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ORIGINAL ARTICLE

Can butterflies (Lepidoptera) serve as effective bioindicators for assessing the health of Algerian cedar forests?

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Abstract. This study investigates the abundance and diversity of diurnal butterflies in two types of forest habitats – a degraded cedar forest and a protected cedar forest – located in Djurdjura National Park, Algeria. The survey was conducted over a one-year period, from April 2022 to March 2023. A total of 1,479 individuals, belonging to 48 species, were recorded. Among them, 13% are endemic to North Africa. The primary factor contributing to the degradation of the cedar forest in Djurdjura National Park appears to be repeated wildfires. Nevertheless, the clearings created by fire may temporarily promote floral diversity and, consequently, butterfly richness. The results reveal complex interactions between butterflies, habitat quality, and seasonal variations. No clear segregation was observed between butterfly communities in the two cedar forest types, although some species exhibited distinct ecological preferences: *Celastrina argiolus*, *Zygaena algira*, *Tomares ballus*, *Zygaena trifolii*, and *Pyronia cecilia* were more associated with the degraded cedar forest, whereas *Pyrgus alveus*, *Zerynthia rumina*, *Pararge aegeria*, and *Issoria lathonia* were linked to the protected forest. However, further analyses are required to confirm their status as reliable bioindicators. The study also demonstrates that butterfly abundance varies significantly with the seasons, peaking in summer, highlighting the critical influence of climatic conditions. These findings could contribute to the enrichment of protected species lists in Algeria and North Africa, as well as to the maintenance of biodiversity and ecosystem services.

INTRODUCTION

Butterflies, those delicate and colorful insects, play a fundamental role in ecosystems (Nwosu & Iwu, 2011). Their diversity and abundance within a given area are valuable indicators of ecosystem health and functioning (Andrew et al., 2011). They are recognized as excellent bioindicators of environmental conditions, habitat quality and ecological network integrity (De Vries, 1988; Lafranchis, 2000; Thomas, 2005; Manil et al., 2007; Andrew et al., 2011), as well as of biodiversity levels and conservation status (Sharma et al., 2020; An & Choi, 2021).

Butterflies respond quickly and sensitively to vegetation changes, climatic variations, and various disturbances (Chettri et al., 2018; Verma & Arya, 2021). They are among the most commonly used groups as indicators of climate change (Stefanescu et al., 2003). They are easy to identify (Van Swaay et al., 2008) and are found in a wide variety of habitats, including forests (Bellmann, 2012).

Forest ecosystems host an abundant and diverse biodiversity (Larrieu & Gonin, 2008). The entomofauna associated with these ecosystems is also of great importance, with Lepidoptera occupying a particularly notable place (Renneson & Delvingt, 2021).

The Atlas cedar (*Cedrus atlantica*) is an emblematic tree of high-altitude forests in Algeria and Morocco, in North Africa. It provides vital habitat for many butterfly species, offering them food, shelter, and breeding sites (Abdelhamid & Allal-Benfekih, 2017). However, the increasing degradation of cedar forests, caused by various factors such as wildfires, may threaten this essential relationship between cedars and butterflies. In Algeria, recurrent fires are the main cause of direct cedar forest degradation. Between 1954 and 2012, wildfires became more frequent, causing significant losses. For example, in Tikjda, within Djurdjura National Park, fires between 1958 and 2012 devastated over 800 ha of cedar forest (Messaoudene et al., 2013). Wildfires, as ecological disturbances, can have contrasting effects: they may be deeply destructive to habitats, leading to massive mortality, or conversely, they may temporarily promote biodiversity by stimulating the abundance of early-succession plant species and increasing the availability of floral resources for pollinators (Gates et al., 2021).

In this context, Djurdjura National Park (DNP), located in northern Algeria in the Greater Kabylia region, represents an important natural site. Rich in a wide variety of landscapes, plant and animal species, the park hosts rich diurnal Lepidoptera communities. However, to the best of our knowledge, no previous research has investigated butterflies in this area. This study therefore provides the first assessment of their diversity and potential as bioindicators. This research aims to compare the initial abundance of butterfly populations in two types of cedar forests in the park: one degraded by wildfires and one protected. By analyzing these two environments, we seek to assess the impact of fire-induced degradation on these insects and determine whether this disturbance has a particularly pronounced negative effect on forest ecosystem biodiversity.

MATERIAL AND METHODS

1. Study site

Djurdjura National Park (DNP) is located in northern Algeria, in the Greater Kabylia region, approximately 140 km southeast of Algiers and 50 km from the Mediterranean Sea. Covering an area of 18,550 ha, it spans the administrative territories of the wilayas of Tizi Ouzou to the north and Bouira to the south. It is divided into five sectors, including the Tikjda sector, which is the focus of the present study (PND, 2015). The Tikjda region, located in the humid bioclimatic zone of Djurdjura southern slope, includes two selected stations: a protected cedar forest (PC) and a degraded cedar forest (DC).

1.1. Protected cedar forest (Tigounatine, fenced reserve)

Coordinates: 36°27′06″N, 4°06′19″E, altitude: 51 m; 36°27′22″N, 4°06′37″E, altitude: 1542 m. This is a mixed forest where Atlas cedar (*Cedrus atlantica*) coexists with holm oak (*Quercus ilex*), holly (*Ilex aquifolium*), yew (*Taxus baccata*), and particularly the Maghreb black pine (*Pinus nigra* subsp. *mauretanica*), a highly remarkable relict species, analogous to *Abies numidica* of the Babors (Fig. 1). The vegetation cover rate is 85%. The most dominant plant species in this station are *Cedrus atlantica*, *Quercus ilex*, and *Juniperus oxycedrus*. The station features two vegetation strata (trees and herbaceous plants) and, from a physiognomic perspective, is considered a closed environment.

1.2. Degraded cedar forest

Coordinates: 36°26′33″N, 4°06′45″E, altitude: 1405 m; 36°26′28″N, 4°06′54″E, altitude: 1490 m. This is a cedar forest degraded by wildfires and overgrazing, located in a region known as Thasjua Twatoufth, below the “Chapeau du Gendarme” (Fig. 1). Its vegetation cover is 95%. The most dominant plant species at this station are *Cedrus atlantica*, *Quercus ilex*, *Sambucus ebulus*, *Rubus ulmifolius*, *Crataegus laciniata*, and *Rosa sempervirens*. The station comprises three vegetation strata (trees, shrubs, and herbaceous plants), characterizing it as a relatively open environment.

2. Methodology

2.1. Butterfly sampling

The chosen method for this inventory was the linear transect method, a standardized protocol for Lepidoptera, known as the Butterflies Monitoring Scheme (BMS) (Pollard, 1977; Pollard & Yates, 1993). A regular visual count of individuals of all encountered species, was carried out by the same observer, at least once every 10 days per station, throughout the year (from April 2022 to March 2023).

Sampling was carried out along a 2 km transect per station, with a width of 5 m. Each transect was walked in a straight line or in a zigzag pattern, maintaining a constant duration (1 h). Following each survey, the transect was continued forward without returning to the initial point. Most of butterflies were captured with a net, identified in the field, and then released. When necessary, key specimens were collected for laboratory identification. Photographs were also taken in the field to confirm doubtful identifications.

In cases where multiple surveys were conducted per month, only the survey with the highest recorded abundance for a given species was considered. The following weather conditions were respected during fieldwork:

