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Fire-Induced Changes in Daily Butterfly Assemblages in Mediterranean Forests: Insights from the Edough Massif, Algeria

Variación diaria de los ensamblajes de mariposas inducida por el fuego en bosques mediterráneos del macizo de Edough, Argelia

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Abstract

Forest fires significantly alter the biodiversity of Mediterranean ecosystems, particularly butterfly communities, which are sensitive bioindicators of environmental changes. This study compares the diversity and structure of diurnal butterflies in two cork oak forests of the Edough Massif (Algeria): a natural forest and a post-fire forest, based on surveys conducted from March to July 2023. Butterfly sampling was carried out using two complementary methods: a modified linear transect approach based on the British Butterfly Monitoring Scheme (BMS) and the Kilometric Abundance Index (KAI). Species abundances were recorded along predefined transects under standardized conditions. The results show a significant decline in species diversity after the fire, with only 11 species recorded in the burned habitat compared to 31 in the natural forest. Abundance analysis reveals that some sensitive species disappear or become rare, while others, more fire-resistant, benefit from the newly created ecological conditions. The Bray-Curtis index highlights a moderate but notable transformation of butterfly communities.

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These findings confirm that fire acts as an ecological filter, structuring populations according to their tolerance to disturbances. The study emphasizes the need for adapted management and restoration strategies to mitigate the effects of wildfires and promote the resilience of Mediterranean ecosystems.

Keywords: Rhopalocera; wildfire; Mediterranean forest; community structure; ecological resilience.

Resumen

Los incendios forestales alteran significativamente la biodiversidad de los ecosistemas mediterráneos, en particular las comunidades de mariposas, que son bioindicadores sensibles de los cambios ambientales. Este estudio compara la diversidad y la estructura de las mariposas diurnas en dos bosques de alcornoques del macizo de Edough (Argelia): un bosque natural y un bosque post-incendio, a partir de muestreos realizados entre marzo y julio de 2023. El muestreo de mariposas se llevó a cabo mediante dos métodos complementarios: un transecto lineal modificado basado en el British Butterfly Monitoring Scheme (BMS) y el Índice de Abundancia Kilométrica (KAI). Las abundancias de las especies fueron registradas a lo largo de transectos predeterminados en condiciones estandarizadas. Los resultados muestran una disminución significativa en la diversidad de especies después del incendio, con solo 11 especies registradas en el hábitat quemado en comparación con 31 en el bosque natural. El análisis de abundancia revela que algunas especies sensibles desaparecen o se vuelven raras, mientras que otras, más resistentes al fuego, se benefician de las nuevas condiciones ecológicas creadas. El índice de Bray-Curtis pone de relieve una transformación moderada pero notable de las comunidades de mariposas. Estos hallazgos confirman que el fuego actúa como un filtro ecológico, estructurando las poblaciones según su tolerancia a las perturbaciones. El estudio destaca la necesidad de estrategias de gestión y restauración adaptadas para mitigar los efectos de los incendios forestales y fomentar la resiliencia de los ecosistemas mediterráneos.

Palabras clave: Rophalocera; incendios forestales; bosque mediterráneo; estructura comunitaria; resiliencia ecológica.

INTRODUCTION

Wildfires represent a major ecological disturbance in Mediterranean ecosystems, shaping landscape dynamics and influencing biological community composition (Aponte et al., 2016; Turco et al., 2017). Due to climate change and anthropogenic activities, the frequency and intensity of wildfires have significantly increased in recent decades, threatening biodiversity and altering ecological processes (Calheiros et al., 2021). Among the affected biological groups, insects, particularly butterflies, play a key role as bioindicators of environmental changes due to their sensitivity to variations in microclimatic conditions and vegetation structure (Faure, 2007; Tarrier & Delacre, 2008; Schlegel et al., 2015; Laref et al., 2022).

