; Harvey et al. 2022) are the major drivers of this decline. Crete complies with this global trend.

Many of these pressures occur in Crete. Habitat loss and degradation, occurring throughout Crete as a result of urban, agricultural and touristic development. This is a major issue since habitat loss is a major threat in Europe for many Arthropod groups, e.g. Butterflies (van

Swaay et al. 2010) Bees (Nieto et al. 2014), Orthoptera (Hochkirch et al. 2016) and Saproxylic Beetles (Cálix et al. 2018). Climate change is predicted to induce scarcer yet more intense precipitation, increase of drought locally (Koutroulis et al. 2011) and shrinkage as well as possible shifts to the rainfall period (Koutroulis et al. 2013). Groups associated with fresh water could be deeply impacted from the locally increased drought and the increase in need of water for irrigation and domestic use, e.g. Odonata (Kalkman et al. 2010), which has become harsher due to the increase of agriculture and land use (Tzanakakis et al. 2020). Stock raising (sheep and goats) has always been an important aspect of Cretan life and economy (Rackham and Moody 1996). Overgrazing impacts severely soil erosion, soil moisture and vegetation (Kairis et al. 2015; Kosmas et al. 2015). And finally, invasive species are a serious issue for an insular biodiversity (Fernández-Palacios et al. 2021). All the above contribute to a worrying trend for Crete, i.e. the higher percentage of Threatened endemic Arthropods when compared with the respective European groups (Supplementary Material 2, Figure 1).

The largest structure of biodiversity conservation in Crete is the Natura 2000 network (N2K). N2K is the only regional assemblage of protected areas worldwide (Crofts 2014). Operating throughout European Union (EU) since 1992, the N2K is the alloy of two EU directives, The Birds Directive (Council Directive 79/409/EEC, 1979) and the Habitats and Species Directive (HSD) (The Council Directive 92/43/EEC, 1992). Although Arthropods are linked with HSD, none of the Cretan endemics are included in the annex (driven by taxonomical, geographical and other biases - Cardoso 2012).

Crete has by far the highest percentage of overlap between threatened species' ranges (flora and fauna) and N2K in Greece (Spiliopoulou et al. 2021). Sfenthourakis and Legakis (2001) investigated the N2K overlap in Crete with land mollusks, Orthoptera, Carabidae, Tenebrionidae and Oniscidea, and found that four out of five endemicity hotspots in Crete (Dia islet, Lefka Ori, Psiloritis and Dikti massifs) reside within N2K. Kougioumoutzis et al. (2021a, b) found a great number of endemicity hotspots and threat-spots of Greek vascular plants in the Cretan mountains with significant overlap with the N2K. In contrast Dimitrakopoulos et al. (2004) focusing on vascular plants, recovered small percentages of overlap between plant endemicity/threat-spots and N2K. Overall, Crete seems to be under an adequate protection regime (Kougioumoutzis et al. 2021b; Spiliopoulou et al. 2021), however, the aforementioned studies do not focus solely on Arthropods, leaving space for a closer up research for their conservation status.

In this study we aim to a) identify Cretan endemicity hotspots (EHs) b) investigate for candidate Key Biodiversity Areas (KBAs) c) examine the overlap of EHs, KBAs and threatened taxa with the N2K areas and d) their relation with the anthropogenic pressures in these sites (Figure 1). To do so, we assembled the accumulated knowledge of the past 200 years of entomological research in Crete with the collections of NHMC for 11 Arthropod groups: Araneae, Scorpiones, Chilopoda, Diplopoda, Coleoptera, Heteroptera, Hymenoptera, Lepidoptera, Odonata, Orthoptera and Trichoptera. Secondly, we committed to the Findable, Accessible, Interoperable and Reproducible (FAIR) principles (Wilkinson et al., 2016) for data and code (see Supplementary Material). Hence Crete could become Greece's spearhead in meta-analyses concerning Arthropods. Thus, we contribute to the ongoing discussion concerning the global conservation status of Arthropods from the perspective of a continental island, rich in endemic species.

2. Methods

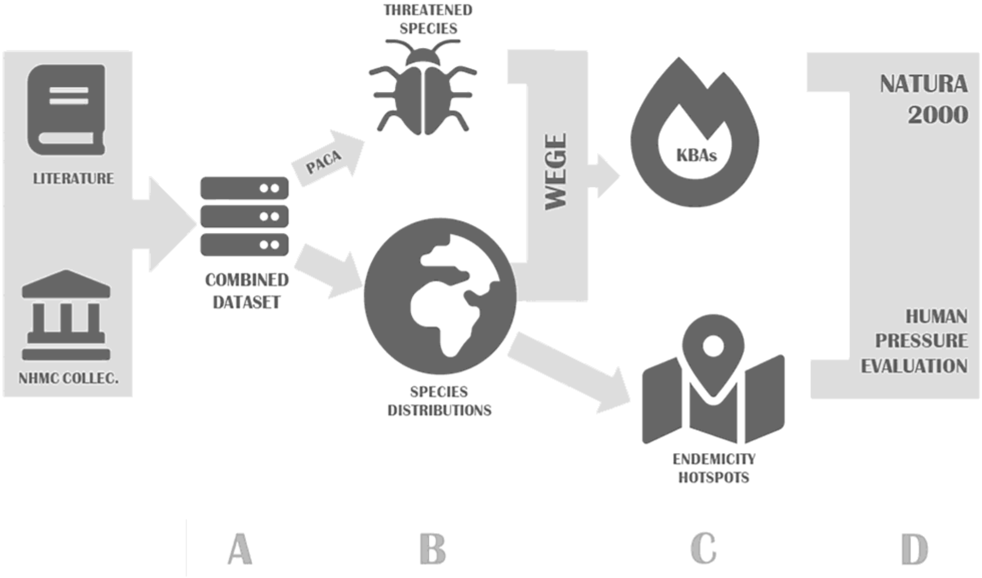


Figure 1. Study's workflow. **A.** Curation of the literature and the NHMC samplings for the endemic Arthropods occurrences. **B.** Preliminary Assessment Conservation Assessments (PACA) of the Arthropods and mapping of their distributions. **C.** Investigation of candidate KBAs and EHs and **D.** Overlap with N2K and Land Use Change evaluation for human pressures.

2.1. Taxa selection criteria

We aggregated data of Cretan endemic Arthropod groups (NHMC collections and bibliography). The taxa included should satisfy the following criteria:

1) There should be at least one authoritative work on the group for Crete which should make clear remarks about the group's taxonomic dynamics, so that future taxonomical or systematic works on the taxon would not severely affect our inferences. In essence, we selected groups whose biodiversity is well studied and we do not expect significant changes in their number of species for Crete.
2) The geographic information about the endemic species distribution should be in a form convertible to coordinates (i.e., either in coordinates or with a precise locality). The included coordinates are precise, while the converted ones do not exceed a radius of certainty more than 2 km.
3) The group should not be dominated by cavernicolous species. We opted to exclude cave dwelling fauna, since it is a special system, governed by different biogeographical and ecological processes. Thus, groups like terrestrial Isopods were excluded for their high

percentage of cavernicolous species (Schamlfuss et al. 2004; Sfenthourakis and Schmalfuss 2018).

Based on the above criteria, the selected groups are: Araneae, Chilopoda, Coleoptera, Diplopoda, Heteroptera, Hymenoptera (Chrysididae, Formicidae, Symphyta), Lepidoptera (Geometridae), Odonata, Orthoptera, Scorpiones and Trichoptera.

2.2. Data assemblage

We curated the bibliography and the NHMC collection to assemble taxa occurrences (Supplementary Material 1; Figure 2C). The bibliography used contains both historical and contemporary published material. Bibliographic records include: 1) Author of the article 2) Species name and 3) Locality coordinates. For the records without coordinates, coordinates approximating the site were given based on the locality and description given. NHMC specimens (over 2 million Arthropods) have been primarily collected by pitfall trapping as part of MSc, PhD studies and environmental monitoring programs, over the last 40 years (details on trapping protocols are discussed more extensively in Salata et al. 2020b and Willemse et al., 2023). NHMC data include: 1) NHMC Field Code, 2) Species name and 3) Locality. The coordinate reference system we used for all location data is WGS84 - EPSG:4326.

We opted for an integrated approach including as many Arthropod taxa as possible. Thus, our dataset is inhomogeneous. Different Orders and/or Families require different sampling methods, while there has been an inconsistent historical interest for various groups. For example Staphylinidae (Coleoptera) are systematically studied in the last 30 years in Crete, while the research in Carabidae (Coleoptera) dates back to the 19th century. Sampling methods vary even within groups. Orthoptera have been classically sampled by net or hand from the beginning of the 20th century, while in the last 30 years, when NHMC started studying the Cretan biodiversity, there are numerous specimens that have been captured with pitfall traps (Willemse et al. 2023).

Different subspecies of the same species were treated separately as in Fattorini (2006b); Dimitrakopoulos et al. (2004); Fattorini and Baselga (2012), because the distinction between species and subspecies is usually arbitrary and unstable, hence excluding subspecies could lead to the neglection of important conservational or evolutionary units. From here on, we refer to both species and subspecies as “taxa”.

2.2. Taxa assessments

For the taxa assessment we used the Preliminary Automated Conservation Assessment (PACA) pipeline (Stévart et al. 2019). PACA is an approximation of the IUCN assessment based on Criterion B, i.e. on the Extent of Occurrence (EOO) and Area of Occupancy (AOO) and cannot be used as a replacement of a full IUCN assessment. Some important differences between PACA and a full IUCN assessment are that PACA always assumes a continuous decline of the species’ habitat quality and automatizes some processes that require the assessors' engagement (e.g. defining locations). PACA is a useful tool to obtain a preliminary image regarding a taxa assemblage of an area, in the absence of a thorough IUCN assessment. Moreover PACA can be really useful for datasets that have incorporated subspecies, which enjoy less attention from IUCN mainly for taxonomic reasons, i.e., the lack of consensus on the subspecies as a biological entity.

Criterion B is the one most widely used for Arthropods (Cardoso et al. 2011a, b; Carpaneto et al. 2015), since most Arthropod groups lack the data for the other criteria (A, C, D and E), i.e., mainly population size and trend information or quantitative analyses. Criterion B could overestimate the danger of Arthropods (Cardoso et al. 2011a), which should always be taken into consideration.

In order to identify locations (as defined by PACA), we used the European Environment Agency (EEA) reference grid with a 10 x 10 km grid cell to assign occurrences to locations. All the occurrences of a taxon that reside in a 10 x 10 km cell constitute one location. The PACA are estimated as shown in Table 1. Subsequently, we converted the PACA categories to the respective IUCN ones (Stévart et al. 2019).

Table 1: The PACA and potential IUCN categories based on the number of locations and EOO or AOO.

Potential IUCN categories	**PACA categories**	**# locations**	**EOO (km^2) OR AOO (km^2)**
Potentially Vulnerable (VU)	Potentially Threatened (PT)	<=10	<20000 OR <2000
Potentially Endangered (EN)	Likely Threatened (LT)	<=5	<5000 OR <500
Potentially Critically Endangered (CR)	Likely Threatened (LT)	1	<100 OR <10
Other	Potentially Not Threatened (PNT)	rest	rest

2.3. Endemicity Hotspots (EHs), and Key Biodiversity Areas (KBAs).

Hotspot definitions vary from quantitative methods to experts opinions and curation. In quantitative methods, grid size and shape influences the determination of the areas of interest such as hotspots and key biodiversity areas (Hurlbert and Jetz, 2007, Nhancale and Smith, 2011). Choosing the size of the grid is not trivial (Mo et al., 2019) and is dependent on the conservation goals (Margules and Pressey, 2000). In the past decade, there have been major advances for conservation standards, guidelines, frameworks and tools available to be put into action (IPBES 2019).

We defined the EHs as the 10% of the grid cells with the highest number of endemic taxa. In order to avoid biases concerning the grid cell size, the same pipeline was tested with cells of different size (4 x 4, 8 x 8 and 10 x 10 km). For the subsequent analyses we opted for the 10 x 10 km grid (see section 3.1) which is also the EEA reference grid, the standard for the reporting format (Groups of Experts, 2017) of the Resolution No. 8 (2012) of the Standing Committee to the Bern Convention on the Emerald Network of Areas of Special Conservation Interest (ASCI). Moreover, the EHs of the various cell sizes are aggregated in the same areas (Figure 3A). We made the same treatment for each of the selected groups separately (Supplementary Material 2,

Figure 2). We redefined EHs as the 10% of the grid cells with max overlap of the orders to check for biases towards more speciose orders (e.g. Coleoptera) (Supplementary Material 2, Figure 3).