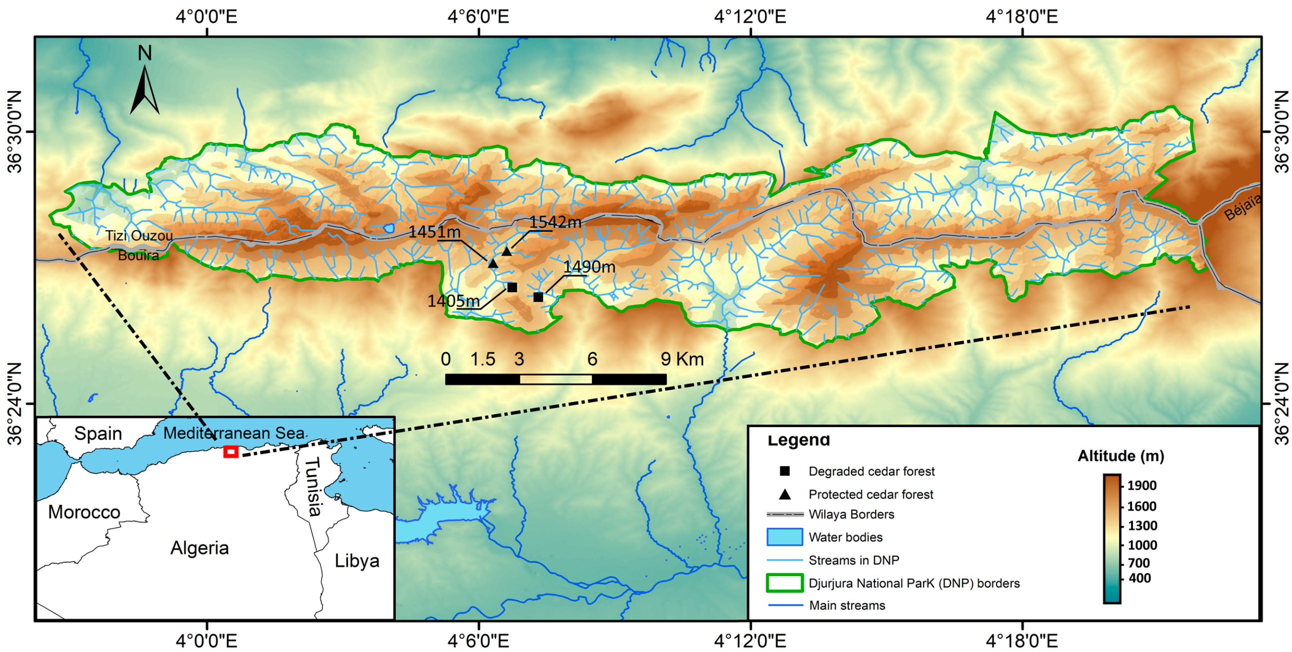


Fig. 1. Locations of the degraded and protected cedar forest sites within Djurdjura National Park, Algeria.

Temperature conditions: 14°C if the weather was sunny or slightly cloudy. 17°C if the weather was cloudy (with clouds covering no more than 50% of the sky). No surveys were conducted under overcast or rainy conditions.

Wind speed: The average wind speed did not exceed 30 km/h (Demerges & Bachelard, 2002).

Species identification was carried out using the field guides by Tennent (1996), and Tolman & Lewington (1999). The full list of identified species, with authors and year of description, is presented in the Results section and associated figures.

2.2. Vegetation sampling

Vegetation data were collected using the linear transect method, following the approach described by Mueller-Dombois & Ellenberg (1974). Sampling was conducted along the same 2 km transect followed for butterfly surveys. The floristic inventory was carried out over a 5-m-wide strip (2.5 m on each side of the transect) using the continuous species survey method, which involves identifying and listing all plant species present within the studied area.

Surveys were conducted during the spring season, a period in which the majority of species were in the flowering phase and easily identifiable. The relative abundance of each species was assessed using the "cover-abundance" approach, which allows for the analysis of floristic diversity and the distribution of vegetation strata (tree, shrub, and herbaceous layers) within the studied habitats. Plant species were identified using the Flora of Algeria (Quézel & Santa, 1962).

2.3. Statistical analysis

All analyses were performed using R version 4.3.2 (R Foundation for Statistical Computing, Vienna, Austria). We examined butterfly diversity in two cedar forest habitat types: degraded cedar forest (DC) and protected cedar forest (PC). The analyses aimed to understand how ecological parameters influence butterfly distribution, abundance, and species composition.

Average monthly abundance: Butterfly abundance was recorded monthly. The data were processed to obtain the mean monthly abundance, highlighting temporal fluctuations in butterfly activity throughout the year.

Comparison of species richness between habitats: Species richness was compared between the two habitat types (DC and PC). A Venn diagram was used to visually illustrate species overlap and specificity between the two sites, thereby highlighting differences and complementarity in species composition between habitats (Fig. 3).

Seasonal trends in abundance: A temporal assessment was carried out to identify seasonal trends in butterfly abundance. This helped determine peak activity periods and assess community responses to seasonal climatic variations.

Analyses by habitat type and season: All analyses were performed in R version 4.3.2 (R Foundation for Statistical Computing, Vienna, Austria). The overall butterfly abundance was also analyzed by habitat type (degraded vs. protected). A non-metric multidimensional scaling analysis (NMDS) was performed using Bray-Curtis dissimilarity to study butterfly distribution between the two habitat types: degraded and protected. This method considers the hierarchical structure of data while identifying species ecological preferences and how they are influenced by factors such as habitat quality.

A second analysis was carried out to examine butterfly distribution across the different seasons. The NMDS was followed by an ANOSIM (Analysis of Similarities), in order to evaluate the statistical significance of the differences observed between groups.

Several diversity indices were calculated, including species richness (^{0}D), Shannon index (^{1}D), and Simpson index (^{2}D). These indices provided an overview of alpha diversity and community structure according to habitat type.

RESULTS

1. Differences in species richness between the degraded cedar forest (DC) and the protected cedar forest (PC)

The Venn diagram illustrates the overlap and unique species between the degraded cedar forest and the protected cedar forest habitats. It indicates that: Both habitats share 25 common species. The degraded cedar forest harbors 16 exclusive species. The protected cedar forest hosts 7 unique species.

This suggests that, although there is a substantial overlap in species composition between the two habitats, each habitat also hosts its own distinct set of unique species (Fig. 2). This result also reveals that both habitats are complementary for the conservation of the whole butterfly community in the study area.

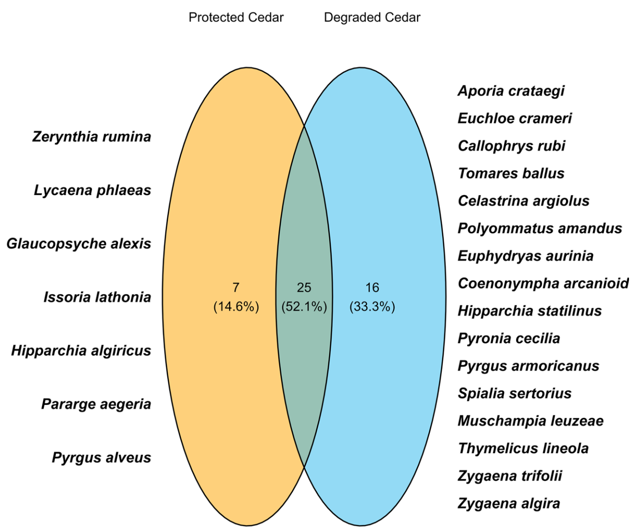


Fig. 2. Butterfly diversity between the degraded cedar forest (DC) and the protected cedar forest (PC).

2. Average monthly abundance

In the Fig. 3 is provided the results of the comparative analysis of the average monthly abundance of all butterfly species recorded in the study area, using mean individual counts per species to explain fluctuations in population density. This analysis reveals significant heterogeneity in population abundance among the species examined, with some showing considerably higher mean abundances.

The distribution pattern also suggests a predominance of species with a mean monthly abundance exceeding two individuals, while a minority do not surpass this threshold.

3. Seasonal trends in abundance

The data illustrate temporal fluctuations in butterfly populations, with a pronounced increase in abundance during the summer months, particularly in June and July in both

