BIOGEOGRAPHIA
The Journal of Integrative Biogeography

Biogeographia – The Journal of Integrative Biogeography 2026, 41 (1): a066

https://doi.org/10.21426/B6.63009

Lights in the Mediterranean night: firefly distribution in Italian islands revealed through citizen-science and scientific field-work

Alessandro LAGROTTERIA[1,2], Leonardo ANCILLOTTO[1,3], Mariella BARATTI[1], Malayka Samantha PICCHI[1], Luiz Felipe LIMA DA SILVEIRA[1,4], Francesco Paolo FARAONE[5], Federico MARRONE[5], Luca VECCHIONI[5], Giuliano MILANA[6], Pietro DI BARI[1,3,5], Damiano FRAGALÀ[7], Lorenzo LAZZERI[8], Leonardo FORBICIONI[9], Enrico SCHIFANI[10], Dario CIOPPA[11], Andrea GUADAGNINI[11], Danilo PISU[12], Andrea VIVIANO[1], Martino MAGGIONI[3,13,19], Elisa SERAFINI[14], Daniele CANESTRELLI[14], Pietro GARDINI[3,15], Norma LELLI[1], Cristiano SPILINGA[16], Mattia MENCHETTI[17], Carlo POLIDORI[18], Federico SOMÀ[2], Manuel SCARFÒ[20], Raphaël DE COCK[21], Emiliano MORI[1,3,*]

[1] *Consiglio Nazionale delle Ricerche, Istituto di Ricerca sugli Ecosistemi Terrestri (CNR-IRET), Via Madonna del Piano 10, 50019 Sesto Fiorentino (FI), Italy*
[2] *Department of Life Sciences and Systems Biology, University of Turin, Via Accademia Albertina 13, 10123 Turin, Italy*
[3] *National Biodiversity Future Center, Piazza Marina 61, 90133 Palermo, Italy*
[4] *Biology Department, Western Carolina University, 1 University Drive, 28723 Cullowhee, North Carolina, United States*
[5] *Department of Biological, Chemical and Pharmaceutical Sciences and Technologies (STEBICEF), University of Palermo, Via Archirafi 18, 90123, Palermo, Italy*
[6] *Associazione Italiana Wilderness (AIW), Via A. Bonetti 83, 17013 Murialdo (SV), Italy*
[7] *Università degli Studi di Catania, Piazza Università 2, 95131 Catania, Italy*
[8] *Dipartimento di Scienze della Vita, Università degli Studi di Siena, Via P.A. Mattioli 4, 53100 Siena, Italy*
[9] *World Biodiversity Association Onlus, Sezione Arcipelago Toscano, Via Cesare Giagnoni 5, 57037 Portoferraio (LI), Italy*
[10] *Institute of Evolutionary Biology (CSIC - Pompeu Fabra University), Passeig Marítim de la Barceloneta 37-49, 08003 Barcelona, Spain*
[11] *Dipartimento di Scienze Biologiche, Geologiche e Ambientali (BiGeA), Università di Bologna, Via Francesco Selmi 3, 40126 Bologna, Italy*
[12] *Regione Pireddu Nieddu snc, 07040 Stintino (SS), Italy*
[13] *Dipartimento di Biologia, Università degli Studi di Firenze, Via Madonna del Piano 6, 50019 Sesto Fiorentino (FI), Italy*
[14] *Department of Ecological and Biological Sciences, University of Tuscia, Largo dell'Università 1, 01100 Viterbo, Italy*
[15] *Department of Biology and Biotechnologies "Charles Darwin", Sapienza Rome University, Viale dell'Università 32, 00185 Rome, Italy*
[16] *Studio Naturalistico Hyla, Via Baroncino 11, 06069 Tuoro sul Trasimeno (PG), Italy*

[17] *Museum für Naturkunde Berlin, Invalidenstraße 43, 10115 Berlin, Germany*
[18] *Department of Environmental Science and Policy (ESP), University of Milan, Via Celoria 2, 20133 Milan, Italy*
[19] *Department of Earth and Marine Science, University of Palermo, Via degli Archirafi 22, 90123 Palermo, Italy*
[20] *ECOMODEL Società Cooperativa, Via Tiberina 149, 00188 Roma, Italy*
[21] *Evolutionary Ecology Group, University of Antwerp, Universiteitsplein 1, 2610 Wilrijk (Antwerp), Belgium*

** corresponding author, email: emilianomori85@gmail.com; emiliano.mori@cnr.it*

Keywords: biodiversity monitoring, conservation ecology, iNaturalist, island biogeography, Lampyridae, nocturnal insects.

SUMMARY

Islands represent living laboratories for investigating biodiversity and animal colonization patterns. Despite this, many insect groups remain poorly investigated in these systems, particularly within the Mediterranean Basin. Fireflies (Coleoptera, Lampyridae), besides their ecological, cultural, and conservation relevance, are no exception. Here, we present the first comprehensive synthesis of firefly occurrence across major and minor Italian islands, integrating standardised nocturnal surveys conducted within the L.U.C.E. ("Lighting up the understudied charismatic fireflies of Europe") project with validated citizen-science records derived from the iNaturalist platform. This integrative approach enabled a complete assessment of species occurrence, spatial patterns, and the complementary value of structured fieldwork and citizen-generated records. Surveys were conducted in Italy between 2023 and 2025 across two major islands (Sardinia and Sicily) and thirteen small islands. Occurrence data were analysed to quantify taxonomic richness, island occupancy, and the relative contributions of each data source across islands. Overall, we recorded 10 taxa (including species and subspecies) on Italian islands, representing 50% of the firefly species currently recognised at the national level. Species richness and record abundance were significantly higher on larger islands. In contrast, small islands generally hosted one or two taxa, reflecting classic island biogeography patterns and limited dispersal abilities linked to firefly life-history traits. Comparison between data sources revealed a strong complementarity. Citizen-science records provided broad spatial coverage, particularly on easily accessible and frequently visited islands, but often lacked fine taxonomic resolution. Conversely, targeted surveys yielded fewer records overall but were essential for detecting poorly known populations, achieving accurate species-level identification, and documenting rare or previously unrecorded taxa. Notably, the detection of *Lampyris pallida* on Linosa, confirmed through DNA barcoding, represents the first record of this species for Italy.

INTRODUCTION

Islands are dynamic ecological systems, in which biodiversity is shaped by geographic isolation, limited spatial extent, and ongoing processes of colonisation and extinction (Whittaker et al., 2017; Thomas et al., 2022; Mori et al., 2025a). These conditions are particularly important for wildlife and especially for insects, whose distribution, dispersal, and diversification patterns can differ markedly from those observed in continental environments, sometimes promoting the emergence of localised endemisms (e.g., Massa and Fontana, 2020; Lhoumeau and Borges, 2023; Ramirez et al., 2024). Consequently, insular faunas have long represented a major focus of entomological and biogeographical research, while, at the same time, exhibiting high vulnerability to environmental changes and anthropogenic pressures (Gillespie and Roderick, 2002; Fattorini et al., 2018). In particular, small islands and archipelagos often host strongly differentiated biological communities compared with nearby mainland areas, making them both scientifically valuable and ecologically fragile systems (Tojo et al., 2017; Calado et al., 2024, 2025).

The Mediterranean Basin is recognised as one of the most important global biodiversity hotspots (Medail and Quezel, 1999; de Jong et al., 2014), characterised by high endemicity rates and a long, complex history of interactions among climatic, geological, and anthropogenic factors.

Within this context, Mediterranean islands, which vary widely in size, geological age, degree of isolation, and intensity of human colonisation, constitute a mosaic of ecosystems which promote both speciation processes and the persistence of relict taxa (Gippoliti and Amori, 2004; Gentile and Argano, 2005; Kondraskov et al., 2015). Larger islands, such as Sicily and Sardinia, feature considerable environmental heterogeneity, including diverse geological substrates and broad elevation and bioclimatic gradients (Salvi et al., 2009; Bonardi et al., 2022). At the same time, smaller islands and satellite islets, often overlooked in biodiversity surveys, play a crucial role as ecological refuges and as privileged settings for investigating evolutionary processes at fine spatial scales (Foggi et al., 2015; Hand et al., 2017; Muscarella and Baragona, 2017; Gallozzi et al., 2023; Faraone et al., 2025). Despite this remarkable complexity, insect communities on Mediterranean islands remain incompletely documented, and their current distribution patterns are increasingly influenced by habitat transformation, local extinctions, and shifts in species composition (e.g., Mavridis, 2003; Palombo, 2018).

In this context, fireflies (Coleoptera, Lampyridae) represent an ecologically and culturally important group of beetles, despite including a low number of species with respect to other beetle groups. Globally, the family Lampyridae includes over 2,600 described species, across 12 subfamilies (Martin et al., 2017, 2019; Ferreira et al., 2020; Bocakova et al., 2022; Keller at al, 2024 [https://lampyridae.world/#/, accessed on 04/Feb/2026]). Bioluminescence, used as a reproductive display by many species of fireflies (Zhu et al., 2024), makes glowing adults easily detectable during nighttime surveys in spring and summer, especially in temperate regions (Picchi et al., 2013; Branchini et al., 2014). In recent times, Eurasian populations of several species have declined significantly, possibly due to habitat loss, light pollution, and pesticide use (Chow et al., 2014; Lewis et al., 2020). Potential competition with recently introduced alien firefly species has also been cited as a further cause for concern (Gil-Tapetado et al., 2024).

Italy represents a biodiversity hotspot in Europe, hosting one of the richest firefly faunas on the continent, with at least nineteen species currently reported (Fanti, 2022). Despite this, fireflies, like many other invertebrate groups, have been largely neglected in global conservation frameworks and initiatives (Lewis et al., 2020). Moreover, a lack of integrative taxonomic revisions has contributed to a historical nomenclatural confusion, with multiple authors assigning different names to the same species (see www.iucnredlist.org, www.lampyridae.it, both accessed on 10.01.2026; Fanti, 2022). As a result, robust and reliable data on population trends for Italian fireflies are still lacking (but see Picchi et al., 2013). Knowledge on their spatial distribution also remains highly uneven, particularly in insular environments, where historical data are fragmented and systematic surveys are still limited.

In this study, we analysed firefly occurrence on Italian islands, by integrating data from structured field sampling conducted within the L.U.C.E. project (www.iret.cnr.it/progetto/luce/ Accessed on 10.01.2026), a national initiative digitising historical and newly collected firefly specimens financed by TETTRIs in the framework of the Horizon Europe Programme (www.tettris.eu accessed on 10.01.2026), and citizen-science records uploaded to iNaturalist (www.inaturalist.org accessed on 09.01.2026). Specifically, we aimed to assess the specific and complementary contributions of these two types of data sources in describing the presence and distribution patterns of insular Lampyridae, providing a more comprehensive and up-to-date overview of firefly occurrence on Italian islands.