Wildfires can have contrasting effects on butterfly populations, depending on several factors such as fire intensity, species dispersal ability, and their dependence on specific host plants (Börschig et al., 2013; Lafranchis et al., 2015). Some species, known as pyrophilous or fire-resistant, experience population growth after a fire, benefiting from habitat opening and the rapid colonization of new resources. Conversely, fire-sensitive species undergo a marked decline due to habitat destruction and reduced food resources (Swengel, 2001). Understanding these dynamics is essential to assess post-fire ecosystem resilience and to guide appropriate conservation strategies.

In this study, we analyze butterfly community diversity and structure in a natural cork oak forest and a burned cork oak forest in the Edough Mountain Massif. This area is considered as a key biodiversity hotspot in northeastern Algeria, and recognized as a regional center of endemism for numerous plant species (Vela & Benhouhou, 2007). As in many Mediterranean regions, the Edough Massif has experienced recurrent wildfires, threatening its ecological integrity and potentially altering the composition of animal communities (Hadiby et al., 2022; Benotmane et al., 2024).

In this study, we analyze butterfly community diversity and structure in a natural cork oak forest and a burned cork oak forest using robust statistical analyses. Our objectives are to (i) assess community similarity between the two habitats using the Bray-Curtis index, (ii) classify species based on their fire tolerance, and (iii) test differences in species group abundances using appropriate non-parametric tests. This approach will allow us to identify the most vulnerable species to disturbances and to evaluate the resilience capacity of Lepidoptera to wildfires.

The results of this study will contribute to a better understanding of wildfire effects on entomological biodiversity and provide concrete insights for the management and restoration of fire-affected Mediterranean ecosystems.

MATERIALS AND METHODS

Study area

The study was carried out in the Edough Peninsula (36°54'–36°59'N, 7°40'–7°49'E), a mountainous forest ecosystem in northeastern Algeria, from March to July. This region, part of the Kabylie–Numidie–Kroumirie biodiversity hotspot (Véla & Benhouhou, 2007), is characterized by dense oak woodlands and a remarkable floristic diversity, including several rare and endemic species (Yahi et al., 2012; Radford et al., 2014). The area experiences a Mediterranean climate, with mild, wet winters and hot, dry summers, influenced by northeastern winds (Fig. 1).

We selected two sampling sites within the Edough forest massif: Aïn Boucal, representing a natural site, and Sidi Nour, representing a post-fire site (Fig. 2). The Aïn Boucal site is located on the northern slope of the massif, between 363 and 510 meters in elevation, and consists of a well-preserved cork oak (*Quercus suber*) forest. The Sidi Nour site, situated at 576 meters near the CW16 road, corresponds to a cork oak stand severely affected by a wildfire in August 2021, and significantly altered the shrub layer and tree canopy.