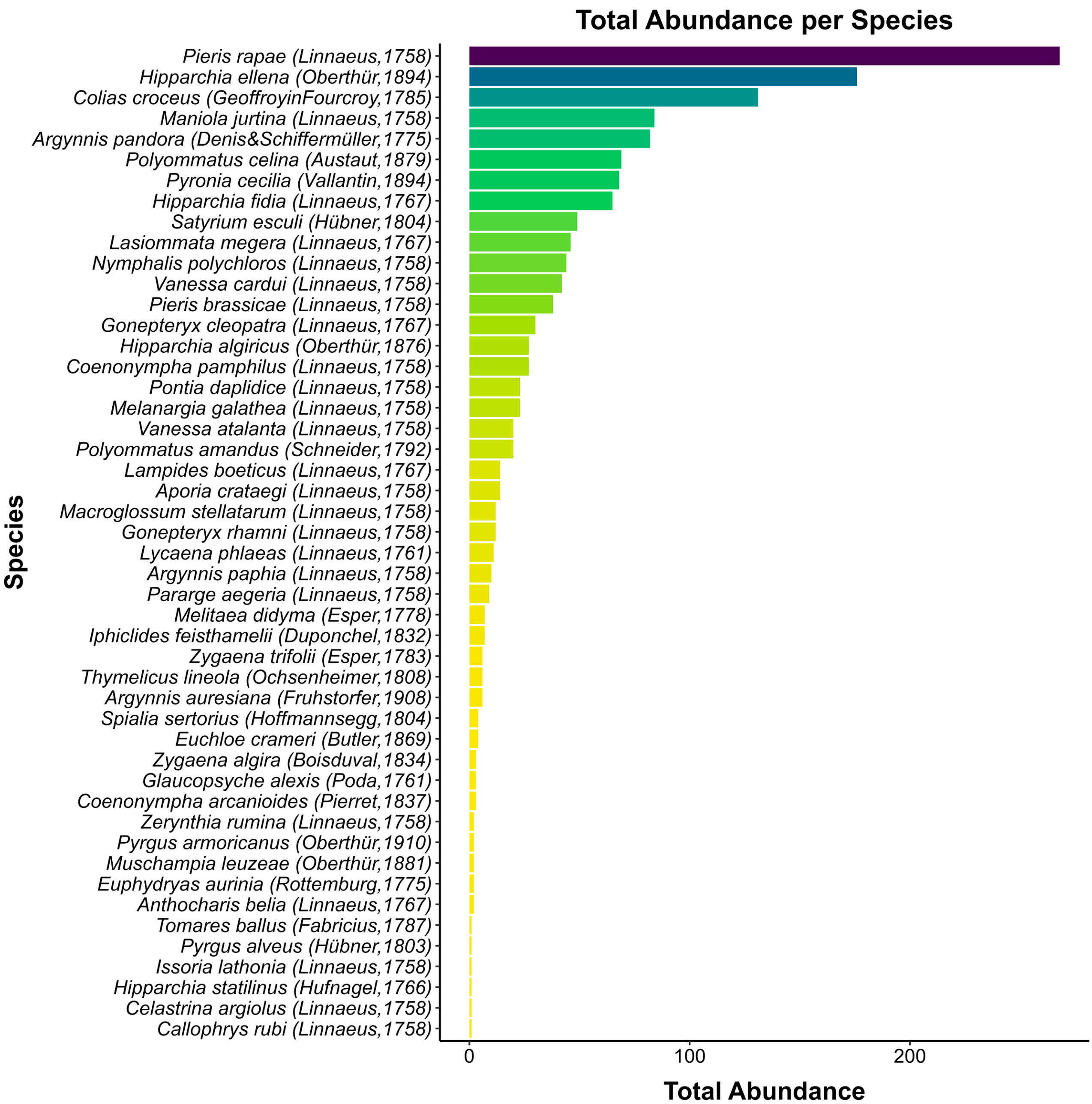


Fig. 3. Average monthly abundance of butterflies in the cedar forests of Djurdjura National Park, Algeria.

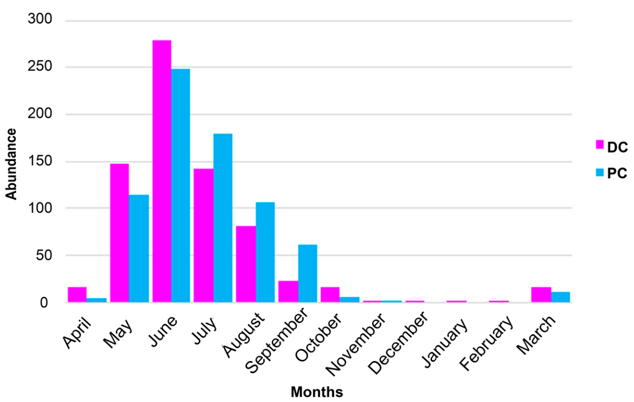


Fig. 4. Temporal fluctuations of butterflies in the degraded cedar forest (DC) and the protected cedar forest (PC) of Djurdjura National Park. Colors in the bars correspond to habitat types as indicated in the figure legend.

habitat types (Fig. 4). A comparative analysis between the degraded forest and the protected forest reveals nuanced variations in butterfly abundance throughout the year, with no consistent pattern emerging. In some months, the degraded forest shows a higher number of butterflies, while at other times, the protected area exhibits greater abundance.

Additionally, a general trend was observed toward a decline in butterfly abundance during winter and early spring.

4. Distribution of butterflies by habitat and season

The ANOSIM results do not indicate clear segregation of species distribution based on habitat (p-value > 0.05). However, some species appear to exhibit characteristic associations with each habitat type (Fig. 5), such as *Celastrina argiolus*, *Zygaena algira*, *Tomares ballus*, *Zygaena trifolii*, and *Pyronia cecilia*, which were associated with the

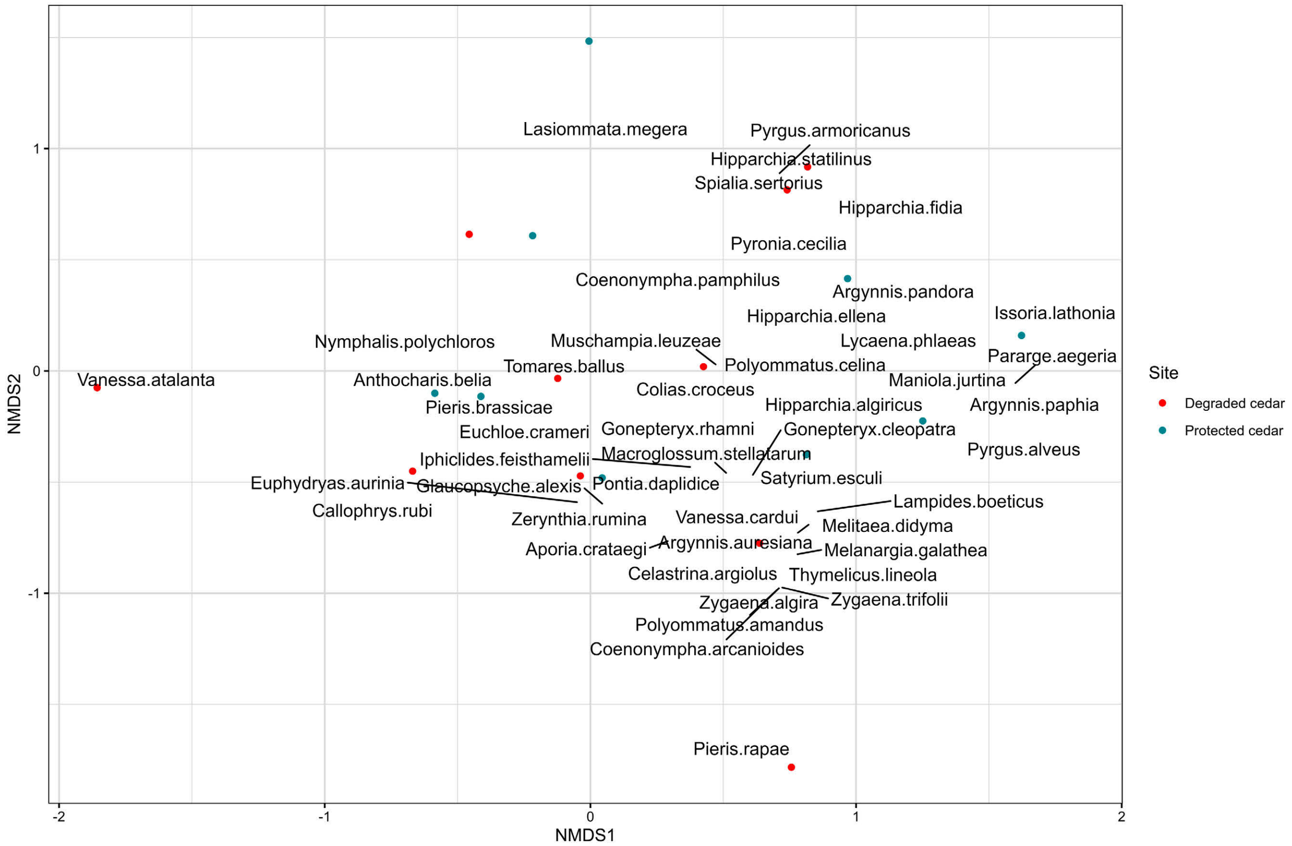


Fig. 5. Distribution of butterflies by type of cedar forest. Non-Metric Multidimensional Scaling (NMDS) ordination of butterfly species assemblages in degraded and protected cedar forests. (Lines connect species names to their centroid positions in ordination space to avoid text overlap.)

degraded cedar forest. In contrast, species such as *Pyrgus alveus*, *Zerynthia rumina*, *Pararge aegeria*, and *Issoria lathonia* were associated with the protected cedar forest.

According to the ANOSIM results, species distribution varied with the season (Figs 6a, b). More specifically, there was a significant difference between summer and spring/autumn in terms of species distribution similarity (ANOSIM statistic R: 0.429; Significance: 0.018).

