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Altitudinal Distribution of Fireflies (Coleoptera: Lampyridae) in the Tacaná Volcano, Mexico

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Fireflies (Coleoptera: Lampyridae) serve as bioindicators due to their sensitivity to environmental changes; however, their ecological distribution remains insufficiently documented. The Tacaná Volcano in Chiapas, Mexico, represents a biodiversity hotspot with diverse altitudinal ecosystems. This study investigates the altitudinal distribution of fireflies in this region through systematic sampling at four sites ranging from 278 to 2181 m a.s.l. between July and November 2023, employing both aerial nets and Malaise traps. A total of 226 specimens, representing 20 species across seven genera and five tribes, were identified. The greatest species richness was observed at mid-elevations (740-1191 m a.s.l.), particularly in shade-grown coffee plantations, where humidity and canopy cover emerged as significant environmental variables. Species richness was quantified using Hill numbers, while the Jaccard index assessed compositional similarities among sites. Generalized linear models (GLMs) and canonical correspondence analysis (CCA) evaluated the relationships between firefly abundance, species richness, and environmental parameters. Firefly abundance demonstrated positive correlations with temperature, humidity, and canopy cover, while precipitation exhibited a negative correlation. Nevertheless, no single environmental variable was identified as a definitive determinant of species richness. New distributional records reinforce the conservation significance of the Tacaná Volcano. Malaise traps proved to be an effective complement to traditional sampling techniques, facilitating the capture of diurnal and non-bioluminescent species. The highest species diversity and abundance were recorded in shaded coffee plantations, which provide stable microclimatic conditions conducive to firefly populations. Conversely, lower diversity was documented at the lowest and highest elevations, likely attributable to habitat constraints. This study highlights the importance of continued research to elucidate the ecological drivers influencing firefly distribution and to inform conservation strategies. Given the identification of novel species and new distributional records, the Tacaná Volcano should be recognized as a priority site for biodiversity conservation and entomological studies.

Keywords: Lampyridae, Tacaná volcano, Altitudinal distribution, Firefly diversity, Ecology.

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BACKGROUND

The family Lampyridae (Coleoptera) is a diverse group, with approximately 2,500 species described worldwide (Zaragoza-Caballero et al. 2023). In Mexico, 301 species of fireflies have been documented (Zaragoza-Caballero et al. 2020 2023 2024), with 44 species recorded in the state of Chiapas (Pérez-Hernández et al. 2022). Despite Coleoptera being among the best-studied orders in Chiapas, no studies have focused specifically on the Lampyridae family (León-Cortés et al. 2005).

Most firefly research has concentrated on taxonomy, particularly in tropical and subtropical regions, often neglecting areas with less favorable climatic conditions (Crisci 2006). Furthermore, most taxonomic descriptions are based on adult males, and only recently have morphological characteristics of females been incorporated (Ballantyne and Menayah 2002; Fu et al. 2012). Few efforts have been made to understand key aspects of their ecology (Vaz et al. 2020), and studies related to altitudinal gradients are even scarcer. In Malaysia, Nada et al. (2023) documented an altitudinal pattern in wich the greatest species richness was concentrated at mid-elevations. Similarly, Macedo et al. (2017) found that fireflies species were predominantly specialists in lowland areas rather in high-altitude regions. Likewise, Smith (2009) reported greater abundance and richness of lampyrids in lowland areas, with much lower diversity in mid-elevation zones.

It is imperative to generate information on the ecology of fireflies along altitudinal gradients, given the susceptibility of many lampyrid species to environmental changes and their distribution being closely linked to environmental factors such as humidity or specific climatic conditions (Branham 2015). A comprehensive understanding of their ecology could facilitate their use as bioindicators of ecosystem health (Nak-eiam et al. 2011), inform the design of tourist attractions in parks (Lewis et al. 2021), or contribute to biological control strategies, as observed in some mollusks species (Ramos-Abuin 2019).

Given the ecological significance of fireflies, their wide distribution, and their sensitivity to environmental changes, this study aims to determine the diversity and altitudinal distribution of fireflies (Coleoptera: Lampyridae) in the Tacaná volcano, Chiapas, Mexico.

MATERIALS AND METHODS

Study area and site selection

The Tacaná volcano is located in the eastern Sierra Madre de Chiapas, in the state of Chiapas (Mexico) and the Department of San Marcos, Guatemala. It covers an area of approximately 300 km^2 and reaches a maximum altitude of 4,092 m above sea level (CONANP 2013). The predominant climate in the area includes humid temperate with summer rains (C(m)(w)ig), humid semi-warm with summer rains (A(c)m(w)ig), and humid warm with summer rains (Am(w")ig), with an annual precipitation of up to 3,640 mm and an average annual temperature of 20.7°C (García 1998; SMN 2019).

Six vegetation types are present in the study area: pine forest, oak forest, cloud forest, evergreen tropical forest, grasslands, and coffee plantations, with cloud forest occupying the largest area (CONANP 2013). However, significant portions of the original vegetation have been converted into coffee plantations and pastures (Martínez-Camilo and Martínez-Meléndez 2010).

Four sampling sites were selected across an altitudinal gradient ranging from 270 to 2,181 meters above sea level (m a.s.l.) (Fig. 1). This range was chosen based on previous studies reporting higher abundances of the Lampyridae at altitudes between 800 and 1,300 m a.s.l. (Nada et al. 2023;

Branham 2015; Colares et al. 2021). Site selection was primarily based on altitude, along with other factors such as vegetation type, site accessibility, and fireflies presence (Table 1).