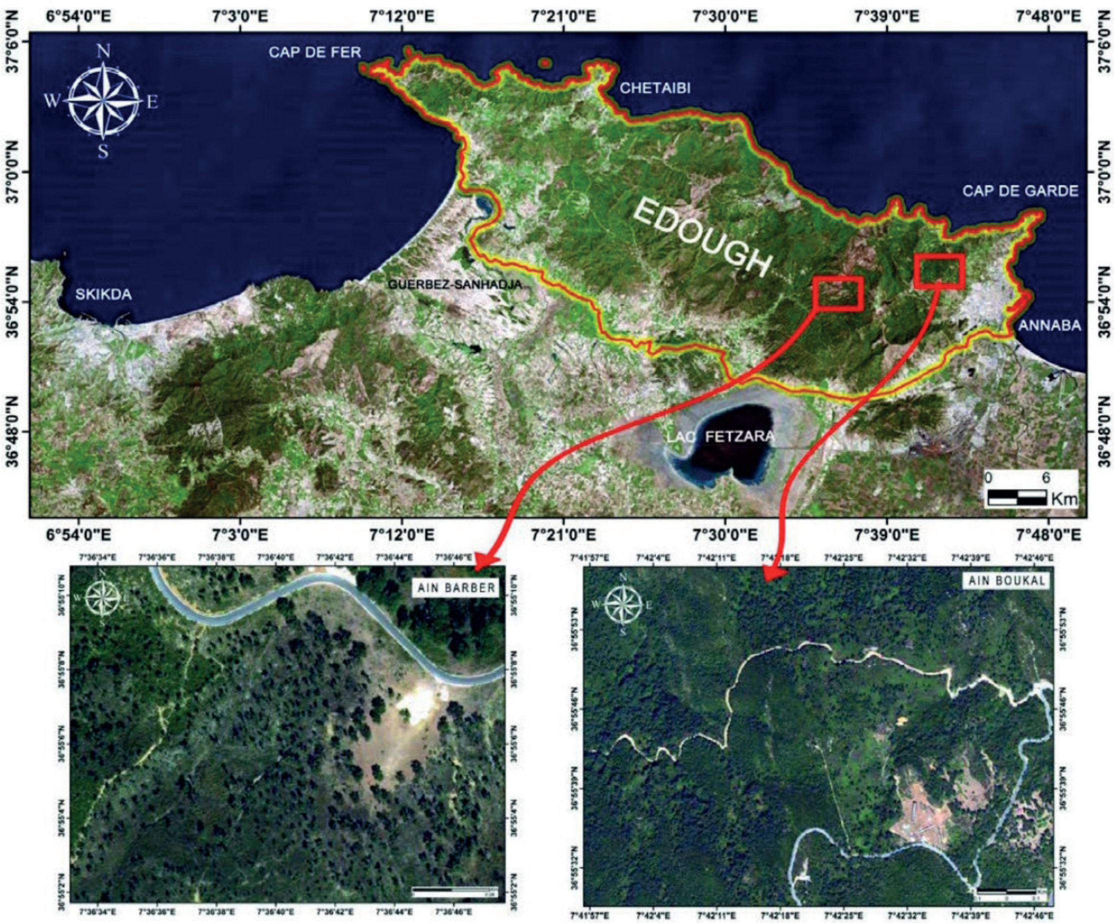

Figure 1. Location of study area and sample localities.

Figure 2. Description of the study sites: the natural oak forest of Ain Boucal and the post-fire oak forest of Sidi Nour.

Despite a slight difference in altitude, both sites fall within the same bioclimatic zone and share similar vegetation formations, primarily dominated by *Quercus suber* and associated Mediterranean shrub species. In the Edough massif, notable changes in floristic composition typically occur only above 700 meters of elevation, which supports the ecological comparability of the two sites.

Procedures

Sampling campaigns were carried out simultaneously at both study sites—the natural cork oak forest of Aïn Bocal and the post-fire cork oak stand of Sidi Nour—between March and July 2023. Two standardized surveys were conducted per month at each site, resulting in ten sampling sessions per site.

Butterfly surveys employed two complementary methods: a modified linear transect protocol based on the British Butterfly Monitoring Scheme (BMS) (Pellet & Gander, 2009; Lafranchis, 2014; Van Swaay, 2015b), and the Kilometric Abundance Index (KAI), allowing for broader-scale abundance estimates. Each survey involved walking a fixed 500-meter linear transect (width: 5 meters; 2.5 m on either side of the observer), following a strictly two-dimensional protocol in line with BMS standards (Manil et al., 2006). The transect was walked over 45 to 60 minutes between 10:00 a.m. and 2:00 p.m.—the peak activity period for diurnal butterflies—at a constant pace of 2 km/h, as recommended by Robineau (2007). To minimize observer-related variability, the same number of trained observers consistently applied the same procedures throughout the study.

Surveys were only conducted under favorable microclimatic conditions, as defined by BMS protocols: ambient temperatures between 20°C and 32°C, wind speeds below 15 km/h (no gusts), and sky conditions with at least 50% sunshine, excluding rainy or foggy days.