For the investigation of KBAs (IUCN 2016) we used the WEGE index (Farooq et al. 2020) on the same grid as hotspots based on the PACA assessments (potential/likely threatened species) and the distributions of the taxa. WEGE can be used to indicate candidate KBAs or prioritize already existing KBAs (given the limited resources available for conservation) but does not replace a throughout KBAs assessment (Farooq et al. 2020).

2.4. Spatial overlaps

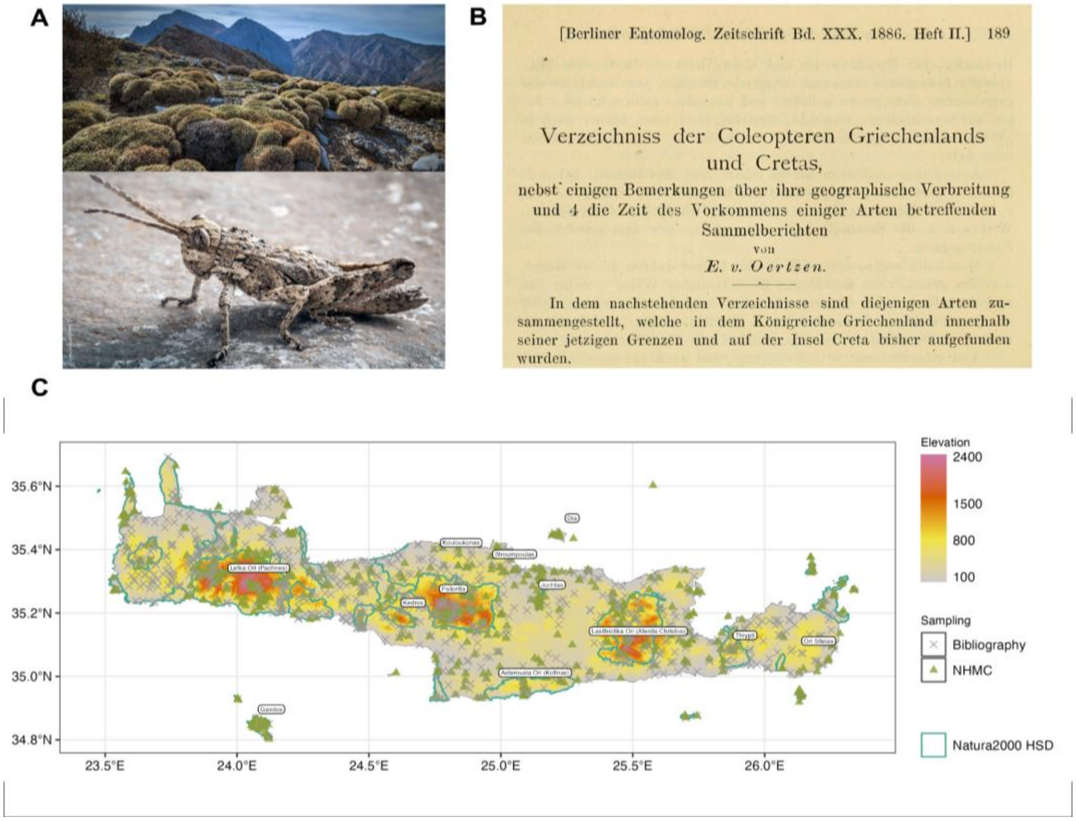
We compared and evaluated the overlap of EHs and KBAs with protected areas and land use categories. The N2K data were downloaded from the European Environment Agency portal and filtered for the Habitats Directive and Crete spatial extent. We retrieved land use categories from the CORINE Land Cover, CLC 2018 version v.2020_20u1 (Copernicus Land Monitoring Service, 2023). To evaluate the current land use of yielded EHs we used the CORINE Land Cover and to examine the human pressure (change in land use, agriculture), we used the Historic Land Dynamics Assessment (HILDA+) dataset (Winkler et al. 2021) to estimate the change of land use the from 1998 to 2018. Furthermore, we examined the overlap of the AOO of each taxon with the N2K.

2.5. Tools and scripts

We performed the analyses using the R Statistical Software (v4.3.2; R Core Team 2023), the visualization using the ggplot2 R package (Wickham, 2016). The figures created are colored using the colorblind-friendly “Okabe-Ito" palette (Ichihara et al., 2009). We calculated EOO and AOO using the ConR R package (Dauby et al. 2017) and PACA using custom scripts. For the spatial data handling, transformations and geometry we used the sf v1.0-14 (Pebesma 2018) and terra v1.7-55 R packages (Hijmans 2023). WEGE index is calculated with the WEGE R package (Farooq et al. 2020). Adaptive grid is created using the quadtree R package (Friend, 2023). Jaccard similarity was calculated with the vegan 2.6-4 r package (Oksanen et al. 2022). All scripts are reproducible by design and available in this GitHub repository:
https://github.com/savvas-paragkamian/arthropoda_assessment_crete.

3. Results

Using over 100 publications (as of 2020) and 733 NHMC sampling events (Supplementary Material 1), we assembled a dataset of 343 taxa (species and subspecies), with 4,924 records across 1,569 distinct sites of Crete (Figure 2C). The taxa are distributed to eleven orders, with Coleoptera having the most taxa (206) and Chilopoda and Scorpiones the least (two) (Table 3).



[Berliner Entomolog. Zeitschrift Bd. XXX. 1886. Heft II.] 189

Verzeichniss der Coleopteren Griechenlands
und Cretas,
nebst einigen Bemerkungen über ihre geographische Verbreitung
und 4 die Zeit des Vorkommens einiger Arten betreffenden
Sammelberichten
von
E. v. Oertzen.

In dem nachstehenden Verzeichnisse sind diejenigen Arten zusammengestellt, welche in dem Königreiche Griechenland innerhalb seiner jetzigen Grenzen und auf der Insel Creta bisher aufgefunden wurden.

Figure 2. A. A high-altitude shrubland on Lefka Ori (top) and the endemic *Orchamus raulinii* (Cretan Stone Grasshopper, Pamphagidae, Acridoidea) (bottom) (photos by A. Trichas). **B.** The seminal work of E.v. Oertzen on the Coleoptera of Greece and Crete, published on 1886 (available at https://www.biodiversitylibrary.org/page/32058852) **C.** The island of Crete with its major mountains, the N2K areas, the sampling localities of the NHMC and the ones compiled from the literature.

3.1. Grid cell size

The grid cell size 10 x 10 km is the most suitable for our study since our dataset - being compiled from numerous different sources and sampling efforts - is rather coarse and inhomogenous for a smaller cell size (Figure 3A). The unique taxa of the EHs of each grid is distributed as follows: 10 km=283, 8 km=278, 4 km=293, adaptive cells=267, with the 4km grid covering most endemic species. The 4 km grid mostly highlighted areas known for their tourist/recreational activities, indicating that it is more sensitive to sampling intensity (Figure 3A).

Focusing on sampling we applied the adaptive grid size with quadtrees resulting in 157 grids with 8 km length, 38 with 4 km and 74 with 2 km (Supplementary Material 2, Figure 5). This indicates the preference of larger cells for the majority of our dataset even though a small percent of regions has higher density of sampling. The highest overlap among all grids is between the 10 km and 8 km reaching 57% (Supplementary Material 2, Table 2). Finally, the 10 km grid has more taxa per cell (Supplementary Material 2, Figure 6) and is a reference grid system. Based on our analysis and interoperability and reproducibility aims we choose the 10 km EEA reference grid for the EHs and candidate KBAs inference. Nevertheless, we also performed the WEGE analysis for KBAs using the adaptive grid, yielding practically the same areas as the 10km grid minus Zakros (Supplementary Material 2, Figure 5C). The same pipeline can not be done with EHs for they require a fixed cell size.

3.2. EHs and Potential KBAs

The EHs cover 17% of Crete (Table 2). They are aggregated in Lefka Ori, Dikti, Psiloritis, Thrypti and Selino at the southwest of Chania (Figure 3B). Four of the five areas are mountainous (the main massifs of Crete). Lefka Ori and Dikti host the highest number of EHs. Psiloritis hosts one, the only EH in central Crete. No satellite island of Crete is yielded as an EH, in spite of their faunas being in essence a subset of the Cretan biodiversity, and Gavdos islet having some single island endemic Arthropods. The reason behind this is a purely numeric one. Compared to the yielded EHs, they have less endemic and local endemic taxa. With finer grids the number of EHs increases (Figure 3A). Gavdos islet is yielded as EH only in the 4 x 4 km grid. The finer grid is less strict and inappropriate for an inhomogeneous dataset as ours, although it does indeed unveil areas that would be otherwise neglected. From now on we discuss our results grounded in the 10 x 10 km grid, but refer to Figure 3A for the other cell sizes.

The different orders display a variation in their respective EHs (Supplementary material 2, Figure 2). Almost unanimously, they exhibit hotspots in one or more massifs, with Trichoptera and Odonata being exceptions, driven from their need of inland waters. When aggregated, the EHs of the different orders generally agree with EHs of Arthropods as a whole (Supplementary Material 2, Figures 3, 4A). Only the latter approach (Arthropods as a whole) is treated onwards.

The proposed KBAs recovered with WEGE cover 17% of Crete (Table 2). They are aggregated in the Cretan mountains (as EHs) in the far west (Selino) and far east (Zakros) Crete (Figure 3C). WEGE utilizes the threat status and the distributions of the taxa to rank potential KBAs (Farooq et al. 2020), thus it is expected for yield areas with high congruence with EHs since many threatened species are concentrated there.

Table 2: Overlap of Arthropod EHs, WEGE KBAs with N2K HSD, Wildlife Refuges and CORINE Land Cover (LEVEL1) areas of Crete.

Type	Area (km^2)	% of Crete	Overlap with Endemic hotspots km^2 (%)	Overlap with WEGE KBAs km^2 (%)
Crete	8347	-	-	-
Endemic hotspots	1400	17%	-	1200 (86%)

(EHs)				
WEGE KBAs	1400	17%	1200 (86%)	-
Natura2000 SAC	2371	28%	858 (61%)	736 (53%)
Wildlife refuges	610	7%	143 (10%)	136 (10%)
Agricultural areas	3618	46%	275 (20%)	301 (22%)
Artificial surfaces	181	2%	5 (0.4%)	4.56 (0.3%)
Forest and semi natural areas	4508	54%	1092 (78%)	1059 (76%)
Water bodies	7	0.08%	1 (0.07%)	0.3 (0.02%)

3.3. Species Assessment

According to the PACA analysis, 75% of the taxa are Likely/Potentially Threatened (from here on referred to as Threatened) and 25% are assessed as Near Threatened/Least Concern (Table 3). These percentages vary between the groups, nevertheless there are some concrete patterns. For example, threatened categories dominate most of the orders except Odonata and Orthoptera (Table 3). Chilopoda and Scorpiones have no threatened taxa at all. Both of these orders display a low endemic diversity (two species each). On the contrary, Heteroptera have only threatened taxa, followed by Coleoptera (82%), Diplopoda (71%), Hymenoptera (68%), Geometridae (67%) and Aranae (65%).

Table 3: Number of taxa included in the dataset in total and per order. In addition, the mean AOO for each taxon and its coverage by N2K are given (Standard Deviation in parentheses), as well as the percentages for PACA and IUCN categories. Categories for PACA: LT - Likely Threatened, PT - Potentially Threatened and LNT - Likely Not Threatened. Categories for IUCN: Threatened (sum of Critically Endangered, Endangered and Vulnerable) and NT/LC - NearThreatened/Least Concern.

Order	**taxa**	**sites**	**occurrences**	**AOO mean km^2 (sd)**	**AOO on N2K mean km^2 (sd)**	**LT**	**PT**	**LNT**	**Threatened**	**NT/LC**
All taxa	343	1539	4924	58 (109)	27 (51)	195 (57%)	62 (18%)	86 (25%)	257 (75%)	86 (25%)
Araneae	40	253	523	55 (63)	21 (19)	16 (40%)	10 (25%)	14 (35%)	26 (65%)	14 (35%)
Chilopoda	2	234	269	552 (560)	223 (251)	0	0	2 (100%)	0	2 (100%)
Coleoptera	206	925	2584	50 (90)	26 (45)	132 (64%)	36 (17%)	38 (18%)	168 (82%)	38 (18%)

Diplopoda	7	74	101	61 (88)	27 (43)	4 (57%)	1 (14%)	2 (29%)	5 (71%)	2 (29%)
Heteroptera	17	46	58	14 (13)	4 (3)	14 (82%)	3 (18%)	NA	17 (100%)	NA
Hymenoptera	25	173	285	48 (70)	20 (30)	14 (56%)	3 (12%)	8 (32%)	17 (68%)	8 (32%)
Lepidoptera (Geometrid moths)	9	40	65	30 (24)	13 (10)	5 (56%)	1 (11%)	3 (33%)	6 (67%)	3 (33%)
Odonata	3	30	49	63 (26)	12 (6)	0	1 (33%)	2 (67%)	1 (33%)	2 (67%)
Orthoptera	20	363	579	122 (133)	61 (64)	7 (35%)	3 (15%)	10 (50%)	10 (50%)	10 (50%)
Scorpiones	2	240	254	518 (619)	240 (279)		0	2 (100%)	0	2 (100%)
Trichoptera	12	66	157	54 (38)	16 (10)	(25%)	4 (33%)	5 (42%)	7 (58%)	5 (42%)

.