MATERIALS AND METHODS

Firefly collection

Fireflies were surveyed on Italian major and on most minor islands (Fig. 1) through targeted field sampling conducted in May-October 2023 and 2025.

Sampling sites were selected by actively searching for areas matching the main ecological requirements of fireflies, and on the current knowledge on their documented distribution (Fanti, 2022 and references therein), including the absence or low presence of artificial lighting, low levels of disturbance and pollution, and the presence of humid habitats with natural or semi-natural vegetation (e.g., Picchi et al., 2013; Camerini, 2022).

At each selected site, fireflies were recorded between May and October 2023-2025, using standardised visual transect surveys, or (for *Luciola*

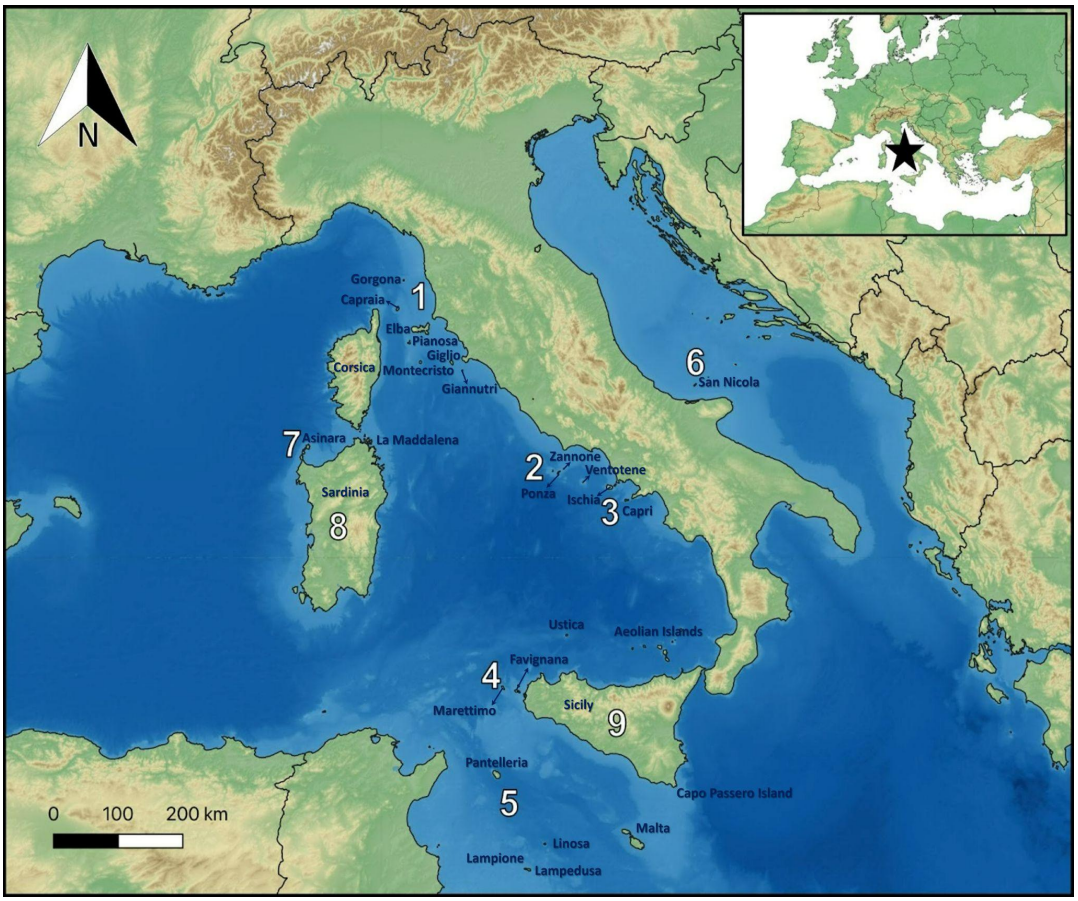

Figure 1. Location of the studied Italian sampling sites. 1: Tuscan Archipelago; 2: Pontine Islands (southern coast of Lazio); 3: Campanian archipelago, 4: Aegadian (Egadi) Islands; 5: Pantelleria and Pelagian Islands (Sicily); 6: Tremiti Islands (Puglia), 7: Asinara Island (Sardinia), 8: Sardinia region, 9: Sicily region. The inset shows the position of Italy within the Mediterranean basin. Islands mentioned in the manuscript are labeled in the figure.

spp.) by inspecting locations with the presence of flashing adults. Surveys were conducted after the sunset, between 21:00 and 00:00 (local solar hour), under favourable weather conditions (i.e., calm winds and no precipitation).

Linear transects (100 m in length) were opportunistically established within suitable habitats to maximise the detectability of adult individuals at night, particularly for the genus *Luciola* Laporte, 1833, which shows very evident and bright males (Camerini, 2025). Females producing and non-producing light were searched for on vegetation and along ground surfaces within the same transects (Camerini, 2025). During these nocturnal surveys, also pre-imaginal stages were recorded when detected on the surface or by turning over stones and leaf litter along the same transects. For species belonging to the genus *Lampyris* Geoffroy, 1762, adult male detection was facilitated using two red LED lights (Kivelä et al., 2023), which proved effective in attracting individuals (Dreisig, 1978; Tisi et al., 2014). Adult female *Lampyris* are wingless and were sampled at night by slow visual searches for their stationary bioluminescent glow close to the ground, followed by hand collection.

Citizen-science data

Citizen science has become an increasingly widespread and valuable tool in the study of entomofauna (e.g., Viviano et al., 2024; Lagrotteria et al., 2025; Roccatello et al., 2025; Sogliani, 2026). Among insects, fireflies are suitable to be studied through citizen science projects as being attractive and charismatic insects (Virić Gašparić et al., 2022). To complement field-collected data and allow comparison with citizen-science records, all firefly records available for the Italian peninsula were downloaded from the online platform iNaturalist using the search keyword “Lampyridae” (accessed on 15 November 2025).

To ensure the reliability of species identifications derived from iNaturalist, we restricted our dataset to observations that had achieved "Research Grade" status. Within the iNaturalist framework, observations are classified as Research Grade when they meet specific quality criteria, including the presence of a verifiable date, geographic coordinates, photographic evidence, and, critically, a community-supported taxonomic identification below the family level, typically reached through agreement among multiple users. While this community-based validation process has been shown to provide generally reliable identifications, we acknowledge that its accuracy ultimately depends on the availability of diagnostic features in the submitted media and on the taxonomic expertise of contributors. In particular, taxa with mild morphological differences or requiring specific viewing angles may be more prone to misidentification. For this reason, we further screened observations by evaluating the visibility of key diagnostic characters and excluding records that were deemed ambiguous or insufficiently documented. We also recognize that, for some groups (e.g., species within the genus *Luciola*), recent taxonomic and molecular evidence suggests a higher level of cryptic diversity than previously assumed, potentially complicating identification based solely on photographic records (Mori et al., 2023). To mitigate this issue, we adopted a conservative approach, retaining only those records for which diagnostic features were clearly discernible, and treating uncertain cases with caution (e.g., exclusion or assignment at a higher taxonomic level where appropriate). Furthermore, all citizen science records were verified and furtherly confirmed at the species level by firefly experts on the platform, using currently known diagnostic traits, wherever possible. When identification at the species level was not possible, individuals were only classified as "Lampyridae" and excluded from our dataset. From this dataset, only occurrences referring to Italian major and minor islands were extracted and retained for subsequent analyses. These data were then compared with specimens and observations collected during field surveys (Fig. 2).

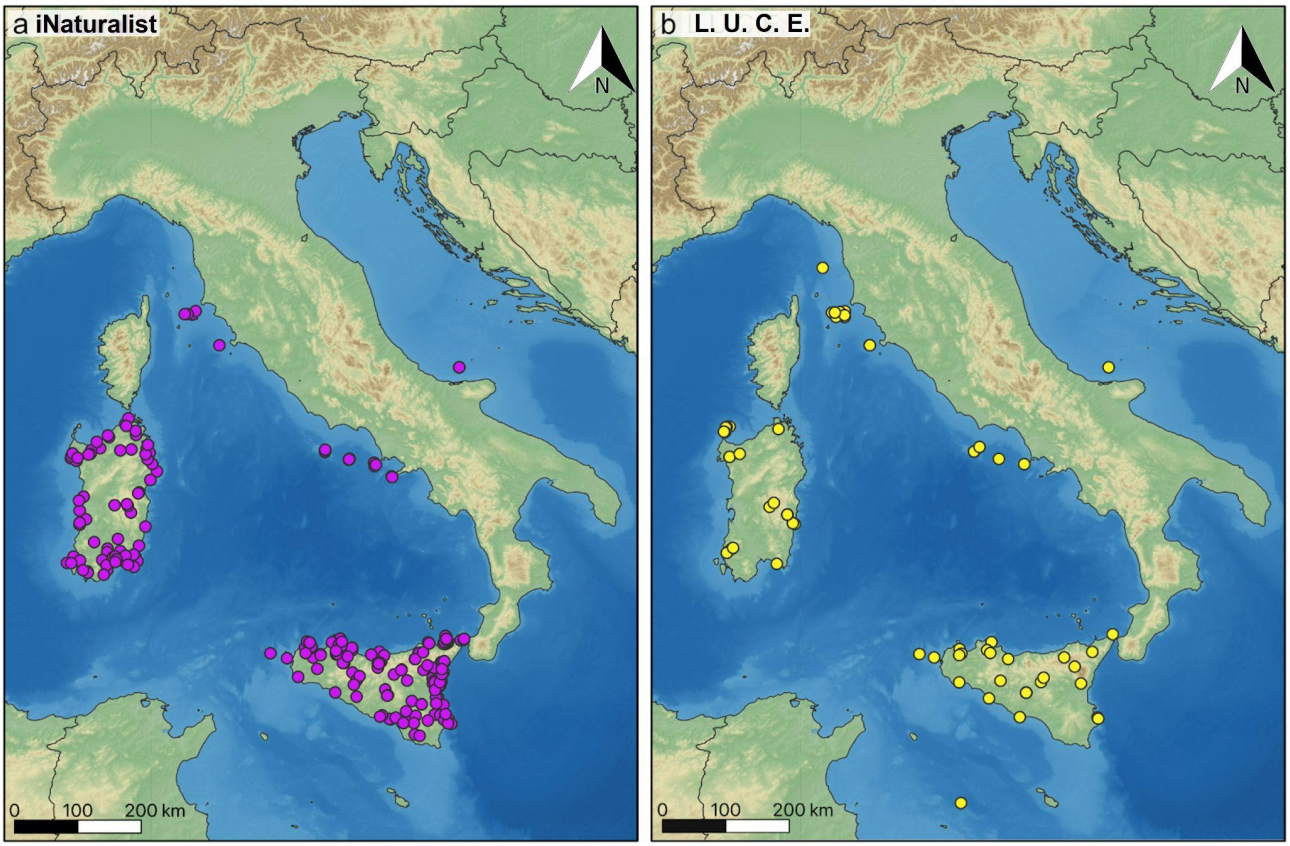

Figure 2. Maps of Italy showing the spatial distribution of firefly (Lampyridae) observations. Violet dots represent citizen-science records downloaded from the iNaturalist platform, whereas yellow dots indicate firefly occurrences collected during the targeted field sampling campaign conducted in 2024–2025 in the framework of the L.U.C.E. project.