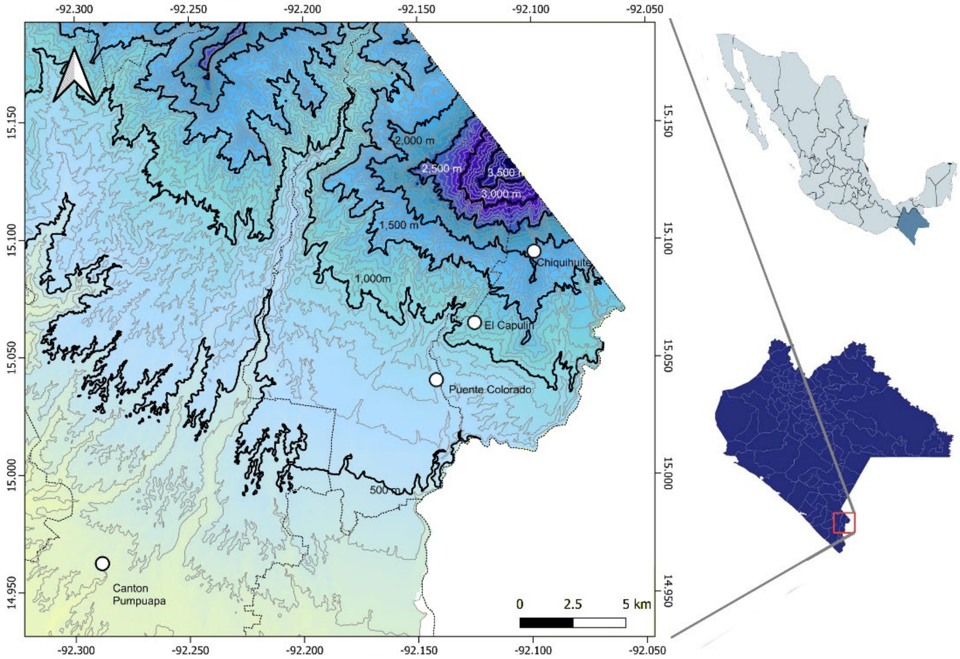

Fig. 1. Study area and sampling sites on the Tacaná volcano, Chiapas.

Table 1. Selection of sampling sites at Tacaná volcano, Chiapas

Sites	Municipality	Altitude (m a.s.l.)	Type of vegetation
Cantón Pumpuapa (CP)	Tapachula	278	Pastures and small proportions of evergreen tropical forest
Ejido Puente Colorado (PC)	Cacahoatán	740	Shade-grown coffee
El Capulín (EC)	Cacahoatán	1,191	Shade-grown coffee
Chiquihuites (CH)	Unión Juárez	2,181	Cloud forest

Sampling of fireflies

A study was designed to sample fireflies during the rainy season, which is typically the period of highest abundance and diversity of fireflies, as documented in other studies (*e.g.* Branham 2015; Zaragoza-Caballero and Ramirez-Garcia 2009). The study was conducted from July to November 2023.

There is no standardized method for sampling fireflies. However, two types of sampling were used in this study: 1) nocturnal search with entomological nets and 2) use of Malaise traps. Both types of sampling were carried out at the selected sites, for which transects were established with a length between 300 to 500 m and an approximate width of 6 m, considering the topography and accessibility of the sites (Nada et al. 2023; Ochoa-García et al. 2019). Direct search was conducted in the transects between 6:00 p.m. and 10:00 p.m., targeting adult firefly specimens, particularly those species that possess bioluminescent organs and are easily discernible during nocturnal hours. This method entailed a sampling effort of two or three individuals during the conducted tours.

Malaise traps is a passive method designed for the capture of Diptera, Hymenoptera, and Lepidoptera. However, its effectiveness in capturing Coleoptera has been reported as limited (Martin 1977), although it has been observed to be a selective method for certain beetle species (Fernández-García and Favila 2007). Based on previous observations, its use has been justified for capturing fireflies that lack bioluminescent organs or primarily exhibit diurnal activity. A Malaise trap was installed at the center of each transect and remained active during the sampling period, with inspections conducted every 15 days (Silveira et al. 2020). Specimen collected were preserved in 80% ethyl alcohol. All biological material was deposited in the Entomological Collection (ECO-TAP-E) of El Colegio de la Frontera Sur (ECOSUR - Unidad Tapachula).

Taxonomic identification

Taxonomic identification was conducted using the taxonomic keys provided by Zaragoza-Caballero (1995), Zaragoza-Caballero et al. (2020), Lima et al. (2021), and Zaragoza-Caballero (2023), as well as original descriptions available in *Biologia Centrali-Americana* (Gorham, 1880-1886). Additionally, the classification proposed by Bouchard et al. (2011) and Martin et al. (2019) was followed. To verify species determinations, a visit was made to the Entomological Collection (IEXA) of Instituto de Ecología A.C. in Xalapa, Veracruz.

A portion of the biological material was dissected and mounted following the technique described by Gutiérrez-Carranza (2023). For most species, dorsal habitus photographs were taken using the stacking technique with a Nikon D3400 camera adapted to a Nikon SMZ-U stereoscopic microscope, utilizing the DigiCamControl and Helicon Focus programs. Finally, images and slides were processed using Adobe Photoshop.

Environmental variables measurement

At each site, environmental variables considered important for fireflies were recorded, including temperature, relative humidity, precipitation, canopy cover, and vegetation structure (Branham 2015; Ramírez-Manzano et al. 2023). Temperature and relative humidity were measured using an ELITECH RC-51H thermohygrometer (accuracy: T ± 1°C, RH ± 5%), while precipitation data were obtained from the National Water Commission (CONAGUA) through monitoring stations located within the study area.

Canopy cover, defined as the ground surface covered by tree crowns, was assessed using the CANOPEO application (Patrignani and Ochsner 2015), with an average of nine measurements per site, following the recommendations of Korhonen and Heikkinen (2009).

Vegetation structure was determined using 50 × 20 m transects (0.1 ha) at each site, following the methodology proposed by Gentry (1982). Within each plot, woody plants with a diameter at breast height (DBH) ≥ 5 cm were recorded and counted. DBH was measured using a diameter tape, and tree height was estimated with a digital laser rangefinder and/or visual assessment. Data collection and plant identification were conducted by Dr. Karen Beatriz Hernández-Esquivel from the Herbarium of El Colegio de la Frontera Sur (ECOSUR, Unidad Tapachula).

