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Temporal Variation in and Influence of Environmental Variables on a Lepidopteran Community in a Mediterranean Mid-Mountain Area

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Abstract: The temporal variation in a community of nocturnal and diurnal Lepidoptera was studied in a Mediterranean mid-mountain area of the SW Iberian Peninsula between 2017 and 2019. Monthly samplings that allowed for the identification of 3528 specimens, belonging to 373 species from 40 different families, also provided data on the temporal and seasonal variation in richness and the abundance (dominated by Geometridae and Noctuidae), diet type (mainly oligophagous), voltinism (mostly univoltine) and biogeography of the community, primarily Mediterranean in scope. Richness, abundance and diversity were also found to be highly positively correlated with temperature and solar radiation, and less negatively correlated with precipitation and humidity. Canonical correspondence analyses (CCAs) also indicate that temperature and radiation are the climatic variables with the greatest influence on species occurrence over the different months of the year. The CCAs gave a cumulative variance value of 84.79% when using the monthly mean values of temperature, solar radiation and minimum relative humidity, and 86.4% if only monovoltine species were considered. Guidelines to maintain diversity in the environment of the study area are provided. It is possible that the area may function as a refuge area for Lepidoptera in the face of climate change and deforestation that are occurring in the geographical environment.

Keywords: Lepidoptera; species richness; abundance; diversity conservation; Mediterranean area

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1. Introduction

Human activity has caused the deterioration of the biosphere, resulting in the extinction of numerous species [1]. The accelerated destruction and transformation of the natural environment, both through direct human action (fires, changes in land use, overgrazing, etc.) and inaction (abandonment of traditional crops or grazing), means that many species, including Lepidoptera, may disappear from large areas [2–4] even before their presence is known, although how to quantify this phenomenon is still poorly understood. One of the most studied effects of anthropogenic influence is climate change caused by the increase in greenhouse gases in the atmosphere [5,6]. Some of its effects on the climate in the Iberian Peninsula are a decrease in precipitation, more accentuated on the Mediterranean coast [7], and an increase in arid conditions, mainly in summer [8]. Globally, rising temperatures cause species to migrate to higher-altitude or higher-latitude settings, fleeing or expanding in response to the increasing temperatures [3,9]. Many species, including butterflies, have modified their range, phenology (with negative effects on plant–host synchrony) or migration dates in response to climate change [3,10–13]. In tropical areas, changes in land use represent one of the most important anthropogenic effects on Lepidoptera communities (e.g., [14]).

The influence of climatic variables on inter-annual oscillations in moth abundance is well known and particularly significant in temperate mid-latitude environments in Europe.

In the British Isles, many moth species have experienced declines in their ranges and populations, while others have shifted or even expanded their ranges northwards as a result of climate change [15]. In the Netherlands, a decline in the number of large moths has also been recorded due to the effects of climate change [16]. Butterflies are more affected by the mean temperature and total precipitation than by extreme climatic events such as drought or land-use changes [17]. Annual fluctuations in the abundance of various British moth species have also been found to be affected by environmental variables, with positive correlations with temperature and negative correlations with precipitation detected [18]. A study under controlled laboratory conditions on three diurnal species (Lycaenidae) found that extremely high temperatures have a greater effect on populations than an increase in average temperature. Moreover, this negative effect decreases during development; that on eggs is more intense than that on larvae, pupae and adults. These effects of stress in early stages are transferred to later stages, reducing the survival rate for individuals [19]. On the other hand, in northern Europe, many moth species have experienced increases in their populations and ranges, showing that they have been favoured by recent climatic and environmental changes [20–23].

Knowledge of the biology, size and distribution of Lepidoptera populations and their relationships with the environment is insufficient in many areas of the Iberian Peninsula [24–26]. In work carried out in the northeast of the Iberian Peninsula, advances in butterfly flight phenology in response to the progressive increase in temperatures have been documented [27,28]. When comparing different butterfly communities, climatic parameters have been found to explain more than 80% of the total variance in species richness in regression models [29]. Greater declines have been observed in the populations of habitat specialist butterflies than the generalist species. This phenomenon is more intense in open spaces than in forests due to the abandonment of grazing and mowing [30,31]. Species that prefer closed habitats have increased following the process of shrub encroachment, a phenomenon that is accentuated in environments with less vegetation diversity and warmer conditions [4]. These authors have also recorded extinction episodes that mainly affect species in open habitats. On the other hand, the importance of water availability as a limiting factor in Mediterranean ecosystems has been noted [32], in addition to the fundamental effect of temperature (positive correlation) on butterfly richness in cold mountain climates (and microclimates). The highest butterfly diversity has been recorded in the altitudinal ranges 500–700 m and 1200–1500 m, demonstrating the great importance of high altitudes for lepidopteran conservation [33]. Related to the above, the optimal health of nutrient plants increases the survival rates for *Pieris napi* (Linnaeus, 1758) caterpillar populations at 500 m and 1031 m. Therefore, at these altitudes, the negative impact of high temperatures is dampened [34]. In more southern areas of the central Iberian Peninsula, it has been observed that greater forest cover and a greater variety of local topography have delayed the impact of climate change on the composition of these communities [35]. Local climatic variations related to topographic differences allow for species to seek cooler and wetter microclimates on north-facing slopes or in narrow valleys [36], or to ascend to higher elevations [37]. In the Sierra de Guadarrama (central Iberian Peninsula), the richness, abundance and diversity of Geometridae species depend, to a large extent, on the conservation status of the *Quercus* forests. The monthly records show a bimodal curve, with peaks in early summer and autumn [38]. In the south of the Iberian Peninsula, it has been found that moths (Noctuidae), mainly univoltine, that feed on woody plants concentrate their larval stages in spring, when suitable food (young leaves) is more abundant, showing a flight phenology that avoids the hottest summer months, emerging shortly before or after the period of extreme heat [39]. However, captures of Noctuidae moths, both in light and bait traps, increase significantly with temperature [40]. On the other hand, the distribution of Cupido spp. species (Lycaenidae) is conditioned by climatic variables such as precipitation at certain times of the year and the mean annual temperature [41]. In the Sierra Nevada, a hotspot of lepidopteran and other arthropod diversity [42], the altitudinal limit of the protected species *Parnassius apollo nevadensis* Oberthür, 1891, has been documented to have risen by 400 metres as a consequence of the global increase in temperature [43].

Butterflies represent less than 10% of the total number of species of the order Lepidoptera in the Iberian Peninsula [44]. However, most of the work in the Mediterranean area refers only to diurnal Lepidoptera communities. The present study concerns a complete community of Lepidoptera, including diurnal and nocturnal species, located in a mountainous area in the southwest of the Iberian Peninsula. Species richness and abundance records refer to both day- and nighttime sampling. For both reasons, their approach is unprecedented in the Mediterranean area. However, the presence of numerous microlepidopteran species has made this research more difficult, as microscopic slides are essential for correct identifications. In fact, despite the small size of the surveyed area, one new species has been identified during the sampling included in the present study, *Agnoea corteganensis* Bernabé, Huertas, Jiménez and Vives, 2024 [45], and another in the sampling carried out in 2020 and 2021, *Lourdesiella falcatum* Bernabé, Huertas and Vives, 2023 [46]. The objectives of this work were as follows. (1) The first was to study the temporal variation in a community of nocturnal and diurnal Lepidoptera in a Mediterranean mid-mountain area in the SW of the Iberian Peninsula. Data on the monthly and seasonal variations in richness, abundance and diversity, diet type, voltinism and biogeographical ascription of species are provided. (2) The second was to establish the relationship between the specific richness, abundance and Shannon diversity index of the lepidopteran community with different environmental parameters related to temperature, humidity and radiation. The results allow us to establish hypotheses related to the future composition of the lepidopteran community in response to the incidence of climate change and the transformations of the territory that are affecting the area. Guidelines that aim to maintain lepidopteran diversity in the environment of the studied area are also provided.

2. Materials and Methods

2.1. Study Area

This work was carried out in a 0.5 ha plot located within the boundaries of the Sierra de Aracena y Picos de Aroche Natural Park (SW, Iberian Peninsula) (Figure 1). The plot, very representative of the protected area under study, is situated at the bottom of the valley of the Carabaña stream with a dominant NW orientation and an average slope of 20%. The average elevation is 600 m above sea level. Despite its small size, 4 different habitats can be distinguished within the plot: chestnut woodland (habitat of community interest *9260-Castanea sativa woodland*), riparian woodland, orchard and hedgerows. The vegetation around the plot is typically Mediterranean. In the area surrounding the plot within a 3 km radius, 347 vascular plants belonging to 74 different families have been identified. The herbaceous stratum is the most diverse (251 species), followed by the shrub stratum (55 species) and the tree stratum (41 species). The most abundant trees are *Castanea sativa* Mill. and *Quercus suber* L., accompanied by *Pinus pinaster* Aiton. The shrub stratum is dominated by *Arbutus unedo* L., *Daphne gnidium* L., *Erica arborea* L., *Genista falcata* Brot., *Hedera maderensis* subsp. *iberica* McAllister, *Ruscus aculeatus* L., *Myrtus communis* L. and *Viburnum tinus* L. (Figure 2). Small orchards, boundary hedges and gallery forests at the bottom of valleys are also frequent [26].

2.2. Climate

The climate is typically Mediterranean, with a significant temperature variation between the winter and summer months. The average annual rainfall is approximately 1000 mm, concentrated between October and May, with a dry summer period (from June to September). As is characteristic of the Mediterranean area, there is a large inter-annual variation in precipitation, as was the case throughout this study (557 mm in 2017 and 1343 mm in 2018). In general, the coldest months correspond to the wettest months. The climatic data, except for rainfall, were obtained from the agroclimatic station HU008-Aracena, belonging to the Red Andaluza de Información Fitosanitaria (RAIF) [47], located approximately

30 km away at the same altitude and latitude as the study area. Rainfall data were directly measured in the study area due to occasional failures in the agroclimatic station records.