Species determination

To provide an overview of the species recorded across major and minor Italian islands, and to assess the relative contribution of citizen-science and scientific data to the overall species checklist, species occurrence data were summarised and compared between island groups and data sources.

Species were identified following morphological diagnostic features on sampled adults, following Fanti (2022) and De Cock (2007). Whenever necessary (e.g., in the case of larvae), genetic features such as DNA barcoding were employed to confirm species identification (Baratti et al., 2025; Mori et al., 2025b). In particular, DNA barcoding was based on sequencing a 638-bp fragment of the mitochondrial COI gene, using standard protocols and generic primers, HCO 2198 (5'-TAAACTTCAGGGTGACCAAAAAATCA-3') and LCO 1490 (5'-GGTCAACAAATCATAAAGATATTGG-3') (Folmer et al., 1994). Given the recent nomenclatural uncertainties upon this taxonomic group, we cautiously decided to use names currently adopted in widely used conservation resources, e.g. the IUCN Red List, which had not yet incorporated the updated nomenclature at the time of our analysis (www.iucnredlist.org Accessed on 10.01.2026). Therefore, we called *Lampyris plurihomonyma* Fanti, 2022 (as proposed by Fanti, 2022, and accepted by the International Commission on Zoological Nomenclature: www.iczn.org Accessed on 02.04.2026) as *Lampyris lareynii maculata* Geisthardt, 1987, and *Lampyris somnambula* Costa, 1874 (as proposed by Fanti, 2022, and accepted by the International Commission on Zoological Nomenclature) as *Lampyris vesuvius* Geisthardt, 2007. Moreover, we considered *Nyctophila* J. E. Olivier, 1884 as a subgenus of *Lampyris*, following Fanti (2022).

To assess differences in the number of records obtained through fieldwork and citizen-science observations, we applied chi-square tests of independence for each species to determine whether significant differences occurred between the two sampling methods (Sokal and Rohlf, 2012). For each taxon, observed frequencies of records derived from the two data sources were compared using a 2×2 contingency table. Tests were conducted with one degree of freedom (df=1). Statistical significance was evaluated at α=0.05. All analyses were performed using R version 4.2.2 (R Core Team, 2022). We used the *ggplot2* package for R (Wickham, 2016).

For each island, species, and data source, the number of records was quantified as the total count of records. Islands were then categorised into major islands (Sicily and Sardinia) and minor islands, allowing for separate visualisation strategies adapted to differences in data density and species richness.

Species occurrence patterns on major islands were visualised using bar plots showing the number of records per species, with data source indicated by colour and islands displayed in separate facets. For minor islands, where occurrences were generally sparser, species–island relationships were represented using bubble plots, in which point size reflected the number of records and colour denoted the data source.

Species–Area Relationship (SAR)

To further support the general biogeographical context, we measured the species–area relationship (SAR), i.e. the increase in species number with area expected by the Theory of Island Biogeography (MacArthur and Wilson, 1967; see also Fattorini et al., 2017), by relating the number of firefly species recorded on each island-to-island area (km²). Observed species richness was calculated as the total number of species detected per island, regardless of the number of records. A log-log linear model was applied for graphical and descriptive purposes only, in order to visualise large-scale patterns and it was not intended to be strictly inferential. We also tested whether species number in each island was related to the shortest distance from the peninsula, also expected by the Theory of Island Biogeography (MacArthur and Wilson, 1967).

RESULTS

We collected 412 firefly occurrences from 15 islands (Sardinia and Sicily, and 13 minor islands; Table 1, Fig. 2, Table S1 and Fig. S1 in Supplementary Material 1). 75% of records (N=307) were derived from iNaturalist, and 25% (N=105) from targeted field searching in the framework of the L.U.C.E. project. Despite targeted field-work, we were not able to find fireflies on 8 other small islands and archipelagos: La Maddalena Archipelago (Sardinia), Montecristo (Tuscany), Pianosa (Tuscany), Capraia (Tuscany), Giannutri (Tuscany), Aeolian Islands (Sicily), Pantelleria (Sicily), and Lampedusa (Sicily).

Table 1. Geographic location of sample collection (coordinates, decimal WGS84), area, maximum elevation, perimeter, and distance to the closest mainland of major and selected small Italian islands.

Archipelago	Island	Latitude N	Longitude E	Area (km²)	Max elevation (m a.s.l.)	Perimeter (km)	Distance to mainland (km)
Major islands							
	Sardinia	37.55°	9.04°	24090.0	1834	1897	188
	Sicily	37.44°	13.41°	25832.4	3403	1637	3
Small islands							
Aegadian	Favignana	37.55°	12.19°	19.7	302	33	6
Aegadian	Marettimo	37.58°	12.03°	12.1	686	18	30
Campane	Capri	40.33°	14.14°	10.4	585	17	5
Campane	Ischia	40.43°	13.54°	46.3	789	34	9
Pelagian	Linosa	35.51°	12.52°	5.3	195	11	162
Pontine	Ponza	40.54°	12.57°	7.5	280	21	33
Pontine	Ventotene	40.47°	13.25°	1.4	139	7	46
Pontine	Zannone	40.58°	13.03°	1.1	194	5	27
Tremiti	San Nicola	42.06°	15.29°	0.4	75	3.7	23
Tuscany	Elba	42.46°	10.16°	223.5	1019	147	9
Tuscany	Gorgona	43.25°	9.53°	2.2	255	5	36
Tuscany	Giglio	42.21°	10.54°	21.2	498	28	26
Circum-Sardinian	Asinara	41.04°	8.18°	52.0	408	110	27

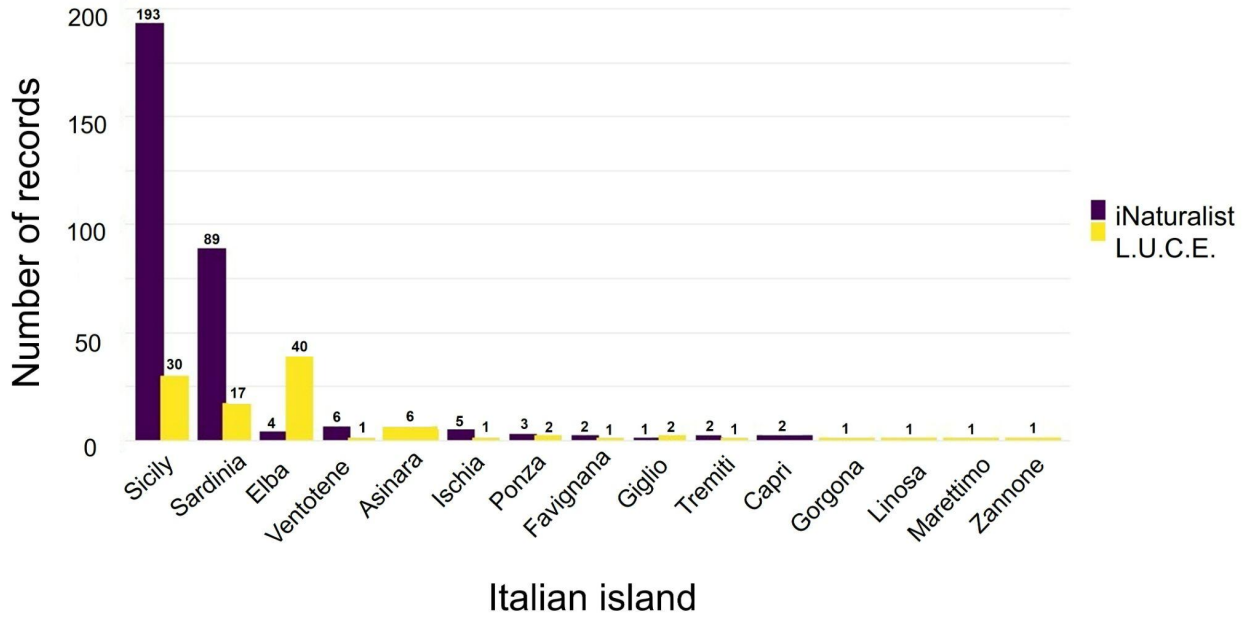

Figure 3. Firefly records from Italian islands from two sources: citizen-science data from iNaturalist (shown in violet) and L.U.C.E. project data (mostly specimens collected, shown in yellow). Bars indicate the total number of records per island, with islands ordered by major islands first (Sicily and Sardinia), followed by minor islands.

Comparison of firefly records through different methods

The qualitative comparison between records collected through the L.U.C.E. project and citizen-science records from iNaturalist revealed a strong complementarity between the two data sources across Italian islands (Fig. 2). Chi-square tests comparing the number of records obtained with the two sampling methods (df=1) showed significant differences only for *Lampyris ambigena* Jacquelin Du Val, 1860 (χ^2=10.9, p=0.001), *Lampyris sardiniae* Geisthardt, 1987 (χ^2=8.6, p=0.003), and *La. lareynii maculata* (χ^2=7.9, p=0.005). The first two species were recorded significantly more frequently through citizen science, whereas *La. l. maculata*, which has a more restricted geographic range, was mainly detected through targeted scientific fieldwork.

On the major islands (Sicily and Sardinia), iNaturalist provided the highest number of records, whereas L.U.C.E. contributed a smaller but still substantial number of records. In contrast, on Elba Island, L.U.C.E. served as the primary source of data, with a significantly higher number of records compared to iNaturalist. On minor islands, several cases clearly emerged in which one of the two sources constituted the only available evidence of firefly presence. In particular, some islands lacked iNaturalist records and were represented exclusively by fieldwork related to the L.U.C.E. project (i.e., Asinara, Linosa, and Marettimo), highlighting the key role of structured sampling in filling information gaps in areas poorly covered by citizen-science data. Conversely, on other islands, firefly records were present only on iNaturalist or were more numerous than those collected by L.U.C.E., as in the case of Ventotene and Capri, emphasising the importance of citizen-science records in frequently visited areas (Fig. 3).