Data analysis

The abundance (number of individuals) and species diversity were assessed using Hill numbers, which quantify the effective number of species in a sample and reflect the distribution of relative abundances among species (Magurran 2004). Three orders of Hill numbers were considered: species richness (^{0}D), the Shannon exponential index (^{1}D), and the inverse Simpson index (^{2}D). To compare Hill numbers across sites, interpolation/extrapolation curves were generated using the *iNEXT* package (Chao et al. 2014; Chao et al. 2016).

The Jaccard index was used to evaluate species composition among sites, and a dendrogram was constructed to visually represent the percentage of similarity between localities (Magurran 1988). Additionally, generalized linear models (GLMs) with a Poisson distribution were applied to determine which environmental variables influenced firefly richness and abundance. To assess the relationship between species and environmental variables, a canonical correspondence analysis (CCA) was performed. Both the dendrogram and CCA were conducted using the *vegan* package. All analyses were performed in *RStudio* (González et al. 2007).

RESULTS

Checklist of the Lampyridae from Tacaná Volcano, Chiapas

The checklist does not include seven morphospecies. Five of them are currently being described by researchers from the Institute of Biology at UNAM (Mexico). One will be assigned to a new genus within the tribe Cratomorphini, while the remaining ones correspond to new species of the genus *Photinus*. The other two morphospecies also belong to the genus *Photinus*. One is a female, and male specimens are required to confirm its taxonomic status, while the other corresponds to a new species, represented by a single male specimen.

Distributional information and additional remarks are provided for each species, with countries and Mexican states listed in alphabetical order.

Family Lampyridae Rafinesque

Subfamily Psilocladinae McDermott

Genus *Psilocladus* Blanchard

1. *Psilocladus scutellaris* (Gorham)

= *Drilolampadius scutellaris* Gorham

Distribution: COSTA RICA, GUATEMALA, MEXICO (**new country record, Chiapas**), PANAMA (Gorham 1880).

2. *Psilocladus stolatus* (Gorham)

= Drilolampadius stolatus Gorham

Distribution: BELIZE, GUATEMALA, HONDURAS, MEXICO (Veracruz), NICARAGUA (Gorham 1880).

Subfamily Lampyrinae Rafinesque

Tribe Photinini LeConte

Genus *Photinus* Laporte

3. *Photinus* aff *malinalxochiltlae* Zaragoza-Caballero & González-Ramírez

Distribution: MEXICO (Estado de México) (Pérez-Hernández et al. 2022).

4. *Photinus paracongruus* Zaragoza-Caballero

Distribution: MEXICO (**new state record, Chiapas,** Veracruz) (Pérez-Hernández et al. 2022).

5. *Photinus pulchellus* Gorham

Distribution: GUATEMALA, MEXICO (**new state record, Chiapas,** Veracruz) (Pérez-Hernández et al. 2022).

6. *Photinus ruficollis* Gorham

Distribution: GUATEMALA, MEXICO (**new state record, Chiapas,** Guerrero, Morelos) (Pérez-Hernández et al. 2022).

Genus *Pyropyga* Motschulsky

7. *Pyropyga alticola* Green

Distribution: JAPAN (Introduced), MEXICO (Coahuila, Chiapas, Guerrero, Morelia, Oaxaca, Puebla, Veracruz) (Pérez-Hernández et al. 2022).

8. *Pyropyga minuta* (LeConte)

= *Ellychnia minuta* LeConte

Distribution: UNITED STATES, GUATEMALA, HONDURAS, MEXICO (Colima, Chiapas, Durango, Guerrero, Guanajuato, Hidalgo, Jalisco, Morelos, Nayarit, Nuevo León, Oaxaca, Puebla, Querétaro, Sinaloa, Veracruz) (Pérez-Hernández et al. 2022).

Tribe Pleotomini Summers

Genus *Phaenolis* Gorham

9. *Phaenolis laciniatus* Gorham

Distribution: COSTA RICA, NICARAGUA, MEXICO (**new country record, Chiapas**) (Gorham 1880).

Subfamily Photurinae Lacordaire

Tribe Photurini Lacordaire

Genus *Bicellonycha* Motschulsky

10. *Bicellonycha amoena* (Gorham)

= *Photuris amoena* Gorham

Distribution: GUATEMALA, MEXICO (Colima, Chiapas, Guerrero, Guanajuato, Hidalgo, Jalisco, Michoacán, Morelos, Nayarit, Oaxaca, Puebla, Quintana Roo, Sinaloa, Tamaulipas, Veracruz), NICARAGUA, PANAMA (Pérez-Hernández et al. 2022).

Genus *Photuris* Dejean

11. *Photuris* aff *lugubris* Gorham

Distribution: GUATEMALA, HONDURAS, MEXICO (Ciudad de México, Guerrero, Jalisco, Morelos, Oaxaca, Tamaulipas), (Pérez-Hernández et al. 2022).

12. *Photuris tenuisignathus* Zaragoza-Caballero

Distribution: MEXICO (Chiapas, Sinaloa, Veracruz) (Pérez-Hernández et al. 2022).

13. *Photuris trivittata* Lloyd & Ballantyne

Distribution: BELIZE, GUATEMALA, HONDURAS, MEXICO (Chiapas, Guerrero, Tabasco, Veracruz) (Pérez-Hernández et al. 2022).

Species richness and diversity of fireflies

A total of 226 individuals were collected, representing 20 species, six genera, five tribes, and three subfamilies (Table 2). The subfamily Lampyrinae was the most representative, accounting for 50% of the individuals collected and 70% of the species recorded in the study. Within this subfamily, the genus *Photinus* was the most abundant.

Table 2. Species and abundance of fireflies from the sampling sites

Tribe	Species	CP	PC	EC	CH
Psilocladini	*Psilocladus scutellaris*			1	
	Psilocladus stolatus		16	42	
Cratomorphini	gen. nov., sp. nov.				1
Photinini	*Photinus* aff *malinalxochiltlae*			1	
	Photinus paracongruus		2	5	
	Photinus pulchellus			4	
	Photinus ruficollis		1	4	
	Photinus sp1			1	
	Photinus sp2			2	
	Photinus sp3			1	
	Photinus sp4			1	
	Photinus sp5		7	44	
	Photinus sp. nov.		1		
	Pyropyga alticola		2	4	
	Pyropyga minuta		3	3	
Pleotomini	*Phaenolis laciniatus*		3	5	
Photurini	*Photuris* aff *lugubris*			1	

Photuris tenuisignathus		3
Photuris trivittata	5	13
Bicellonyca amoena	32	

CP: Cantón Pumpuapa, PC: Puente Colorado, EC: El Capulín, CH: Chiquihuite.