These parameters were recorded systematically during each session to ensure sampling consistency and control for weather-related biases.

When in-field identification was uncertain, specimens were temporarily captured and examined using standard identification keys (Demerges & Bachelard, 2002; Tennent, 1996; Tolman & Lewington, 1999).

Data analysis

Several statistical analyses were performed to assess the impact of the fire on community structure. The Bray-Curtis index was used to measure compositional similarity between habitats. Species were classified into three categories based on their abundance ratio (burned/natural): sensitive (ratio < 0.8), indifferent ($0.8 \leq$ ratio ≤ 1.2), and resistant (ratio > 1.2). Statistical tests were then applied: the Shapiro-Wilk test to check data normality, the Mann-Whitney test to compare abundances between habitats and species groups, and the Kruskal-Wallis test to analyze overall differences among the three groups. Finally, bar plots were generated to visualize the distribution and variation of mean abundances. All analyses were conducted by used Minitab 19.1.0, and Past 5.0.2 software's.

RESULTS

Characterization of the Lepidopteran Community

At the end of the sampling campaigns, 31 species belonging to four families (Lycaenidae, Papilionidae, Nymphalidae, and Pieridae) were identified in the natural cork oak forest of Ain Boucal. In contrast, the burned forest of Sidi Nour harbored only 11 species, indicating a significant decline in species diversity following the fire (Tab. 1).

Comparison of Abundances Between Habitats

At the end of the sampling campaigns, we recorded 480 individuals belonging to 31 species in the natural cork oak forest of Ain Boucal, compared to 422 imagos from 11 species in the burned cork oak forest of Sidi Nour.

The following graph (Fig. 3) highlights the differentiated impact of fire on species abundance. Some species, such as Glaucopsyche melanops and Polyommatus icarus, are sensitive and experience a decline in abundance in the burned oak forest, suggesting a dependence on conditions altered by the fire. Conversely, Glaucopsyche alexis and Pararge aegeria show an increase after the fire, indicating a certain level of resilience. Other species, such as Celastrina argiolus, remain stable and appear indifferent to disturbances.

Table 1. Composition of butterfly assemblages in natural and post-fire cork oak forests, showing species presence (√) or absence (0).

Families	Species	Natural cork oak forest	Burnt cork oak forest
Lycaenidae	*Celastrina argiolus*	√	√
	Glaucopsyche melanops	√	0
	Glaucopsyche alexis	√	√
	Polyommatus icarus	√	0
	Lampides boeticus	√	0
	Tomares ballus	√	0
	Cigaritis siphax	√	0
	Aricia cramera	√	0
	Lycaena phlaeas	√	0
Papilionidae	*Iphiclides feisthamelii*	√	√
	Zerynthia rumina	√	0
Nymphalidae	*Coenonympha arcaniodes*	√	0
	Pararge aegeria	√	√
	Charaxes jasius	√	0
	Vanessa atalanta	√	√
	Lasiommata megera	√	0
	Vanessa cardui	√	√
	Danaus chrysippus	√	0
	Melanargia galathea	√	0
	Argynnis paphia	√	0
	Maniola jurtina	√	√
Pieridae	*Gonepteryx cleopatra*	√	√
	Colias crocea	√	√
	Pieris brassicae	√	0
	Pieris rapae	√	√
	Anthocharis belia	√	√
	Gonepteryx rhamni	√	0
	Aporia crataegi	√	0
	Euchloe crameri	√	0
	Pontia daplidice	√	0
	Thymelicus acteon	√	0