Species occurrence among islands

Bar plots showing the number of records per species in major islands are shown in Figure 4a, whereas bubble plots, where point size reflects the number of records on minor islands, are represented in Figure 4b.

Overall, by combining the two data sources, nine firefly species were recorded on Italian islands. On the major islands (Sardinia and Sicily), the species composition of fireflies and the relative contribution of the two data sources (L.U.C.E. and iNaturalist) show distinct patterns in terms of both taxonomic richness and numbers of records. *Lampyris sardiniae* in Sardinia and *La. ambigena* in Sicily were the most represented species, with the highest total numbers of records. Other taxa were recorded exclusively through citizen-science data, highlighting that iNaturalist records often do not reach species-level identification and are limited to genus-level assignments in over 20% of occurrences. In contrast, L.U.C.E. data provided more accurate taxonomic identification. In this context, *Luciola pedemontana* Curtis, 1843 was recorded exclusively through L.U.C.E. data on both islands, and *Lampyris (Nyctophila) bonvouloirii* Jacquelin du Val, 1860 only in Sicily, where it appears widespread and sympatric with *La. ambigena* (Fig. 5).

On the minor Italian islands, firefly records were generally sparse and heterogeneous, with most species recorded on only one or a few islands and a limited number of records per species. Overall, data from iNaturalist provided the majority of records across islands, whereas data collected within the L.U.C.E. project contributed fewer samples, but with higher taxonomic resolution (Fig. 4).

Several species were recorded exclusively on a single island, highlighting the fragmented and localised nature of firefly distributions in small insular systems. For instance, *La. bonvouloirii* was detected only on Favignana (besides Sicily main island), *Lampyris brunnea* Geisthardt, 1987 only on Asinara (northern Sardinia), and *Lampyris pallida* Geisthardt, 1987 only on Linosa (Fig. 5). In particular, two larvae of this last species were detected in Linosa island, and their ID was confirmed through molecular barcoding (Baratti et al., 2025: COI GenBank accession number: PV988323, 100% identity with samples of the same species from Malta, GenBank accession numbers: MT909026 and MH510746), representing the first record of the species for Italy.

Additionally, some species were documented exclusively through either citizen-science records or targeted surveys conducted by the L.U.C.E. project. For instance, *Lampyris vesuvius* was detected on the Pontine (Ventotene and Ponza) and the Campanian Islands (Ischia and Capri) based only on citizen-science data, whereas *Lu. pedemontana* was recorded only through L.U.C.E. data and on a larger number of islands.

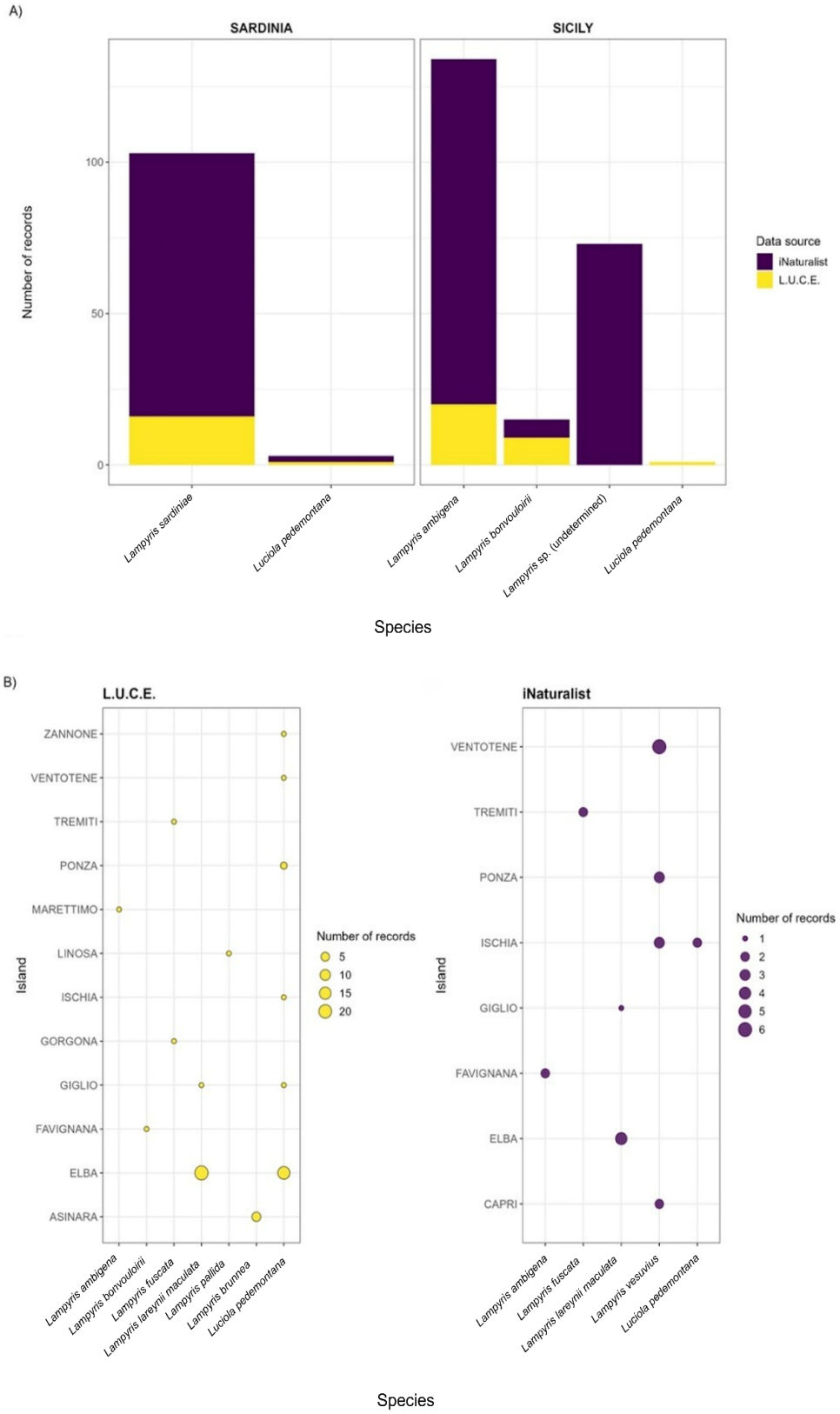

Figure 4. Number of records per firefly species on the major (a) and minor (b) Italian islands. Islands are displayed in separate panels to facilitate comparison of species composition and the relevant contribution of the two data sources.

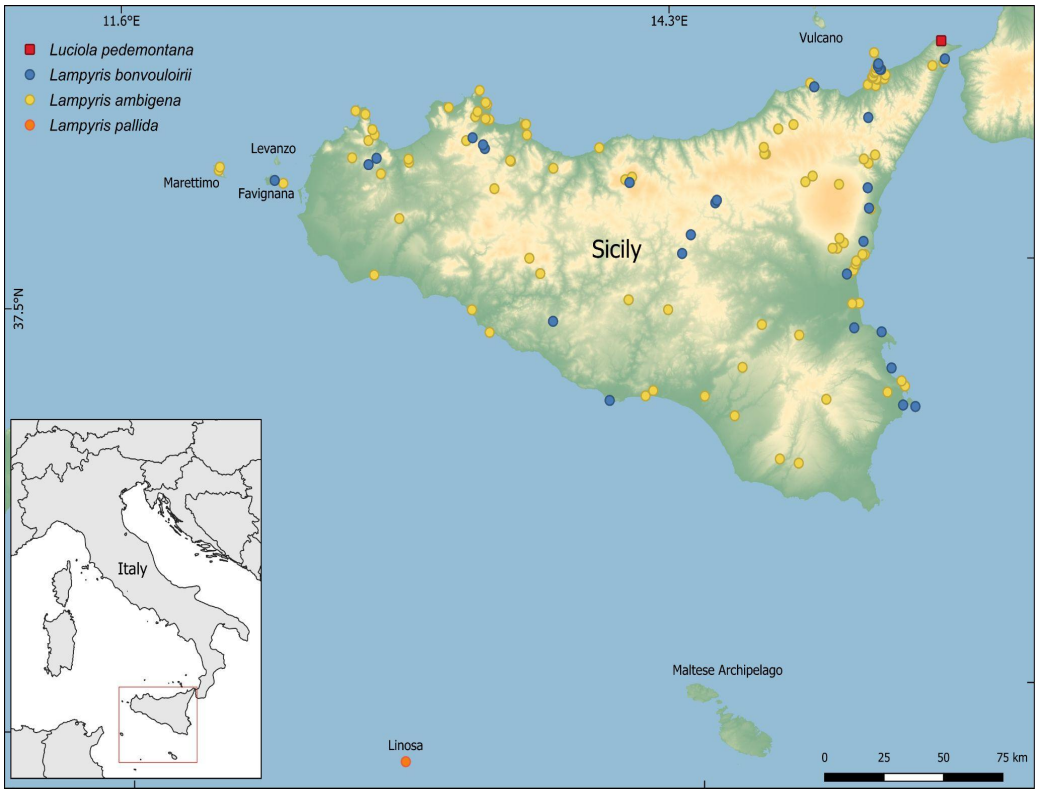

Figure 5. Distribution of firefly species records in Sicily and the surrounding islands, based on a combination of iNaturalist and L.U.C.E. data.