Firefly activity was observed throughout the sampling period, with the highest abundance and species richness recorded in August, while November showed the lowest representation (Fig. 2A and 2B). Similarly, September was the only month in which firefly activity at three of the four sites, as Pumpuapa had firefly activity only in August and Chiquihuite only in September.

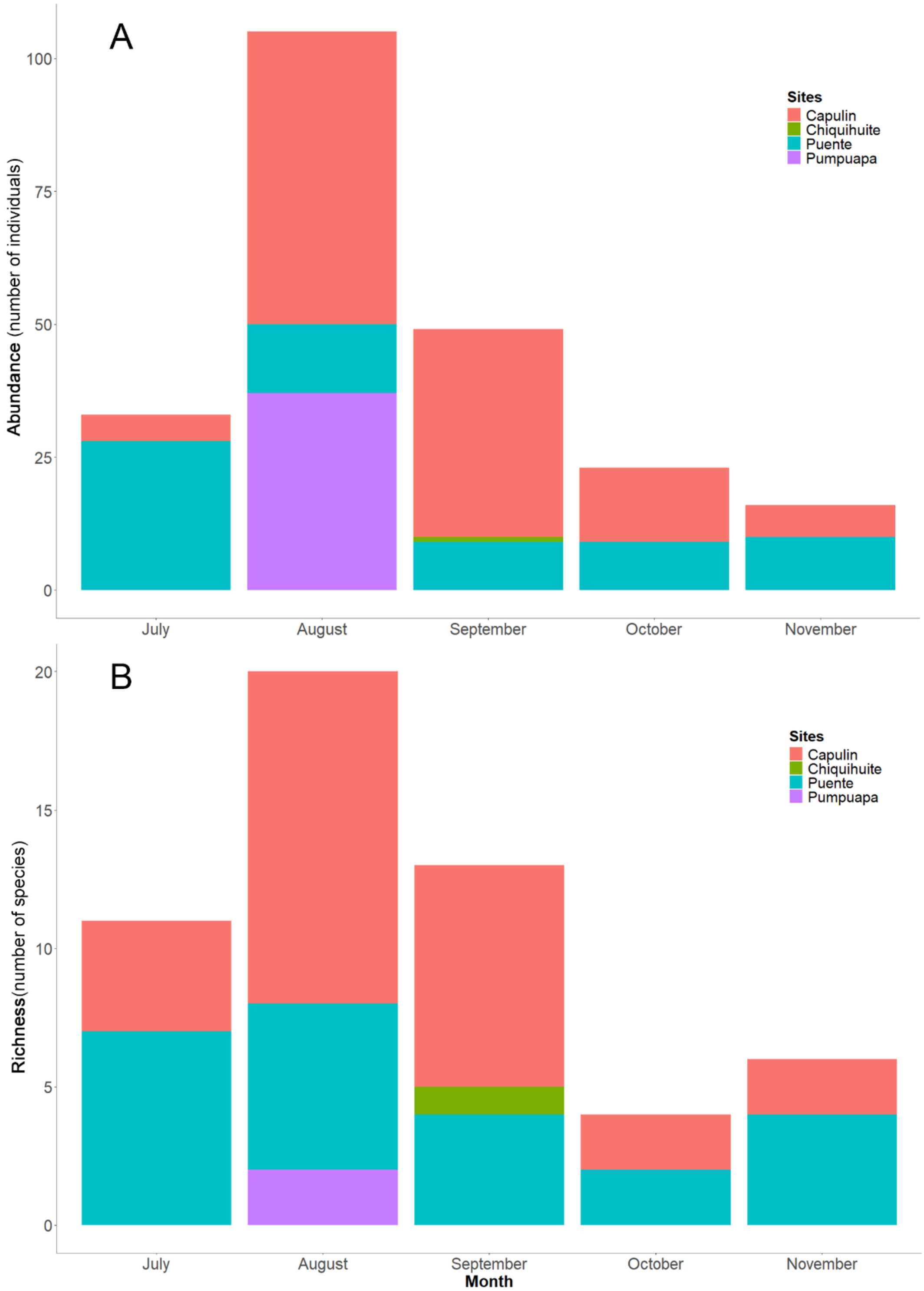

Fig. 2. Variation in Firefly abundance (A) and richness (B) during the sampling period across the studied sites.

Regarding the altitudinal range studied, the highest species richness was found at intermediate elevations, with 80% of the captured species recorded between 740 and 1,191 m above sea level (Fig. 3). Likewise, when considering the tribes to which the collected species belong, the tribe Photurini was found at low elevations, whereas tribe Cratomorphini was recorded above 2,000 m above sea level. The remaining tribes were observed at intermediate elevations.