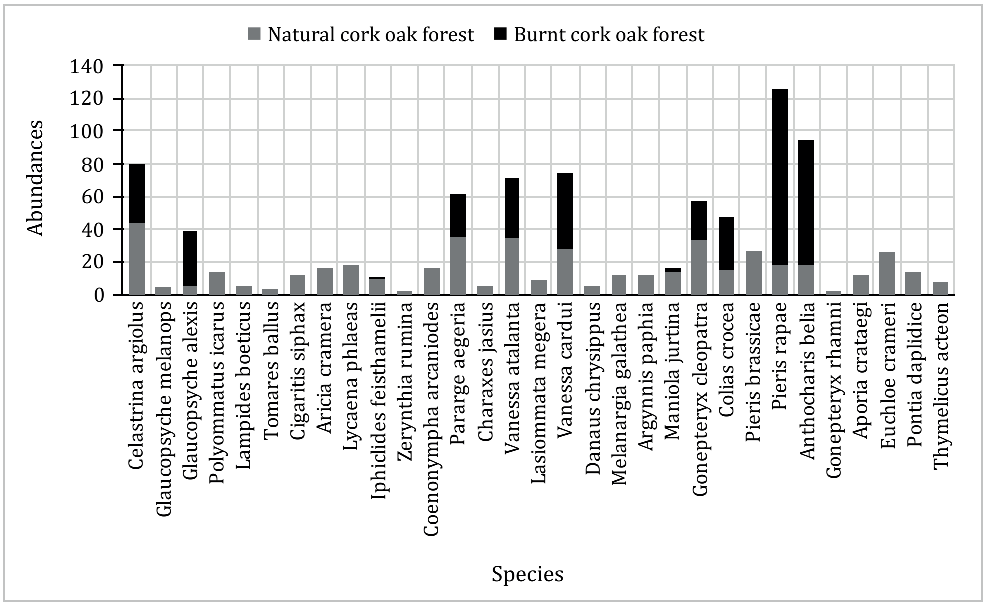

Figure 3. Comparison of butterfly abundances between natural and post-fire cork oak forests.

The analysis of species abundances between the natural and burned cork oak forests reveals significant differences. On average, species abundance is higher in the natural forest (39.2 ± 12.4) than in the burne forest (27.6 ± 10.8). The Mann-Whitney test indicates a significant difference between these two habitats ($U = 234$, $p = 0.005$), confirming a measurable impact of the fire on community structure. The Bray-Curtis index, used to quantify dissimilarity between the communities of both habitats, is 0.44, indicating a moderate but notable shift in species composition following the fire.

Classification of species according to their response to fire

Based on the abundance ratio between the two habitats, species were classified into three groups: resistant, sensitive, and indifferent species. Among the studied species, 35% were sensitive (< 0.8), 20% were resistant (> 1.2), and 45% showed low variation ($0.8 \leq \text{ratio} \leq 1.2$). The overall comparison of abundances among these three groups using the Kruskal-Wallis test revealed a significant difference ($H = 13.22$, $p = 0.0013$), indicating that abundances vary significantly depending on species classification (Fig. 4).

Sensitive species include Glaucopsyche melanops, Polyommatus icarus, and Lampides boeticus, whose abundance drops drastically after the fire. Resistant species, such as Glaucopsyche alexis and Vanessa cardui, show a notable increase in abundance in the burned cork oak forest. Finally, indifferent species, like Celastrina argiolus and Vanessa atalanta, maintain stable abundance levels between the two habitats.

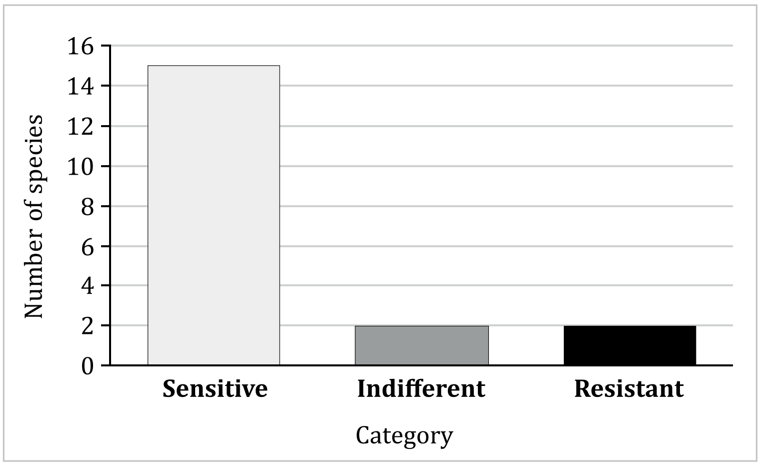

Figure 4. Distribution of species based on their response to fire.