Seasonal associations were observed among several butterfly species. In winter, the most notable species were *Vanessa atalanta* and *Pieris rapae*. In autumn, species such as *Hipparchia fidia*, *Hipparchia ellena*, *Nymphalis polychloros*, *Argynnis pandora*, and *Lasiommata megera* were predominant. Conversely, spring was marked by a high abundance of species such as *Pieris rapae*, *Colias croceus*, *Polyommatus celina*, *Pieris brassicae*, and *Vanessa cardui*.

5. Seasonal analysis of butterfly diversity

Overall, summer exhibited the highest diversity, as indicated by both the Shannon index and species richness, with 41 species observed. This is also the season with the highest total butterfly abundance, suggesting a population peak during the summer months (Fig. 7).

However, despite this high diversity, the evenness of species distribution remained relatively constant across seasons.

In contrast, winter showed the lowest diversity and abundance, with only two species observed (*Vanessa atalanta* and *Pieris rapae*) and a total abundance of three individuals. Surprisingly, evenness was highest in winter, suggesting a more equitable distribution of individuals among the limited number of species present. Spring and autumn fall between summer and winter in terms of diversity and abundance, with spring showing slightly higher values than autumn. The Simpson index indicated that summer species are more evenly distributed than those in other seasons, while winter showed the lowest evenness (Fig. 7).

DISCUSSION

1. Analysis of the overall diversity in Djurdjura National Park Cedar Forests

This study examines annual variations in the abundance and diversity of butterflies in the cedar forests of Djurdjura National Park, Algeria. Sampling was conducted in a degraded cedar forest and a protected cedar forest. We identified 1,479 individuals belonging to 48 species (Fig. 3). These species are distributed across seven families: Papilionidae, Pieridae, Lycaenidae, Nymphalidae, Hesperiidae, Sphingidae, and Zygaenidae. The first five families comprise 45 species, representing 37.5% of the species present in Algeria, estimated at 120 species according to Tennent

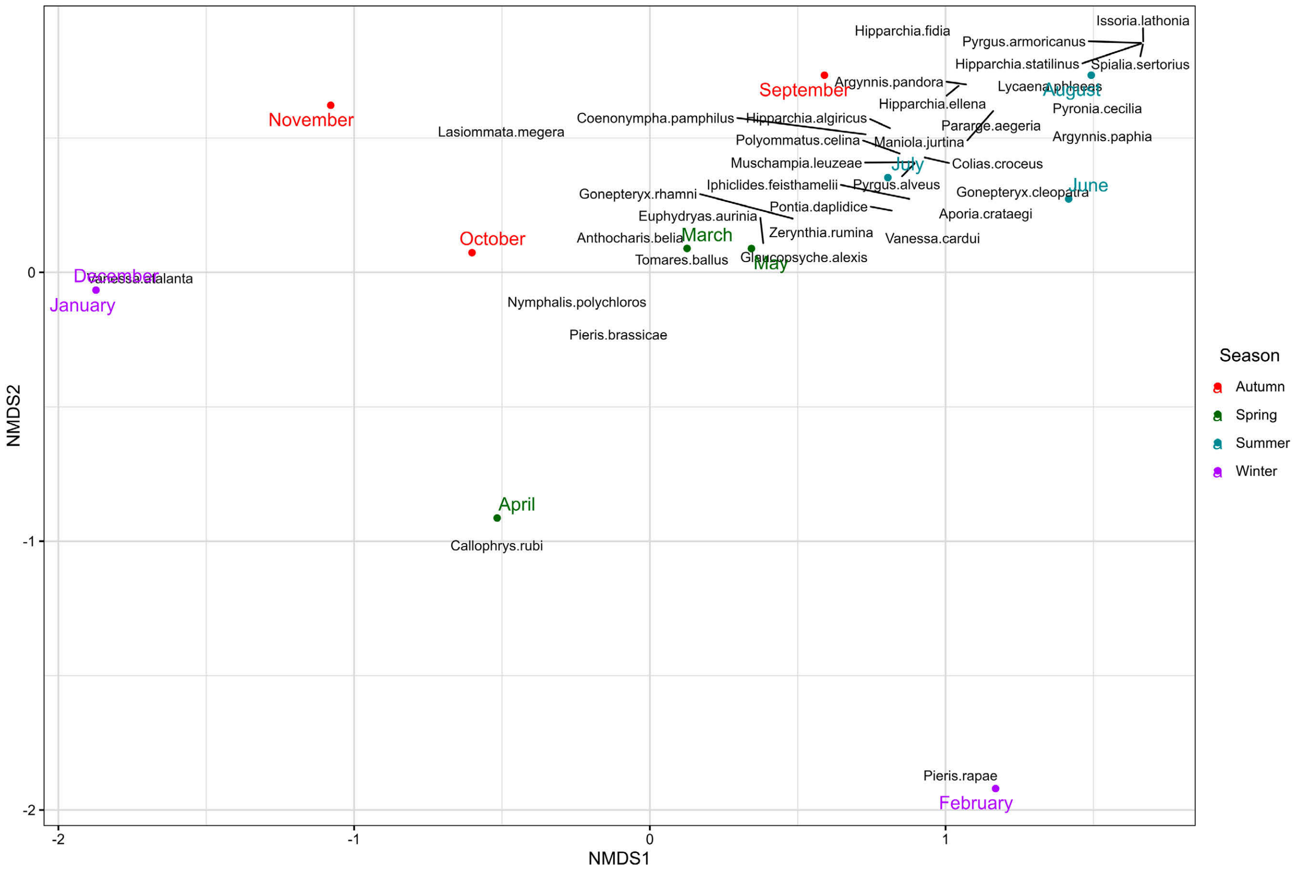
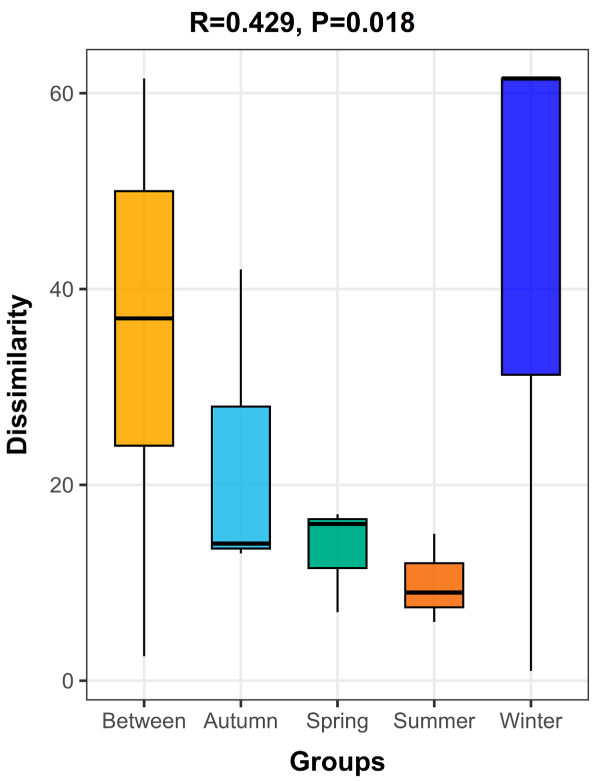


Fig. 6a. Distribution of butterflies by season. Non-Metric Multidimensional Scaling (NMDS) ordination of butterfly species assemblages in degraded and protected cedar forests. (Lines connect species names to their centroid positions in ordination space to avoid text overlap.)



Pairs	anosimR	p.value	p.adj
Autumn vs Winter	0.15	0.03	0.01
Spring vs Autumn	0.41	0.10	0.60
Spring vs Summer	0.67	0.10	0.60
Spring vs Winter	0.33	0.02	0.01
Summer vs Autumn	0.52	0.10	0.60
Summer vs Winter	0.48	0.02	0.01

Fig. 6b. ANOSIM applied to the seasonal distribution of butterflies in the cedar forests of Djurdjura National Park.