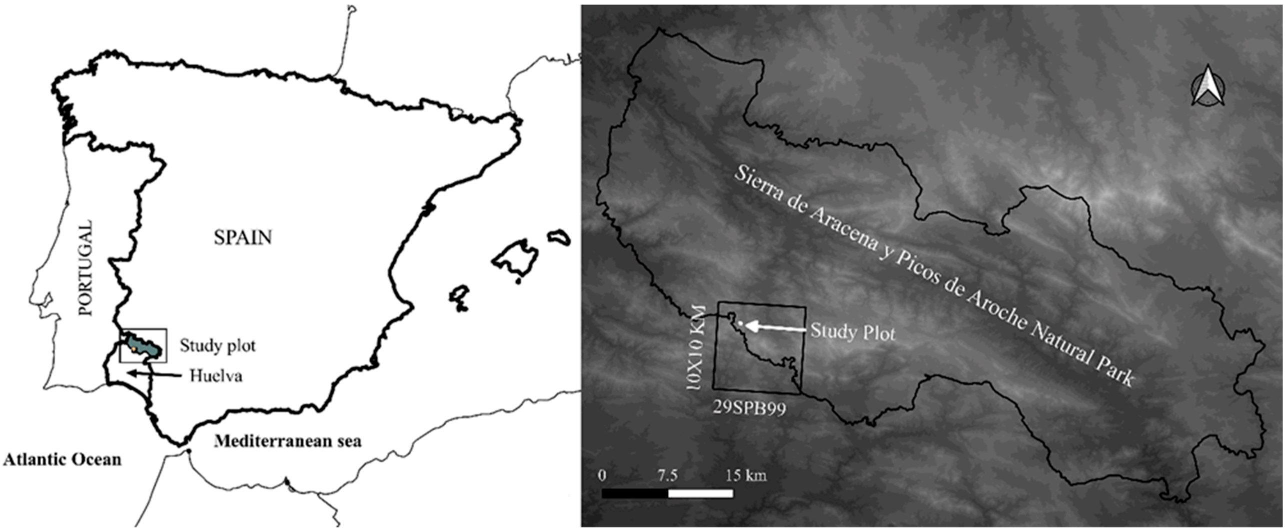

Figure 1. Location of the study plot.

Figure 2. Forest in the study area during autumn.

Large differences were observed in the climatic parameters across the three years studied (Table 1). The year 2017 was the warmest (monthly average maximum temperature (Tma), monthly average temperature (Tme) and monthly average minimum temperature (Tmi)) and driest (total monthly precipitation (Pre), monthly average maximum relative humidity (Hra), monthly average relative humidity (Hrm) and monthly average minimum relative humidity (Hri)). During 2018, the high rainfall led to the highest humidity records of the three years (Hrm, Hra and Hri), coinciding with the lowest temperature values (Tme and Tmi) and the lowest solar radiation record (monthly average solar radiation (Ras)). From a climatic point of view, 2019 showed intermediate values for all environmental parameters, except Ras. The monthly data for climatic parameters are shown in Supplementary Materials (Table S1).

Table 1. Summary of annual climatic parameters: monthly average maximum temperature (Tma), monthly average temperature (Tme), monthly average minimum temperature (Tmi), total monthly precipitation (Pre), monthly average maximum relative humidity (Hra), monthly average relative humidity (Hrm), monthly average minimum relative humidity (Hri) and monthly average solar radiation (Ras).

Year	Tma (°C)	Tme (°C)	Tmi (°C)	Pre (mm)	Hra (%)	Hrm (%)	Hri (%)	Ras (Mj/m^2)
2017	25.0	16.8	10.0	557	79.3	56.2	32.7	15.9
2018	23.1	15.2	9.0	1343	88.5	66.6	40.9	14.8
2019	22.4	16.1	9.9	772	76.6	57.7	37.1	16.1

The monthly average values of Tme, Tma, Tmi and Pre are shown in Figure 3. In 2017, a total rainfall of only 557 mm was recorded, well below the annual average (≈1000 mm) [23], while high summer temperatures extended well into autumn. During 2018, there was much more rainfall (1343 mm), especially in spring, with the March record being 570 mm (more than during the whole of 2017) and lower average monthly temperatures. Finally, 2019 recorded intermediate rainfall data (772 mm) and milder temperatures. All three years suffered from the dry period characteristic of the Mediterranean climate, which runs from May to September, except in 2017, during which it lasted until November. According to these data, 2017 and 2019 can be considered agroclimatically dry years (mainly 2017), although their winters were not [48].

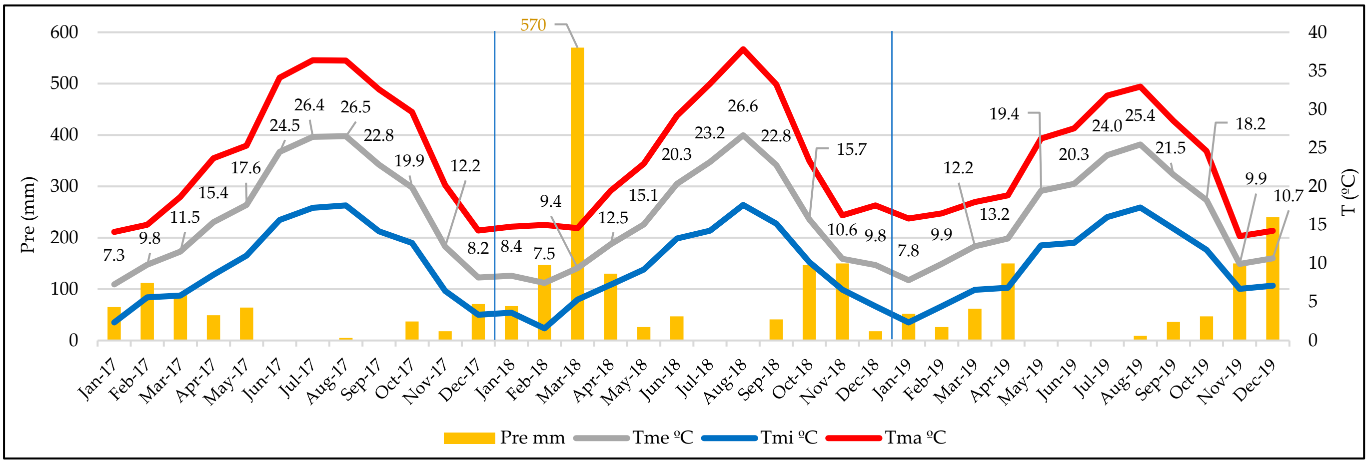

Figure 3. Total monthly precipitation (Pre, mm), monthly average temperature (Tme, °C), monthly average minimum temperature (Tmi, °C) and monthly average maximum temperature (Tma, °C) for the study area during the 2017–2019 period.

2.3. Techniques for Data Collection

Nocturnal and diurnal sampling was carried out monthly between January 2017 and December 2019. For nocturnal sampling, we used two actinic light traps spaced 45 m apart, placed less than 10 m from the gallery forest. The aim of this arrangement was to capture individuals from species with a lower flight capacity. Due to their proximity, the specimens captured at both points have been added together. Light traps have been operated for a minimum of four hours from sunset, coinciding with the period of the maximum activity of these insects [49]. Moonless and windless nights were chosen. On these same sampling days, diurnal transects of 250 m in length were carried out, including the different habitats present in the study area (chestnut grove, orchard, hedgerows and gallery forest) (Figure 4), counting the number of adult individuals observed following the methodology of Pollard and Yate (1993) [50]. The specimens of all Lepidoptera species observed in each diurnal and nocturnal sampling were counted. The captured specimens were deposited in the Faculty of Experimental Sciences of the University of Huelva or in the National Museum of Natural Sciences in Madrid. The preparation of genitalia for the identification of the different species was based on Robinson (1976) [51], using DMHF (2,5-dimethyl-4-hydroxy-3(2H)-furanone) water-soluble resin.

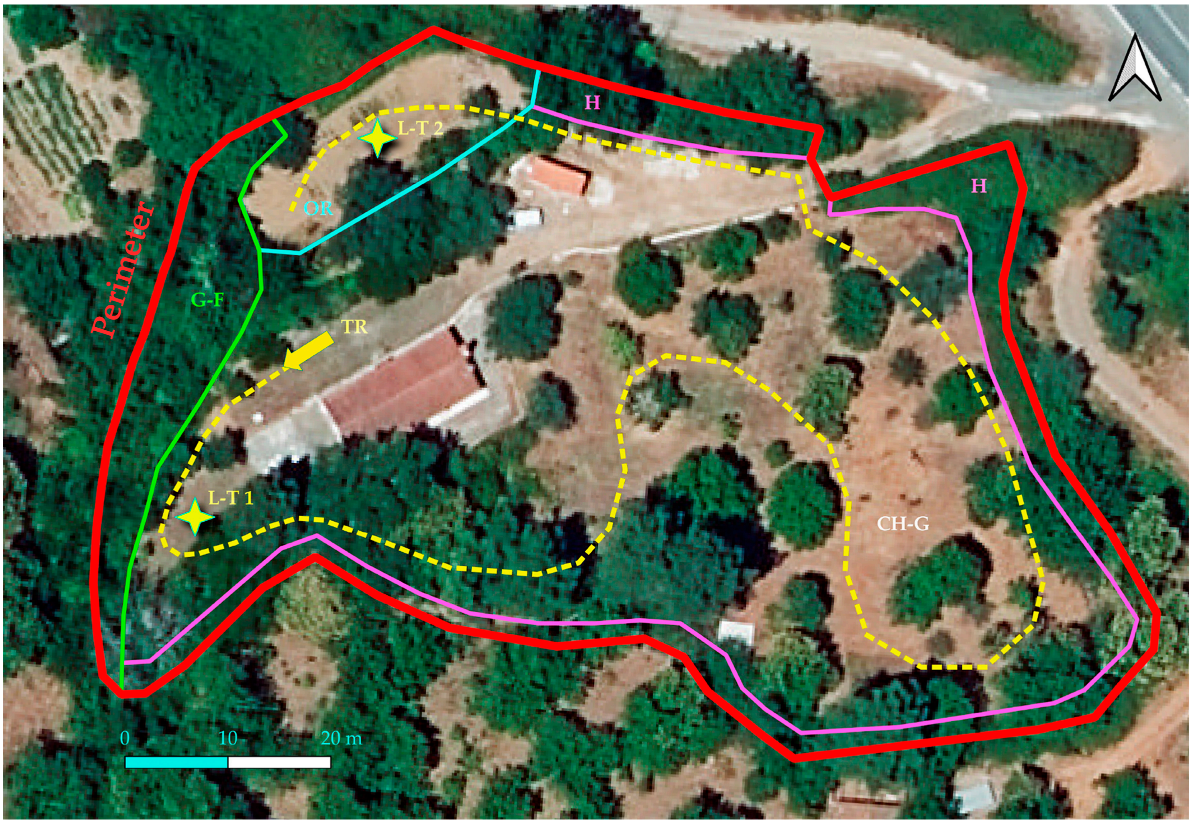

Figure 4. Map of the sampling plot, location of the two light traps and the 250 m transect route. Start of the transect, TR; location of the light traps, L-T 1 and L-T 2; hedgerows, H; chestnut grove, CH-G; orchard, OR; gallery forest, G-F.