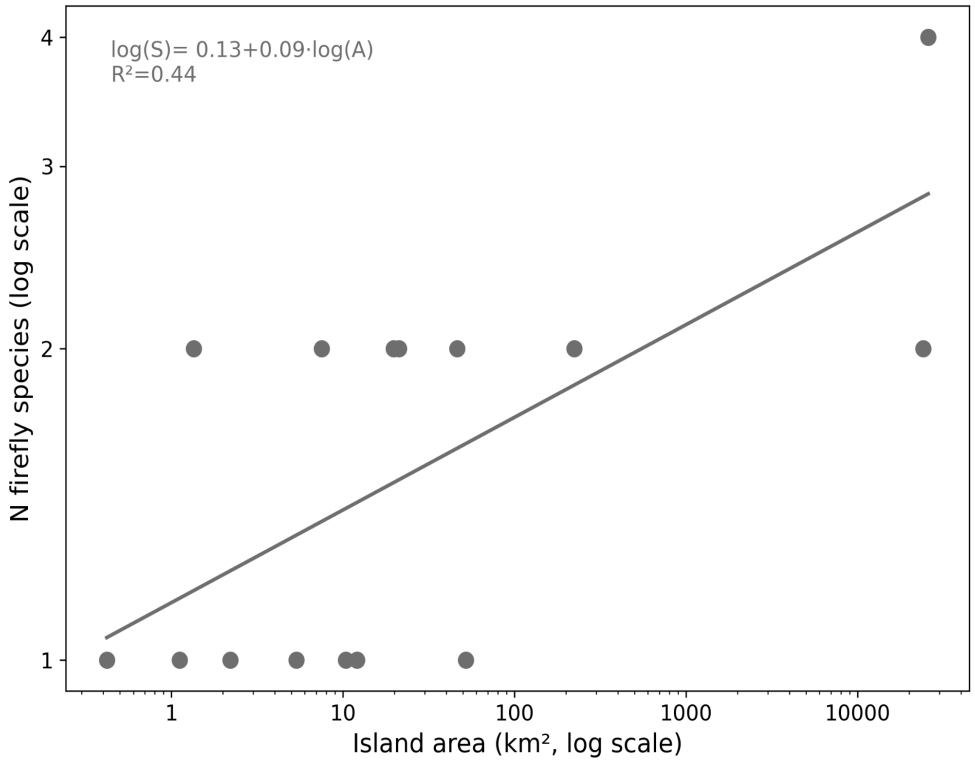

Figure 6. Species–area relationship (SAR) of fireflies on Italian islands. The log plot shows how species richness increases with island area.

While the major islands (Sardinia and Sicily) host relatively widespread and well-documented firefly species, the minor islands are characterised by sparse and highly localised occurrences. A positive species-area relationship was detected, with larger islands hosting a higher number of species than smaller ones (Fig. 6). However, the low scaling exponent suggests that island area alone only partially accounts for the observed patterns, with localized distributions and island-specific factors likely contributing substantially. Distance from the peninsula was not related to the number of firefly species found on islands (R^2=0.12).

DISCUSSION

We here provide the first comprehensive synthesis of firefly occurrence on Italian islands by integrating targeted scientific fieldwork and citizen-science data. By combining standardised surveys conducted within the L.U.C.E. project with records from iNaturalist, we substantially improved knowledge on the distribution and taxonomic composition of insular firefly populations across a wide range of Mediterranean island systems. Our results highlight both the ecological uniqueness of island firefly assemblages and the strong complementarity between structured and citizen-science data, while also spatial and taxonomic gaps which may have important implications for guiding future conservation and monitoring efforts.

Only eight out of the 20 firefly species mentioned for Italy (Fanti, 2022) were recorded across Italian islands, confirming that insular Lampyridae assemblages are taxonomically depauperate compared to the mainland fauna. With respect to previous literature (Fanti, 2022), we reported for the first time *Lampyris pallida* for Italy (Linosa island), and we detected first records of *Lampyris fuscata* Geisthardt, 1987 in Gorgona island (possibly as a result of an introduction, as occurring on the Italian mainland at the same latitude), of *La. bonvouloirii* and *La. ambigena* in Favignana, and of *La. vesuvius* in Ventotene.

Luciola pedemontana was confirmed to occur also in Sardinia (Liberti, 1995; Day, 2009; De Cock et al., 2010) and Sicily (Bologna et al., 2021; Fanti, 2022), as also confirmed by our genetic analyses on samples collected in those islands. In support of this hypothesis, Corsican and Sardinian populations of *Luciola pedemontana* are genetically strikingly similar to that of Central Po River Valley, in the north of Italy – a pattern otherwise difficult to explain if not by recent unintended human-mediated colonization.

In Sicily, *Lu. pedemontana* was observed near Messina (Fig. 5), in close geographical proximity to the Calabrian populations; previous records from Sicily lacked precise locality information and were reported only at the regional level ("Sicily"), making the GPS-referenced records presented here particularly valuable. Previous anecdotal reports of *Lu. pedemontana* dating back approximately 10–15 years suggested the presence of this species in the Parco Jalari area (Barcellona Pozzo di Gotto, Messina) and near a lake in the Palermo area (possibly Lake Poma or Lake Piana degli Albanesi), but these lacked specimen-based confirmation (Raphael De Cock, personal communication, 2026). Therefore, a late Pleistocene colonization via land bridges should be considered in future studies, as it occurs in other species (Canestrelli and Nascetti 2008, Stöck et al., 2008, Colomba et al., 2022). *Luciola pedemontana* was also found in several small islands, including Elba and Giglio (see Fanti, 2022). Additional records from Ischia, Ponza, Ventotene, and Zannone, which were not reported by Fanti (2022), are presented here as well. *Luciola pedemontana* was also recorded from Gorgona Island by Fanti (2022) based on a specimen preserved at the Natural History Museum of Firenze "La Specola".

In addition to the occurrences reported here, Fanti (2022) reported *La. sardiniae* from four circum-Sardinian islands (La Maddalena, San Pietro, Isola La Vacca, and Sant'Antioco), based on specimens collected in the 1980s-1990s; *La. lareynii maculata* (under the name "*La. plurihomonyma*") from Pianosa island (Natural History Museum of Pisa in Calci collection), and *La. vesuvius* (under the name "*La. somnambula*") from Zannone and Palmarola (collected in 1950). However, they could not be confirmed in our survey.

This pattern is consistent with classic predictions of island biogeography theory (MacArthur and Wilson, 1967), whereby species richness is constrained by isolation and habitat availability, as well as by dispersal limitations and extinction dynamics (Shaw et al., 2010; Gillespie and Will, 2018). Fireflies, in particular, show traits which limit their colonisation ability, including short adult lifespans, habitat specificity, and, in all species in Italy, flightless females (South et al., 2011; Fanti,

2022; Lewis et al., 2020; Lewis, 2024). These characteristics have most likely contributed to the fragmented and localised distribution patterns recorded on minor islands, where most species were recorded on only one or a few islands and often with very low numbers of records.

The remarkable differences in the number of firefly occurrences between major and minor islands further support the role of island area and environmental heterogeneity in shaping assemblages (Simberloff, 1976). Sicily and Sardinia, the two largest Mediterranean islands, included the highest number of records and the greatest taxonomic diversity, including both widespread (i.e., *Lu. pedemontana*) and island-associated (i.e., *La. ambigena*, *La. bonvouloirii*, and *La. sardiniae*) taxa. In contrast, smaller islands generally supported only one or two species, often represented by a handful of records. Besides the low sample size, the positive Species–Area Relationship (SAR) observed across the investigated islands seems to support the hypothesis that island size constrains firefly community diversity. This pattern is consistent with the limited dispersal ability and the marked habitat specificity reported for several firefly species (Lewis et al., 2024; Fallon et al., 2021), which may reduce colonization rates and increase local extinction probabilities on smaller islands. The relatively low slope of the relationship ($z=0.09$) suggests that island area alone is not sufficient to explain variation in insular firefly diversity. Given that isolation from the Peninsula was also not a significant predictor of richness, additional factors such as habitat availability and heterogeneity, as well as island-specific historical processes are likely to play an important role in shaping species richness patterns. This pattern mirrors findings from other insect groups in Mediterranean islands, where reduced habitat diversity and increased stochasticity may strongly limit species persistence on islands (Sfenthourakis and Triantis, 2009; Tscharntke et al., 2002). However, the occurrence of distinct taxa on individual minor islands also suggests that isolation may promote long-term persistence of localized lineages, especially where suitable habitats have remained relatively undisturbed (e.g., *La. sardiniae* in Sardinia: De Cock, 2007; *La. pallida* in Malta: De Cock, 2024; *Lampyris lareynii* Jacquelin du Val, 1859 in Corsica: De Cock and Henriques, 2024).

Several species showed highly restricted insular distributions, reinforcing the idea that Mediterranean islands can function as ecological refugia for some firefly populations (Alvarez et al., 2011; De Cock, 2007, 2024; De Cock and Henriques, 2024). For instance, *La. brunnea* only occurs in Asinara, and *La. pallida* is endemic to the Maltese Archipelago and Linosa.

The Asinara has been geologically separated from Sardinia for millions of years as a result of tectonic movements and long-term sea-level changes (Carmignani et al., 2016), supporting the occurrence of two distinct *Lampyris* species, one on each island (Sardinia and Asinara), which may explain the presence of the Sardinian species up to the Sardinian coast facing Asinara.

The record of *La. pallida* larvae on Linosa, confirmed by DNA barcoding (Baratti et al., 2025), represents the first documented occurrence of this species in Italy and highlights the potential for islands to harbour overlooked or previously unknown components of national biodiversity.

Among the missing species from our dataset, *Lamprohiza foliacea* (Baudi, 1871) is a mysterious and possibly currently extinct firefly species endemic to central Sardinia, which was collected only once in the late 19th century, with a single male specimen now preserved at the Museo Regionale di Scienze Naturali in Turin (Baudi, 1872; Fanti, 2022); despite several field campaigns organized on Sardinia in 2020 (R. De Cock, personal communication), and 2025 (by five authors, FM, FPF, LFLDS, LV and GM) to search for it, it has never been found again. As such, more targeted efforts may be needed to clarify the existence of this latter species.

Our findings are particularly relevant in light of the ongoing decline of firefly populations across Europe (e.g, Picchi et al., 2013; Lewis et al., 2020). In general, animal populations on islands, despite often being small and vulnerable, may represent important reservoirs of genetic diversity and evolutionary distinctiveness (Losos and Ricklefs, 2009; Dapporto et al., 2017; Vecchioni et al., 2019; Ancillotto et al., 2026). At the same time, their isolation and limited extent make them particularly sensitive to habitat degradation and demographic stochasticity (Hager, 1998; Fordham and Brook, 2010; Symeonakis et al., 2016). The absence of fireflies from many islands where they were searched in spring-summer 2025 (e.g., La Maddalena, Pantelleria, Lampedusa, Aeolian islands and part of the Tuscan Archipelago) may reflect either their actual local absence (most Italian species are distributed only in northernmost or Apennine

regions: Fanti, 2022), insufficient sampling effort, or island-specific phenologies, underscoring the need for continued monitoring. Moreover, several small Italian islands (e.g., the circum-Sardinian islands, Sant'Andrea Island in Apulia, and islands of the Venice lagoon) were not sampled for fireflies during the L.U.C.E. project, and no information on local firefly occurrence is available either in the literature or on citizen science platforms. To fill this knowledge gap, a targeted survey campaign could be implemented, combining systematic field sampling with structured public questionnaires disseminated through social media, press, radio, and television. Historical observations reported by older human residents may provide valuable information on former firefly populations and regions where lampyrid abundance has declined.