3.4. N2K overlap

EHs display 61% overlap with the N2K (Table 2, Figure 3B), mostly of which is in the mountains (Figure 2C, 3B). The greatest overlap occurs in Psiloritis and Dikti (Figure 3B) In contrast, the EHs outside the Cretan mountains (Selino, Kritsa - near Dikti) display lower overlap with the respective protected areas near them (Figure 3B). The areas of agreement of KBAs with N2K are aggregated in the Cretan mountains, while Selino, Kritsa and Zakros are the areas with the smallest overlap (Figure 3C). The average overlap of taxa AOO with N2K is 52% and increases to 55% when only the threatened taxa are considered (Table 3). Orthoptera have the highest average % overlap (62.38%), while Odonata have the lowest (20.39%) (Figure 4).

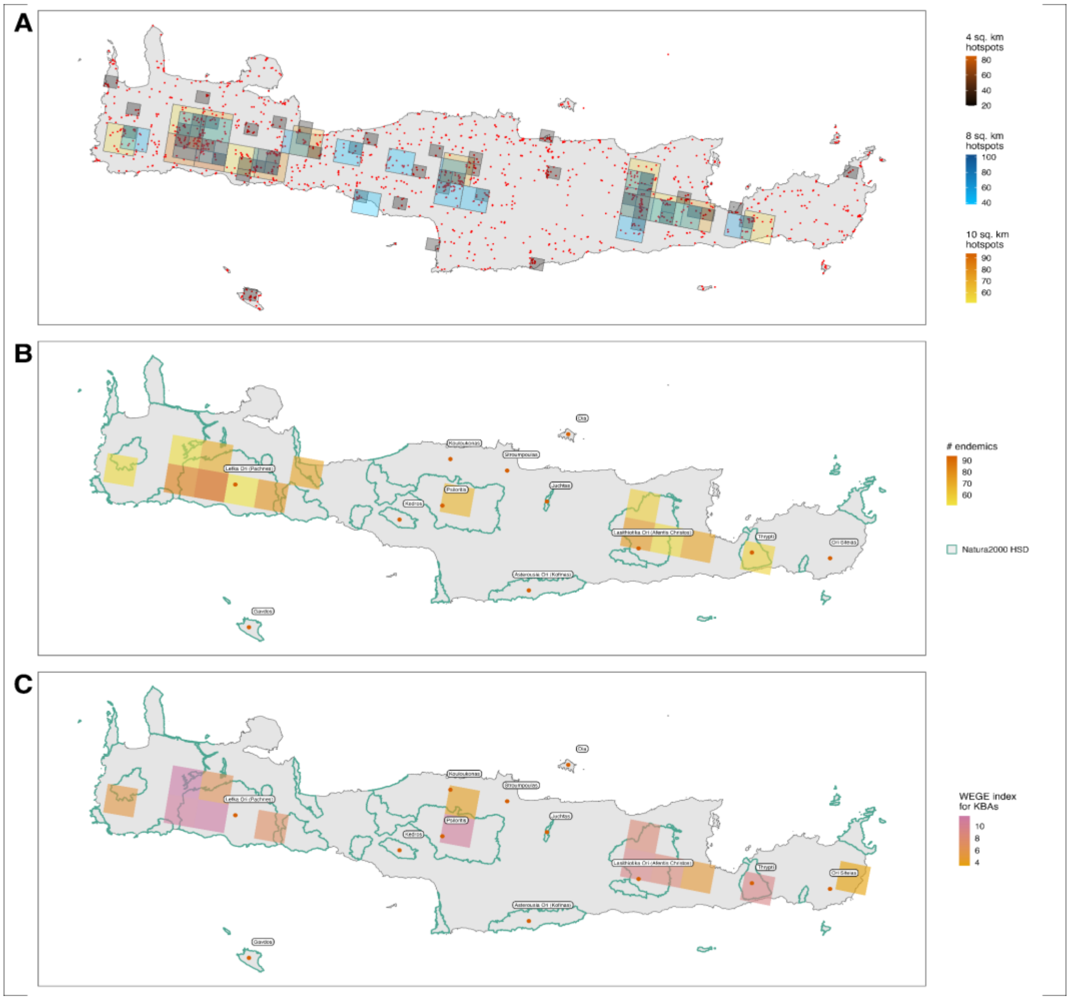


Figure 3: **A.** EHs with different grids, 4, 8 and 10 km^2. The top 10% of cells with most species are considered as hotspots. **B.** EHs and their overlap with Natura 2000 HSD sites. **C.** Top 10% WEGE index grids to approximate KBAs.

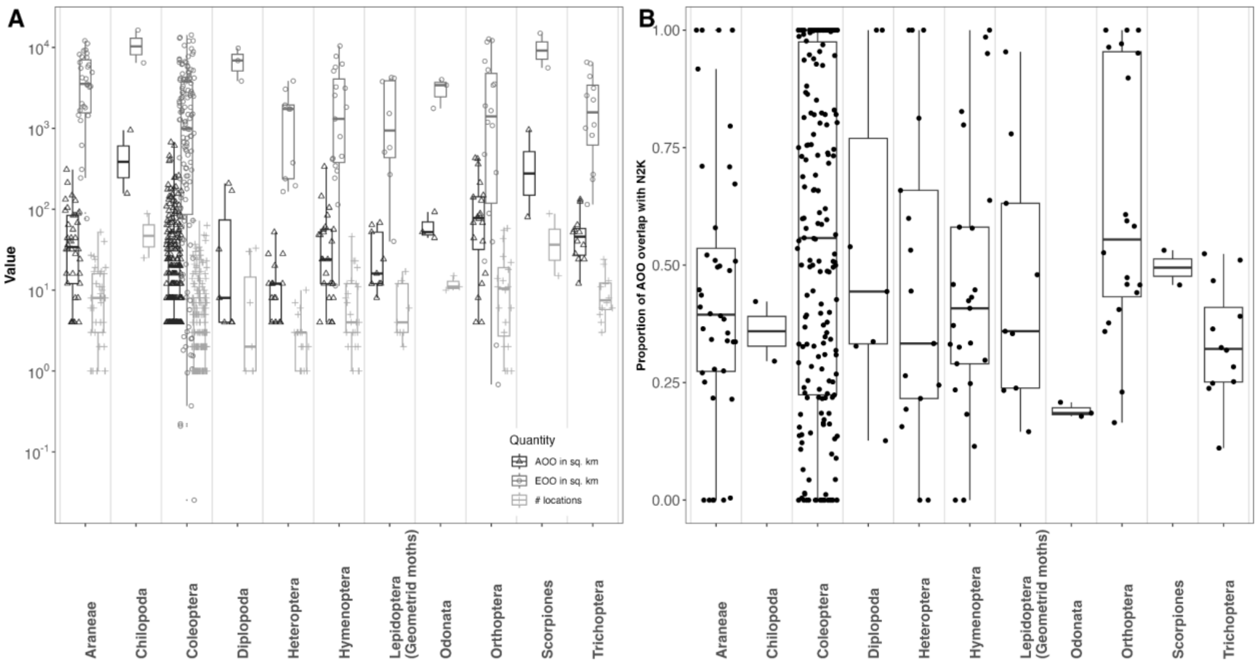


Figure 4. A. Locations, EOO and AOO of all orders. Each dot represents one taxon and boxplots show the mean value and the first and third quantiles. The y axis is in log10 scale. **B**. Proportion of overlap of AOO with Natura 2000 areas per Order. Each dot is a taxon with its respective proportion of AOO overlap. The horizontal line of the boxplot shows the average, and the box shows the 1st and 3rd quantiles of the values.

3.5. Human Intervention

In order to evaluate the human impact in the yielded EHs and candidate KBAs we used CORINE layers (Supplementary Material 2, Figure 8A). At LEVEL 1 of the classification, the dominant habitat is “Forest and semi-natural areas”, covering ~ 76-78% of the EHs/KBAs, while agricultural areas also display coverage of 20-22%. This exhibits the presence of human activity in the EHs/KBAs (Table 2). Using the LEVEL 2 CORINE layer, we acquired a more detailed image of the coverage. The dominant habitat seems to consist of scrub and/or herbaceous vegetation (56% coverage), forests (12%), permanent crops (10%) and open spaces with little or no vegetation (10%) (Supplementary Material 2, Table 3). With HILDA+ we estimated some negative and some positive transitions within the EHs/KBAs in the previous two decades (Table 4). Around 10-12% of forest area has been transformed to cropland. Likewise 22-25% of cropland has been transformed to pastureland. On the other hand, 15-26% of cropland area has been transformed to forest. Worryingly urban areas have increased for about 16.8%, although outside EHs and KBAs mainly at the expense of croplands and pasturelands (Table 4). Finally, water areas remain stable, albeit more research is needed to assess potential decreases in the quality of this habitat, especially given the aggressive urban and touristic expansion.

Table 4: The land use transitions in the 20 year period (1998-2018) from the HILDA+ dataset.

HiLDA+ transitions	**rete (km^2)**	**Natura2000 (km^2)**	**EHs (km^2)**	**WEGE KBAs (km^2)**
urban (stable)	26	46	14	8
urban to pasture/rangeland		NA	NA	NA
cropland to urban	2	1	NA	NA
cropland (stable)	314	186	71	63
cropland to pasture/rangeland	65	74	32	28
cropland to forest	78	40	20	33
cropland to unmanaged grass/shrubland		1	NA	NA
cropland to sparse/no vegetation		3	3	NA
pasture/rangeland to urban	3	NA	NA	NA
pasture/rangeland to cropland	2	15	3	3
pasture/rangeland (stable)	124	2594	1198	1210
pasture/rangeland to forest	1	6	3	3
pasture/rangeland to unmanaged grass/shrubland	37	73	38	33
pasture/rangeland to sparse/no vegetation		2	2	1
forest to pasture/rangeland	4	33	25	20

HiLDA+ transitions	**rete (km^2)**	**Natura2000 (km^2)**	**EHs (km^2)**	**WEGE KBAs (km^2)**
urban (stable)	26	46	14	8
forest (stable)	64	182	174	177
forest to unmanaged grass/shrubland		1	2	2
unmanaged grass/shrubland (stable)		NA	NA	NA
sparse/no vegetation (stable)		2	2	NA
water	65	78	5	3

4. Discussion

4.1. Endemicity Hotspots

Mountains host a great amount of Earth's biodiversity, being a main driver for the birth of species (Antonelli et al. 2018; Noroozi et al. 2018; Rahbek et al. 2019a, b) and a crucial frontier for their fate (Steinbauer et al. 2018; Urban 2018). Crete is not an exception to this trend (Trigas et al. 2013; Kougioumoutzis et al. 2020). Our results conform to that, since the EHs are gathered primarily in the major Cretan mountains (Figure 3B). Lefka Ori and Dikti are the sites with the most EHs, in agreement with studies focused on vascular plants (Dimitrakopoulos et al. 2004; Kougioumoutzis et al. 2020). Sfenthourakis and Legakis (2001), employing invertebrate groups, also recovered these mountains as EHs.

Only one EH was recovered for Psiloritis in this study. This could result from Psiloritis' position in the center of the island, with Lefka Ori and Dikti filtering taxa moving from west and east, from its relatively smaller volume (when compared with Lefka Ori), the intense human intervention, and the less intense topography and relief compared to the other Cretan mountains (for the importance of topography and relief in speciation - biodiversity see: Stuessy et al. 2006; Muellner-Riehl 2019; Igea and Tanentzap 2021). Thrypti as EH is consistent with the aforementioned literature. Isolated in the far east part of the island, Thrypti could be of a major conservational importance for Crete. A novelty of our study is the relative importance (participating with more grid cells) of Dikti when compared with the aforementioned studies, even though it is always obtained as an EH site.

Dia islet, although obtained as an EH for invertebrate fauna in Sfenthourakis and Legakis (2001), is not recovered as a hotspot for Arthropods in our study. The island of Dia has indeed some importance for Arthropod taxa, such Isopods, hosting some single island endemics (Schmalfuss et al. 2004), but its endemic diversity is mostly driven by snails (Vardinoyannis pers. communication), which are not treated here.