Statistical analysis of abundance differences within groups

The Mann-Whitney tests applied to each group show that the effect of the fire is significant only for sensitive species ($U = 78$, $p < 0.0001$). For resistant species, although their average abundance is higher after the fire, this difference is not statistically significant ($U = 45$, $p = 0.33$). Indifferent species show no significant variation ($U = 100$, $p = 1.0$) (Fig. 5). These results indicate that the fire has a strong impact on sensitive species, while resistant and indifferent species do not show significant changes in their abundance. This classification helps to better understand community dynamics in response to environmental disturbances.

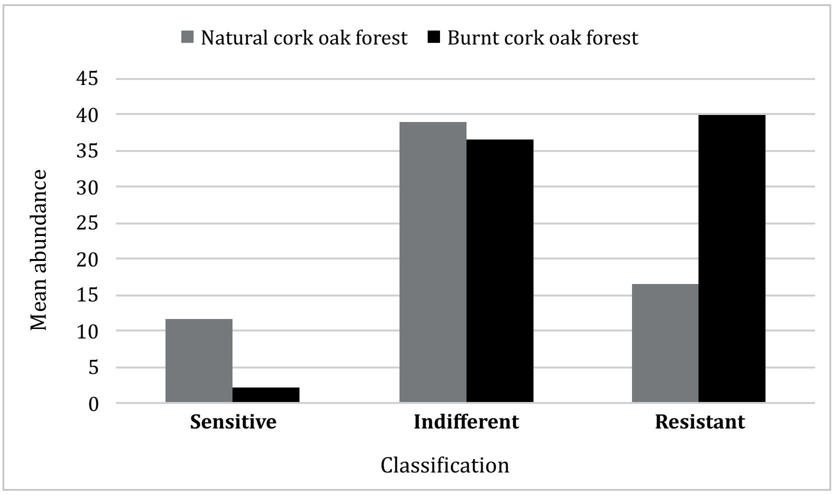

Figure 5. Comparison of Average Abundances by Species Group.

DISCUSSION

Due to their high taxonomic diversity, key ecological functions, and sensitivity to environmental changes, butterflies have long been recognized as effective bioindicators and have been integrated into conservation and natural area management strategies for over a decade (Syaripuddin et al., 2021). While research has predominantly focused on open habitats, forest ecosystems also constitute essential refuges for many butterfly species. These environments provide a staggered floral succession across seasons, particularly valuable during intercropping periods when cultivated plants are not in bloom (Staab et al., 2023). The richness of nectar sources and availability of shelter are among the primary factors influencing butterfly diversity (Schlegel & Hofstetter, 2021), making species richness a reliable proxy for assessing habitat quality (Rija, 2022).

Our results indicate that forest fires have a significant impact on butterfly communities. The analysis of population structure reveals a sharp decline in species richness in burned forests, with only 11 species recorded compared to 31 in natural forests. This reduction aligns with Swengel's (2001) findings, which underscore the sensitivity of butterflies to habitat alteration following major disturbances. The Bray-Curtis index (0.44) confirms a moderate but significant dissimilarity in community composition between burned and unburned sites, reflecting the structuring effect of fire on faunal assemblages (Moretti et al., 2006).