The characteristics of the 373 species identified in the study area during the 2017–2019 period have been described in previous work [45]. Specifically, for each species, the monthly flight phenology, number of generations, biogeographic ascription (Atlanto-Mediterranean, Asiatic-Mediterranean, Cosmopolitan, Endemic, Eurasian, Holarctic, Palaearctic or Subtropical) and type of feeding (monophagous, oligophagous, polyphagous, detritus or unknown), among other parameters, are detailed. In the present study, the monthly specific richness (Rsm), monthly abundance (Asm) and monthly Shannon diversity index exponential (Shannon_H′Ex) are included. For all of them, their temporal and, in some cases, seasonal variation are described. Species richness and abundance data can be found at the Global Biodiversity Information Facility (GBIF: https://www.gbif.org accessed on 19 April 2024; open access link: https://doi.org/10.15470/jcqxxt accessed on 19 April 2024) [52].

2.4. Statistical Analysis

Statistical analyses were performed using PAST V. 4.10 (http://palaeo-electronica.org/ (accessed on 4 December 2022)) [53] and the Excel software XLSTAT (https://www.xlstat.com/es (accessed on 4 December 2022)) [54] for the canonical correspondence analysis (CCA). Prior to the statistical analyses, the values were checked for the normality and homogeneity of variance. Where appropriate, the necessary transformations were performed to fit them to a normal distribution (Shapiro–Wilk and Lilliefors) with homogeneity of variance (Levene). The correlations (Pearson) between the environmental parameters Tma, Tme, Tmi, Pre, Hra, Hrm, Hri and Ras and the dependent variables Rsm, Asm and Shannon_H′Ex were studied. The regression functions between them with the lowest values of Akaike's information criterion (AIC) [55] are also indicated.

Finally, multivariate analyses of canonical correspondence (CCAs) were carried out [56,57]. In a first analysis, a CCA was performed on a presence–absence matrix, integrating the 8 environmental variables (Tme, Tmi, Tma, Ras, Hrm, Hri, Hra and Pre), 373 species and 36 months sampled, with 1000 random permutations. Over the study period, 90 species were detected that were only caught on one occasion in only one of the 36 months sampled. To check whether these possibly anecdotal species interfere with the result, another CCA was carried out in which these 90 species were removed, using a new presence–absence matrix with the remaining 283 species. After verifying that the second CCA (283 species) improved the fit with respect to the first, a third CCA was carried out on the matrix of 283 species, considering only the environmental variables that had the greatest influence on the distribution of months and species in the two previous CCAs (Tme, Ras and Hri, as described in the Section 3). Finally, three CCAs were carried out considering voltinism, i.e., a CCA was applied independently on the sets of monovoltine (144 species), bivoltine (97) and polyvoltine (42) species to test whether environmental variables affect these groups of species differently.

3. Results

3.1. Species Abundance and Diversity

The highest values of Rsm, Asm and Shannon_H'Ex were reached in 2019, a year in which intermediate values were recorded for all parameters related to humidity and temperature. Over the study period, 212 species were recorded in 2017, 207 in 2018 and 258 in 2019. The lowest richness values were recorded in the year of maximum rainfall during the study period, while the highest annual specific richness corresponded to the year of intermediate rainfall (2019). The monthly variation in specific richness during 2017 follows a bimodal distribution (Figure 5), with a first peak of richness in May (42 species) and a second, higher peak in September (61 species). However, during 2018 and 2019, the annual pattern of monthly specific richness was not as clear. The peak values in 2018 were recorded in June (67 species) and September (76 species). In 2019, the peak of richness was recorded in June (101 species), which was the highest value during the study period, with a second peak in September (77 species). The lowest richness value was in January 2017, with only one species. The monthly mean values of the Shannon_H'Ex were 22.36 (year 2017), 24.14 (year 2018) and 29.53 (year 2019). The annual evolution of this index follows a similar pattern to that of Rsm (Figure 5), with annual peaks recorded in September 2017 (47.94), August 2018 (55.2) and June 2019 (75.41). The Rsm and Shannon_H'Ex parameters were highly correlated (Pearson: $R = 0.87$; $p = 3.19 \times 10^{-12}$).

Throughout the study, 3528 specimens were identified. The monthly variation in abundance (number of specimens/sample) is shown in Figure 6. A bimodal pattern is observed, with two annual peaks, the first in Spring (May–June) and the second in late summer or early autumn (September). The highest monthly value was recorded in June 2019 (393 specimens) and the lowest in January 2017 (1 specimen). The highest annual value was recorded in 2019 (1389 specimens) and the lowest in 2017 (882 specimens), which was the driest year with the highest temperatures since spring. During 2018, a very wet year, very high abundance was also reached (1257 specimens), which contrasts the lowest richness value for the study period.

The total diversity and abundance (373 species and 3528 specimens) are mainly distributed among seven families (Figure 7). The percentage represented by each of them in the three studied years is shown. The relative importance (%) is also shown, considering the 101 species that are repeated during the three years (hereafter, permanent species). The increase in the species richness and abundance of Pyralidae in 2017, the warmest and driest year, stands out. The relative importance of Gometridae and Noctuidae is higher in the group of 101 permanent species. These include the most frequently recorded *Pieris brassicae* (Linnaeus, 1758) (Pieridae) in twenty of the thirty-six total samplings in the period February to November, and *Watsonalla uncinula* (Borkhausen, 1790) (Drepanidae) in seventeen samplings, from April to December. Also included are the species with the most reported catches, *Eudonia delunella* (Stainton, 1849) (Crambidae), 171 specimens; *Eilema caniola* (Hübner, [1808] 1796) (Erebidae), 148 specimens; *Eudonia angustea* (Curtis, 1827) (Crambidae), 143 catches; and *P. brassicae*, 103 specimens. The rest of the species did not exceed a hundred specimens counted during the three years. The most representative family of the studied community, both in terms of species richness and abundance, Geometridae, did not provide the most ubiquitous or numerous species. In fact, the most abundant species of this family, *Idaea ochrata albida* (Zerny, 1936), with 83 total captures, concentrates its flight between May and June. Something similar occurs with the second most representative family, Noctuidae: *Cerastis faceta* (Treitschke, 1835), the most abundant species, which contributes 64 specimens in total and flies exclusively in autumn and winter.

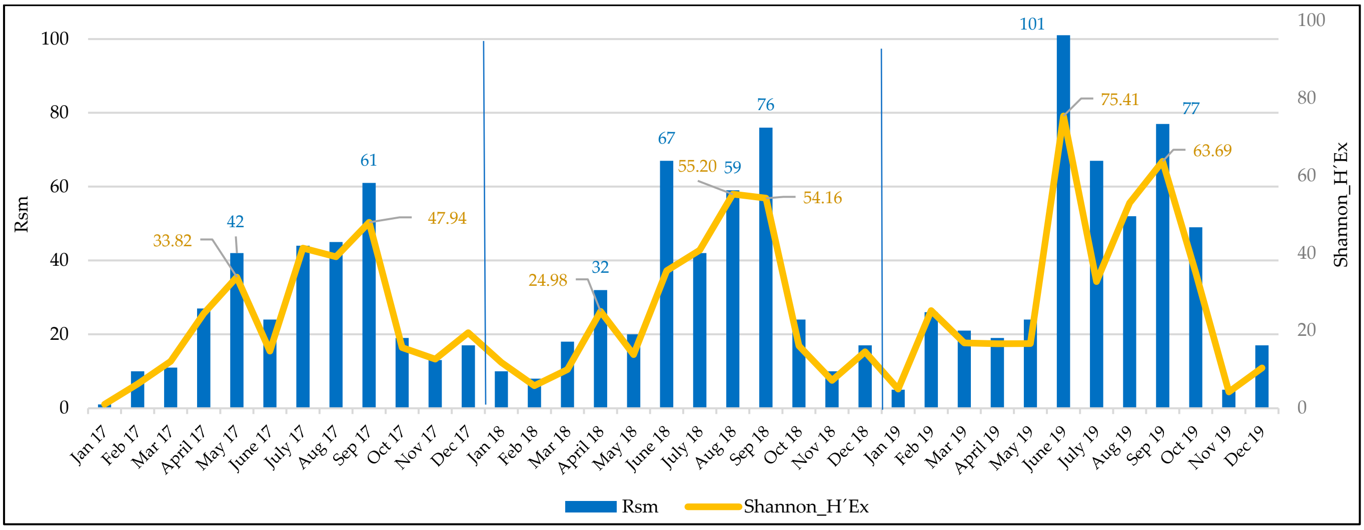

Figure 5. Monthly specific richness (Rsm, number of species per monthly sampling) and monthly Shannon diversity index exponential (Shannon_H′Ex) during the 2017–2019 period.