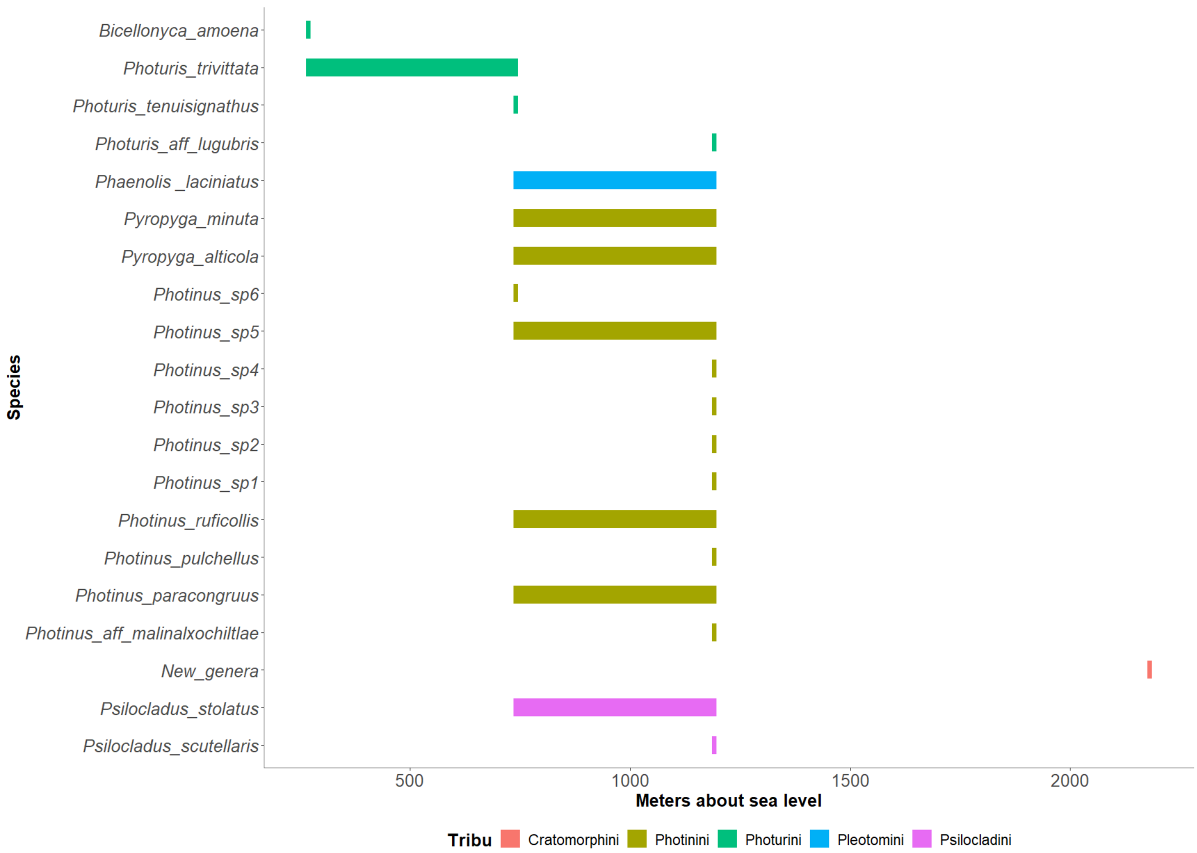

Fig. 3. Altitudinal distribution of fireflies on Tacaná Volcano, Mexico

Sample coverage was high across all sites, reaching 94% at El Capulín, 96% at Puente Colorado, and 100% at Cantón Pumpuapa. Species diversity varied among the studied sites (Fig. 4). Puente Colorado and El Capulín exhibited similar diversity across the three orders of diversity and had the highest values, whereas Pumpuapa showed the lowest values and differed significantly from the other sites. The highest diversity values were recorded at the two sites that located at mid-elevations (740 to 1,191 m a.s.l.). Species composition similarity was moderate between El Capulín and Puente Colorado (38%), while the remaining sites exhibited lower similarity (Fig. 5).

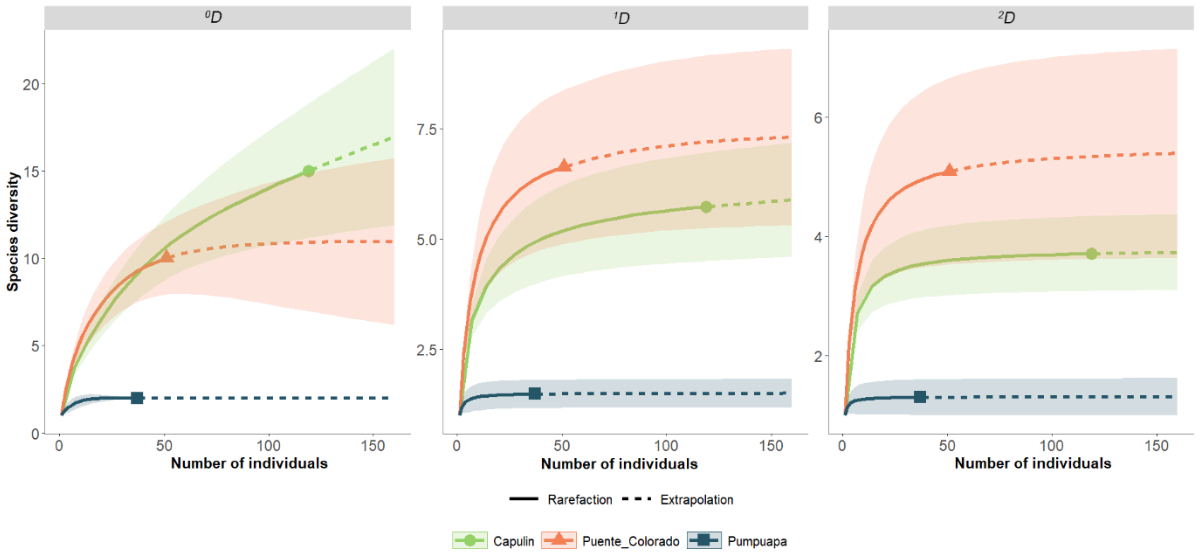

Fig. 4. Diversity of firefly species at each site based on Hill numbers (^0D = species richness, ^1D = Shannon exponential index, ^2D = inverse Simpson index).