The accumulation of more EHs in the West (Lefka Ori and west of Lefka Ori) and East (Dikti and Thrypti) Crete can be explained by their isolation today and in the past, when Crete was divided in palaeo-islands during the Pliocene (see Poulakakis et al. 2014 and Fassoulas 2018 for a review). Moreover, the west and east parts of Crete function as "sinks" for Balkan and Eastern species respectively. The footprint of the Balkans and the Middle East in the Cretan fauna is discussed in various studies (Vardinoyannis 1994; Trichas 1996; Chatzaki 2003; Trichas et al. 2020). The "redness" of West and East Crete as endemic centers is also obtained in other studies (e.g. Assing 2019; Kougioumoutzis et al. 2020).

Islands are biodiversity sanctuaries (Whitaker and Fernández-Palacios 2007), and so are mountains (Rhabek et al. 2019b). Our work advocates for approaches that treat islands and mountains under a holistic perspective. The combination of the two provides a complex biogeographical interplay governing the forces of speciation, preservation and extinction of biodiversity (Steinbauer et al. 2016). This synergistic effect of mountains-islands has also been recovered in other areas such as the Balearic islands (Guardiola and Sáez 2023).

4.2. Species assessment

The species assessment from PACA showed that 75% (Table 3) of the taxa assessed are Potentially/Likely Threatened (hereafter referred as Threatened). The variation between the different orders is not substantial (most of them score above 50% in Threatened taxa) (Table 3). Local endemic or restricted taxa increase an order’s Threatened percentage. Chilopoda and Scorpiones, have zero Threatened taxa. For Odonata we also recovered a low Threatened percentage (33.3% - 2 taxa) compared to the 100% (2 taxa) of IUCN (Supplementary Material 2, Figure 1). That is an artifact of the PACA assessment, not taking into consideration population data and population fragmentation. This factor, albeit an important aspect of criterion B for the IUCN assessments, is excluded from PACA for it requires special treatment for each taxon (Dauby et al. 2019). There are multiple reasons for the disagreement between the two assessments. An IUCN assessment is an exhaustive, overall assessment, performed by experts and focusing on each species separately. A PACA assessment is a rather automated pipeline that allows researchers to have a preliminary approach on understudied taxa and areas, but in no way an alternative of a thorough IUCN assessment.

Arthropods with wider ranges that are not assessed as Threatened under criterion B, are not necessarily Least Concern and should not be neglected. Arthropod communities can be affected by the reduction of the abundance of common and abundant species that offer important functions to the biocommunity. Wide range does not guarantee high abundance (even though this is true for many taxa) and even common species can be threatened (Habel and Schmitt 2018; Klink et al. 2023).

With 75% Threatened taxa, Cretan Arthropods appear to be in better fate than the Cretan vascular plants, assessed as Threatened in their totality (Kougioumoutzis et al. 2020). This is most likely a result of the combined use of Criteria A and B in the vascular plant assessment (Kougioumoutzis et al. 2020) - something impossible for the Arthropods since their data are too coarse for the utilization of criterion A. This dominant trend of Crete is also true for land mollusks with 41.7% of the Cretan endemics being Threatened (IUCN) compared to the 20.5% of Threatened endemics for Europe (Neubert et al. 2019). This is particularly worrying given Crete’s significance as a biodiversity hotspot (Myers et al. 2000; Médail, 2017) and the fact that it refers to single island endemics. Cretan taxa display a worse trend not only compared to Europe (Supplementary Material 2, Figure 1), but also when compared to Greece. For example, 46.1% of the Greek endemic vascular flora is recovered as Threatened according to Kougioumoutzis et al. (2021b), compared to the 100% of the Cretan endemic flora (Kougioumoutzis et al. 2020).

Of course, the bias of Criterion B towards a more severe categorization (Cardoso et al. 2011a) and the fact that we are using a preliminary assessment advocate a conservative interpretation of our results which are explorative and not concrete assessments.

4.3. Potential KBAs

The traditional framework of KBAs (IUCN 2016) is area hungry, with more area required with the increasement of species used in the assessment (Farooq et al 2023), raising management and conservation issues. WEGE seems to resolve this weakness of KBAs (Farooq et al. 2020). Furthermore, the use of WEGE overcomes obstacles in the ranking of areas for conservation such as the lack of robust phylogenetic information regarding the taxa under focus (Farooq et al. 2020).

The candidate KBAs yielded by WEGE are gathered in Lefka Ori, Dikti, Thrypti, Psiloritis, Selino and Zakros. Our results are congruent with previous studies that enquire about EHs or threat-spots in Crete (Dimitrakopoulos et al. 2004; Kougioumoutzis et al. 2020; Kougioumoutzis et al. 2021b). The KBAs obtained here refer to Arthropods and are not mandatory in any way. Other areas of Crete could be candidates as well. First of all, when it comes to Arthropods, areas such as Gavdos islet are yielded as EHs with a different grid (Figure 3A). Moreover, other areas may be important for other organisms. For example, Asteroussia are a KBA for Birds (Key Biodiversity Areas Partnership, 2024), while they are also recovered as a potential climatic refuge for plants (Kougioumoutzis et al. 2020). The essence is that KBAs should always be under inquiry grounded on the available resources and will of the stakeholders and political authorities. From the simple proposal of some KBAs to the implementation of a conservation plan there are many steps to follow that do not all abide by quantifiable scientific thresholds. Venter et al. (2018) found that KBAs have been selected in order to avoid incorporating areas with agricultural activities, while there is a need for mediation between national and global sites of conservation interest (Kougioumoutzis et al. 2021b; Lim et al. 2023). In this international and interdisciplinary questioning, the effective selection of candidate areas is of great importance (Plumptre et al. 2024). Our work contributes to this matter by highlighting the significance of island mountains as KBAs.

4.4. N2K overlap

N2K has been characterized as the only protection structure that “has the political chance to be implemented in the island” (Dimitrakopoulos et al. 2004). The overlap of threatened taxa, EHs and KBAs with N2K is thus of major conservation importance.

Crete is by far the area of Greece with the highest mean complementary percentage between threatened species distribution and N2K (Spiliopoulou et al. 2021). Focusing on vascular endemic plants Kougioumoutzis et al. (2021b) also obtained high complementarity between the endemicity/threat hotspots (obtained with various indices) and the N2K. Our work contributes to this discussion, exhibiting a high overlap between EHs and KBAs with N2K and obtaining a satisfactory coverage of EHs/KBAs by N2K (Table 2). Additionally, N2K covers many areas of Crete (peninsulas, gorges, islets and massifs) which, even though they are not yielded as EHs/KBAs, host a plethora of endemic Arthropods.

We examined the overlap of each taxon’s AOO with N2K to obtain a more detailed overview of its conservation status. The mean percentage of coverage was 52%, and increased to 55% for the Threatened taxa. This percentage is close, albeit lower, to the 62.3% recovered from Spiliopoulou et al. (2021) for Crete. This can be attributed to the innate differences of our datasets and methodologies. We focused strictly on Arthropods, while Spiliopoulou et al. (2021) examined all the species of Greece (flora and fauna) assessed in a Threatened category. Moreover, we converted the PACA assessment to the respective IUCN category, while Spiliopoulou et al. (2021) used the actual IUCN assessments. Despite these methodological differences, another explanation could be that the Arthropods are indeed in a worse conservation position than other groups, an inference which rhymes with the ongoing global discussion around Arthropods’ decline (Chowdhury et al. 2022, 2023).

Orthoptera have the highest average overlap with N2K (62.38%) (Figure 4B). This is mainly caused by the genus *Eupholidoptera* which is responsible for a great part of Orthopteran endemism in Crete (Willemse et al. 2023), which differentiate areas mostly covered by N2K. Odonata and Trichoptera exhibit the lowest average overlap (Figure 4B). A closer investigation towards the freshwater species of Crete, especially those associated with seasonal streams or ponds, is recommended. The overdrafting of Crete’s natural water reservoirs and the aggressive urbanization and agricultural intensification could be a hazard for smaller springs and streams. Kalkman et al. (2010) highlight the need for a freshwater plan for the conservation of the Cretan dragonflies. The ill fate of aquatic insects is a global phenomenon (Deacon et al. 2019; Roth et al. 2020; Dia-Silva et al. 2021), although there are studies that recover more positive trends (Klink et al. 2020, but see also Desquilbet et al. 2020).

In our dataset, 29 (8.4%) of the taxa have zero overlap with N2K. All of them are Threatened. Additionally, 44 (17%) of the Threatened taxa have less than 10% overlap with N2K. The percentages (25.4% in aggregate) of disagreement obtained here are higher than those obtained from Spiliopoulou et al. (2021). This becomes more acute since only nine Insect species out of 124 (7.2%) that were analyzed in Spiliopoulou et al. (2021) are excluded from the protected areas.

The inclusion of Arthropod taxa in protected areas is often insufficient, with Arthropods experiencing declines inside the protected areas (Borges et al. 2005; Harry et al. 2019; Rada et al. 2019, Chowdhury et al. 2022). In fact, even when certain Arthropod groups are adequately included in N2K, there are gaps and omissions (Sánchez-Fernández et al. 2008; Verovnik et al. 2011). At a global level 75% of Insects are not sufficiently covered by protected areas (Chowdhury et al. 2023). Crete stands in an intermediate position, following the general trend of Greece’s N2K adequacy, being the best covered area at a national level (Kougioumoutzis et al. 2021b; Spiliopoulou et al. 2021). However, there are some clear gaps regarding certain taxa, encouraging more locally focused conservation policies complementary to N2K. For example actions need to be taken for KBAs that fall outside N2K like Kritsa and Zakros.

Biases towards Arthropods cause their poor coverage by protected areas (D’Amen et al. 2013; Delso et al. 2021; Chowdhury et al. 2022). These biases derive from geography, size, color and charisma (Cardoso 2012; Mammola et al. 2020; Wang et al. 2021), and even from political/economic reasons (Dias-Silva et al. 2021). For example, the strongest driver for a conservation program funding within the European Union is the online popularity (Mammola et al. 2020). The unpopularity of Arthropods has begun to change (Wagner et al. 2021), especially through citizen science, which is a trend we should build on to properly conserve the Arthropods.

4.5. Human Intervention in Arthropods’ EHs

Human activities account for almost 20% of the EHs. The primary human activity in the EHs is agriculture (~19.6%). Agricultural intensification is one of the most important drivers of Arthropods’ decline (Habel et al. 2019; Brühl and Zaller 2019; Raven and Wagner 2021). Moreover, threats associated with agriculture are the number one threat for Insect species inside protected areas in Europe (Chowdhury et al. 2022). Nevertheless, regarding change in land use, there is a somewhat equal transition trend from cropland to forest and vice versa inside EHs and KBAs (Table 4). This means that while some sites are being degraded others may recover. More research within EHs and KBAs is essential in order to quantify the impact (negative or positive) of these transitions to the endemic Arthropods. A vast amount of cropland has been transformed to pasture lands (Table 4) which requires further examination, since grazing has both positive [eg. on Gnaphosidae (Spiders) communities (Kaltsas et al. 2019)] and negative effects [e.g. Carabidae (Coleoptera) (Kaltsas et al. 2013)]. The reduction of croplands could be interpreted under the general trend of urbanization (Table 4), which occurs outside EHs and KBAs, but a shift towards montane areas especially under new forms of tourism could deeply impact the sites of conservation importance.

4.6. Perspectives and Actions

Arthropods are rarely approached as a whole, for biological and practical reasons. The study of Arthropods is usually limited to a family or even to a lower taxonomic level and to certain biogeographical areas (e.g. Borges et al. 2017, 2018). Treatises tackling Arthropod issues in a wider scope are: Azores – Gaspar et al. (2010), Atacama coast – Pizarro-Araya et al. (2021), Neotropical area - Barahona-Segovia and Zúñiga-Alonso (2021), or meta-data studies (Klink et al. 2020; Chowdhury et al. 2023). In this study we compiled a detailed and diverse dataset integrating different Arthropod groups. Our goal was to obtain a holistic image of Crete's Arthropods' conservation status and place it in the wider frame of the global issues of Arthropod conservation.

Crete follows the global pattern of island biodiversity, with the island biota being under constant extinction pressure (Triantis et al. 2010; Fernández-Palacios et al. 2021). All four main culprits for the impoverishing of island biota identified by Fernández-Palacios et al. (2021) have an intense presence in Crete. The lowlands of Crete are experiencing significant habitat loss due to urbanization and transformation to olive tree cultivations. Natural resources are overexploited - especially water reservoirs - mainly from agriculture and aggressive touristic development. Invasive species have established populations (D'Agata et al. 2009; Affre et al. 2010; Christopoulou et al. 2021) and the impact of climate change is prominent. The aggregation of most of the endemic Arthropods in the mountains renders them vulnerable not only due to their insularity but adds extra pressure from mountain related processes. The lack of space to retreat from climate change and their inability to outcompete with lowland populations/species moving to higher elevations drives the extinction of montane populations (Alexander et al. 2015; Steinbauer et al. 2018; Urban 2018; Yadav et al. 2018; Frishkoff et al. 2019). Thus, the alloy of mountain-island can act not only as a driver for biodiversity but also as the ground for its loss. Our work highlights the need for a simultaneous evaluation of mountain and island driven phenomena inside biodiversity hotspots, as is the Mediterranean basin.