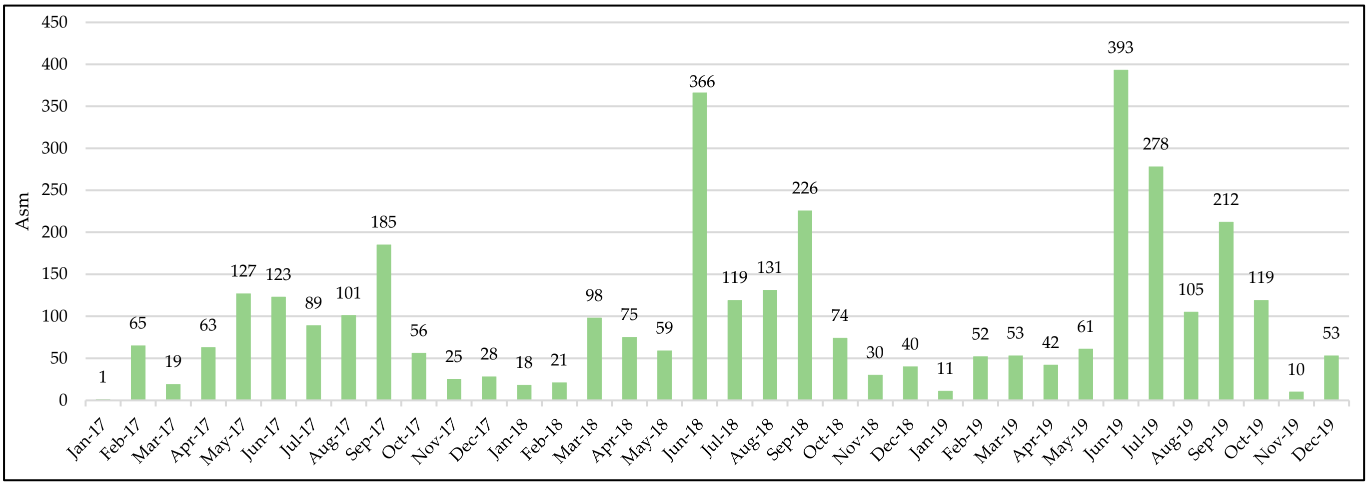

Figure 6. Monthly abundance (Asm, number of individuals/sample) during the 2017–2019 period.

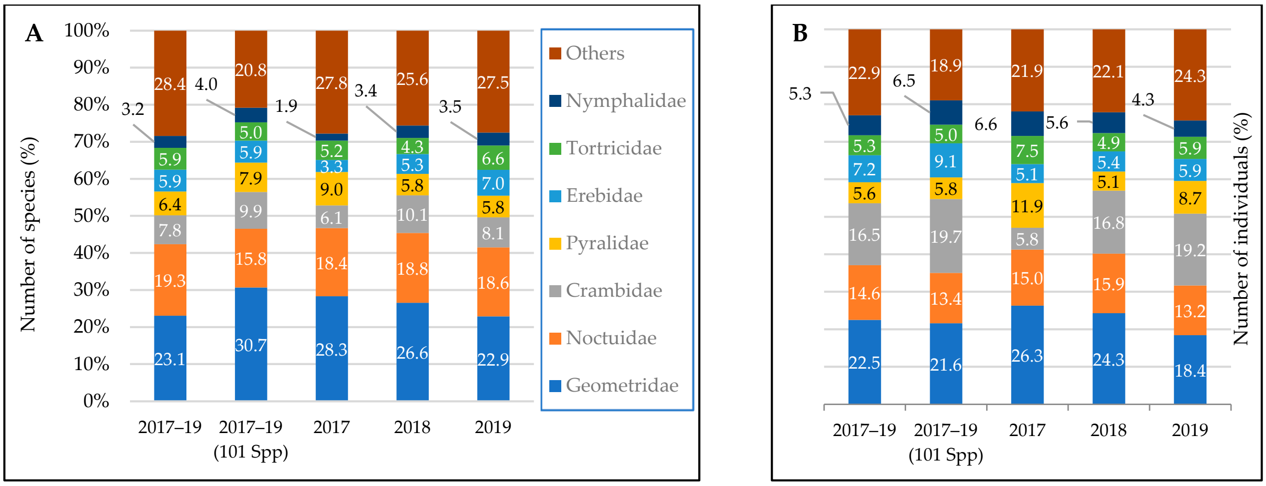

Figure 7. Relative distribution of species richness (**A**) and abundance (**B**) (%) in the seven most representative families.

The temporal variations in the type of feeding and the number of generations of the species studied are shown in Figure 8. In relation to the type of diet, oligophagous species were predominantly detected, although, during 2017, a decrease in these and an increase in polyphagous species were observed. In terms of the number of generations (voltinism), the results were similar in the different years when all the species were included; however, when only the group of 101 permanent species was considered within the 2017–2019 period, the proportion of monovoltine species decreased, and the bivoltine (two generations) and polyvoltine (three generations or more than three) species increased.

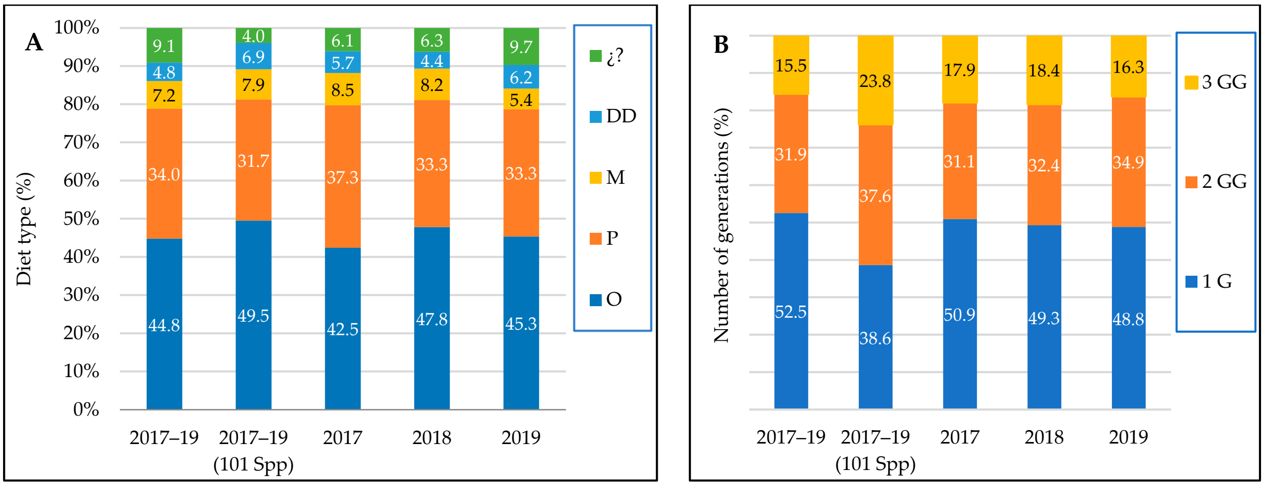

Figure 8. Relative distribution (%) in diet type: O, oligophagous; P, polyphagous; M, monophagous; DD, detritus; ¿?, unknown (**A**). Relative distribution (%) in the number of generations: 1 G, one generation; 2 GG, two generations; 3 GG, three or more than three generations each year (**B**).

The distribution of the species identified among the different chorotypes present (biogeographical distribution) is shown in Figure 9. This reflects that the relative importance of the Mediterranean chorotypes far exceeds that of the others in the 2017–2019 period (57.4%), and it is even higher for the 101 permanent species (>61%). When comparing each year, a decrease in Asian–Mediterranean and endemic chorotypes in 2017 compared to 2018 and 2019 stands out.

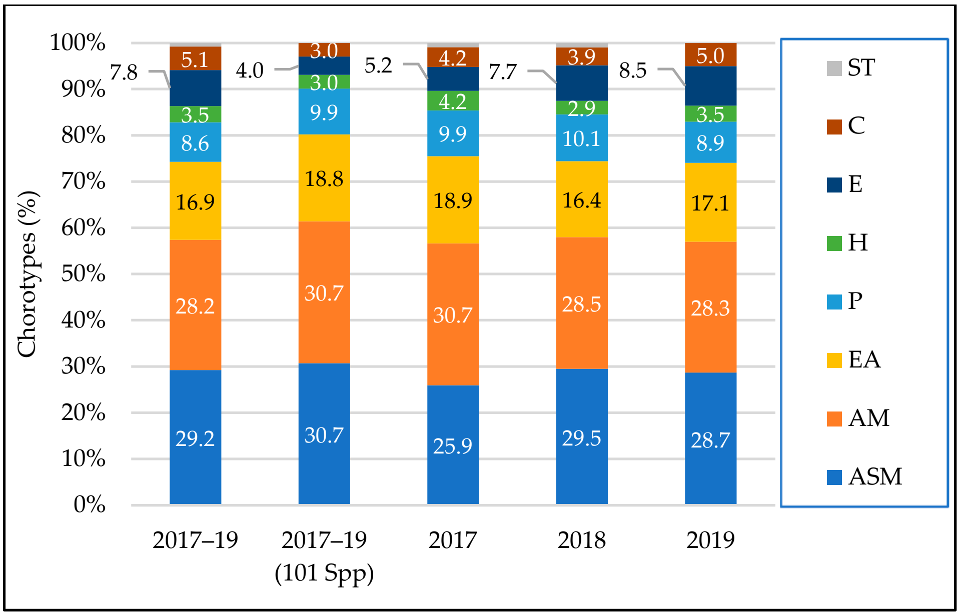

Figure 9. Proportion (%) in biogeography (chorotypes): ASM, Asian–Mediterranean; AM, Atlantic–Mediterranean; EA, Eurasian; P, Palaearctic; H, Holarctic; E, endemic; C, cosmopolitan; ST, subtropical.

3.2. *Seasonal Variation in the Lepidoptera Community*

A small group of 41 species has been recorded as having flown exclusively in autumn and winter. Among them, there are nine that have contributed a single record in the three years, such as *Vanessa atalanta* (Linnaeus, 1758), a widespread species that may be anecdotal at these dates in the area. If we discount these 9 species, only 32 are characteristic of autumn and winter in the studied area. In this group of species exclusive to the “wet–cold” climate, most of them are univoltine (84.4%) and polyphagous (43.8%), and the percentage of Atlanto-Mediterranean (40.6%) and endemic (12.5%) chorotypes increases in relation to the whole community, grouped in only seven families. The best represented is Noctuidae, with 13 species, dominated by *C. faceta*, with 64 captures. The second most important family is Geometridae, with 12 species, dominated by *Chemerina caliginearia* (Rambur, 1833), with 10 catches. The next family, Crambidae, only contributed three species, although *E. angustea* was the most abundant, with 143 catches. The other families represented, Eriocottidae, Glyphipterigidae, Lycaenidae and Pterophoridae, only contributed one species each.