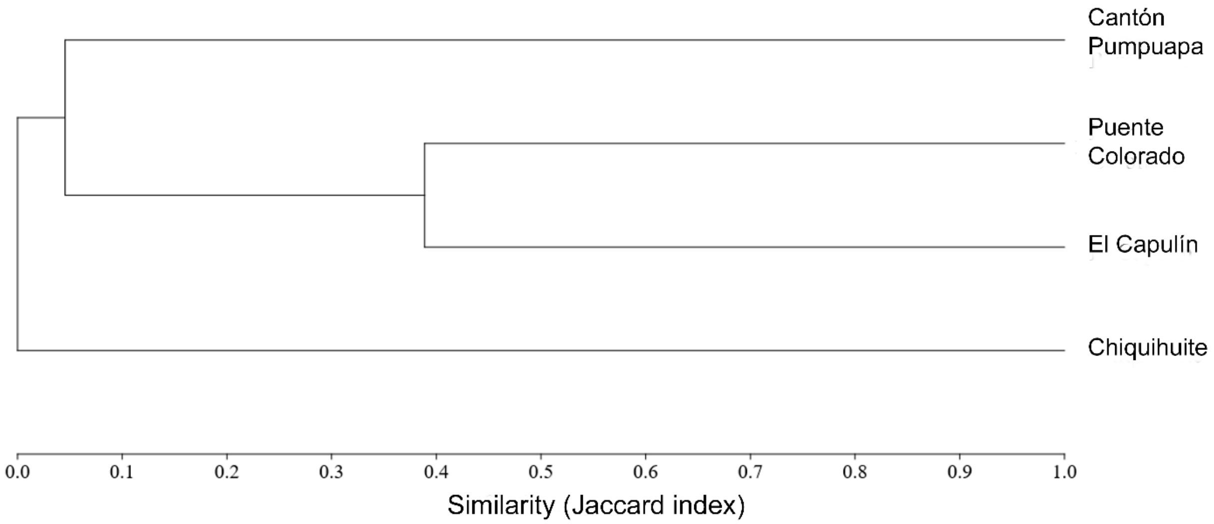

Fig. 5. Dendrogram showing the similarity among studied sites based on the Jaccard index.

The results obtained from the GLM indicated that firefly species richness was not influenced by the studied variables; however, abundance was negatively related to precipitation (Z = -3.91, p-value < 0.001) and positively related to temperature (Z = 5.75, p-value < 0.001), humidity (Z = 5.27, p-value < 0.001) and canopy cover (Z = 2.45, p-value = 0.01) (Table 3).

Table 3. Summary of statistics of two generalized linear models (GLM) to analyze the richness and abundance of fireflies on the environmental variables. The values in parentheses are the standard errors of the estimate

Variable*	Estimate (SE)	*Test statistic (Z)*	*P*
Richness			
Temperature	-0.1577 (8.95)	-1.761	0.0782
Precipitation	-0.0011 (0.00073)	-1.572	0.1160
Humidity	14.90 (6.812)	2.187	0.6880
Canopy cover	3.024 (3.173)	0.953	0.3406
Abundance			
Temperature	0.4530 (0.078)	5.755	< 0.001
Precipitation	-0.00142 (0.0003)	-3.911	< 0.001
Humidity	0.02073 (3.932)	5.273	< 0.001
Canopy cover	4.213 (1.717)	2.454	0.014

*Vegetation structure was omitted from this analysis due to the limited data available.

The canonical correspondence analysis (CCA) showed that the relationship between species abundance, sampling sites, and environmental variables explained 85.3% of the total variance for the two ordination axes, with eigenvalues of 0.89 (axis 1) and 0.35 (axis 2) (Fig. 6). The CCA accounted for 36% of the species-environment variation in axis 1, indicating that the factors most strongly influencing species composition and distribution were tree richness (r = 0.99), temperature (r = 0.56), and humidity (r = -0.94). Axis 2 explained 24 % of the species-environment variation, with canopy cover (r = -0.94) being the most important factor influencing species distribution along this axis.