For a better fate for the Cretan Arthropods under the global urgencies for Arthropods' conservation, we propose actions that could improve the conservation status/framework of this special fauna:

1) The conservation situation inside the N2K should be examined to ensure the correct implementation of the N2K goals and directives, especially given the studies which have shown a significant decline of Arthropods inside protected areas (Hallmann et al. 2017; Chwowdhury et

al. 2022). This is also true for our study, which demonstrates contradictory results regarding the human pressures inside EHs and KBAs. Research efforts focused on the Arthropods species' populations, abundances and communities will provide empirical data for the interaction of human activities and the Arthropods of Crete. A multidisciplinary study, utilizing molecular and geographical tools as well as the local stakeholders in the spirit of Lehmann et al. (2021), would provide the much-needed research framework regarding the interaction dynamics of human activities and Arthropods inside N2K in Crete.

2) The discussion for the expansion or optimization of already existing protected areas like N2K, is imminent in the global bibliography (Chowdhury et al. 2023). Ignoring important sites outside N2K would lead to neglect some threatened taxa, and also encourage further human disturbance in unprotected areas (Borges et al. 2005). Enquiries considering the incorporation of areas outside N2K to the network and/or communication with local/centralized authorities and stakeholders to form policies for the management of such areas could optimize the conservation status of Cretan Arthropods. Despite the admittedly beneficial function of protected areas in conservation targets such as the reducing of habitat loss (Geldmann et al. 2013), the need of additional protection actions to tackle certain issues is highlighted (D'Amen et al. 2013; Hochkirch et al. 2013). In essence, it is important for protected areas to be treated individually for the achievement of different conservation goals instead of just complying with a general protection trend. This issue is also brought up for the Greek reality (Dimitrakopoulos et al. 2004; Kougioumoutzis et al. 2020, 2021b). Our study adds to this conversation, pointing to KBAs for Arthropods. Finally, the expansion of the protected areas in order to protect future hotspots and climatic refugia should also be seriously considered from conservationists, given that potential future climatic refugia are not adequately covered by protected areas (Doxa et al. 2022).

3) Educational/citizen science programs focused on the awareness of the local communities towards the specificity and sensitivity of Cretan Arthropods could build a social dynamic that would lighten Arthropods from the burden of unpopularity (Wang et al. 2021). Given that Cretan Arthropods suffer from biases related to their regional geographical position within the EU (Cardoso 2012), the rise of awareness towards their threats and needs will improve their study and conservation. Moreover, it would medicate the bias of Habitats Directive towards central/northern European species and ground a more integrating conservation approach within the EU.

4) PACA is utilized to map uncharted areas and biota that suffer from reduced conservational focus. A thorough assessment of as many as possible of the Cretan Arthropods under IUCN should be carried out and would provide a concrete image of their threat status. This Herculean task is tackled in the upcoming Red Data Book of Greece. Besides the value of a detailed IUCN assessment itself, a Red Data Book will also provide a detailed dataset to test the effectiveness and the limits of the PACA method, given its common use (e.g., Kougioumoutzis et al. 2021b; Iniesta et al. 2023).

5) Our study is a perfect example of the importance of contemporary research in faunistics and taxonomy for conservation. Many core elements of our dataset have been published only in the last five years (e.g., Assing 2019; Salata et al. 2020a). In fact, 42.5% (47 species) of the endemic Staphylinidae (Coleoptera) have been described in 2019 (Assing et al. 2019). Knowledge shortfalls (Hortal et al. 2015) regarding the Cretan Arthropods create an imperative need for basic taxonomic and faunistic knowledge, i.e., the discovery of new taxa (tackling

Linnean shortfall), and for the better understanding of the species' distributions (tackling Wallacean shortfall). Under this spirit, samplings utilizing fermenting traps, malaise traps, litter/soil shifting/washing focusing in the saproxylic, soil and aquatic invertebrate fauna of the island (underrepresented in our dataset) would mediate the effects of the aforementioned shortfalls. Thus, more funding should be focused on faunistic data assemblage studies. In contrast to Garnett and Christidis (2017), we believe that taxonomy does not hinder conservation biology, but instead makes conservation possible, since when unaware of the existence of a species (whether species are considered as real entities or not - see Raposo et al. 2017), it is impossible to protect it. Therefore, trailing the voices of those who advocate for a better incorporation of taxonomy in conservation (Dubois 2003; de Carvalho et al. 2007; Boero 2010; Andreone et al. 2022) while acknowledging its innate value (Engel et al. 2021), we passionately call for an extensive taxonomic and faunistic scrutiny of Cretan Arthropod biodiversity.

Conclusions

The high percentage of potentially/likely Threatened taxa recovered (75%), points to immediate need for conservation actions and policies concerning Crete, as well as a robust assessment of their threat status. These results are worrying under the light of the "Insect Apocalypse". Even though none of the Cretan Arthropods was considered when the N2K was designed for Crete, N2K appears to be an adequate conservation network for Cretan Arthropods. The EHs and KBAs recovered here are the "usual suspects" also obtained in other studies with different datasets. Lefka Ori, Psiloritis, Dikti, Thrypti, Selino and Zakros are identified as EHs and KBAs for the Cretan Arthropods. A point of contradiction recovered here is the double role of an island-mountain system to the birth and loss of biodiversity. Another contradiction is the one regarding human activity and N2K coverage of the EHs/KBAs. Therefore, we suggest multidisciplinary research efforts and policies that are not restricted to scientific practice but welcome the participation of local communities to achieve a better perspective for Cretan Arthropods.

Funding

SP was funded by the 3rd H.F.R.I. (Hellenic Foundation for Research and Innovation) Scholarships for PHD Candidates (no. 5726). GB was funded by ELKE.uoc scholarship (no.11526)

Author Contributions - Credit

Conceptualization: AT, GB; Data curation: AT, GB, LK, MC, NK; Formal Analysis: SP; Methodology: GB, SP; Software: SP; Supervision: AT; Validation: AT, GB, NK; Visualization: SP, AT; Writing – original draft: GB; Writing – review & editing: All authors reviewed the manuscript.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Acknowledgements

We would like to thank Katerina Vardinoyannis (Curator of Invertebrates - excluding Arthropods, in NHMC) and Manolis Nikolakakis for their help in construction and design of the databases used here. Moreover, we are also deeply obliged to professor Moysis Mylonas, for his crucial theoretical remarks and advice and Leonidas Maroulis (PhD candidate - University of Cete) for his insights regarding our methodology. Also, we would like to thank all researchers and students of the NHMC and University of Crete who methodically collected, sorted and identified Arthropod specimens during their studies in various NHMC projects. Finally, we are deeply indebted to the comments of the two anonymous reviewers, which have greatly improved our work.

Dedication

We dedicate this work to Volker Assing (1956 - 2022). His research in Cretan Staphylinidae has been remarkable in quantity and quality. Over the course of numerous articles, he managed to exhibit and highlight the taxonomical and biogeographical importance of Cretan rove beetles, by describing numerous new species and unraveling interesting distributional patterns. His work is of most significance for the conservation of this special fauna.

Data Availability

Data, scripts and results of the analysis are available and documented here:
https://github.com/savvas-paragkamian/arthropods_assessment_crete
Supplementary Material are available at the Zenodo repository
https://doi.org/10.5281/zenodo.10635645
Supplementary Material 1 is the Supplementary-material-1.xlsx file which contains the occurrences as compiled from the literature and the specimens of the NHMC. In addition all references of the literature are included in a separate sheet.
Supplementary Material 2 is the Supplementary-material-2.docx which contains five (5) supplementary figures and four (4) supplementary tables.
Supplementary Material 3 is the Supplementary-material-3-hilda_crete_1998_2018.mp4 timelapse video of yearly changes of Land Use based on HILDA+ dataset

References

Anastasiou I, Papadopoulou A and Trichas A (2018) Tenebrionid Beetles of the Aegean Archipelago: Historical Review, Current Knowledge and Future Directions. A Review. In: Sfenthourakis S, Pafilis P, Parmakelis A, Poulakakis N and Triantis K (Eds) Biogeography and Biodiversity of Aegean. In Honour of Prof. Moysis Mylonas. Broken Hill Ltd, pp, 151-167.

Andreone F, Boero F, Bologna MA, Carpaneto GM, Castiglia R, Gippoliti S, Massa B, Minelli A (2022) Reconnecting research and natural history museums in Italy and the need of a national collection biorepository. ZooKeys 1104: 55-68. https://doi.org/10.3897/zookeys.1104.79823.

Affre L, Suehs CM, Charpentier S, Vilà M, Brundu G, Lambdon P, Traveset Anna, Hulme PE (2009) Consistency in the habitat degree of invasion for three invasive plant species across Mediterranean islands. Biological Invasions 12(8): 2537–2548. https://doi:10.1007/s10530-009-9662-6.

Alexander J, Diez J, Levine J (2015) Novel competitors shape species' responses to climate change. Nature 525: 515–518 https://doi.org/10.1038/nature14952.

Antonelli A, Kissling WD, Flantua SGA et al. (2018) Geological and climatic influences on mountain biodiversity. Nature Geoscience 11: 718–725. https://doi.org/10.1038/s41561-018-0236-z.

Armijo R, Lyon-Caen H, Papanastassiou D (1992) East-West extension and Holocene normal-fault scraps in Hellenic arc. Geology 20: 491-494. https://doi.org/10.1130/0091-7613(1992)020<0491:EWEAHN>2.3.CO;2.

Assing V (2019) Monograph of the Staphylinidae of Crete (Greece). Part I. Diversity and endemism (Insecta: Coleoptera). Contributions to Entomology 69 (2): 197–238. https://doi.org/10.21248/contrib.entomol.69.2.197-239.

Assing V, Brachat V, Meybohm H (2019) Monograph of the Staphylinidae of Crete (Greece). Part II. Descriptions of new species (Insecta: Coleoptera). Contributions to Entomology 69 (2): 239–289. https://doi.org/10.21248/contrib.entomol.69.2.239-289.

Barahona-Segovia RM and Zúñiga-Reinoso Á (2021) An overview of Neotropical arthropod conservation efforts using risk assessment lists. Journal of Insect Conservation 25: 361–376. https://doi.org/10.1007/s10841-021-00306-x

Boero F (2010) The Study of Species in the Era of Biodiversity: A Tale of Stupidity. Diversity 2(1): 115–126. https://doi:10.3390/d2010115.

Borges PAV, Aguiar C, Amaral J, Amorim IR, André G, Arraiol A et al. (2005) Ranking protected areas in the Azores using standardized sampling of soil epigean arthropods. Biodiversity and Conservation 14(9): 2029–2060. https://doi:10.1007/s10531-004-4283-y.

Borges PAV, Lamelas-López L, Amorim IR, Danielczak A, Nunes R, Serrano ARM, Boieiro M, Rego C, Hochkirch A and Vieira V (2017) Conservation status of the forest beetles (Insecta, Coleoptera) from Azores, Portugal. Biodiversity Data Journal, 5: e14557. DOI:10.3897/BDJ.5.e14557

Borges PAV, Pérez Santa-Rita JV, Nunes R, Danielczak A, Hochkirch A, Amorim IR, Lamelas-López L, Karsholt O and Vieira V (2018) Species conservation profile of moths (Insecta, Lepidoptera) from Azores, Portugal. Biodiversity Data Journal 6: e23311. DOI:10.3897/BDJ.6.e23311

Branco VV and Cardoso P (2020) An expert-based assessment of global threats and conservation measures for spiders. Global Ecology and Conservation, 24: e01290. https://doi:10.1016/j.gecco.2020.e01290.

Brühl CA and Zaller JG (2019) Biodiversity Decline as a Consequence of an Inappropriate Environmental Risk Assessment of Pesticides. Frontiers in Environmental Science 7:177. https://doi: 10.3389/fenvs.2019.00177.

Cálix M, Alexander KNA, Nieto A, Dodelin B, Soldati F, Telnov D, Vazquez-Albalate X, Aleksandrowicz O, Audisio P, Istrate P, Jansson N, Legakis A, Liberto A, Makris C, Merkl O, Mugerwa Pettersson R, Schlaghamersky J, Bologna MA, Brustel H, Buse J, Novák V and Purchart L (2018). European Red List of Saproxylic Beetles. Brussels, Belgium: IUCN. http://www.iucnredlist.org/initiatives/europe/publications.