A key result of our study is the further confirmation of the complementary roles played by citizen-science data and structured scientific surveys, particularly when involving charismatic species (Virić Gašparić et al., 2022; Di Febbraro et al., 2023). iNaturalist provided the majority of records on large and the most frequently visited islands, such as Sicily, Sardinia, and Capri, reflecting higher human presence and accessibility (Canale and De Siano, 2021; Ruggieri and Calò, 2022; Acierno and Pistone, 2024). These data confirmed the occurrence of widespread species and identified areas of recurrent firefly activity. However, citizen-science records related to uncollected specimens were sometimes limited in taxonomic resolution, frequently stopping at the genus level (mostly for Sicily, where two *Lampyris* species occur), and were unevenly distributed across islands. Thus, there is an urgent need for simple, easily observable field characters to distinguish these species (*La. ambigena* and *La. bonvouloirii*) in females, larvae, and males, including features usable for photographic identification on platforms, e.g. iNaturalist. A dedicated website providing comparative images and practical identification guidance for non-specialists would facilitate accurate data collection and citizen science contributions.

The L.U.C.E. project contributed fewer records overall but proved essential for filling geographic and taxonomic gaps. Targeted surveys were the only source of data for several islands, including Asinara, Linosa, and Marettimo, which are poorly represented in citizen-science platforms due to restricted access or low tourist pressure (e.g., Corbau et al., 2019; Agius and Briguglio, 2021; Romagnoli et al., 2021). Moreover, L.U.C.E. data allowed for precise species identification, including the detection of rare, cryptic, or morphologically challenging taxa and the application of molecular tools when necessary. The exclusive detections of *Lu. pedemontana* through structured surveys in Sicily, of *La. fuscata* in Gorgona, and of *La. pallida* in Linosa further clarify the importance of active field-work and the need for integrative taxonomic methods to identify species which may be underreported or overlooked by non-specialists. Therefore, our results support the growing consensus that citizen science and professional research should not be viewed as alternative approaches but rather as synergistic components of modern biodiversity assessment (Di Febbraro et al., 2023). Citizen-science validated data are particularly effective for broad-scale detection and temporal coverage, whereas standardised surveys are pivotal for taxonomic accuracy, detection of rare species, and sampling in low-visibility areas.

Our study also highlights several methodological challenges inherent to firefly research in insular environments. Detectability varies strongly among genera and species, influenced by differences in signalling behaviour, phenology, and habitat use (Fanti, 2022). Abundant species with conspicuous bioluminescent displays and flying males are more likely to be detected through citizen-science, whereas taxa with weak signals, short activity periods, or ground-dwelling larvae require targeted search effort. The integration of larval surveys and the use of red light to minimise disturbance proved particularly effective for improving detection during standardised transects.

From a conservation perspective, our findings highlighted the diversity of insular firefly populations and the urgency of integrating them into broader biodiversity monitoring and management frameworks. Accordingly, many of the islands where fireflies were recorded are subject to increasing touristic pressure (Canale and De Siano, 2021; Ruggieri and Calò, 2022; Acierno and Pistone, 2024), habitat fragmentation, and artificial nighttime lighting, all of which are known threats to Lampyridae (Lewis et al., 2024), calling for national and regional red lists of threatened species of fireflies. Future research should prioritise long-term monitoring on islands where fireflies are known to occur, as well as targeted surveys on islands where they are currently undetected, but potentially present.

Strengthening training and funding for integrative taxonomy would help evaluate the identity of the sampled individuals, elucidate the evolutionary relationships among insular populations, and refine their conservation assessment. In this regard, citizen science projects would benefit from including training aimed at collecting samples suitable for genetic analyses. Finally, strengthening collaborations between researchers, protected area managers, and citizen scientists will be essential to ensure that these charismatic yet overlooked insects persist with viable populations on islands. Applied to fireflies, the integrative approach combining citizen-science and scientific fieldwork reveals a complex mosaic of distribution patterns shaped by island biogeography, ecological specialization and sampling effort, offering a solid baseline for future ecological and conservation-oriented investigations.

ACKNOWLEDGEMENTS

Cristina Mascalchi, Roberto Bruno, Luca Coraci, Mirko Santilli & Alessandra Gentili (CNR IRET Sesto Fiorentino) and Isabella Vitali (CNR IBE Roma) provided valuable technical, administrative and management support. The thermal cycler used in this work has been funded by EU - Next Generation EU Mission 4 "Education and Research" - Component 2: "From re-search to business" - Investment 3.1: "Fund for the realisation of an integrated system of research and innovation infrastructures" - Proj-ect IR0000032 – ITINERIS - Italian Integrated Environmental Re-search Infrastructures System - CUP B53C22002150006. The authors would also like to thank the personnel of protected areas involved (e.g., Maremma Regional Park, Tuscan Archipelago and Asinara National Parks) and all the other sample collectors: Rosario Balestrieri, Marco Rinaldi, Francesco Cappuccio, Chiara Tatti, Luca Bartolozzi, Michele Bertacchi, Elvira Castiglione, Andrea Colla, Luca Colonnelli, Marida Corradetti, Fabio Dartora, Camila Di Gregorio, Bianca Gabbrielli, Vittorio Gallerati, Daniele Giannetti, Francesco Manti, Jacopo Martino, Danilo Molfese, Giorgia Mocilnik, Calogero Muscarella, Luigi Musco, Romano Papi, Vito Petragallo, Gabriella Reggiani, Emanuele Repetto, Davide Scaccini, Alessio Tarani, Luigi Urru and Fabio Ussi. Lesley Ballantyne kindly provided us with useful comments, which significantly improved our manuscript.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

AUTHOR CONTRIBUTIONS

AL, LA and EM conceived this work; MB performed genetic analyses; AV and EM validated citizen-science data; NL and CV provided logistical and administrative support to the project; MSP, LFLDS, FPF, FM, LV, GM, PDB, DF, LL, LF, ES, DC, AG, DP, MMa, ES, PG, MMe, FS, CP, CS and MS collected field data; AL, LA and EM wrote the first draft. All authors participated in writing up the final draft and approved the Manuscript before submission.

FUNDING

This work was funded by the project L.U.C.E. (Lighting up the Understudied but Charismatic fireflies of Europe: mentoring early-career researchers to improve access to knowledge on fireflies of the Italian Peninsula Hotspot using TETTRIs' name matching and linking workflows), a Third-Party Project Grant (Reference N° 11/T6) under the TETTRIs Project (Grant Agreement N° 101081903). This part was the first output of the bilateral project SAS-CNR 2025-2026 (CNR-SAS-2024-10) named "The beaver's legacy: A look at ecosystem impacts in Italy and Slovakia". LA, FM, PDB, PG, MMa, LM and EM were funded by the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.4—Call for tender No. 3138 of 16 December 2021, rectified by Decree n.3175 of 18 December 2021 of Italian Ministry of University and Research funded by the European Union – NextGenerationEU; Project code CN_00000033, Concession Decree No. 1034 of 17 June 2022 adopted by the Italian Ministry of University and Research, CUP B83C22002930006, Project title "National Biodiversity Future Center—NBFC". ES was supported by the Juan de la Cierva postdoctoral fellowship (grant no. JDC2024-054485-I) financed by the MICIU/AEI/10.1303 9/501100011033 and FSE+. AL was supported by the Fondazione Cecilia Gilardi and the Fondazione Sanlorenzo through a fellowship, which partially funded the study for the Tuscan Archipelago. MMe was supported by the European Union's Horizon 2020 research and innovation programme under the

Marie Skłodowska-Curie grant agreement No 101206623.

DATA AVAILABILITY

All data are available via the corresponding author, as well as on GenBank and on the iNaturalist free online platform (www.inaturalist.org).

ETHICAL APPROVAL

The study involved mostly a photographic survey, coupled with a limited number of insect specimens per species collected in protected (e.g., Arcipelago Toscano National Park: Nulla Osta n. 38 of 26.02.2025; Asinara National Park: permits prot. n. 1620/2025 of 08.04.2025) non-protected areas. Although fireflies are not currently covered by specific animal welfare legislation in Italy, all specimens were euthanised using methods consistent with internationally accepted standards for animal welfare, in order to minimise suffering.

REFERENCES

Acierno, A. & Pistone, I. (2024) Sustainable planning and overtourism in the island of Capri. International Symposium on New Metropolitan Perspectives, 1, 93–106. DOI: 10.1007/978-3-031-74608-6_9

Agius, K. & Briguglio, M. (2021) Mitigating seasonality patterns in an archipelago: the role of ecotourism. Maritime Studies, 20, 409–421. DOI: 10.1007/s40152-021-00238-x

Álvarez, J.G., De Cock, R. & Day, J.C. (2011) The biology and distribution of glow-worms (Coleoptera: Lampyridae) in Spain. Lampyrid: The Journal of Bioluminescent Beetle Research, 1, 22–31.

Ancillotto, L., Baratti, M., Rocha, R., et al. (2026) Island as biodiversity arks: the role of insular populations in preserving bat DNA-barcoding diversity. Mammal Research, 71, 3. DOI: 10.1007/s13364-025-00833-x

Baratti, M., Picchi, M.S., Lima da Silveira, L.F., et al. (2025) Illuminating firefly diversity: molecular taxonomy and conservation of Italian Lampyridae. Proceedings of the Congress of the European Society for Evolutionary Biology, Barcelona (Spain), 17-22 August 2025, 2025, 1.

Baudi, F. (1872) Europeae et circummediterraneae Faunae Dascillidum et Malacodermatum specierum, quae Comes Dejean in suo Catalogo ed 3a consigliavit, ex ejusdem collectione in R. Taurinensi Museo asservata, cum auctorum hodierne recepta dominatione, collatio. Berliner Entomologische Zeitschrift, 15, 89–130.