The values of abundance, species richness and number of captured specimens of the dominant species in each season are shown in Table 2. The seasonal flight pattern of the seven most representative families is shown in Figure 10. The months with the highest species richness and abundance are June (spring) and September (summer). A general decline in richness and abundance is also observed in autumn and, especially, winter (Figures 5 and 6). The most representative families (Geometridae and Noctuidae) also contribute to records in autumn and winter. The rest of the families fly preferentially in summer (Crambidae, Pyralidae, Erebidae and Tortricidae) and spring (Nymphalidae). In reality, these are bimodal patterns, with maximum richness and abundance records in spring (usually June) and summer (September), with declines in July and August and, particularly, in autumn and winter. It is also noteworthy that the maximum species richness of Geometridae occurs in summer (in September, except in 2019) and abundance peaks in spring (June). On the contrary, in the rest of the families, the maximum richness and abundance occur in summer (September), except in Nymphalidae, a family that flies preferably in spring (May and June).

Table 2. Abundance, species richness and number of captured individuals of the dominant species, in each season.

Season	Abundance	Species Richness	Dominant Species	Number of Individuals
Winter, 2017	85	18	*Eudonia angustea* (Curtis, 1827)	33
Winter, 2018	137	27	*Eudonia angustea* (Curtis, 1827)	35
Winter, 2019	116	41	*Cerastis faceta* (Treitschke, 1835)	22
Spring, 2017	313	81	*Eilema caniola* (Hübner, [1808] 1796)	27
Spring, 2018	500	101	*Eudonia delunella* (Stainton, 1849)	50
Spring, 2019	496	124	*Eilema caniola* (Hübner, [1808] 1796)	30
Summer, 2017	375	123	*Cydia triangulella* (Goeze, 1783)	15
Summer, 2018	476	126	*Eilema caniola* (Hübner, [1808] 1796)	38
Summer, 2019	595	140	*Eudonia delunella* (Stainton, 1849)	96
Autumn,2017	109	41	*Aporophyla nigra* (Haworth, 1809)	12
Autumn, 2018	144	43	*Eudonia angustea* (Curtis, 1827)	41
Autumn, 2019	182	67	*Eilema caniola* (Hübner, [1808] 1796)	22

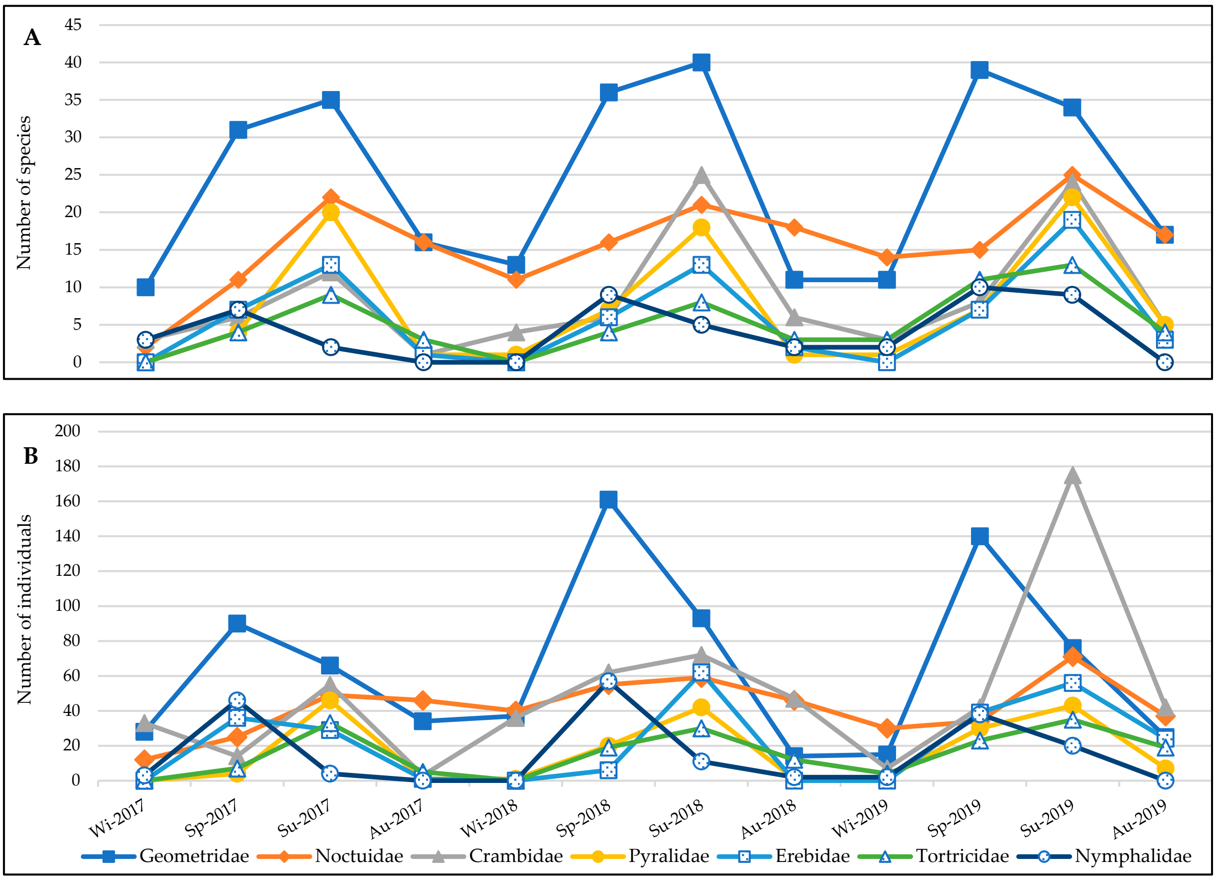

Figure 10. Seasonal flight of the seven most representative families—Geometridae, Noctuidae, Crambidae, Pyralidae, Erebidae, Tortricidae and Nymphalidae—during the seasons of each year: Wi, winter; Sp, spring; Su, summer; Au, autumn. (**A**) Number of species in each season; (**B**) number of individuals in each season.

3.3. Statistical Results

The analysis of the overall abundance (3528 individuals) and specific richness (373 species) data shows a very low dominance value (0.012), indicating that all taxa have a similar representation in the community. The global Shannon index (logarithmic) is high (5.16). The Chao1 value of the total species richness ranges between 450 and 470, presupposing new species additions in the future [53]. The statistical values of the correlations and regressions between the environmental parameters (Tme, Tma, Tmi, Ras, Pre, Hrm, Hra and Hri) and the dependent variables specific richness (Rsm), abundance (Asm) and diversity index (Shannon_H′Ex), analysing the monthly values over the three years studied (N = 36) and each year separately (N = 12), are shown in Supplementary Materials (Tables S2 and S3). The best-fitting polynomial regression function among the variables with the lowest Akaike information criterion (AIC) value is shown. The fit between the parameters related to radiation (Ras) and temperature (Tme, Tma and Tmi) and those of the lepidopteran community (Rsm, Asm and Shannon_H′Ex) is positive and superior to that between these and the parameters related to humidity (Hrm, Hra, Hri and Pre), which, on the contrary, is negative.

The highest fit of the monthly values for the whole period, 2017–2019 (N = 36), is between Tmi and Rsm ($R^2 = 0.63$; $p < 0.00000001$; AIC = 5.76), and Tme and Rsm ($R^2 = 0.63$; $p < 0.00000001$; AIC = 5.79), with almost identical statistical values. The fits between Tme and Shannon_H′Ex ($R^2 = 0.62$; $p < 0.0000001$; AIC = 5.42), and between Tmi and Asm ($R^2 = 0.57$; $p < 0.0000001$; AIC = 6.95) are also very high (Figure 11). When analysing the 3 years independently (N = 12), Rsm and Asm have the best fit with Tmi in 2017 and 2018 and with Tme in 2019. However, Shannon_H′Ex offers a better fit with Tme in 2017 and 2018, and with Tma in 2019.

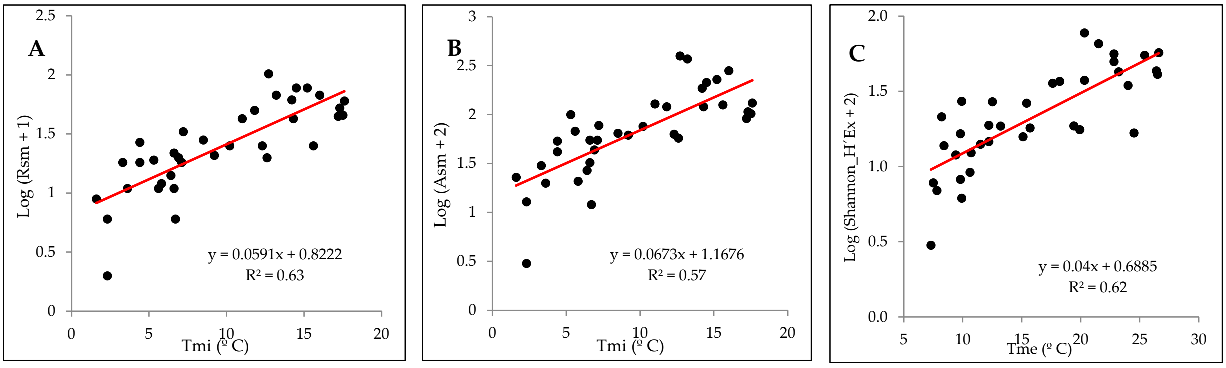

Figure 11. Regression between Tmi and Rsm (**A**), Tmi and Asm (**B**), and Tme and Shannon_H′Ex (**C**).

On the other hand, the best fit of the monthly values of the 2017–2019 period (N = 36) between the parameters related to humidity and those of the lepidopteran community occurs between Hri and Shannon_H′Ex ($R^2 = 0.72$; $p < 0.000001$; AIC = 5.79), followed by Hrm and Rsm ($R^2 = 0.45$; $p < 0.00001$; AIC = 6.66), and Hri and Rsm ($R^2 = 0.44$; $p < 0.00001$; AIC = 6.67), with almost equal statistical values. Also noteworthy are the fits between Hrm and Asm ($R^2 = 0.32$; $p < 0.001$; AIC = 8.66) (Figure 12). When we analyse the years independently (N = 12), Rsm and Shannon_H′Ex have the best fit with Hrm in 2017 and with Hri in 2018 and 2019. Asm's fit is more accurate with Hrm in 2017 and 2018 and with Hri in 2019. The lowest fit between environmental variables and lepidopteran community parameters (Rsm, Shannon_H′Ex and Asm) occurs with precipitation (Pre), both for all three years (N = 36) and for each year separately (N = 12) (Table S3). In fact, the regressions of Pre with Rsm and Asm are not statistically significant in 2017 and 2018 ($p > 0.05$). Pre best fits with Shannon_H′Ex in both 2017–2019 (N = 36) ($R^2 = 0.30$; $p < 0.001$; AIC = 6.64) and 2019 ($R^2 = 0.38$; $p < 0.04$; AIC = 4.87).