Cardoso P (2012) Habitats Directive species lists: urgent need of revision. Insect Conservation and Diversity, 5(2): 169–174. https://doi:10.1111/j.1752-4598.2011.00140x.

Cardoso P and Leather SR (2019) Predicting a global insect apocalypse. Insect Conservation and Diversity 12 (4): 263 – 267. https://doi: 10.1111/icad.12367.

Cardoso P, Borges PAV, Triantis KA, Ferrández MA, Martín JL (2011a) Adapting the IUCN Red List criteria for invertebrates. Biological Conservation, 144(10): 2432–2440. https://doi:10.1016/j.biocon.2011.06.020.

Cardoso P, Erwin TL, Borges PAV, New TR (2011b) The seven impediments in invertebrate conservation and how to overcome them. Biological Conservation, 144(11): 2647–2655. https://doi:10.1016/j.biocon.2011.07.024.

Cardoso P, Borges PAV, Triantis KA, Ferrández MA, Martín JL (2012) The underrepresentation and misrepresentation of invertebrates in the IUCN Red List. Biological Conservation 149(1): 147–148. https://doi:10.1016/j.biocon.2012.02.011.

Cardoso P, Barton PS, Birkhofer K, Chichorro F, Deacon C, Fartmann T, Fukushima CS, Gaigher R, Habel JC, Hallmann MJH, Hochkirch A, Mackenzie LK, Mammola S, Noriega JA, Orfinger AB, Pedraza F, Pryke JS, Roque FO, Settele J, Simaika JP, Nigel ES, Suhling F, Vorster C, Samways, M. J. (2020). Scientists' warning to humanity on insect extinctions. Biological Conservation, 108426. https://doi:10.1016/j.biocon.2020.108426.

Carpaneto GM, Baviera C, Biscaccianti AB, Brandmayr P, Mazzei A, Mason F, Battistoni A, Teofili C, Rondinini C, Fattorini S, Audisio P (2015). A Red List of Italian Saproxylic Beetles: taxonomic overview, ecological features and conservation issues (Coleoptera). Fragmenta Entomologica, 47(2): 53-126 https://doi:10.4081/fe.2015.138.

Carvalho MR de, Bockmann FA, Amorim DS, Brandão CRF, Vivo M de, Figueiredo JL de, Britski HA, de Pinna MCC, Menezes NA, Marques FPL, Papavero N, Cancello EM, Crisci JV (2007) Taxonomic impediment or impediment to taxonomy? A commentary on systematics and the cybertaxonomic-automation paradigm. Evolutionary Biology 34: 140–143.

Chatzaki M (2003) The ground Spider-fauna of Crete (Family: Gnaphosidae). Systematics, ecology and biogeography. PhD Dissertation, University of Crete, Biology Department.

Chatzaki M, Pitta E, Poursanidis D, Komnenov M, Gloor D, Nikolakakis M, Nentwig W (2015) SPIDOnet.gr Spiders of Greece. Version 1.0. Available from: http://www.Aranae.unibe.ch/spidonet/. Accessed (7/2020).

Chowdhury S, Jennions MD, Zalucki MP, Maron M, Watson JEM, Fuller RA (2022) Protected areas and the future of insect conservation, Trends in Ecology & Evolution 38(1): 85-95. https://doi.org/10.1016/j.tree.2022.09.004.

Chowdhury S, Zalucki MP, Hanson JO, Tiatragul S, Green D, Watson JEM, Fuller RA (2023) Three-quarters of insect species are insufficiently represented by protected areas. One Earth 6: 1-7. https://doi.org/10.1016/j.oneear.2022.12.003.

Christopoulou A, Christopoulou A, Fyllas NM, Dimitrakopoulos PG, Arianoutsou M (2021) How Effective Are the Protected Areas of the Natura 2000 Network in Halting Biological Invasions? A Case Study in Greece. Plants. 10(10): 2113. https://doi.org/10.3390/plants10102113.

Crofts R (2014) The European NATURA 2000 protected area approach: a practitioner’s perspective. Parks 20(1): 79-90. https://doi.org/10.2305/IUCN.CH.2014.PARKS-20-1.RC.en.

D’Agata CDC, Skoula M, Brund G (2009) A preliminary inventory of the alien flora of Crete (Greece). Bocconea 23: 301-315.

D’Amen M, Bombi P, Campanaro A, Zapponi L, Bologna MA, Mason F (2013) Protected areas and insect conservation: questioning the effectiveness of Natura 2000 network for saproxylic beetles in Italy. Animal Conservation, 16(4): 370–378. https://doi:10.1111/acv.12016.

Dauby G, Stévart T, Droissart V, Cosiaux A, Deblauwe V, Simo-Droissart M, Sosef MSM, Lowry PP 2nd, Schatz GE, Gereau RE, Couvreur TLP (2017). ConR: An R package to assist large-scale multispecies preliminary conservation assessments using distribution data. Ecology and Evolution 7(24):11292-11303. https://doi: 10.1002/ece3.3704.

Deacon C, Samways MJ Pryke JS (2019) Aquatic insects decline in abundance and occupy low-quality artificial habitats to survive hydrological droughts. Freshwater Biology 64: 1643– 1654. https://doi.org/10.1111/fwb.13360.

Delso Á, Fajardo J, Muñoz J (2021) Protected area networks do not represent unseen biodiversity. Scientific Reports 11: 12275. https://doi.org/10.1038/s41598-021-91651-z.

Desquilbet M, Gaume L, Grippa M, Céréghino R, Humbert J-F, Bonmatin J-M, Cornillon P-A, Maes D, Van Dyck H Goulson D (2020) Comment on “Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances.”. Science 370(6523): eabd8947. https://doi:10.1126/science.abd8947.

Dias-Silva K, Vieira TB, Moreira FFF, Juen L, Hamada N (2021) Protected areas are not effective for the conservation of freshwater insects in Brazil. Scientific Reports 11: 21247 (https://doi.org/10.1038/s41598-021-00700-0.

Dimitrakopoulos PG, Memtsas D and Troumbis AY (2004) Questioning the effectiveness of the Natura 2000 Special Areas of Conservation strategy: the case of Crete. Global Ecology and Biogeography 13: 199-207. https://doi.org/10.1111/j.1466-822X.2004.00086.x.

Doxa A, Kamarianakis Y, Mazaris AD (2022) Spatial heterogeneity and temporal stability characterize future climatic refugia in Mediterranean Europe. Global Change Biology 28: 2413–2424. https://doi.org/10.1111/gcb.16072.

Dubois A (2003) The relationships between taxonomy and conservation biology in the century of extinctions. Comptes Rendus Biologies 326: 9–21. https://doi:10.1016/s1631-0691(03)00022-2.

Engel MS et al. (2021) The taxonomic impediment: a shortage of taxonomists, not the lack of technical approaches. Zoological Journal of the Linnean Society 193(2): 381-387. https://doi.org/10.1093/zoolinnean/zlab072.

European Union, Copernicus Land Monitoring Service (2023), European Environment Agency (EEA).

Farooq H, Antonelli A and Faurby S (2023) A call for improving the Key Biodiversity Areas framework. Perspectives in Ecology and Conservation 21: 85-91. https://doi.org/10.1016/j.pecon.2023.02.002

Farooq H, Azevedo J, Belluardo F, Nanvonamuquitxo C, Bennett D, Moat J,Soares A, Faurby S and Antonelli A (2020) WEGE: a new metric for rankinglocations for biodiversity conservation. Diversity and Distributions 26(11): 1456–1466. http://dx.doi.org/10.1111/ddi.13148.

Fassoulas C (2018) The Geodynamic and Paleogeographic Evolution of the Aegean in the Tertiary and Quaternary: A Review. In: Sfenthourakis S, Pafilis P, Parmakelis A, Poulakakis N and Triantis K (Eds) Biogeography and Biodiversity of Aegean. In Honour of Prof. Moysis Mylonas. Broken Hill Ltd, 26 – 45.

Fattorini S (2006a) Spatial patterns of diversity in the tenebrionid beetles (Coleoptera, Tenebrionidae) of the Aegean Islands (Greece). Evolutionary Ecology Research 8: 237–263.

Fattorini S (2006b) Spatial variations in rarity in the Aegean tenebrionid beetles (Coleoptera, Tenebrionidae). Fragmenta Entomologica 38(2): 227-249. https://doi:10.4081/fe.2006.8.

Fattorini S (2008) Ecology and conservation of tenebrionid beetles in Mediterranean coastal areas. In: Fattorini S, (Ed.) Insect ecology and conservation. Trivandrum, Kerala: Research Signpost, pp 165–297.

Fattorini S and Baselga A (2012) Species richness and turnover patterns in European tenebrionid beetles. Insect Conservation and Diversity 5: 331-345. https://doi.org/10.1111/j.1752-4598.2011.00164.x.

Fernández-Palacios JM, Kreft H, Irl SD, Norder S, Ah-Peng C, Borges PA, Burns KC, de Nascimento L, Meyer JY, Montes E, Drake DR (2021) Scientists' warning–The outstanding biodiversity of islands is in peril. Global Ecology and Conservation 31: e01847. https://doi.org/10.1016/j.gecco.2021.e01847.

Friend D (2023). quadtree: Region Quadtrees for Spatial Data. https://github.com/dfriend21/quadtree/, https://dfriend21.github.io/quadtree/.

Frishkoff LO, Gabot E, Sandler G, Marte C, Mahler DL (2019) Elevation shapes the reassembly of Anthropocene lizard communities. Nature Ecology and Evolution 3: 638–646. https://doi.org/10.1038/s41559-019-0819-0.

Garnett ST, Christidis L (2017) Taxonomy anarchy hampers conservation. Nature 546: 25–27. https://doi.org/10.1038/546025a.

Gaspar C, Gaston KJ, Borges PAV, Cardoso P (2010) Selection of priority areas for arthropod conservation in the Azores archipelago. Journal of Insect Conservation 15(5): 671–684. https://doi:10.1007/s10841-010-9365-4.

Geldmann J, Barnes M, Coad L, Craigie ID, Hockings M, Burgess ND (2013) Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. Biological Conservation 161: 230–238. https://doi:10.1016/j.biocon.2013.02.018.

Guardiola M and Sáez L (2023) Are Mediterranean Island Mountains Hotspots of Taxonomic and Phylogenetic Biodiversity? The Case of the Endemic Flora of the Balearic Islands. Plants 12(14): 2460. https://doi.org/10.3390/plants12142640.

Habel JC and Schmitt T (2018) Vanishing of the common species: Empty habitats and the role of genetic diversity. Biological Conservation 218: 211–216. https://doi:10.1016/j.biocon.2017.12.018.

Habel JC, Ulrich W, Biburger N, Seibold S and Schmitt T (2019) Agricultural intensification drives butterfly decline. Insect Conserv Divers 12: 289-295. https://doi.org/10.1111/icad.12343.

Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H, Stenmans W, Müller A, Sumser H, Hörren, Goulson D, de Kroon H (2017) More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLOS ONE, 12(10): e0185809. https://doi.org/10.1371/journal.pone.0185809.

Harry I, Höfer H, Schielzeth H, Assmann T (2019) Protected habitats of Natura 2000 do not coincide with important diversity hotspots of arthropods in mountain grasslands. Insect Conservation and Diversity 12: 329-338. https://doi:10.1111/icad.12349.

Harvey JA et al. (2022) Scientists' warning on climate change and insects. Ecological Monographs. e1553. https://doi.org/10.1002/ecm.1553.

Hijmans R (2022) terra: Spatial Data Analysis. R package version 1.7-55. https://CRAN.R-project.org/package=terra.

Hochkirch A, Schmitt T, Beninde J, Hiery M, Kinitz T, Kirschey J, Matenaar D, Rohde K, Stoefen A, Wagner N, Zink A, Lötters S, Veith M, Proelss A (2013) Europe Needs a New Vision for a Natura 2020 Network. Conservation Letters 6: 462-467. https://doi.org/10.1111/conl.12006.

Hochkirch A, Nieto A, García Criado M, Cálix M, et al. (2016) European Red List of Grasshoppers, Crickets and Bush-crickets. Luxembourg: Publications Office of the European Union.

Hortal J, de Bello F, Diniz-Filho JAF, Lewinsohn TM, Lobo JM, Ladle RJ (2015) Seven Shortfalls that Beset Large-Scale Knowledge of Biodiversity. Annual Review of Ecology, Evolution, and Systematics 46(1): 523–549. https://doi:10.1146/annurev-ecolsys-112414-054400.