Bocakova, M., Campello-Gonçalves, L. & Da Silveira, L.F.L. (2022) Phylogeny of the new subfamily Cladodinae: neotenic fireflies from the Neotropics (Coleoptera: Lampyridae). Zoological Journal of the Linnean Society, 195, 1181–1199. DOI: 10.1093/zoolinnean/zlab091

Bologna, M.A., Zapparoli, M., Oliverio, M., Minelli, A., Bonato, L., Cianferoni, F., & Stoch, F. (2021) Checklist of the Italian fauna, version 1.0. Available at https://www.lifewatchitaly.eu/iniziative/checklist-fauna-italia-it/ Accessed on 02.10.2025

Bonardi, A., Ficetola, G.F., Razzetti, E., Canedoli, C., Falaschi, M., Lo Parrino, E., Rota, N., Padoa-Schioppa, E., & Sindaco, R. (2022). ReptIslands: Mediterranean islands and the distribution of their reptile fauna. Global Ecology and Biogeography, 31, 840–847. DOI: 10.1111/geb.13490

Branchini, B.R., Southworth, T.L., Fontaine, D.M., Davis, A.L., Behney, C.E., & Murtiashaw, M.H. (2014). A *Photinus pyralis* and *Luciola italica* chimeric firefly luciferase produces enhanced bioluminescence. Biochemistry, 53, 6287–6289. DOI: 10.1021/bi501202u

Calado, H.R.M., Borges, P.A., Heleno, R. & Soares, A.O. (2024) A comparative analysis of island vs. mainland arthropod communities in coastal grasslands belonging to two distinct regions: São Miguel Island (Azores) and mainland Portugal. Diversity, 16, 624. DOI: 10.3390/d16100624

Calado, H.R.M., Soares, A.O., Heleno, R. & Borges, P.A. (2025) Arthropod communities of insular (São Miguel Island, Azores) and mainland (Portugal) coastal grasslands. Biodiversity Data Journal, 13, e144915. DOI: 10.3897/BDJ.13.e144915

Camerini, G. (2022) Habitat selection by *Luciola pedemontana* (Coleoptera Lampyridae) in a lowland landscape in Northern Italy: implications for conservation. Biologia Ambientale, 36, 64–72. DOI: 10.30463/ao221.007

Camerini, G. (2025) Observations on *Luciola pedemontana* (Coleoptera Lampyridae) male courtship. Arthropod Structure & Development, 86, 101426. DOI: 10.1016/j.asd.2025.101426

Canale, R.R. & De Siano, R. (2021) Territorial pressure and tourism contribution to GDP: The case of Italian regions. International Journal of Tourism Research, 23, 891–900. DOI: 10.1002/jtr.2451

Canestrelli, D. & Nascetti, G. (2008) Phylogeography of the pool frog *Rana (Pelophylax) lessonae* in the Italian

peninsula and Sicily: multiple refugia, glacial expansions and nuclear-mitochondrial discordance. Journal of Biogeography, 35, 1923–1936. 10.1111/j.1365-2699.2008.01946.x

Chow, A.T., Chong, J.H., Cook, M. & White, D. (2014) Vanishing fireflies: A citizen-science project promoting scientific inquiry and environmental stewardship. Science Education and Civic Engagement, 6, 1.

Colomba, M., Lo Verde, G., Liberto. F., Gregorini A. & Sparacio I. (2022) Molecular and biometric data on *Carabus (Macrothorax) morbillosus* Fabricius, 1792 (Coleoptera, Carabidae) from Mid Mediterranean areas. ZooKeys, 1127: 119–134. DOI: 10.3897/zookeys.1127.84920

Carmignani, L., Oggiano, G., Funedda, A., Conti, P., & Pasci, S. (2016) The geological map of Sardinia (Italy) at 1: 250,000 scale. Journal of Maps, 12, 826–835. DOI: 10.1080/17445647.2015.1084544

Corbau, C., Benedetto, G., Congiatu, P.P., Simeoni, U., & Carboni, D. (2019). Tourism analysis at Asinara Island (Italy): carrying capacity and web evaluations in two pocket beaches. Ocean & Coastal Management, 169, 27–36. DOI: 10.1016/j.ocecoaman.2018.12.004

Dapporto, L., Cini, A., Menchetti, M., et al. (2017) Rise and fall of island butterfly diversity: Understanding genetic differentiation and extinction in a highly diverse archipelago. Diversity and Distributions, 23, 1169–1181. DOI: 10.1111/ddi.12610

Day, J.C. (2009) The evolution of beetle bioluminescence. Ph.D. Thesis in Life Sciences, Oxford Brookes University, Oxford, United Kingdom.

De Cock, R. (2007) Description of the adult female and larval stages of *Lampyris sardiniae* Geisthardt, 1987 (Coleoptera: Lampyridae). Entomologische Zeitschrift, 117, 99–102.

De Cock, R., Moiseff, A., Day, J., & Castle, S. (2010) Discovery of synchronous flashing in a population of *Luciola* sp. nov. from Europe, Paxos (Greece, Ionian islands). Proceedings of the 2nd International Firefly Symposium 2010, 2-5 August, Selangor, Malaysia.

De Cock, R. (2024) Lampyris pallida. The IUCN Red List of Threatened Species 2024: e.T216125843A216918604. DOI: 10.2305/IUCN.UK.2024-1.RLTS.T216125843A216918604.en

De Cock, R. & Henriques, S. (2024) Lampyris lareynii. The IUCN Red List of Threatened Species 2024: e.T216125765A220508972. DOI: 10.2305/IUCN.UK.2024-1.RLTS.T216125765A220508972.en

de Jong, Y., Verbeek, M., Michelsen, V., et al. (2014) Fauna Europaea – all European animal species on the web. Biodiversity Data Journal, 2, e4034. DOI: 10.3897/BDJ.2.e4034

Di Febbraro, M., Bosso, L., Fasola, M., et al. (2023) Different facets of the same niche: integrating citizen-science and scientific survey data to predict biological invasion risk under multiple global change drivers. Global Change Biology, 29, 5509–5523. DOI: 10.1111/gcb.16901

Dreisig, H. (1978) The circadian rhythm of bioluminescence in the glowworm, *Lampyris noctiluca* L. (Coleoptera, Lampyridae). Behavioral Ecology and Sociobiology, 3, 1–18. DOI: 10.1007/BF00300044

Fallon, C.E., Walker, A.C., Lewis, S., Cicero, J., Faust, L., Heckscher, C.M., Pérez-Hernández, C.X., Pfeiffer, B. & Jepsen, S. (2021) Evaluating firefly extinction risk: Initial red list assessments for North America. PLoS One, 16, e0259379. DOI: 10.1371/journal.pone.0259379

Fanti, F. (2022) Guida alle lucciole d'Italia. Lampyridae. Effigi Editions, Arcidosso (Grosseto), Italy.

Faraone, F.P., Vecchioni, L., Giacalone, G., Muscarella, C., Di Nicola, M. R., Arculeo, M. & Marrone, F. (2025) Patterns of genetic and phenotypic diversity of the Mediterranean banded centipede *Scolopendra cingulata* Latreille, 1829 (Chilopoda: Scolopendromorpha) in Sicily and adjacent areas. Zoological Journal of the Linnean Society, 204, zlaf031. DOI: 10.1093/zoolinnean/zlaf031

Fattorini, S., Mantoni, C., De Simoni, L. & Galassi, D.M. (2018) Island biogeography of insect conservation in urban green spaces. Environmental Conservation, 45, 1–10. DOI: 10.1017/S0376892917000121

Ferreira, V.S., Keller, O. & Branham, M.A. (2020) Multilocus phylogeny support the nonbioluminescent firefly *Chespirito* as a new subfamily in the Lampyridae (Coleoptera: Elateroidea). Insect Systematics and Diversity, 4, 1–13. DOI: 10.1093/isd/ixaa014

Folmer, O., Black, M., Hoeh, W., Lutz, R. & Vrijenhoek, R. (1994) DNA primers for amplification of mitochondrial cytochrome c oxidase subunit I from diverse metazoan invertebrates. Molecular Marine Biology and Biotechnology, 3, 294–299.

Foggi, B., Lastrucci, L., Geri, F. & Rocchini, D. (2015) Recent landscape changes on a small Mediterranean Island. Landscape Research, 40, 437–450. DOI: 10.1080/01426397.2014.902920

Fordham, D.A. & Brook, B.W. (2010) Why tropical island endemics are acutely susceptible to global change.

Biodiversity and Conservation, 19, 329–342. DOI: 10.1007/s10531-008-9529-7

Gallozzi, F., Corti, C., Castiglia, R., Avramo, V., Senczuk, G., Mattioni, C., & Colangelo, P. (2023) The intriguing biogeographic pattern of the Italian Wall Lizard *Podarcis siculus* (Squamata: Lacertidae) in the Tuscan Archipelago reveals the existence of a new ancient insular clade. Animals, 13(3), 386. DOI: 10.3390/ani13030386

Garnier, S., Ross, N., Rudis, R., et al. (2024) viridis(Lite) - Colorblind-Friendly Color Maps for R. DOI: 10.5281/zenodo.4679423

Gentile, G. & Argano, R. (2005) Island biogeography of the Mediterranean Sea: the species–area relationship for terrestrial isopods. Journal of Biogeography, 32, 1715–1726. DOI: 10.1111/j.1365-2699.2005.01329.x

Gentile, G., Argano, R., & Taiti, S. (2022). Evaluating the correlation between area, environmental heterogeneity, and species richness using terrestrial isopods (Oniscidea) from the Pontine Islands (West Mediterranean). Organisms Diversity & Evolution, 22(1), 275-284. DOI: 10.1007/s13127-021-00523-x

Gillespie, R.G. & Roderick, G.K. (2002) Arthropods on islands: colonization, speciation, and conservation. Annual Review of Entomology, 47, 595–632. DOI: 10.1146/annurev.ento.47.091201.145244

Gillespie, R.G. & Will, K. (2018) Biodiversity of arthropods on islands. Insect Biodiversity, 2, 81–104. DOI: 10.1002/9781118945582.ch4

Gil-Tapetado, D., Koken, M., De Cock, R., Gómez, J.F., Cabrero-Sañudo, F.J., & Polidori, C. (2024). Across the firefly-verse: comparison of niche suitability of an exotic firefly in its native and colonized range. Journal of Insect Conservation, 28(1), 43–56. DOI: 10.1007/s10841-023-00522-7

Gippoliti, S. & Amori, G. (2004) Mediterranean Island mammals: are they a priority for biodiversity conservation?. Biogeographia – The Journal of Integrative Biogeography, 25, 135–144. DOI: 10.21426/B6110135

Hager, H.A. (1998) Area-sensitivity of reptiles and amphibians: Are there indicator species for habitat fragmentation?. Ecoscience, 5, 139–147. DOI: 10.1080/11956860.1998.11682463

Hand, R., Grossmann, A. & Lauterbach, D. (2017) Endemics and their common congener plant species on an East Mediterranean island: a comparative functional trait approach. Plant Ecology, 218, 139–150. DOI: 10.1007/s11258-016-0673-y

Kivelä, L., Elgert, C., Lehtonen, T.K. & Candolin, U. (2023) The color of artificial light affects mate attraction in the common glow-worm. Science of The Total Environment, 857, 159451. DOI: 10.1016/j.scitotenv.2022.159451

Kondraskov, P., Schütz, N., Schüßler, C., et al. (2015) Biogeography of mediterranean hotspot biodiversity: re-evaluating the 'tertiary relict' hypothesis of macaronesian laurel forests. PLoS One, 10, e0132091. DOI: 10.1371/journal.pone.0132091

Lagrotteria, A., Roccatello, S. & Doretto, A. (2025) Contribution of citizen science data on the evaluation of local biodiversity of benthic macroinvertebrate communities. Ecologies, 6, 31. DOI: 10.3390/ecologies6020031

Lewis, S.M., Wong, C.H., Owens, A.C., et al. (2020) A global perspective on firefly extinction threats. BioScience, 70, 157–167. DOI: 10.1093/biosci/biz157

Lewis, S.M., Jusoh, W.F.A., Walker, A.C., Fallon, C.E., Joyce, R., & Yiu, V. (2024). Illuminating firefly diversity: Trends, threats and conservation strategies. Insects, 15, 71. DOI: 10.3390/insects15010071

Lhoumeau, S. & Borges, P.A. (2023) Assessing the impact of insect decline in islands: exploring the diversity and community patterns of indigenous and non-indigenous arthropods in the Azores native forest over 10 years. Diversity, 15, 753. DOI: 10.3390/d15060753

Liberti, G. (1995) Famiglia Lampyridae. In: Audisio, P., Liberti, G., Nardi, G., Poggi, R. (Eds.) Coleoptera Polyphaga VIII (Cantharoidea, Dermestoidea). Edizioni Calderini, Bologna, Italy.