The result of the CCA performed on the matrix including only the 283 species with more than one record over the study period is shown in Figure 13. The months are distributed in two clearly differentiated environments, the first dominated by temperature (Tme, Tmi and Tma) and solar radiation (Ras), and the second by humidity (Hri, Hrm and Hra) and, to a lesser extent, precipitation (Pre). The statistical parameters (F, p, eigenvalues and cumulative variance) shown in Table 3 allow us to affirm that the sites (months)–objects (species) are linearly related to the environmental variables. These values show the relative importance of Tme, which stands out from the rest of the parameters, including Tmi and Tma. They are followed by Ras, Hri, Hrm, Hra and, finally, Pre, in both CCAs. A better fit is also found in the CCA carried out with the 283 species recorded more than once in the study period.

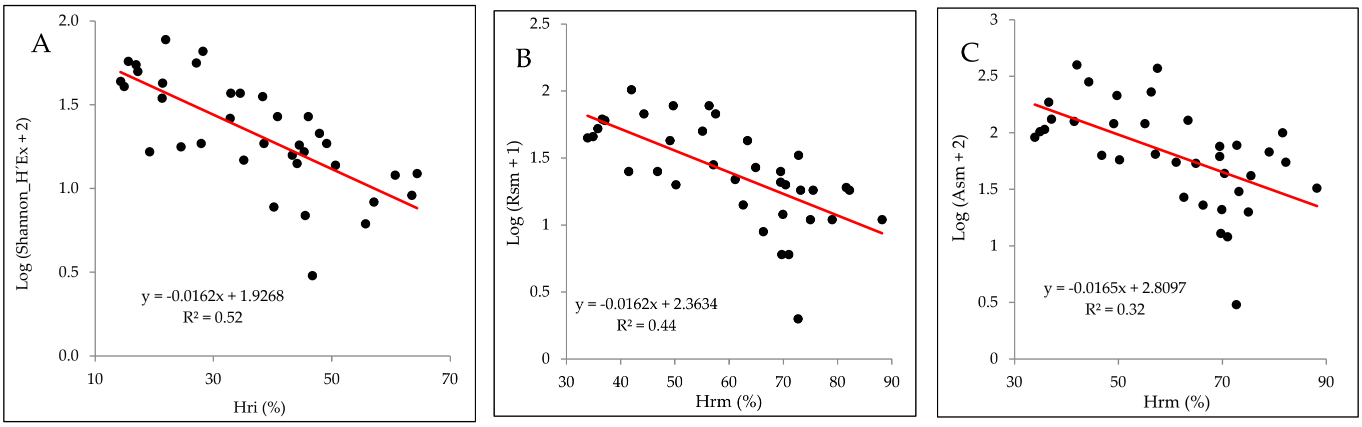

Figure 12. Regression between Hri and Shannon_H´Ex (**A**), Hrm and Rsm (**B**), and Hrm and Asm (**C**).

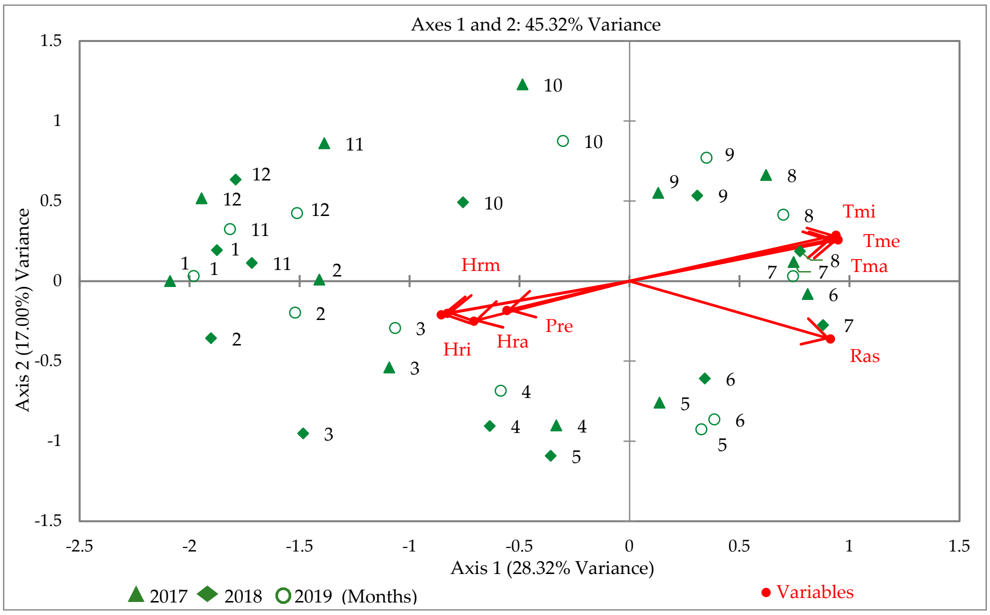

Figure 13. CCA on presence–absence matrix of 283 species and the 8 environmental parameters recorded in the study. The numbers correspond to the different months of the year. The months of each year are represented by a triangle (2017), rhombus (2018) and circle (2019).

Table 3. Statistical parameters of the CCAs.

CCA	F	*p*	Axis	Eigen-Value	Cumulative Variance (%)	Standard Coordinates							
						Tme	Tmi	Tma	Ras	Hrm	Hri	Hra	Pre
373 species	1.316	<0.0001	1	0.68	25.08	0.95	0.94	0.92	0.91	−0.83	−0.85	−0.71	−0.55
			2	0.45	41.68	−0.26	−0.29	−0.26	0.37	0.20	0.20	0.25	0.15
283 species	1.490	<0.0001	1	0.66	28.32	0.95	0.94	0.92	0.91	−0.83	−0.86	−0.71	−0.56
			2	0.40	45.32	0.26	0.29	0.26	−0.36	−0.20	−0.21	−0.25	−0.18

When we perform a CCA on the 283 species occurring more than once using only Tme, Ras and Hri, we find that the distribution of the months is practically unchanged when compared to the CCA, including all the environmental parameters. This shows that the three chosen ones can explain, with high statistical significance (F = 2.043; $p < 0.0001$), the distribution of the months and species (Figures 14 and 15, respectively). The supplementary statistics are as follows: eigenvalues of 0.655 and 0.386, and cumulative variance of 53.37 and 84.79% for axes 1 and 2, respectively. The two environments are clearly visible, with

Tme and Ras in the positive part and Hri in the negative part of axis 1. In the Tme–Ras environment, it is observed that both parameters agglutinate the months with the highest number of species and, therefore, the highest diversity and abundance of specimens; moreover, Tme and Ras are highly correlated (Pearson: R = 0.86; $p = 2.20 \times 10^{-11}$). The months most influenced by Tme are July 2017, the Augusts of the three years and, positioned between Tme and Ras, June 2017; to a lesser extent, it influences the Septembers of the three years. Ras has a clear influence on July 2018 and 2019, followed by June 2018 and 2019 and May 2017 and 2019. In the humidity-dominated environment (Hri), the months with the strongest influence are March, February and, to a lesser extent, April and May 2018; finally, the influence of Hri decreases over January, December, November and, lastly, October. In the "wet–cold" period (October to March), the number of species recorded (117) is significantly lower than that in the "warm–dry" period (April to September) (253 species). Of these 117 species, only 32 species fly exclusively during that period.

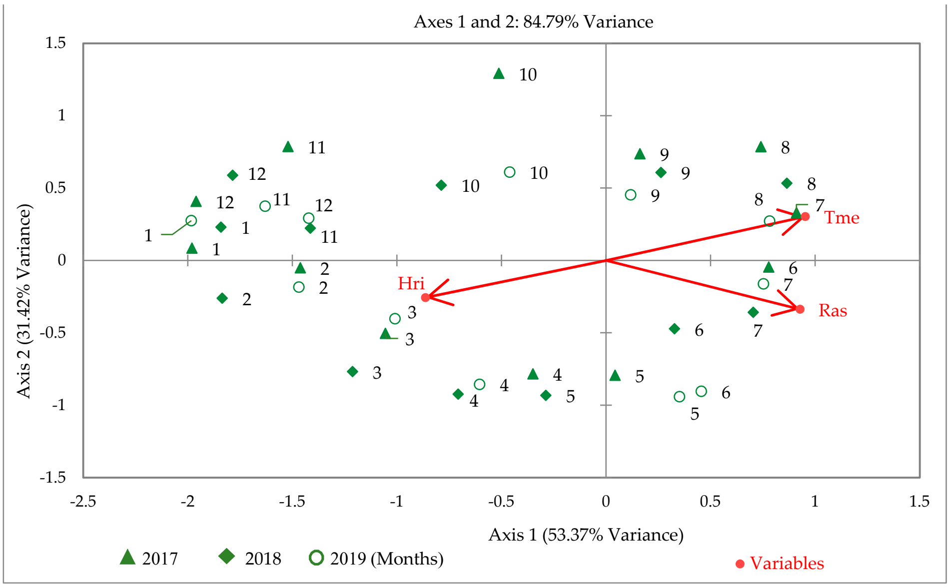

Figure 14. CCA on the presence–absence matrix of 283 species including only the environmental parameters Tme, Hri and Ras. The numbers correspond to the different months of the year.