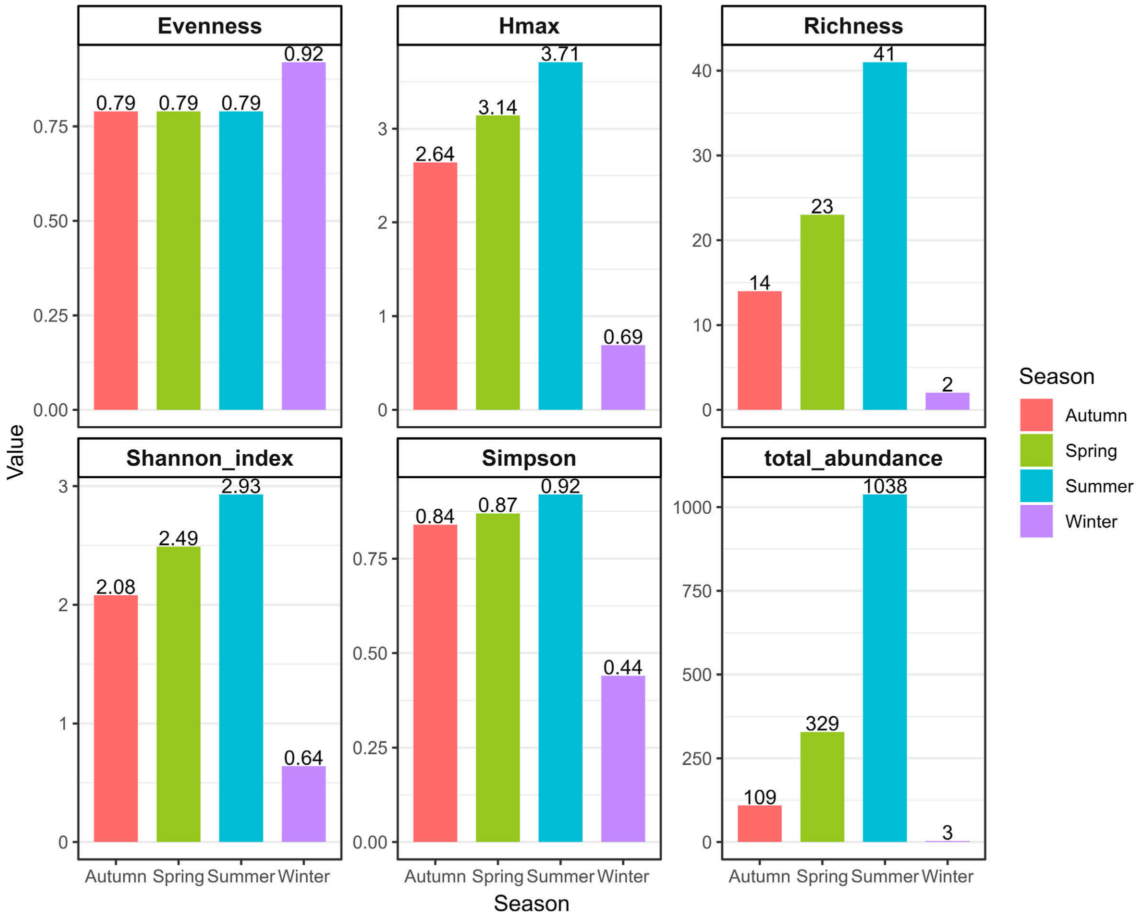


Fig. 7. Seasonal variation of diversity indices of diurnal butterflies in the cedar forests of Djurdjura National Park.

(1996), while the Sphingidae and Zygaenidae families include only three species in total.

Among these species, 12.5% are endemic to North Africa, including one species, *Muschampia leuzeae*, which is endemic to Algeria.

In comparison, our results show higher richness and abundance than those reported for the cedar forests of Theniet el Had National Park, which are located further west in the Ouarsenis Massif, where 39 species and 188 individuals were recorded (Kacha et al., 2017), and for the cedar forests of Belezma National Park in the Aurès, where 379 individuals representing 17 species were reported (Berkane et al., 2019).

It should be noted that the two previous studies were carried out on an annual cycle (Kacha et al., 2017; Berkane et al., 2019). This difference is likely due to the climatic conditions prevailing in the three parks. Theniet El Had National Park and Belezma National Park have subhumid bioclimate or even semi-arid bioclimate in some areas, resulting in lower floristic richness compared to the cedar forests of Djurdjura National Park, which are under a humid bioclimate (Quezel & Santa, 1962).

According to our data, the Nymphalidae family exhibits the highest diversity and abundance, with 20 species (41.67% of the total observed species) and 743 individuals (50.24% of the total observed individuals) (Table 1). This is attributed to their ability to adapt to various environmental conditions (Koneri & Maabuat, 2016) and the high survival capacity of its species, which are generally characterized by a cosmopolitan distribution (Ilhamidi et al., 2023).

Table 1. Species richness and abundance of butterfly families in the degraded and protected cedar forests of Djurdjura.

Family	Degraded cedar		Protected cedar		Totals	
	Specific richness	Abundance	Specific richness	Abundance	Specific richness	Abundance
Papilionidae	1	5	2	4	2	9
Pieridae	9	270	7	252	9	522
Lycaenidae	7	115	5	54	9	169
Nymphalidae	17	331	16	412	20	743
Hesperidae	4	14	1	1	5	15
Sphingidae	1	3	1	9	1	12
Zygaenidae	2	9	0	0	2	9
Totals	41	747	32	732	48	1479

Nymphalidae utilize a diverse range of plants, including members of the Asteraceae, Annonaceae, Fabaceae, and Poaceae families, as natural food sources (Peggie & Amir, 2006). These species are also easily observed throughout the year, due to their ubiquitous distribution (Ilhamidi et al., 2023).

Pieris rapae was the predominant species among those captured in both cedar forest types (Tables S1 and S2), representing 18.12% of all recorded individuals. Its high presence in both degraded and protected cedar forests can be explained by its adaptability to different environments and its rapid life cycle, enabling multiple generations per year. Moreover, as a polyphagous and ubiquitous species in all ecosystems (Tarrier & Delacre, 2008).

2. Monthly fluctuations in butterfly abundance

The results indicate strong heterogeneity in the abundance of observed species in both habitats (protected cedar forest and degraded cedar forest). Compared to other species, the average abundances of *Pieris rapae*, *Hipparchia ellena*, and *Colias croceus* are significantly high (Fig. 3). Which is explained by their diversity in terms of adaptability to environmental fluctuations, availability of food resources, and resilience to climatic changes (Pollard & Yates, 1993).

Indeed, these species are characterized by a polyphagous diet, allowing them to exploit a wider variety of nutritional resources. This trophic plasticity promotes population stability, enabling them to survive the scarcity of certain host plants and increasing their resilience to seasonal fluctuations (Thomas, 2005), whereas specialists are more vulnerable to habitat changes.

Roy & Sparks (2000) demonstrated that *Pieris rapae* is minimally sensitive to seasonal variations, such as temperature and humidity changes, explaining its relative abundance. Similarly, *Colias croceus* is known for its ability to rapidly colonize new habitats and adapt to various ecological conditions. A study by Stefanescu et al. (2003) highlighted its capacity for long-distance migration, thus compensating for local population variations through the influx of individuals from other regions. Additionally, this species exhibits remarkable adaptability to a wide range of host plants, particularly Fabaceae, giving it exceptional resilience to seasonal and climatic fluctuations. Finally, *Hipparchia ellena* displays notable resilience and adaptation to unfavorable environmental conditions. According to Tolman & Lewington (1997), this ability is a key factor in its ecological stability and high population density.

In contrast, other species, such as *Tomares ballus*, *Celastrina argiolus*, and *Hipparchia statilinus*, exhibit lower abundances (Fig. 3). These species may be particularly sensitive to seasonal variations and environmental disturbances due to their specific ecological requirements. Their low abundance could make them ecological indicators, reflecting the fragility of certain habitats. The presence and abundance of certain species are influenced by various physical and chemical factors (Ilhamidi et al., 2023).

3. Distribution and diversity of butterflies between cedar forest types

Out of 48 observed species, 41 species are present in the degraded cedar forest and 32 in the protected cedar forest. Among them, 16 species are exclusive to the degraded cedar forest and 7 to the protected cedar forest (Fig. 2). This suggests that, although substantial overlap exists, each habitat supports a distinct subset of butterfly species, likely influenced by habitat quality, vegetation diversity, and microclimatic conditions. Similar findings have been reported in other Mediterranean ecosystems, where management diversification was shown to increase habitat availability for butterflies (Quinto et al., 2025).

The results of the Non-Metric Multidimensional Positioning Analysis (NMDS) and Analysis of Similarities (ANOSIM) reinforce these trends. Although the ANOSIM results (p-value > 0.05) do not indicate statistically significant separation of species between the two habitat types, some species show characteristic associations with degraded or protected cedar forests (Fig. 5). For example, *Celastrina argiolus*, *Zygaena algira*, and *Pyronia cecilia* are more associated with the degraded cedar forest. However, the lack of statistical significance ($p > 0.05$) suggests their occurrence may be more influenced by broader ecological factors, such as climatic variables, particularly temperature and precipitation, play a determining role (Gupta et al., 2019; Beirão et al., 2021), rather than a strict preference for this specific habitat. In contrast, *Lycaena phlaeas* and *Hipparchia algiricus* are more linked to the protected cedar forest and show a statistically significant preference ($p < 0.05$), suggesting their dependence on stable ecological conditions characteristic of better-quality forest environments (Lafranchis, 2000).