Post-fire habitat opening appears to benefit certain generalist or opportunistic species, such as Glaucopsyche alexis and Vanessa cardui, whose abundances increased in burned areas. This trend supports the observations of Pausas & Keeley (2009), who describe how fire-favored environments are rapidly colonized by mobile, fast-reproducing species. In contrast, specialist species such as Glaucopsyche melanops and Polyommatus icarus experienced a pronounced decline, confirming that species with narrow ecological niches are more vulnerable to abrupt habitat changes (Stefanescu et al., 2009).

Statistical analyses reinforce these observations: the Mann-Whitney test shows a significant difference in abundance between the two habitats ($U = 234$, $p = 0.005$), and the Kruskal-Wallis test ($H = 13.22$, $p = 0.0013$) highlights significant variation among species grouped into three ecological categories: resistant, sensitive, and indifferent. These results corroborate the hypothesis that fire acts as an ecological filter (Lloret et al., 2002), favoring the persistence or establishment of certain traits while excluding others (Ruchin, 2021).

Interestingly, not all observed trends reached statistical significance. For species categorized as resilient, a general post-fire increase in abundance was noted, yet this difference was not statistically significant ($p = 0.33$). This result may be attributed to high intra-group ecological variability. Although grouped under a single functional label, resilient species exhibit marked differences in their dispersal capacities, microhabitat preferences, and phenological patterns, leading to asynchronous or divergent responses to post-disturbance conditions (Mason et al., 2021). Such functional heterogeneity tends to attenuate group-level signals, limiting the detection of statistically significant effects (Pavlick et al., 2017). Similarly, no significant variation was observed in the abundance of indifferent species ($p = 1.0$), a result likely stemming from compensatory dynamics within the group. Slight increases in some taxa may be offset by concurrent declines in others, yielding a net neutral trend at the aggregate level. This internal balancing effect reflects the complexity of post-disturbance community restructuring and illustrates the limitations of broad functional classifications, which, while operationally useful, may obscure species-specific ecological responses and adaptive trajectories (Smith et al., 2021; Kahilainen et al., 2024).

Beyond these quantitative patterns, butterflies may play a pivotal role in post-fire ecosystem recovery. Several studies suggest that recolonization of burned sites by butterflies — especially from nearby unburned refuges — contributes to ecological restoration (Swengel, 2001; Gongalsky, 2017). The open habitats created by fire offer new floral resources and basking sites, facilitating the return of nectar-feeding adults. In turn, their pollination activity supports the regeneration of herbaceous and woody vegetation, especially for plant species that rely on lepidopteran pollinators (Ruchin, 2021; Marty, 2019).

Moreover, an emerging hypothesis highlights a possible role in passive seed dispersal. Some seeds may adhere to butterfly wings or bodies during nectar foraging or oviposition, allowing transport across the post-fire mosaic (Nakazawa, 2023). While this mechanism remains understudied, it could represent a complementary pathway contributing to the spatial dynamics of plant community recovery.

Finally, when fire regimes are not excessively severe or frequent, they can enhance landscape heterogeneity and promote biodiversity at broader spatial scales (Lloret et al., 2002). In these mosaic landscapes, the presence of larval host plants becomes critical, not only for butterfly survival but also for sustaining forest floor dynamics. Caterpillars contribute to nutrient cycling and organic matter decomposition (Souchko, 2022), thereby participating in the functional recovery of burned soils.

In summary, although forest fires disrupt butterfly communities and reduce species richness in the short term, they may also create conditions conducive to ecological renewal. Butterflies — through their pollination services, trophic interactions, and potential role in seed transport — emerge as both victims and agents of post-disturbance dynamics. Their response offers valuable insights into the resilience and trajectory of Mediterranean forest ecosystems under increasing fire pressure.

CONCLUSIONS

This study highlights the varying impact of forest fires on butterfly communities, with opportunistic species benefiting from habitat opening while specialists decline. The significant reduction in diversity and species reorganization underscores the need for conservation strategies that support recolonization and habitat restoration. Long-term monitoring is essential to guide adaptive management.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon request from the authors.

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