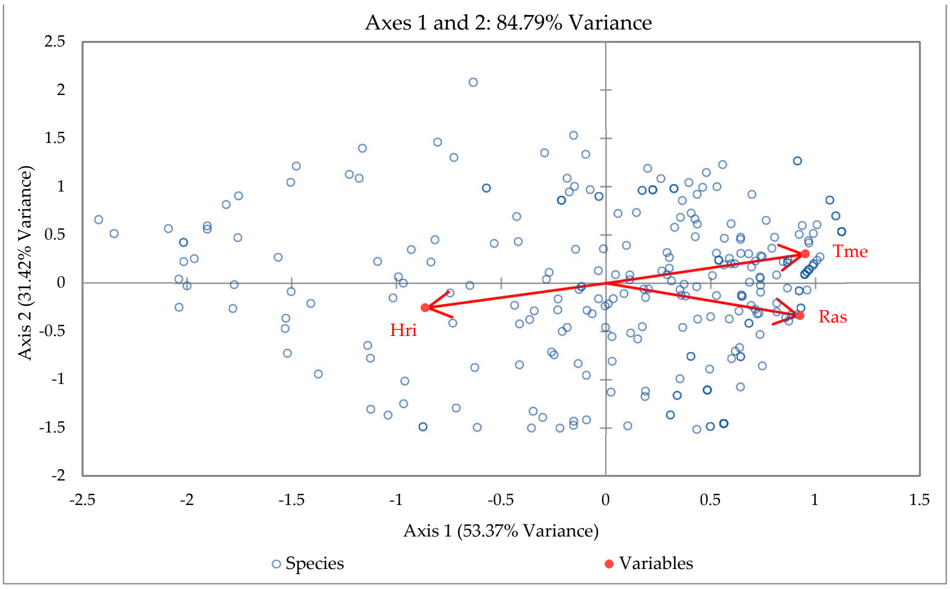

Figure 15. CCA on the presence–absence matrix of 283 species and the environmental parameters Tme, Hri and Ras. The dots correspond to the different Lepidoptera species.

Independent CCAs were performed for monovoltine (144 species), bivoltine (97 species) and polyvoltine (42 species) species [45]. The results are shown in Table 4, where it can be observed that the environmental parameters (Tme, Ras and Hri) are linearly related to the distribution of the months and species in the monovoltine (V1) and bivoltine (V2) options, with a higher fit in the former. This fit (V1) is also higher than that obtained for the total species (283 spp, variables Tme, Ras and Hri) of the previous CCA.

Table 4. Statistical parameters corresponding to the CCAs of monovoltine (V1-144 species), bivoltine (V2-97 species) and polyvoltine species (V3-42 species).

CCA	F	*p*	Axis	Eigenvalue	Inertia %	C. Variance (%)
V1-144 species	2.177	<0.0001	1	0.83	49.77	49.77
			2	0.61	36.64	86.42
V2-97 species	1.928	<0.0001	1	0.56	52.63	52.63
			2	0.29	27.21	79.84
V3-42 species	1.698	0.053	1	0.40	55.41	55.41
			2	0.23	31.71	87.12

4. Discussion

This study is the only one in the Mediterranean area that includes the monitoring of the abundance, richness and diversity of the entire lepidopteran community, both nocturnal and diurnal, during an uninterrupted period of three years. The percentage of diurnal species represents 9.3% of the total (8.5% if we refer only to species with more than one record), a value close to ≈5% of diurnal species out of the total of the order Lepidoptera in the Iberian Peninsula [44]. The paper describes the temporal–seasonal variation in the community and assesses the relationship between environmental variables (temperature, radiation, precipitation and humidity) and the abundance, richness and diversity of the lepidopteran community. The results show that a rich community dominated by Geometridae was studied, revealing positive relationships between lepidopteran richness, abundance and diversity with radiation and temperature, and negative relationships with humidity. Subsequent CCAs confirmed these results and further elucidated the relationships between environmental variables and lepidopteran species. Finally, the work provides guidelines for conserving the high diversity recorded and suggests that the area studied may be functioning as a refuge area for many species.

4.1. Temporal Variation Patterns in the Lepidopteran Community

The studied community shows a bimodal flight pattern, with peaks in richness (Rsm), abundance (Asm) and diversity (Shannon_H'Ex) in spring (May or June) and September. In addition to the decline in autumn and winter due to low temperatures, the extreme high temperature and low humidity values in July and August cause a decline in these community parameters between the two annual maxima (Figures 5 and 6). Our results coincide with studies in Mediterranean mountain environments, where a greater richness of species in flight is recorded during early summer and early autumn [38,39,58]. Many species avoid the hottest summer months and fly shortly before or shortly after the period of extreme heat. On the other hand, in these Mediterranean forests, characterised by the presence of well-structured and conserved plant communities dominated by *Quercus*, Geometridae also predominate over other families [38]. Moreover, considering the three years, the values obtained are more homogeneous in September (Rsm = 71.3 ± 9.0 SE; Asm = 207.7 ± 20.8 SE) than in spring (Rsm in June = 64.0 ± 38.6 SE; Asm = 294.0 ± 148.7 SE). According to these data, the lepidopteran community shows greater sensitivity to environmental changes at the spring maximum than in September. It is also significant that in May of the warmest and driest year (2017), there was an advance in the richness and abundance curves. In addition, 2017 contributes the lowest abundance, but not the lowest richness, which occurred in 2018, the wettest and coldest year of the study period. Overall, Rsm, Asm and

Shannon_H′Ex showed upward trends throughout the study period, except for the decline in Rsm in 2018. This decrease was probably caused by the high rainfall leading to unusually high moisture values (Hri, Hrm and Hra), especially in spring (570 mm Pre in March). Late winter and spring are a critical period for butterfly larval development [11,17], and it is likely that this excess moisture, together with below-normal temperature and solar radiation for a Mediterranean environment, negatively affected caterpillar and chrysalis development in the area [28]. The positive trends in Rsm, Asm and Shannon H′Ex in the study period could be associated with an upward movement of Lepidoptera from the surrounding (lower-altitude and more-xeric) areas in a climate change scenario [9,37]. During the 2017–2019 period, *Coscinia cribaria benderi* Marten, 1957, and *Evergestis maroccana* (D. Lucas, 1956) were recorded in the study area, which have never been located so far north and inland [45]. Previous research has detected *Charaxes jasius* (Linnaeus, 1767) in the study area only since 2011 [26], which seems to confirm the movement of this species to higher altitudes and inland areas [13]. Butterflies may also seek cooler and more-humid microclimates on north-facing slopes and in narrow valleys in the Mediterranean area [36]. The presence in a small area of several different habitats supporting a very diverse flora would favour the presence of Lepidoptera, as many species could easily find their food plants [35].

The study of the seven main families shows that Geometridae and Noctuidae contribute the highest species richness and abundance, and that their relative importance is higher in the group of 101 permanent species during the three years of the 2017–2019 period (Figure 7). In addition, these families are best represented in the small and distinctive group of 32 species that fly exclusively in autumn and winter. However, these families do not usually provide the dominant species (Table 2), a role frequently played by Crambidae (*E. angustea* in autumn–winter and *E. delunella* in spring–summer) and Erebidae (*E. caniola*, in spring–summer). Geometridae is the only family that records the highest richness in summer (September) and the highest abundance in spring (May–June). This fact may be due to a better adaptation of numerous species of this family to the resources offered by the cork oak (*Quercus suber* L.), a tree characteristic of the climactic forests of the area, which presents an emergence of leaf buds that develop in spring–summer, and diffuse flowering that can be prolonged during the summer and autumn [26]. The rest of the families show maximum values for both richness and abundance in summer (September), except for Nymphalidae, which peaks in spring (Figure 10). The increase in Pyralidae in 2017, which was drier and warmer compared to other years, may show greater adaptation of the species of this family to the current climatic trend (Figure 7). In that year, we also observed an increase in polyphagous species and a decrease in oligophagous species (Figure 8), a probable response of the studied community to more xeric climatic conditions. There are no significant differences between the groups of the different chorotypes when comparing the three years studied. The higher percentage of Mediterranean chorotypes stands out, exceeding 60% of the total in the 101 permanent species (Figure 9). In this group, there is also a greater balance between the percentage of monovoltine species and bivoltine and polyvoltine species (Figure 8). Both facts reveal the peculiar characteristics of this group of species that have shown greater ecological adaptation to the Mediterranean conditions of the studied environment.

4.2. Relationships between Environmental Variables and the Lepidopteran Community

This study shows that in Mediterranean areas, the environmental factors that most influence the richness, abundance and Shannon diversity index exponential of lepidopteran communities are those related to temperature (mainly Tme and Tmi) and, to a lesser extent, Ras. These three parameters show a highly significant positive correlation with Rsm, Asm and Shannon_H′Ex (Table S2). This result corresponds with the positive influence of temperature in Mediterranean environments on the increase in Noctuidae captures in nocturnal traps [40]. It has also been found that higher temperature records correlated with phenological advances in Mediterranean diurnal species, mainly in winter and spring [27,28].

Another paper [29] records a negative correlation between species richness and the mean temperature, which could be due to the negative effect of increasing mean and extreme temperatures [19]. In the British Isles, different effects on the phenology of butterflies have been observed as a result of increased temperatures: earlier first and maximum spring flight, prolongation of the flight period of generalist species and asynchronies in the plant–host cycles [3,11]. In this regard, it is noteworthy that mature specimens of the most ubiquitous species included in our study (*Pieris brassicae* (Linnaeus, 1758)) were detected from February to November. During spring of the warmest year (2017), no adults of a common butterfly, *Zerynthia rumina* (Linnaeus, 1758), were observed in flight, a phenomenon possibly due to asynchrony between its biological cycle and that of its nutrient plant, *Aristoloquia baetica*, L. In our sphere, a positive effect of temperature on the variables Rsm, Asm and Shannon_H′Ex was observed even in winter. After the first frosts or sudden drops in temperature recorded in November 2018 and 2019, increases in these three dependent parameters were observed in December, in line with the increase in temperature recorded in that month. Species such as *Operophtera brumata* (Linnaeus, 1758) and *Cosmia trapezina* (Linnaeus, 1758), which, in the British Isles, benefit from colder winters [15], were not observed in the study area.