Losos, J.B. & Ricklefs, R.E. (2009) Adaptation and diversification on islands. Nature, 457, 830–836. DOI: 10.1038/nature07893

MacArthur, R.H., & Wilson, E.O. (1967) The theory of island biogeography. Princeton University Press, Princeton, New Jersey, USA.

Martin, G.J., Branham, M.A., Whiting, M.F. & Bybee, S.M. (2017) Total evidence of phylogeny and the evolution of adult bioluminescence in fireflies (Coleoptera: Lampyridae). Molecular Phylogenetics and Evolution, 107, 564–575. DOI: 10.1016/j.ympev.2016.12.017

Martin, G.J., Stanger-Hall, K.F., Branham, M.A., et al. (2019) Higher-level phylogeny and reclassification of Lampyridae (Coleoptera: Elateroidea). Insect Systematics and Diversity, 3, 11. DOI: 10.1093/isd/ixz024

Massa, B. & Fontana, P. (2020) Endemism in Italian Orthoptera. Biodiversity Journal, 11, 405–434. DOI: 10.31396/BIODIV.JOUR.2020.11.2.405.434

Mavridis, F. (2003) Early island archaeology and the extinction of endemic fauna in the eastern Mediterranean: problems of interpretation and methodology. British School at Athens Studies, 65–74.

Medail, F. & Quezel, P. (1999) Biodiversity hotspots in the Mediterranean Basin: setting global conservation priorities. Conservation Biology, 13, 1510–1513. DOI: 10.1046/j.1523-1739.1999.98467.x

Mori, E., Viviano, A., Baratti, M., Serafini, E., Gabbrielli, B., Picchi, M.S., Giannetti, D., Mascalchi, C. & Ancillotto, L. (2025a) A light in the dark: DNA barcoding provides new data about the taxonomy of the Italian *Luciola* (Coleoptera: Lampyridae) fireflies. Zootaxa, 5609, 525–536. DOI: 10.11646/zootaxa.5609.4.4

Mori, E., Ancillotto, L., Di Nicola, M.R., Vecchioni, L., & Faraone, F.P. (2025b). Genetic Insights into the identity and distribution of *Tarentola* spp. geckos on Lampedusa Island. Biogeographia – The Journal of Integrative Biogeography, 40, a048. DOI: 10.21426/B6.47132

Muscarella, C. & Baragona, A. (2017) The endemic fauna of the Sicilian islands. Biodiversity Journal, 8, 249–278.

Palombo, M.R. (2018) Insular mammalian fauna dynamics and paleogeography: A lesson from the Western Mediterranean islands. Integrative Zoology, 13, 2–20. DOI: 10.1111/1749-4877.12275

Picchi, M.S., Avolio, L., Azzani, L., Brombin, O., & Camerini, G. (2013). Fireflies and land use in an urban landscape: the case of *Luciola italica* L. (Coleoptera: Lampyridae) in the city of Turin. Journal of Insect Conservation, 17, 797–805. DOI: 10.1007/s10841-013-9562-z

R Core Team (2022) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project org. Accessed on 15.01.2026.

Ramirez, I.E., Yar, J., Sinclair, B.J., Torres, A.K., Causton, C.E., & Heimpel, G.E. (2024). Competition among invasive and endemic carrion fly species in the Galapagos Islands with implications for biological control risk assessment. Insect Conservation and Diversity, 17, 409–418. DOI: 10.1111/icad.12706

Roccatello, S., Lagrotteria, A., Andrà, C. & Doretto, A. (2025) Bridging science and society: Developing a citizen science biomonitoring approach for river ecosystems in Italy. Ecological Indicators, 171, 113199. DOI: 10.1016/j.ecolind.2025.113199

Romagnoli, B., Grasselli, F., Costantini, F., Abbiati, M., Romagnoli, C., Innangi, S., Di Martino, G., & Tonielli, R. (2021). Evaluating the distribution of priority benthic habitats through a remotely operated vehicle to support conservation measures off Linosa Island (Sicily Channel, Mediterranean Sea). Aquatic Conservation: Marine and Freshwater Ecosystems, 31, 1686–1699. DOI: 10.1002/aqc.3554

Ruggieri, G. & Calò, P. (2022) Tourism dynamics and sustainability: A comparative analysis between Mediterranean islands—evidence for post-COVID-19 strategies. Sustainability, 14, 4183. DOI: 10.3390/su14074183

Salvi, D., Capula, M., Bombi, P. & Bologna, M.A. (2009) Genetic variation and its evolutionary implications in a Mediterranean island endemic lizard. Biological Journal of the Linnean Society, 98, 661–676. DOI: 10.1111/j.1095-8312.2009.01313.x

Sfenthourakis, S. & Triantis, K.A. (2009) Habitat diversity, ecological requirements of species and the Small Island Effect. Diversity and Distributions, 15, 131–140. DOI: 10.1111/j.1472-4642.2008.00526.x

Shaw, J.D., Spear, D., Greve, M. & Chown, S.L. (2010) Taxonomic homogenization and differentiation across Southern Ocean Islands differ among insects and vascular plants. Journal of Biogeography, 37, 217–228. DOI: 10.1111/j.1365-2699.2009.02204.x

Simberloff, D. (1976) Experimental zoogeography of islands: effects of island size. Ecology, 57, 629–648. DOI: 10.2307/1936179

Sogliani, D. (2026) Citizen science-based distribution update of invasive *Corytucha* species in Italy. Biogeographia – the Journal of Integrative Biogeography, 41, s010. DOI: 10.21426/B6.62203

Sokal, R.R., & Rohlf, F.J. (2012) Biometry. Third Edition. W.H. Freeman and Company, London, UK.

South, A., Stanger-Hall, K., Jeng, M.L. & Lewis, S.M. (2011) Correlated evolution of female neoteny and flightlessness with male spermatophore production in fireflies (Coleoptera: Lampyridae). Evolution, 65, 1099–1113. DOI: 10.1111/j.1558-5646.2010.01199.xa

Stöck, M., Sicilia, A., Belfiore, N.M., Buckley, D., Lo Brutto, S., Lo Valvo, M. & Arculeo, M. (2008) Post-Messinian evolutionary relationships across the Sicilian channel: mitochondrial and nuclear markers link a new green toad from Sicily to African relatives. BMC Evolutionary Biology, 8, 56. DOI: 10.1186/1471-2148-8-56

Symeonakis, E., Karathanasis, N., Koukoulas, S. & Panagopoulos, G. (2016) Monitoring sensitivity to land degradation and desertification with the environmentally sensitive area index: the case of Lesvos Island. Land Degradation & Development, 27, 1562–1573. DOI: 10.1002/ldr.2285

Thomas, E.A., Böhm, M., Pollock, C., Chen, C., Seddon, M., & Sigwart, J.D. (2022). Assessing the extinction risk of insular, understudied marine species. Conservation Biology, 36, e13854. DOI: 10.1111/cobi.13854

Tisi, L.C., De Cock, R., Stewart, A.J.A., Booth, D., & Day, J.C. (2014). Bioluminescent leakage throughout the body of the glow-worm *Lampyris noctiluca* (Coleoptera: Lampyridae). Entomologia Generalis, 35, 47–151. DOI: 10.1127/0171-8177/2014/0003

Tojo, K., Sekiné, K., Takenaka, M., Isaka, Y., Komaki, S., Suzuki, T., & Schoville, S.D. (2017). Species diversity of insects in Japan: Their origins and diversification processes. Entomological Science, 20, 357–381. DOI: 10.1111/ens.12261

Tscharntke, T., Steffan-Dewenter, I., Kruess, A. & Thies, C. (2002) Characteristics of insect populations on habitat fragments: a mini review. Ecological Research, 17, 229–239. DOI: 10.1046/j.1440-1703.2002.00482.x

Vecchioni, L., Marrone, F., Rodilla, M., Belda, E. J., & Arculeo, M. (2019). An account on the taxonomy and molecular diversity of a marine rock-pool dweller, *Tigriopus fulvus* (Copepoda, Harpacticoida). Ciencias Marinas, 45, 59–75. DOI: 10.7773/cm.v45i2.2946

Virić Gašparić, H., Mikac, K.M., Pajač Živković, I., Krehula, B., Orešković, M., Galešić, M.A., Ninčević, P., Varga, F., & Lemić, D. (2022). Firefly occurrences in Croatia – one step closer from citizen science to open data. Interdisciplinary Description of Complex Systems: INDECS, 20, 112–124. DOI: 10.7906/indecs.20.2.4

Viviano, A., Cocco, A., Colangelo, P., Delitala, G. M., Pantaleoni, R. A., & Loru, L. (2024). Worldwide distribution and phylogeography of the agave weevil *Scyphophorus acupunctatus* (Coleoptera, Dryophthoridae): the rise of an overlooked invasion. NeoBiota, 90, 53–78. DOI: 10.3897/neobiota.90.101797

Whittaker, R.J., Fernández-Palacios, J.M., Matthews, T.J., Borregaard, M.K., & Triantis, K.A. (2017). Island biogeography: taking the long view of nature's laboratories. Science, 357, 6354. DOI: 10.1126/science.aam8326

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

Zhu, C., Lu, X., Cai, T., Zhu, K., Shi, L., Chen, Y., … & Zhen, Y. (2024). Firefly toxin lucibufagins evolved after the origin of bioluminescence. PNAS Nexus, 3, page 215. DOI: 10.1093/pnasnexus/pgae215

Submitted: 17 February 2026

First decision: 27 March 2026

Accepted: 3 April 2026

Published online: 8 April 2026

Edited by Diego Fontaneto