The difference in species between the two habitats indicates that some butterflies may benefit from or even require the specific conditions of disturbed environments. These species would exploit niches created by degradation (Pollard & Yates, 1993), such as open spaces, as in our fire-degraded cedar forest, where specific host plants thrive in these areas. Conversely, the lower number of exclusive species in the protected habitat suggests that some species are highly sensitive to environmental disturbances and require stable, undisturbed conditions to survive. The number of butterfly species present in an area depends directly on the habitat type, with each species occupying a specific ecological niche (Ilhamidi et al., 2023).

Our results confirm this hypothesis, as the degraded cedar forest is considered an open habitat in the regeneration phase after fire, dominated by Hemicryptophytes (42%) and featuring a significant proportion of Phanerophytes (28%). In contrast, the protected cedar forest is a closed habitat, dominated by Phanerophytes (42%), characteristic of a dense and stable forest (Fig. 8).

Butterflies prefer open habitats with patches of woodland and shrubs (Stefanescu et al., 2005), as they require elements that provide shelter and specific resources, such as protected sites for egg-laying (Dover et al., 1997; Ouin & Burel, 2002). This type of environment is particularly

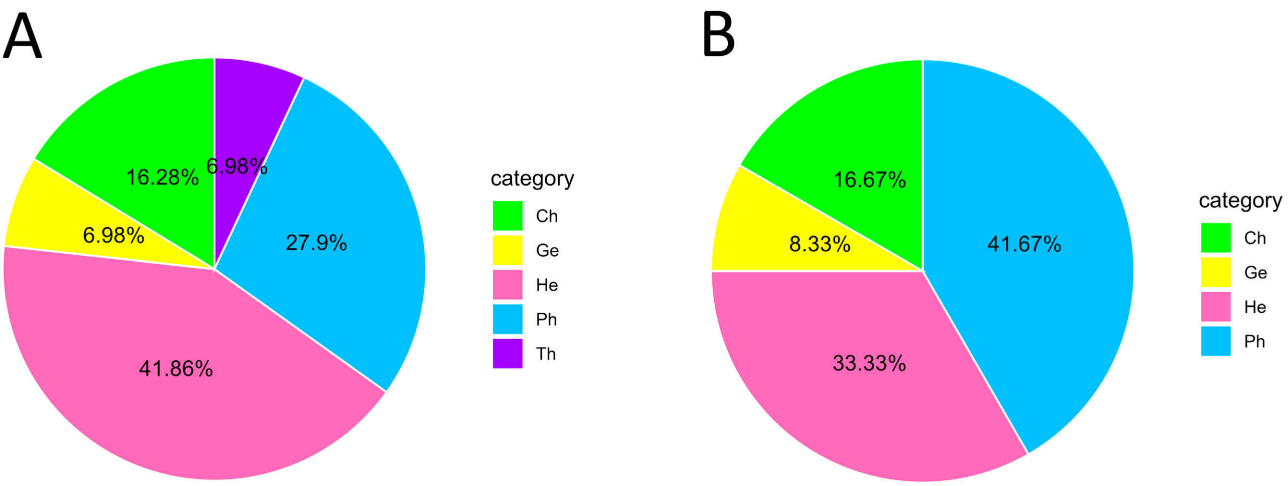


Fig. 8. Biological structure of the flora in the degraded cedar forest (A) and the protected cedar forest (B). Ph – Phanerophyte; Th – Therophyte; Ch – Chamaephyte; Ge – Geophyte; He – Hemicryptophyte.

favored by butterflies, especially those serving as bioindicators of open habitats (Faure, 2007; Demerges & Bachelard, 2002).

In this context, the distribution and rarity of Lepidoptera species can be directly influenced by the presence and location of their host plants (Tolman & Lewington, 1999) and by the richness of shrub and herb species (Özden & Hodgson, 2011; Koch et al., 2015). Brown (1997) emphasizes the crucial importance of plants for butterfly biodiversity, stating that the ecological value of an ecosystem largely depends on the number of species interacting with each other and with their physical environment. Furthermore, according to Bonneil (2005), Lepidoptera richness is closely and positively correlated with plant diversity. The presence of host plants, in particular, is a fundamental factor for maintaining insect populations within a given habitat (Deschamps-Cottin et al., 1997).

The degradation of the cedar forest favors the presence of heliophilous and thermophilous butterfly species, which prefer open environments (Pasquet, 2006; Fauré, 2007). When the forest cover is dense, as in the protected cedar forest, certain species that depend on open environments and warm microclimates are at a disadvantage. Trees create a cooler microclimate, which is less favorable to butterflies that prefer sunny conditions. Additionally, a high density of trees can reduce light availability and limit the growth of flowering plants, which serve as host plants for butterflies, with some plant species outcompeting others (Skórka et al., 2007). Furthermore, the height of vegetation can have a negative influence on the species richness of butterflies (Collinge et al., 2003), as vegetation that is too high can hinder their flight between flowers.

This difference is reflected in the floristic composition of the two habitats: the degraded cedar forest has 42 plant species, including 38 flowering plants, while the protected cedar forest has only 12 plant species, of which only 7 are flowering plants (Table S3). The degraded cedar forest proved to be the richest station in terms of butterfly species (41 species), compared with the protected cedar forest (32 species). This richness is likely due to the high presence of flowering plants (90.47%), a determining factor for the concentration of adult butterflies (Manil & Chague, 2014).

4. Seasonal variations in butterfly abundance and diversity

Seasonal fluctuations in butterfly populations were observed, with a peak in abundance during summer (June and July) (Fig. 4). This peak can be explained by rising temperatures (Pollard, 1988; Turner et al., 1989; Dennis, 1993; Lourenço et al., 2019). Higher temperatures generally accelerate the development of plants and insects, whether phytophagous or natural predators (Sauvion & Van Baaren, 2013). Moreover, the predicted impacts of climate change on butterflies are expected to be primarily positive, due in particular to the increase in flight-related activities, such as mate-searching, egg-laying, foraging, predator avoidance, and dispersal (Dennis & Shreeve, 1991). This trend could also be linked to favorable climatic conditions and the availability of essential resources, such as host plants for larvae and nectar sources for adults, which facilitate optimal reproductive and feeding activities (Thomas, 2005).

Many species require warmth and light to fly and access floral resources, the availability of which is also stimulated by sunlight. Additionally, understory plants, which constitute the primary food source for caterpillars, also benefit from these favorable conditions (Brown, 1997).

Conversely, the low abundance observed in winter and early spring suggests a period of diapause, reduced activity, or migration due to unfavorable climatic conditions (Chowdhury, 2023). Insects can adapt to unfavorable thermal conditions by entering diapause. This phenomenon is typically triggered by factors signaling future harsh conditions, such as a reduction in photoperiod, or by a drop in temperature (Sauvion & Van Baaren, 2013). Indeed, these insects adjust their life cycles to seasonal variations in available resources (Szigeti et al., 2018).

Temporal fluctuations in butterfly abundance between the degraded and protected cedar forests, with no clear or consistent trend emerging over the year, could indicate the influence of other seasonal or environmental factors on butterfly populations beyond the mere degradation status of the forest. The absence of significant and consistent disparity in butterfly abundance between the two habitats suggests a potential adaptability or migratory responses of butterflies to fluctuating environmental conditions across seasons. This adaptability underscores the complexity of butterfly population dynamics and highlights the need for more nuanced conservation strategies that account for these migratory patterns and the species' ability to exploit varied habitats.

The ANOSIM results on seasonal differences (Figs 6a, b) reveal a significant difference in species distribution between summer and spring/autumn (ANOSIM statistic R: 0.429, p = 0.018). These trends highlight the dynamic nature of butterfly populations and their preferences for specific environmental conditions throughout the year.

The seasonal analysis of butterfly diversity (Fig. 8) confirms these results by demonstrating that butterfly populations exhibit distinct seasonal dynamics:

Winter. Lowest diversity and abundance, with only two species observed (*Vanessa atalanta* and *Pieris rapae*). However, evenness is highest, suggesting equitable distribution among the few present species.

Spring. Moderate diversity, with dominant species such as *Pieris rapae*, *Colias croceus*, *Polyommatus celina*, and *Vanessa cardui*.

Summer. Highest species richness and abundance (41 species observed). The Shannon index indicates a peak in diversity, suggesting optimal environmental conditions for butterfly activity.