Conversely, there is a negative correlation between precipitation (Pre) and community parameters, as has previously been shown in the British Isles [18] and Mediterranean environments [28]. In the latter work, the authors propose that precipitation has a negative effect on daytime temperatures and, thus, caterpillar and chrysalis development, derived from the reduced levels of insolation associated with cloudy skies. In our case, the statistical fit is very low (N = 36, $R^2 < 0.4$; $p > 0.05$–0.04) and even non-significant (Table S3). This fact could be associated with the irregular rainfall pattern, characterised by extreme spatio-temporal contrasts, typical of the Mediterranean climate. An impoverishment of diurnal species richness has also been recorded in arid communities, with water scarcity acting as the main limiting factor [32]. The positive effect of summer rainfall on British grass-feeding species [15] does not occur in our case because, in the Mediterranean area, the phenology of herbaceous annuals determines that practically all species are dry from late spring onwards.

The climatic variable that most influences Lepidoptera in the autumn and winter months is humidity, specifically Hri (Figures 13–15). Although there is a high positive correlation with Pre-Hri (Pearson, R = 0.88; $p = 1.51 \times 10^{-10}$), other climatic factors such as fog or dew, not considered in the present work, can also influence humidity records. There is also a high negative correlation between Tme and Hri (Pearson, R = −0.88; $p = 7.93 \times 10^{-13}$). In fact, we have found that the lowest values of Rsm, Asm and Shannon_H′Ex are recorded in the autumn and winter months, when the cold is more intense and humidity is higher. We have also observed that there are decreases in these parameters in July and August compared to June and September (Figures 5 and 6), when there is extreme heat and high environmental dryness [38,39,58]. Another paper [19] reports the negative effects of extreme temperatures, due to desiccation, on the early developmental stages of butterflies. It may be possible to establish optimal humidity thresholds, maximum and minimum, within which lepidopteran life cycles are not interrupted, both for the autumn and winter months and for the hottest and driest months of summer. Future work in Mediterranean environments should consider, in addition to temperature, humidity and radiation, other variables such as dew and fog, because they could significantly affect the biological cycles of Lepidoptera and be relevant for the characterisation of their communities.

The CCA on 283 species with more than one record shows that Tme, Ras and Hri can explain, with high statistical significance (F = 2.043; $p < 0.0001$), the distribution of months and species. The relative importance of the variables Tme and Ras, which are highly correlated (Pearson, R = 0.86; $p = 2.20 \times 10^{-11}$), can be seen graphically, and they include the months with the highest diversity and abundance and, therefore, most of the species; moreover, these are the warmest months. In contrast, humidity (Hri) has a greater influence on the months of autumn, winter and early spring. Of the 283 species, 253 fly in the “warm–dry” period (April to September) and only 117 in the “cold–wet” period

(October to March). Characterisation of the two groups shows no significant differences in their percentages of voltinism and chorotypes. The small group of 32 species that only fly in autumn and winter is clearly different. They are univoltine and polyphagous, and have numerous Atlantic–Mediterranean elements and Iberian endemisms. This fact, together with the high percentage of widely distributed elements (Eurasian, Palearctic and Holarctic species account for a third of the total), coincides with previous studies carried out in Mediterranean mountain areas, where rich communities have been documented, formed by species from different biogeographical origins, habitat specialists and Mediterranean endemic elements, highlighting their enormous importance from a conservation perspective [33,35,59]. Our results seem to confirm that, in Mediterranean areas, the altitudinal range studied (500–700 m) may host a higher diversity of Lepidoptera than other adjacent ranges [33]. In fact, two species new to science have recently been discovered in the area where this work was carried out [45,46]. The independent CCAs for each of the three voltinism strategies considered show a higher fit for the monovoltine group (144 species) (Table 4), which is also higher than that obtained in the CCA for the total number of species with more than a single record. It is likely that the studied lepidopteran community, which is dominated by monovoltine and restricted distribution species, more predictable but also more vulnerable to climate change, may suffer more acutely from the effects of global warming [3,60]. Previous studies have shown how, in mid-latitude temperate climate environments, meteorological factors have a strong influence on the annual fluctuations of moths [15,16,18,61] and butterflies [17]. In our case, the CCA offers a high cumulative variance (84.79% for all species and 86.42% for monovoltine species), although with values similar to those recorded in other studies in the Mediterranean area [29]. These results suggest that, in the Mediterranean region, these climatic parameters have a greater influence on the richness, abundance and diversity index of Lepidoptera communities than in higher latitudes. Moreover, temperature (particularly Tme) is the factor that most influences the interannual variations in lepidopteran populations in the Mediterranean area studied.

Migrations from relatively nearby forest areas (≈70 km), recently transformed into intensive crops, could also explain the high richness and abundance of Lepidoptera in the study area, as they could be using it as a refuge area. The progressive invasion of scrubland and the presence of more enclosed habitats, phenomena that are widespread throughout the Iberian Peninsula and are also visible in areas close to the study area, may also have had an effect. The effect that changes in land use may have on Mediterranean Lepidoptera populations may be more significant than that of global warming [28]. Their incidence is higher in habitat specialist butterflies (rare and locally distributed) than in generalist butterflies. A greater decline has also been observed in populations associated with open spaces than those associated with forest environments, as a consequence of the abandonment of traditional grazing and mowing practices [30,31]. Increased temperature and aridity, combined with habitat loss, are expected to lead to a decline in butterfly populations linked to specific habitats in mountainous areas [37] and generalist species in lowland areas [33]. Likewise, butterfly extinction episodes have been documented in Mediterranean ecosystems in habitats with lower plant diversity and warmer habitats at low altitudes [4].

For lepidopteran species to have a better chance of survival, particular attention should be paid to the connectivity of different areas with high diversity and different geographical, ecological and climatic characteristics. This will enable communities to be more resilient to ongoing changes in both climate and land use [36,62]. However, these areas, many of which are protected, are often impossible to interconnect due to their mountainous nature. Recent studies suggest that the effects of global climate change will be even more severe in these areas [63]. In this case, it is crucial to preserve the characteristics that have enabled them to maintain this high diversity. In the study area, actions to promote the conservation of lepidopteran biodiversity should aim to maintain the diversity and structural variety of its flora. Anthropised chestnut and *Quercus* forests should maintain a small and floristically varied shrub cover, minimising competition with trees, and a predominance of the herbaceous stratum in the rest of the area, characteristic of Mediterranean pasture systems [26]. This previous work describes the effect produced when the chestnut or *Quercus* forest is abandoned and the habitat is occupied by dense thickets composed mainly of rockroses (*Cistus* spp.) and pines (*P. pinaster*): the lepidopteran diversity drops drastically. Recent lepidopteran records in the study area [46,64,65] show that it is also very important to respect the hedgerows of agricultural and forest enclosures in the area because they serve as refuges for numerous species. It is also important to improve control measures on phytosanitary conditions that negatively affect the forest, such as "*Quercus* decline" in the Iberian Peninsula, which also affects chestnut forests [66]. The management of roadside vegetation should avoid herbicide treatments and indiscriminate weeding. The conservation of native herbaceous vegetation in Mediterranean areas [67] and elsewhere [68,69] is of great benefit to butterfly species. The flow of permanent watercourses is also vital, especially in the warmer, xeric seasons. These watercourses support gallery forests that provide an appropriate microclimate (with shade and high humidity) necessary for the survival of Lepidoptera in summer and early autumn, when climatic conditions in open Mediterranean environments are very unfavourable due to the high temperature and dryness of the air. In addition, these riparian habitats favour the presence of numerous plants that serve as food or produce nectar. They also provide the only mud available over large areas for many species to suck up minerals essential for their metabolism, such as sodium [70,71]. During the summer of 2023, underground boreholes in several streams in the Sierra de Aracena y Picos de Aroche Natural Park, made to meet human needs, have completely dried up ancient watercourses [72]. The effects of these actions on the lepidopteran community and other living beings have yet to be quantified, but we suspect that they may be significant.

5. Conclusions

The increase in the richness and abundance of Lepidoptera over the study period suggests that the area studied (a Mediterranean mountainous area in the SW of the Iberian Peninsula) could be functioning as a refuge area for numerous species. Some are found at the lower latitudinal limits of their European range; others may have migrated from lower-altitude, drier and less floristically diverse areas. These species form part of a rich community that includes rare and endemic Mediterranean elements, some of which have only recently been discovered. The high diversity of species highlights the great importance of the area from the point of view of lepidopteran conservation. Once the high influence of temperature on the studied lepidopteran community was determined, its high vulnerability was also evident, due to climate change trends leading to even hotter and more arid scenarios, with progressive loss of habitats associated with direct and indirect human action. We do not know how long the area studied will be able to retain the characteristics that allow it to retain this apparent function as a refuge from the factors that threaten it (climate change, changes in land use, forest fires, etc.), and it is even possible that it has already lost it. In this case, the studied community and the description of its relationship with the environment will serve as a reference for checking its subsequent composition.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/d16070408/s1: Table S1: Monthly data for climatic parameters. Table S2: Statistical values of correlations and regressions between the environmental parameters' monthly average temperature (Tme), monthly average maximum temperature (Tma), monthly average minimum temperature (Tmi) and monthly average solar radiation (Ras), and the dependent variables' specific richness (Rsm), abundance (Asm) and Shannon diversity index exponential (Shannon_H'Ex). Table S3: Statistical values of correlations and regressions between the environmental parameters total monthly precipitation (Pre), monthly average relative humidity (Hrm), monthly average maximum relative humidity (Hra) and monthly average minimum relative humidity (Hri), and the parameters specific richness (Rsm), abundance (Asm) and Shannon diversity index exponential (Shannon_H'Ex).

Author Contributions: Conceptualisation, P.M.B.-R., F.J.J.-N. and J.C.P.-Q.; methodology, P.M.B.-R., F.J.J.-N. and J.C.P.-Q.; software, P.M.B.-R., F.J.J.-N. and J.C.P.-Q.; validation, F.J.J.-N. and J.C.P.-Q.; formal analysis, P.M.B.-R., F.J.J.-N. and J.C.P.-Q.; investigation, P.M.B.-R. and F.J.J.-N.; resources, P.M.B.-R. and F.J.J.-N.; data curation, P.M.B.-R. and F.J.J.-N.; writing—original draft preparation, P.M.B.-R.; writing—review and editing, P.M.B.-R., F.J.J.-N. and J.C.P.-Q.; visualisation, P.M.B.-R. and F.J.J.-N.; supervision, F.J.J.-N. and J.C.P.-Q.; project administration, P.M.B.-R. and F.J.J.-N.; funding acquisition, P.M.B.-R. All authors have read and agreed to the published version of the manuscript.

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