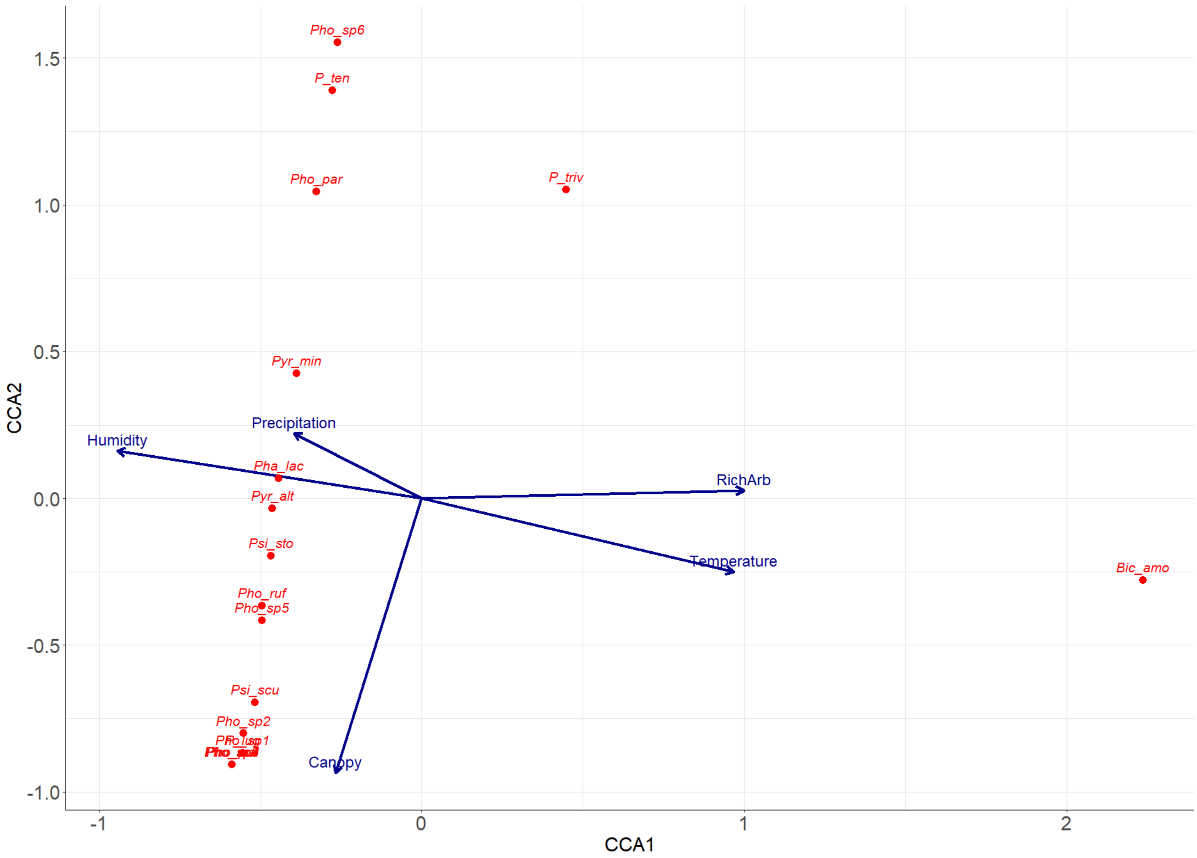

Fig. 6. Canonical Correspondence Analysis (CCA) of firefly species in relation to environmental variables. Abbreviations: RichArb = Tree richness, *Pho_sp1* = *Photinus* sp1, *Pho_sp2* = *Photinus sp*2, *Pho_sp3* = *Photinus sp3*, *Pho_sp4* = *Photinus sp*4, *Pho_sp5* = *Photinus sp*5, *Pho _sp6* = *Photinus sp*6, *P_ten* = *Photuris tenuisignathus*, *Pho_par* = *Photinus paracongruus*, *Pho_ruf* = *Photinus ruficollis*, *P_triv* = *Photuris trivittata*, *Pyr_min* = *Pyropyga minuta*, *Pha_lac* = *Phaenolis laciniatus*, *Psi_sto* = *Psilocladus stolatus*, *Psi_scu* = *Psilocladus scutellaris*, *Bic_amo* = *Bicellonyca amoena*.

Regarding species distribution, *Bicellonyca amoena* was associated with Pumpuapa, where the highest temperature values and greatest tree richness were recorded. Meanwhile, *Photinus* aff *malinalxochiltlae*, *Photinus pulchellus*, *Photinus* sp1, *Photinus* sp2, *Photinus* sp3, *Photinus* sp4, *Photuris* aff *lugubris*, and *Psilocladus scutellaris* were associated with El Capulín, which exhibited the highest canopy cover and lowest humidity values.

The results do not indicate a clear altitudinal pattern in firefly richness or abundance. Instead, individual environmental variables appear to determine the presence and distribution of species within the sampled sites, resulting in species turnover along the gradient. No relationship with floristic diversity was observed either, as both Puente Colorado and El Capulín exhibited very high firefly diversity despite relatively low plant diversity (Fig. 7). In contrast, Pumpuapa Canton, although characterized by greater floristic diversity, harbored only a few firefly species.

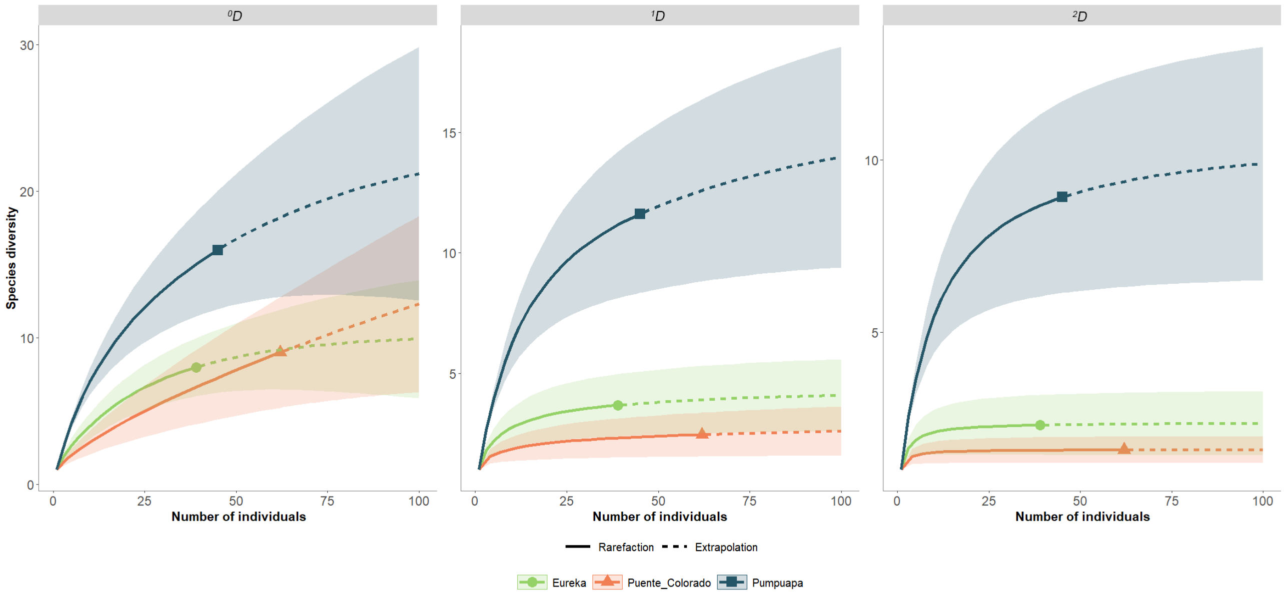

Fig. 7. Diversity of floristic species at each site based on Hill numbers (^{0}D = species richness, ^{1}D = Shannon exponential index, ^{2}D = inverse Simpson index).

DISCUSSION

Globally, knowledge about fireflies remains limited. However, in Mexico, efforts over the past four years have significantly expanded current understanding, particularly in the central and northwestern regions, with the description of 85 new species (Zaragoza-Caballero et al. 2020 2023). This suggests that as research on firefly fauna progresses in other regions of Mexico, the number of recorded firefly species in the country will likely continue to grow.

The number of species recorded in this study represents only 7% of the total firefly fauna reported for Mexico (Zaragoza-Caballero et al. 2023) and 35% of the species documented in Chiapas (Pérez-Hernández et al. 2022). However, the Tacaná Volcano is recognized as one of the most important firefly hotspots in the Americas (Gutiérrez-Carranza et al. 2023), a status supported by our findings. Notably, 35% of the species identified in this study correspond to new species in the process of description.