Autumn. Intermediate diversity, with species such as *Hipparchia fidia*, *Hipparchia ellena*, and *Nymphalis polychloros* dominating.

These seasonal patterns underscore the importance of temperature, photoperiod, and resource availability in structuring butterfly communities. According to Stefanescu et al. (2011) and Pires et al. (2020), butterfly abundance and diversity are largely determined by climatic factors, such as temperature variations, as well as the availability of essential resources, such as water.

CONCLUSION

Our study highlights the subtle interactions between butterflies, their habitats, and seasonal variations. Although species composition does not show significant segregation between degraded and protected cedar forests, certain species exhibit notable ecological preferences. Seasonal changes in butterfly abundance clearly demonstrate the major impact of climatic conditions on the establishment and evolution of butterfly communities.

These findings underscore the importance of preserving habitat heterogeneity and adopting adaptive management strategies capable of supporting both generalist and specialist species (Dennis et al., 2011). Long-term monitoring is needed to better understand the links between habitat quality, climatic variability, and population dynamics.

Indeed, this study shows that cedar forest degradation, particularly due to wildfires, alters vegetation structure and indirectly influences the diversity of butterflies and their seasonal patterns, although these effects vary by species. Some butterfly species appear more resilient to habitat degradation, while others are much more fragile (Larrieu & Gonin, 2008). The clearings created by fire may temporarily promote floral diversity and, consequently, butterfly richness.

Our results suggest that heterogeneous environments with varying vegetation structures could support the habitat of various butterfly species, depending on the season and the succession stage. Fire was indirectly associated with an increase in butterfly species richness, through the alteration of vegetation structure in the degraded cedar forest. Butterflies respond positively to forest fires by colonizing fire-created clearings, where they can exploit flowering plants. They also respond differently by favoring a greater plant diversity. However, insect responses are not only influenced by the physical effects of fire on their environment (Warchola et al., 2015), they are also affected by complex ecological factors which deserve to be explored in greater depth, particularly through genetic studies and detailed analyses of interactions within communities.

This study confirms the role of butterflies as relevant bioindicators of habitat quality and environmental changes, and highlights the need to investigate the long-term effects of habitat degradation, incorporating additional ecological factors such as host plant diversity and predator-prey interactions, which could enrich our understanding of seasonal and ecological community dynamics.

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CONFLICT OF INTEREST. The authors declare no conflict of interests.

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Supplementary Tables S1–S3 follow on next pages.

Table S1. The abundance of butterflies in the degraded cedar of Djurdjura national Park, Algeria.

Species	April	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Totals
	Degraded cedar												
Iphiclides feisthamelii (Duponchel, 1832)	0	1	2	2	0	0	0	0	0	0	0	0	5
Zerynthia rumina (Linnaeus, 1758)	0	0	0	0	0	0	0	0	0	0	0	0	0
Anthocharis belia (Linnaeus, 1767)	0	0	0	0	0	0	0	0	0	0	0	1	1
Aporia crataegi (Linnaeus, 1758)	0	4	10	0	0	0	0	0	0	0	0	0	14
Colias croceus (Geoffroy in Fourcroy, 1785)	0	33	39	19	2	1	0	0	0	0	0	0	94
Euchloe crameri (Butler, 1869)	0	1	0	0	0	0	0	0	0	0	0	3	4
Gonepteryx cleopatra (Linnaeus, 1767)	0	1	13	3	0	0	0	0	0	0	0	0	17
Gonepteryx rhamni (Linnaeus, 1758)	0	0	3	2	0	0	0	0	0	0	0	6	11
Pieris brassicae (Linnaeus, 1758)	1	9	0	2	0	0	0	0	0	0	0	2	14
Pieris rapae (Linnaeus, 1758)	8	39	43	11	0	0	0	0	0	0	1	3	105
Pontia daplidice (Linnaeus, 1758)	0	6	4	0	0	0	0	0	0	0	0	0	10
Satyrium esculi (Hübner, 1804)	0	0	41	2	0	0	0	0	0	0	0	0	43
Callophrys rubi (Linnaeus, 1758)	1	0	0	0	0	0	0	0	0	0	0	0	1
Tomares ballus (Fabricius, 1787)	0	0	0	0	0	0	0	0	0	0	0	1	1
Lycaena phlaeas (Linnaeus, 1761)	0	0	0	0	0	0	0	0	0	0	0	0	0
Lampides boeticus (Linnaeus, 1767)	0	0	4	0	0	0	0	0	0	0	0	0	4
Celastrina argiolus (Linnaeus, 1758)	0	0	1	0	0	0	0	0	0	0	0	0	1
Glaucopsyche alexis (Poda, 1761)	0	0	0	0	0	0	0	0	0	0	0	0	0
Polyommatus amandus (Schneider, 1792)	0	0	20	0	0	0	0	0	0	0	0	0	20
Polyommatus celina (Austaut, 1879)	0	23	14	6	0	2	0	0	0	0	0	0	45
Nymphalis polychloros (Linnaeus, 1758)	4	3	4	0	0	0	8	0	0	0	0	9	28
Vanessa atalanta (Linnaeus, 1758)	2	7	0	1	0	0	1	1	1	1	0	1	15
Vanessa cardui (Linnaeus, 1758)	0	15	5	0	0	0	0	0	0	0	0	0	20
Argynnis pandora (Denis & Schiffermüller, 1775)	0	0	0	2	0	2	0	0	0	0	0	0	4
Argynnis paphia (Linnaeus, 1758)	0	0	1	0	0	0	0	0	0	0	0	0	1
Argynnis auresiana (Fruhstorfer, 1908)	0	0	3	0	0	0	0	0	0	0	0	0	3
Issoria lathonia (Linnaeus, 1758)	0	0	0	0	0	0	0	0	0	0	0	0	0
Melitaea didyma (Esper, 1778)	0	0	3	0	0	0	0	0	0	0	0	0	3
Euphydryas aurinia (Rottemburg, 1775)	0	2	0	0	0	0	0	0	0	0	0	0	2
Melanargia galathea (Linnaeus, 1758)	0	0	21	0	0	0	0	0	0	0	0	0	21
Coenonympha arcanioides (Pierret, 1837)	0	0	3	0	0	0	0	0	0	0	0	0	3
Hipparchia ellena (Oberthür, 1894)	0	0	3	42	7	1	0	0	0	0	0	0	53
Hipparchia algiricus (Oberthür, 1876)	0	0	0	0	0	0	0	0	0	0	0	0	0
Hipparchia statilinus (Hufnagel, 1766)	0	0	0	0	1	0	0	0	0	0	0	0	1
Hipparchia fidia (Linnaeus, 1767)	0	0	0	0	24	10	0	0	0	0	0	0	34
Maniola jurtina (Linnaeus, 1758)	0	0	22	5	0	0	0	0	0	0	0	0	27
Pyronia cecilia (Vallantin, 1894)	0	0	2	36	30	0	0	0	0	0	0	0	68
Coenonympha pamphilus (Linnaeus, 1758)	0	1	1	0	11	3	0	0	0	0	0	8	24
Pararge aegeria (Linnaeus, 1758)	0	0	0	0	0	0	0	0	0	0	0	0	0
Lasiommata megera (Linnaeus, 1767)	0	3	0	7	1	4	7	0	0	0	0	2	24
Pyrgus alveus (Hübner, 1803)	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrgus armoricanus (Oberthür, 1910)	0	0	0	0	2	0	0	0	0	0	0	0	2
Spialia sertorius (Hoffmannsegg, 1804)	0	0	0	0	4	0	0	0	0	0	0	0	4
Muschampia leuzeae (Oberthür, 1881)	0	0	0	2	0	0	0	0	0	0	0	0	2
Thymelicus lineola (Ochsenheimer, 1808)	0	0	6	0	0	0	0	0	0	0	0	0	6
Macroglossum stellatarum (Linnaeus, 1758)	0	0	2	1	0	0	0	0	0	0	0	0	3
Zygaena trifolii (Esper, 1783)	0	0	6	0	0	0	0	0	0	0	0	0	6
Zygaena algira (Boisduval, 1834)	0	0	3	0	0	0	0	0	0	0	0	0	3
Abundance	16	148	279	143	82	23	16	1	1	1	1	36	747

Table S2. The abundance of butterflies in the protected cedar of Djurdjura national Park, Algeria.