Hurlbert AH, Jetz W (2007) Species richness, hotspots, and the scale dependence of range maps in ecology and conservation. Proceedings of the National Academy of Sciences 104(33):13384-13389. doi:10.1073/pnas.0704469104

Ichihara Y G, Okabe M, Iga K, Tanaka Y, Musha K, Ito K (2008) Color universal design: the selection of four easily distinguishable colors for all color vision types. Proc. SPIE 6807, Color Imaging XIII: Processing, Hardcopy, and Applications, 68070O. https://doi.org/10.1117/12.765420

Igea J and Tanentzap AJ (2021) Global topographic uplift has elevated speciation in mammals and birds over the last 3 million years. Nature Ecology and Evolution 5: 1530–1535. https://doi.org/10.1038/s41559-021-01545-6.

Iniesta LFM, Bouzan RS, Means JC et al. (2023) Where are they from and where are they going? Detecting areas of endemism, distribution patterns and conservation status of the order

Spirostreptida in Brazil (Diplopoda, Juliformia). Biodivers Conserv 32: 1591–1615. https://doi.org/10.1007/s10531-023-02566-2.

IPBES (2019) Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). IPBES secretariat, Bonn, Germany. 1148 pages. https://doi.org/10.5281/zenodo.3831673

IUCN Red List of Threatened Species. Version 2022-2. https://www.iucnredlist.org Accessed : 12/2022.

IUCN (2016). A Global Standard for the Identification of Key Biodiversity Areas, Version 1.0 . First edition. Gland, Switzerland

Johnson CN, Balmford A, Brook BW, Barry WB, Buttel JC, Galetti M, Guangchun L, Wilmshurst JM (2017) Biodiversity losses and conservation responses in the Anthropocene. Science. 356 (6335): 270–275. https://doi:10.1126/science.aam9317.

Jong Yd, Verbeek M, Michelsen V, Bjørn Pde P, Los W, Steeman F, Bailly N, Basire C, Chylarecki P, Stloukal E, Hagedorn G, Wetzel FT, Glöckler F, Kroupa A, Korb G, Hoffmann A, Häuser C, Kohlbecker A, Müller A, Güntsch A, Stoev P, Penev L (2014) Fauna Europaea - all European animal species on the web. Biodivers Data J. 2014 Sep 17;(2):e4034. doi: 10.3897/BDJ.2.e4034.

Kairis O, Karavitis C, Salvati L, Kounalaki A, Kosmas K (2015) Exploring the Impact of Overgrazing on Soil Erosion and Land Degradation in a Dry Mediterranean Agro-Forest Landscape (Crete, Greece). Arid Land Research and Management 29(3): 360–374. https://doi:10.1080/15324982.2014.968691.

Kalkman VJ, Boudot JP, Bernard R, Conze KJ, De Knijf G, Dyatlova E, Ferreira S, Jović M, Ott J, Riservato E, Sahlén G (2010) European Red List of Dragonflies. Luxembourg: Publications Office of the European Union.

Kaltsas D, Trichas A, Kougioumoutzis K, Chatzaki M (2013) Ground beetles respond to grazing at assemblage level, rather than species-specifically: the case of Cretan shrublands. Journal of Insect Conservation 17(4): 681 – 697. https://doi.org/10.1007/s10841-013-9553-0.

Kaltsas D, Panayiotou E, Kougioumoutzis K, Chatzaki M (2019) Overgrazed shrublands support high taxonomic, functional and temporal diversity of Mediterranean ground spider assemblages. Ecological Indicators, 103: 599–609 https://doi:10.1016/j.ecolind.2019.04.024.

Karam-Gamael M, Izzo T, Chagas-Jr A (2018) Why be red listed? Threatened Myriapoda species in Brazil with implications for their conservation. ZooKeys 741: 255 – 269. https://doi: 10.3897/zookeys.741.21971.

Key Biodiversity Areas Partnership (2024) Key Biodiversity Areas factsheet: Mount Asterousia (Kofinas), Crete. Extracted from the World Database of Key Biodiversity Areas. Developed by the Key Biodiversity Areas Partnership: BirdLife International, IUCN, American Bird Conservancy, Amphibian Survival Alliance, Conservation International, Critical Ecosystem Partnership Fund, Global Environment Facility, Re:wild, NatureServe, Rainforest Trust, Royal Society for the Protection of Birds, World Wildlife Fund and Wildlife Conservation Society. Downloaded from https://keybiodiversityareas.org/ on 31/01/2024.

Kidane YO, Steinbauer MJ, Beierkuhnlein C (2019) Dead end for endemic plant species? A biodiversity hotspot under pressure. Global Ecology and Conservation, e00670. https://doi:10.1016/j.gecco.2019.e00670.

Klink van R, Bowler DE, Gongalsky KB, Shen M, Swengel AB and Chase JM (2023) Disproportionate declines of formerly abundant species underlie insect loss. Nature. https://doi.org/10.1038/s41586-023-06861-4

Klink van R, Bowler DE, Gongalsky KB, Swengel AB, Gentile A, Chase JM (2020) Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. Science 368(6489): 417–420. https://doi:10.1126/science.aax9931.

Kosmas C, Detsis V, Karamesouti M, Kounalaki K, Vassiliou P, Salvati L (2015) Exploring Long-Term Impact of Grazing Management on Land Degradation in the Socio-Ecological System of Asterousia Mountains, Greece. Land 4(3): 541-559. https://doi.org/10.3390/land4030541.

Kougioumoutzis K, Valli AT, Georgopoulou E, Simaiakis SM, Triantis KA, Trigas P (2017) Network biogeography of a complex island system: the Aegean Archipelago revisited. Journal of Biogeography 44: 651-660. https://doi.org/10.1111/jbi.12920.

Kougioumoutzis K, Kokkoris IP, Panitsa M, Trigas P, Strid A, Dimopoulos P (2020) Plant Diversity Patterns and Conservation Implications under Climate-Change Scenarios in the Mediterranean: The Case of Crete (Aegean, Greece). Diversity 12(7): 270. https://doi.org/10.3390/d12070270.

Kougioumoutzis K, Kokkoris IP, Panitsa M, Kallimanis A, Strid A, Dimopoulos P (2021a) Plant Endemism Centres and Biodiversity Hotspots in Greece. Biology 10(2): 72. https://doi.org/10.3390/biology10020072.

Kougioumoutzis K, Kokkoris IP, Panitsa M, Strid A, Dimopoulos P (2021b) Extinction Risk Assessment of the Greek Endemic Flora. Biology 10(3): 195. https://doi.org/10.3390/biology10030195.

Koutroulis AG, Vrohidou AEK, Tsanis IK (2011) Spatiotemporal Characteristics of Meteorological Drought for the Island of Crete. Journal of Hydrometeorology 12(2): 206–226. https://doi:10.1175/2010jhm1252.1.

Koutroulis AG, Tsanis IK, Daliakopoulos IN, Jacob D (2013) Impact of climate change on water resources status: A case study for Crete Island, Greece. Journal of Hydrology 479: 146–158. https://doi.org/10.1016/j.jhydrol.2012.11.055.

Legakis A, Constantinidis T, Petrakis PV (2018) Biodiversity in Greece. In: Pullaiah T (ed) Global biodiversity. Apple Academic Press Inc., London, pp 71–124.

Lim D, Starnes T and Plumptre AJ (2023) Global priorities for biodiversity conservation in the United Kingdom. Biological Conservation 277: 109798. https://doi.org/10.1016/j.biocon.2022.109798

Lehmann GUC, Bakanov N, Behnisch M et al (2021) Diversity of Insects in Nature protected Areas (DINA): an interdisciplinary German research project. Biodiversity and Conservation 30: 2605–2614. https://doi.org/10.1007/s10531-021-02209-4.

Mammides C (2019) European Union’s conservation efforts are taxonomically biased. Biodivers Conserv 28, 1291–1296. https://doi.org/10.1007/s10531-019-01725-8.

Mammola S, Riccardi N, Prié V, Correia R, Cardoso P, Lopes-Lima M, Sousa R (2020) Towards a taxonomically unbiased European Union biodiversity strategy for 2030. Proceedings in Royal Science B: Biological Sciences 287(1940): 20202166. doi: 10.1098/rspb.2020.2166.

Margules, C, Pressey, R (2000) Systematic conservation planning. Nature 405, 243–253. https://doi.org/10.1038/35012251

Médail F, and Quezel P (1997) Hot-spots analysis for conservation of plant biodiversity in the Mediterranean Basin. Annals of the Missouri Botanical Garden 84: 112–127. https://doi.org/10.2307/2399957.

Médail F (2017) The specific vulnerability of plant biodiversity and vegetation on Mediterranean islands in the face of global change. Regional Environmental Change. 17: 1775–1790. https://doi.org/10.1007/s10113-017-1123-7.

Meng H, Gao X, Song Y, Cao G, Li J (2021) Biodiversity arks in the Anthropocene. Regional Sustainability 2(2): 109–115. https://doi:10.1016/j.regsus.2021.03.001.

Mo Y., Kim G H, Huber R P, Thorne H J, Hijioka Y, Lee K D (2019) Influences of planning unit shape and size in landscapes dominated by different land-cover types on systematic conservation planning, Global Ecology and Conservation, Volume 20, e00739, ISSN 2351-9894, https://doi.org/10.1016/j.gecco.2019.e00739.

Muellner-Riehl AN (2019) Mountains as Evolutionary Arenas: Patterns, Emerging Approaches, Paradigm Shifts, and Their Implications for Plant Phylogeographic Research in the Tibeto-Himalayan Region. Frontiers in Plant Science 10: https:/doi:10.3389/fpls.2019.00195

Mühle H, Brandl P and Niehuis M (2000) CATALOGUS FAUNAE GRAECIAE Coleoptera: Buprestidae. Ausburg, Selbstverlag.

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403, 853–858. https://doi.org/10.1038/35002501.

Neubert E, Seddon MB, Allen DJ, Arrébola J, et al. (2019) European Red List of Terrestrial Molluscs. IUCN: Cambridge, UK and Brussels, Belgium. https://portals.iucn.org/library/node/48439.

Nhancale, B.A., Smith, R.J (2011) The influence of planning unit characteristics on the efficiency and spatial pattern of systematic conservation planning assessments. Biodivers Conserv 20, 1821–1835. https://doi.org/10.1007/s10531-011-0063-7

Nieto A, Roberts SPM, Kemp J, Rasmont P, Kuhlmann M, García Criado M, Biesmeijer JC, Bogusch P, Dathe HH, De la Rúa P, De Meulemeester T, Dehon M, Dewulf A, Ortiz-Sánchez FJ, Lhomme P, Pauly A, Potts SG, Praz C, Quaranta M, Radchenko VG, Scheuchl E, Smit J, Straka J, Terzo M, Tomozii B, Window J and Michez D (2014) European Red List of bees. Luxembourg: Publication Office of the European Union.

Noroozi J, Talebi A, Doostmohammadi M, Rumpf SB, Linder HP, Schneeweiss GM (2018) Hotspots within a global biodiversity hotspot - areas of endemism are associated with high mountain ranges. Scientific Reports 8: 10345. https://doi.org/10.1038/s41598-018-28504-9.

Oertzen E. v. (1886) Verzeichniss der Coleopteren Griechenlands und Cretas, nebst einigen Bemerkungen über ihre geographische Verbreitung und 4 die Zeit des Vorkommens einiger Arten betreffenden Sammelberichten. – Berliner Entomologische Zeitschrift 30 [1886] (2): 189–293.

Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'Hara R, Solymos P, Stevens M, Szoecs E, Wagner H, Barbour M, Bedward M, Bolker B, Borcard D, Carvalho G, Chirico M, De Caceres M, Durand S, Evangelista H, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill M, Lahti L, McGlinn D, Ouellette M, Ribeiro Cunha E, Smith T, Stier A, Ter Braak C, Weedon J (2022) vegan: Community Ecology Package. R package version 2.6-4, https://CRAN.R-project.org/package=vegan.

Pizarro-Araya J, Alfaro FM, Ojanguren-Affilastro AA, Moreira-Muñoz A (2021) A Fine-Scale Hotspot at the Edge: Epigean Arthropods from the Atacama Coast (Paposo-Taltal, Antofagasta Region, Chile). Insects 12(10): 916. https://doi.org/10.3390/insects12100916.

Pebesma E (2018) Simple Features for R: Standardized Support for Spatial Vector Data. The R Journal 10 (1): 439-446. https://doi.org/10.32614/RJ-2018-009.

Potapov AM, Dupérré N, Jochum M, Dreczko K, Klarner B, Barnes AD, Krashevska V, Rembold K, Kreft H, Brose U, Widyastuti R, Harms D and Scheu S (2019) Functional losses in ground spider communities due to habitat structure degradation under tropical land-use change. Ecology 101(3): e02957. https://doi.org/10.1002/ecy.2957.

Poulakakis N, Kapli P, Lymberakis P, Trichas A, Vardinoyiannis K, Sfenthourakis S, Mylonas M (2014) A review of phylogeographic analyses of animal taxa from the Aegean and surrounding regions. Journal of Zoological Systematics and Evolutionary Research, 53(1): 18–32. https://doi:10.1111/jzs.12071.