Although there is no single optimal collection method for firefly sampling, the combination of Malaise traps and direct sampling provides a comprehensive representation of lampyrid diversity in a given region. In our study, six unique species were recorded exclusively in Malaise traps, 11 species were found only through direct sampling, and three species were collected using both methods. Additionally, light traps have proven to be a complementary method in other regions, such as the Sierra de Huautla (Zaragoza-Caballero et al. 2003), and could enhance the completeness of the firefly inventory for the Tacaná Volcano.

The activity pattern of fireflies observed in this study is similar to that reported by Zaragoza Caballero (1995) in Los Tuxtlas and by Zaragoza-Caballero et al. (2003) in the Sierra de Huautla, where peak activity occurred during the rainy season, with high values beginning in August and subsequently declining toward the end of the season (November). As in those studies, species distribution throughout the sampling months was not homogeneous, as some species were present only for short periods. In our study, 50% of the recorded species were observed in only one month of sampling, whereas *Psilocladus stolatus* and *Photinus* sp5 were recorded throughout the entire sampling period in both El Capulín and Puente Colorado, confirming distinct temporal patterns for each especies.

Firefly species distribution was not homogeneous across the altitudinal gradient, showing differentiation among the sampled sites. Luna-Luna et al. (2022) reported a similar pattern, where approximately 40% of aquatic beetles species in their study were found at sites below 1,200 m a.s.l. in the study area. Similarly, studies conducted by Nada et al. (2023) in Malaysia and Wattanachaiyingcharoen et al. (2016) in Thailand found that fireflies diversity was highest at low and medium altitudes, no exceeding 1,250 m a.s.l. This pattern may be influenced by the transition between vegetation types in lowland and high-altitude, which generates a greater number of microhabitats and environmental variations, ultimately supporting a higher species richness (Olson 1994).

The limited ecological available does not allow us to determine whether the tribes or genera exhibit any specific association with certain altitudes. However, the data obtained indicate that the tribe Photurini is found in the lower zone (<750 m a.s.l.), the tribe Cratomorphini occurs above 2,000 m a.s.l., while Photinini, Pleotomini and Psilocladini are distributed in the middle portion of the studied gradient.

Among the species recorded, *Photuris trivittata* and *Bicellonycha amoena* are considered the most tolerant. *Photuris trivittata* has a broad distribution (Chiapas, Quintaná Roo, Tabasco, Veracruz, Belize, Guatemala and Honduras) and exhibits high tolerance to environmental changes, as it has even been observed along roadsides (Pérez-Hernández et al. 2022; Lloyd and Ballantyne 2003). Similarly, *Bicellonycha amoena*, the third most abundant species, has been recorded in grasslands and open areas at elevations up to 2,100 m a.s.l. (Arrivillaga-Cano et al. 2023), suggesting that it could be present at other sites along the studied altitudinal gradient.

The sites Puente Colorado and El Capulín exhibited the highest firefly richness and abundance, despite having the lowest floristic diversity. Both sites are shaded coffee plantations, where canopy cover helps maintains moderate temperatures and high relative humidity (Sosa et al. 2020), conditions that favor the presence of Lampyridae (Branham 2015). In contrast, Cantón Pumpuapa and Chiquihuite have lower species richness, with only two and one species recorded, respectively. This distribution pattern is consistent with the findings of Nada et al. (2023), who reported that firefly diversity peaks at intermediate altitudes, not exceeding 1,300 m a.s.l. (Braham 2015; Nak-eiam et al. 2011).

Among the significant environmental variables influencing fireflies, Nada et al. (2023) suggested that canopy cover can affect species richness. Although precipitation was not significant in our study, Zaragoza-Caballero et al. (2003) reported that firefly abundance peaked during periods of higher rainfall. In Thailand, Jaikla et al. (2020) found a positive relationship between humidity and the abundance of *Pteroptyx asymmetria* Ballantyne, a pattern similar to our findings, where humidity favored a group of fireflies (*Photinus* sp. nov., *Photuris tenuisignathus, Photuris trivittata, and Photinus paracongruus*) in the Puente Colorado locality.

For *Bicellonycha amoena*, its higher occurrence was associated with temperature, an environmental variable that may benefit certain firefly species by increasing their activity, such as enhancing flash frequency during mate searching (Arrivillaga-Cano et al. 2023). However, temperature could also negatively affect some firefly species, as observed with *Photinus palaciosi* (Zaragoza-Caballero) in the "Firefly Sanctuary" in Tlaxcala (Ramírez-Manzano et al. 2023) and with *Pteroptyx bearni* Olivier and *Pteroptyx malaccae* (Gorham) in Malaysia (Abdullah et al. 2020).

Despite growing attention towards fireflies, information on the environmental factors influencing their distribution and abundance in Mexico remains limited. The few existing studies have focused on geographically distant regions, highlighting the need for local research (Nada et al. 2023; Viviani 2001). This suggests that further studies are essential to better understand the ecology of additional Mexican firefly species. The heterogeneity of landscapes, such as shade-grown coffee plantations, is likely to play a crucial role in the structuring firefly communities by providing a variety of microhabitats for different species. Previous studies on other insect groups suggest that these agroecosystems can be function as biodiversity hotspots (Arellano et al. 2008).

As one of the most important biodiversity hotspots in the region, the Tacaná volcano stands out for its high endemism, particularly among insects, with numerous new species or genera already described or currently in the process of description. It is therefore essential to continue studying taxonomic groups that inhabit these high-biodiversity sites to develop effective conservation strategies and promote the sustainable use of natural resources.

CONCLUSIONS

The altitudinal distribution of fireflies on the Tacaná volcano is not homogeneous, with a greater representation at medium altitudes than at high or low altitudes.

For future firefly inventories, the use of Malaise traps is recommended as a complementary method to traditional aerial net sampling, as it allows for the collection of different species that may not be captured using other techniques.

There appears to be a relationship between humidity and canopy cover with the distribution of some firefly species on the Tacaná volcano. However, it was not possible to determine a single environmental factor driving species distribution in the region; rather, site-specific condictions likely play a determining role.

The new records for Mexico and Chiapas, along with the six potentially new species identified, highlight the Tacaná volcano as a crucial area for biodiversity conservation. Givens its relatively unexplored status, further studies on Lampyridae diversity in the region are strongly recommended.

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