Species	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Totals
	Protected cedar												
Iphiclides feisthamelii (Duponchel, 1832)	0	1	1	0	0	0	0	0	0	0	0	0	2
Zerynthia rumina (Linnaeus, 1758)	0	2	0	0	0	0	0	0	0	0	0	0	2
Anthocharis belia (Linnaeus, 1767)	0	0	0	0	0	0	0	0	0	0	0	1	1
Aporia crataegi (Linnaeus, 1758)	0	0	0	0	0	0	0	0	0	0	0	0	0
Colias croceus (Geoffroy in Fourcroy, 1785)	0	7	21	7	1	1	0	0	0	0	0	0	37
Euchloe crameri (Butler, 1869)	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonepteryx cleopatra (Linnaeus, 1767)	0	3	8	2	0	0	0	0	0	0	0	0	13
Gonepteryx rhamni (Linnaeus, 1758)	0	0	0	1	0	0	0	0	0	0	0	0	1
Pieris brassicae (Linnaeus, 1758)	2	15	1	3	0	0	1	0	0	0	0	2	24
Pieris rapae (Linnaeus, 1758)	0	41	98	21	1	1	0	0	0	0	0	1	163
Pontia daplidice (Linnaeus, 1758)	0	5	6	2	0	0	0	0	0	0	0	0	13
Satyrium esculi (Hübner, 1804)	0	0	5	1	0	0	0	0	0	0	0	0	6
Callophrys rubi (Linnaeus, 1758)	0	0	0	0	0	0	0	0	0	0	0	0	0
Tomares ballus (Fabricius, 1787)	0	0	0	0	0	0	0	0	0	0	0	0	0
Lycaena phlaeas (Linnaeus, 1761)	0	0	4	3	3	1	0	0	0	0	0	0	11
Lampides boeticus (Linnaeus, 1767)	0	0	10	0	0	0	0	0	0	0	0	0	10
Celastrina argiolus (Linnaeus, 1758)	0	0	0	0	0	0	0	0	0	0	0	0	0
Glaucopsyche alexis (Poda, 1761)	0	3	0	0	0	0	0	0	0	0	0	0	3
Polyommatus amandus (Schneider, 1792)	0	0	0	0	0	0	0	0	0	0	0	0	0
Polyommatus celina (Austaut, 1879)	0	4	8	11	1	0	0	0	0	0	0	0	24
Nymphalis polychloros (Linnaeus, 1758)	2	3	3	0	0	2	3	0	0	0	0	3	16
Vanessa atalanta (Linnaeus, 1758)	0	3	0	0	0	0	0	0	0	0	0	2	5
Vanessa cardui (Linnaeus, 1758)	0	9	13	0	0	0	0	0	0	0	0	0	22
Argynnis pandora (Denis & Schiffermüller, 1775)	0	0	16	29	24	9	0	0	0	0	0	0	78
Argynnis paphia (Linnaeus, 1758)	0	0	3	4	2	0	0	0	0	0	0	0	9
Argynnis auresiana (Fruhstorfer, 1908)	0	0	3	0	0	0	0	0	0	0	0	0	3
Issoria lathonia (Linnaeus, 1758)	0	0	0	0	1	0	0	0	0	0	0	0	1
Melitaea didyma (Esper, 1778)	0	0	4	0	0	0	0	0	0	0	0	0	4
Euphydryas aurinia (Rottemburg, 1775)	0	0	0	0	0	0	0	0	0	0	0	0	0
Melanargia galathea (Linnaeus, 1758)	0	0	2	0	0	0	0	0	0	0	0	0	2
Coenonympha arcanioides (Pierret, 1837)	0	0	0	0	0	0	0	0	0	0	0	0	0
Hipparchia ellena (Oberthür, 1894)	0	0	8	52	42	21	0	0	0	0	0	0	123
Hipparchia algiricus (Oberthür, 1876)	0	6	18	0	0	3	0	0	0	0	0	0	27
Hipparchia statilinus (Hufnagel, 1766)	0	0	0	0	0	0	0	0	0	0	0	0	0
Hipparchia fidia (Linnaeus, 1767)	0	0	0	0	16	15	0	0	0	0	0	0	31
Maniola jurtina (Linnaeus, 1758)	0	0	11	32	12	2	0	0	0	0	0	0	57
Pyronia cecilia (Vallantin, 1894)	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenonympha pamphilus (Linnaeus, 1758)	0	0	0	0	1	0	0	0	0	0	0	2	3
Pararge aegeria (Linnaeus, 1758)	0	0	0	7	2	0	0	0	0	0	0	0	9
Lasiommata megera (Linnaeus, 1767)	0	5	5	2	0	7	2	1	0	0	0	0	22
Pyrgus alveus (Hübner, 1803)	0	0	0	1	0	0	0	0	0	0	0	0	1
Pyrgus armoricanus (Oberthür, 1910)	0	0	0	0	0	0	0	0	0	0	0	0	0
Spialia sertorius (Hoffmannsegg, 1804)	0	0	0	0	0	0	0	0	0	0	0	0	0
Muschampia leuzeae (Oberthür, 1881)	0	0	0	0	0	0	0	0	0	0	0	0	0
Thymelicus lineola (Ochsenheimer, 1808)	0	0	0	0	0	0	0	0	0	0	0	0	0
Macroglossum stellatarum (Linnaeus, 1758)	0	7	1	1	0	0	0	0	0	0	0	0	9
Zygaena trifolii (Esper, 1783)	0	0	0	0	0	0	0	0	0	0	0	0	0
Zygaena algira (Boisduval, 1834)	0	0	0	0	0	0	0	0	0	0	0	0	0
Abundance	4	114	249	179	106	62	6	1	0	0	0	11	732

Table S3. List of the main plant species present in the two types of habitats (Degraded cedar and Protected cedar).

Plant species	Biological type	Degraded cedar	Protected cedar
1 – *Anacyclus clavatus*	Therophyte	+	–
2 – *Anagallis arvensis*	Therophyte	+	–
3 – *Ampelodesmos mauritanicus*	Hemicryptophyte	+	+
4 – *Artemisia absinthium*	Hemicryptophyte	+	–
5 – *Asperula hirsuta*	Chamaephyte	+	–
6 – *Asphodelus microcarpus*	Geophyte	+	+
7 – *Astragalus armatus* ssp. *numidicus*	Chamaephyte	+	+
8 – *Berberis hispanica*	Phanerophyte	+	–
9 – *Blackstonia perfoliata*	Therophyte	+	–
10 – *Calicotome spinosa*	Phanerophyte	+	–
11 – *Carduus nutans*	Hemicryptophyte	+	–
12 – *Carduus pycnocephalus*	Hemicryptophyte	+	–
13 – *Carthamus pinnatus*	Hemicryptophyte	+	–
14 – *Centaurea calcitrapa*	Hemicryptophyte	+	–
15 – *Cedrus atlantica*	Phanerophyte	+	+
16 – *Cichorium intybus*	Hemicryptophyte	+	–
17 – *Cistus albidus*	Chamaephyte	+	–
18 – *Cistus salvifolius*	Chamaephyte	+	–
19 – *Convolvulus arvensis*	Geophyte	+	–
20 – *Convolvulus cantabrica*	Chamaephyte	+	–
21 – *Convolvulus sabatius* ssp. *mauritanicus*	Hemicryptophyte	+	–
22 – *Coronilla valentica*	Chamaephyte	+	–
23 – *Crataegus laciniata* Ucria	Phanerophyte	+	–
24 – *Daphne gnidium*	Phanerophyte	+	+
25 – *Dianthus caryophyllus*	Hemicryptophyte	+	–
26 – *Erysimum bocconei*	Hemicryptophyte	+	+
27 – *Eryngium triquetum*	Hemicryptophyte	+	+
28 – *Ferula communis*	Hemicryptophyte	+	+
29 – *Genista ulicina* Spach	Phanerophyte	+	–
30 – *Hyoseris radiata*	Hemicryptophyte	+	–
31 – *Ilex aquifolium*	Phanerophyte	+	–
32 – *Juniperus oxycedrus*	Phanerophyte	–	+
33 – *Lonicera implexa*	Phanerophyte	+	+
34 – *Malva sylvestris*	Hemicryptophyte	+	–
35 – *Mantisalca salmantica*	Hemicryptophyte	+	–
36 – *Muscaro comosum*	Geophyte	+	–
37 – *Pallenis spinosa*	Hemicryptophyte	+	–
38 – *Quercus ilex*	Phanerophyte	+	+
39 – *Rosa sempervirens*	Phanerophyte	+	–
40 – *Rubus ulmifolius* Schott	Phanerophyte	+	–
41 – *Ruscus aculeatus*	Chamaephyte	–	+
42 – *Sambucus ebulus*	Hemicryptophyte	+	–
43 – *Santolina pectinata*	Chamaephyte	+	–
44 – *Vicia ochroleuca*	Hemicryptophyte	+	–