Plumptre AJ, Baisero D, Brooks TM, Buchanan G, Butchart SHM, Bowser A, Boyd C, Carneiro APB, Davies T, Elliot W, Foster M, Langhammer PF, Marnewick D, Matiku P, McCreless E, Raudsepp-Hearne C, Tordoff AW, Azpiroz AB, Trisurat Y and Upgren A (2024) Targeting site conservation to increase the effectiveness of new global biodiversity targets. One Earth 7(1): 11-17. https://doi.org/10.1016/j.oneear.2023.12.007

R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rackham O and Moody J (1996) The Making of the Cretan Landscape. Manchester University Press, 237 pp.

Rahbek C, Borregaard MK, Antonelli A, Colwell RK, Holt BG, Nogues-Bravo D, Rasmussen CMØ, Richardson K, Rosing MT, Whittaker RJ, Fjeldså J (2019a) Building mountain biodiversity: Geological and evolutionary processes. Science. Sep 13;365(6458):1114-1119. doi: 10.1126/science.aax0151.

Rahbek C, Borregaard MK, Colwell RK, Dalsgaard B, Holt BG, Morueta-Holme N, Nogues-Bravo D, Whittaker RJ, Fjeldså J (2019b) Humboldt's enigma: What causes global patterns of mountain biodiversity? Science 365(6458): 1108–1113. https://doi:10.1126/science.aax0149

Raposo MA, Stopiglia R, Brito GRR, Bockmann, FA, Kirwan GM, Gayon J, Dubois A (2017) What really hampers taxonomy and conservation? A riposte to Garnett and Christidis (2017). Zootaxa, 4317(1): 179-184. https://doi:10.11646/zootaxa.4317.1.10.

Raven PH and Wagner DL (2021) Agricultural intensification and climate change are rapidly decreasing insect biodiversity. PNAs vol. 118(2): 2 e2002548117. https://doi.org/10.1073/pnas.2002548117.

Rada S, Schweiger O, Harpke A, Kühn E, Kuras T, Settele, Musche M (2019) Protected areas do not mitigate biodiversity declines: A case study on butterflies. Biodiversity Research 25: 217– 224. https://doi.org/10.1111/ddi.12854.

Roth N, Zoder S, Zaman AA, Thorn S, Schmidl J (2020) Long-term monitoring reveals decreasing water beetle diversity, loss of specialists and community shifts over the past 28 years. Insect Conservation and Diversity, 13(2): 140–150. https://doi:10.1111/icad.12411.

Salata S, Borowiec L, Trichas A (2020a). Review of ants (Hymenoptera: Formicidae) of Crete, with keys to species determination and zoogeographical remarks. Monographs of the Upper Silesian Museum 12, 5–296. http://doi.org/10.5281/zenodo.3738001.

Salata S, Kalarus K, Borowiec L, Trichas A, Kujawa K (2020b). How estimated ant diversity is biased by the sampling method? A case study of Crete: a Mediterranean biodiversity hotspot. Biodiversity Conservation 29: 3031–3050. https://doi.org/10.1007/s10531-020-02014-5.

.

Sánchez-Bayo F and Wyckhuys KAG (2019). Worldwide decline of the entomofauna: A review of its drivers. Biological Conservation 232: 8–27. https://doi:10.1016/j.biocon.2019.01.020.

Sánchez-Fernández D, Bilton DT, Abellán P, Ribera I, Velasco J, Millán A (2008) Are the endemic water beetles of the Iberian Peninsula and the Balearic Islands effectively protected? Biological Conservation, 141(6): 1612–1627 https://doi:10.1016/j.biocon.2008.04.005.

Schmalfuss H, Paragamian K and Sfenthourakis S (2004) The terrestrial isopods (Isopoda: Oniscidea) of Crete and the surrounding islands. Stuttgarter Beiträge Zur Naturkunde, Series A 662: 1-77.

Sfenthourakis S and Legakis A (2001) Hotspots of endemic terrestrial invertebrates in southern Greece. Biodiversity and Conservation 10: 1387–1417. https://doi.org/10.1023/A:1016672415953.

Sfenthourakis S and Schmalfuss H (2018) Biogeography of Greek Terrestrial Isopods. In: Sfenthourakis S, Pafilis P, Parmakelis A, Poulakakis N, Triantis K (Eds.) Biogeography and Biodiversity of Aegean. In Honour of Prof. Moysis Mylonas. Broken Hill Ltd, pp 91-105.

Spiliopoulou K, Dimitrakopoulos PG, Brooks TM et al (2021) The Natura 2000 network and the ranges of threatened species in Greece. Biodiversity Conservation 30: 945–961. https://doi.org/10.1007/s10531-021-02125-7.

Steinbauer MJ, Field R, Grytnes J-A, Trigas P, Ah-Peng C, Attorre F, Birks HJB, Borges PAV, Cardoso P, Chou C-H, De Sanctis M, de Sequeira MM, Duarte MC, Elias RB, Fernández-Palacios JM, Gabriel R, Gereau RE, Gillespie RG, Greimler J, Harter DEV, Huang T-J, Irl SDH, Jeanmonod D, Jentsch A, Jump AS, Kueffer C, Nogué S, Otto R, Price J, Romeiras MM, Strasberg D, Stuessy T, Svenning,J-C, Vetaas OR, Beierkuhnlein C (2016) Topography-driven isolation, speciation and a global increase of endemism with elevation. Global Ecology and Biogeography 25: 1097-1107. https://doi.org/10.1111/geb.12469.

Steinbauer MJ, Grytnes JA, Jurasinski G et al. (2018) Accelerated increase in plant species richness on mountain summits is linked to warming. Nature 556: 231–234 https://doi.org/10.1038/s41586-018-0005-6.

Stévart T, Dauby G, Lowry II PP, Blach-Overgaard A, Droissart V, Harris DJ, Mackinder BA, Schatz GE, Sonké B, Sosef M, Svenning J-C, Wieringa JJ, Couvreur TLP (2019) A third of the tropical African flora is potentially threatened with extinction. Science Advances 5(11): eaax9444. https://doi:10.1126/sciadv.aax9444.

Stork N (2018) How many species of insects and other terrestrial arthropods are there on Earth? Annual Review of Entomology 63: 31–45. https://doi.org/10.1146/annurev-ento-020117-043348.

Stuessy TF, Jakubowsky G, Salguerò Gómez R, Pfosser M, Schlüter PM, Fer T, Sun BY, Kato H (2006) Anagenetic evolution in island plants. Journal of Biogeography 33: 1259 - 1265. https://doi.org/10.1111/j.1365-2699.2006.01504.x.

Triantis KA, Borges PAV, Ladle RJ, Hortal J, Cardoso P, Gaspar C, Dinis F, Mendonça O, Silveira LMA, Gabriel R, Melo C, Santos AMC, Amorim IR, Ribeiro SV, Serrano ARM, Quartau JA, Whittaker RJ (2010). Extinction debt on oceanic islands. Ecography 33: 285–294. https://doi.org/10.1111/ j.1600-0587.2010.06203.x.

Trichas A (1996). Ecology and Biogeography of ground-living Coleoptera in South Aegean arc. PhD Dissertation, University of Crete, Biology Department.

Trichas A, Smirli M, Papadopoulou A, Anastasiou I, Keskin B, Poulakakis N (2020) Dispersal versus vicariance in the Aegean: combining molecular and morphological phylogenies of Eastern Mediterranean Dendarus (Coleoptera: Tenebrionidae) sheds new light on the phylogeography of the Aegean area. Zoological Journal of the Linnean Society XX: 1–20. https://doi:10.1093/zoolinnean/zlaa022 .

Trigas P, Panitsa M, Tsiftsis S (2013) Elevational Gradient of Vascular Plant Species Richness and Endemism in Crete – The Effect of Post-Isolation Mountain Uplift on a Continental Island System. PLoS ONE 8(3): e59425. https://doi:10.1371/journal.pone.0059425.

Tzanakakis VA, Angelakis AN, Paranychianakis NV, Dialynas YG, Tchobanoglous G (2020) Challenges and Opportunities for Sustainable Management of Water Resources in the Island of Crete, Greece. Water 12(6): 1538. https://doi:10.3390/w12061538.

Tzoraki O, Kritsotakis M, Baltas E (2014) Spatial water use efficiency index towards resource sustainability: application in the island of Crete, Greece. International Journal of Water Resources Development 31(4) 669–681. https://doi.org/10.1080/07900627.2014.949637.

Urban MC (2018). Escalator to extinction. Biological Sciences 115 (47): 11871-11873 https://doi.org/10.1073/pnas.1817416115.

Van Swaay C, Cuttelod A, Collins S, Maes D, López Munguira M, Šašić M, Settele J, Verovnik R, Verstrael T, Warren M, Wiemers M and Wynhof I (2010) European Red List of Butterflies Luxembourg: Publications Office of the European Union.

Vardinoyannis K. (1994). Biogeography of the land mollusks at the south Aegean arc. PhD Dissertation, University of Athens, Biology Department.

Vardinoyannis K, Parmakelis A, Triantis KA, Giokas S (2018) Land Molluscs in Greece: The Rich, Unique, Diverse and Unprotected Animal Models. In: Sfenthourakis S, Pafilis P, Parmakelis A, Poulakakis N, Triantis K (Eds.) Biogeography and Biodiversity of Aegean. In Honour of Prof. Moysis Mylonas. Broken Hill Ltd, pp 47-66.

Vitali F and Schmitt T (2017) Ecological patterns strongly impact the biogeography of Western Palearctic longhorn beetles (Coleoptera: Cerambycoidea). Organisms Diversity and Evolution 17: 163-180. https://doi.org/10.1007/s13127-016-0290-6.

Verovnik R, Govedič M, Šalamun A (2011) Is the Natura 2000 network sufficient for conservation of butterfly diversity? A case study in Slovenia. Journal of Insect Conservation 15: 345–350. https://doi.org/10.1007/s10841-010-9308-0.

Venter O, Magrach A, Outram N, Klein CL, Possingham HP, di Marco M and Watson JEM (2018) Bias in protected-area location and its effects on long-term aspirations of biodiversity conventions. Conservation Biology 32: 127–134. https://doi.org/10.1111/cobi.12970

Wagner DL (2019) Global insect decline: Comments on Sánchez-Bayo and Wyckhuys (2019) Biological Conservation 233: 332-333. https://doi:10.1016/j.biocon.2019.03.005.

Wagner DL (2020) Insect declines in the anthropocene. Annual Review of Entomology 65: 457–480. https://doi.org/10.1146/annurevento-011019-025151.

Wagner DL, Grames EM, Forister ML, Berenbaum MR, Stopak D (2021) Insect decline in the Anthropocene: Death by a thousand cuts. PNAs vol. 118(2): 2 e2023989118. https://doi.org/10.1073/pnas.2023989118.

Wang Z, Zeng J, Meng W, Lohman DJ, Pierce NE (2021) Out of sight, out of mind: public and research interest in insects is negatively correlated with their conservation status. Insect Conserv Divers, 14: 700-708. https://doi.org/10.1111/icad.12499.

Whittaker RJ and Fernández-Palacios JM (2007). Island Biogeography. Ecology, evolution and conservation. Oxford University Press, Oxford.

Wickham H. (2016) ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York

Wilkinson, M., Dumontier, M., Aalbersberg, I. et al. The FAIR Guiding Principles for scientific data management and stewardship. Sci Data 3, 160018 (2016). https://doi.org/10.1038/sdata.2016.18

Willemse L, Tilmans J, Kotitsa N, Trichas A, Heller K-G, Chobanov D, Odé B (2023) A review of Eupholidoptera (Orthoptera, Tettigoniidae) from Crete, Gavdos, Gavdopoula, and Andikithira. ZooKeys 1151: 67-158. https://doi.org/10.3897/zookeys.1151.97514.

Winkler K, Fuchs R, Rounsevell M and Herold M (2021) Global land use changes are four times greater than previously estimated. Nature Communications 12: 2501. https://doi.org/10.1038/s41467-021-22702-2

Yadav S, Stow AJ, Harris RM, Dudaniec RY (2018) Morphological Variation Tracks Environmental Gradients in an Agricultural Pest, Phaulacridium Vittatum (Orthoptera: Acrididae). Journal of Insect Science 18: 13. https://doi.org/10.1093/jisesa/iey121.

Zhang ZQ (2013) Animal biodiversity: An update of classification and diversity in 2013. In: Zhang, Z.-Q. (Ed.) Animal Biodiversity: An Outline of Higher-level Classification and Survey of Taxonomic Richness (Addenda 2013). Zootaxa 3703 (1): 005-011. http://dx.doi.org/10.11646/zootaxa.3703.1.3