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Intensive monitoring of the butterflies of the UNESCO MAB reserve of Monte Peglia (Central Italy) reveals strong potential for local extinctions in a Mediterranean area

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Abstract

The impact of human activities is resulting in increased losses of biodiversity on a local and global scale. Detecting local extinctions requires historical data and intensive field surveys, so as to ascertain the actual absence of a species. In this study, we fortnightly sampled 90 plots within the Monte Peglia UNESCO MAB Reserve (~60 km^2) from April to October 2022. We also collected all available records for the Reserve in literature and iNaturalist. After our sampling, the Reserve appears in the 4% of the richest cells with similar size and altitude in central Italy. By applying the Potential-Extinction-upon-Time-Series (PETS) algorithm we evaluated the possibility for faunistic erosion in time. A total of 13 species that were recorded prior to 2010 but not confirmed in our field surveys produce a moderate PETS value of 23.5%. Based on literature and iNaturalist data, we also identified rare species as those occurring within a 50 km radius of the Reserve in the lowest quartile of occurrences. More than half of the unconfirmed species belonged to regionally rare taxa, while the others belonged to taxa generally found at higher altitudes in the last decades. Monte Peglia Reserve qualifies as a perfect model for documenting possible local extinctions of butterflies in Mediterranean areas in the near future.

Key words: Butterflies, Lepidoptera, Occurrence data, Extinction, Rarity, Species richness

Introduction

The Anthropocene has seen the earth entering its sixth mass extinction event since the last one, determining the end of the Cretaceous Period (66 Mya) in which more than 80% of species were lost (Barnosky *et al.* 2011; Wagner *et al.* 2021). The terrestrial vertebrates have decreased their population sizes and ranges by one-third (Ceballos *et al.* 2020) and current data suggest an overall pattern of decline in insect biomass, species richness, range sizes and abundance (Hallmann *et al.* 2017; Sánchez-Bayo & Wyckhuys 2019; Wagner 2020). Global decline in insect diversity and abundance is expected to provoke disastrous effects on food webs due to their fundamental contribution to ecosystem functioning. As a main example, 80% of wild plants are estimated to depend on insects for pollination (Hallmann *et al.* 2017; Ollerton 2017).

Regional and global extinctions follow repeated events of local population decrease and loss, thus, understanding and halting local declines is becoming a pressing matter (Chowdhury *et al.* 2022). In addition to negatively impacting

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local biodiversity, regional extinctions could also negatively affect genetic diversity since evolutionary significant units could be lost (Brooks *et al.* 2015; Minter *et al.* 2020; Sistri *et al.* 2022).

Sothern European areas show the greatest diversity and richness of butterfly species (Numa *et al.* 2016) with the Italian butterfly fauna counting almost 290 native species (Bonelli *et al.* 2018). The highest values of species richness are represented by the mountain chains of the Alps due to their geomorphological structures and to the great altitudinal range providing great environmental variability and the existence of post-glacial refugia during the current inter-glacial (Ohlemüller *et al.* 2008; Menchetti *et al.* 2021). In the last decades climatic changes are altering the habitat suitability for many butterfly species forcing them to shift their local distribution toward higher altitudes (Rödder *et al.* 2021). The mountain areas of central Italy show a minor altitudinal gradient compared to the Alps, implementing possible local extinction trends of butterflies. The availability of specific information such as the collection of historical data together with present data from parks and reserves is an essential tool for describing ecological situations and for identifying potential losses. However, information on the occurrence of many butterfly species is still scanty and biased since historical collection and scientific literature are often not complete and available in online databases (Sobral-Souza *et al.* 2021). Despite, the central and southern regions of Italy have received increasing attention in recent times due to their highly diverse genetic and faunistic composition (Bonifacino *et al.* 2022; Sistri *et al.* 2022), there are still profound gaps of knowledge about butterfly faunas that could resolve in a lower capacity to detect local events of extinction.

The Monte Peglia MAB UNESCO World Biosphere Reserve in central Italy (Umbria region) with a maximum elevation of 837 m a.s.l., represents a typical hilly area where several butterfly populations could be at risk of local extinctions. In the present study, we gathered all the available information about the butterfly fauna recorded in the Monte Peglia Reserve to: 1) define a checklist of the butterflies present in the area and evaluate the species richness of the Reserve compared to the neighbouring areas of similar altitude; 2) evaluate the change over time in the butterfly community; 3) objectively identify the regionally rare species through comparison with similar surrounding areas to complement the list of species that could have undergo local extinction or are at high risk.

Materials and Methods

Study area

The study was conducted in the Monte Peglia MAB UNESCO World Biosphere Reserve with an extension of about 60 km^2 (Fig. 1A). It is characterised by a relatively compact system of low hills, dominated by the Peglia mountain (837 m a.s.l.) situated in the southern part of the Reserve, with the presence of ancient volcanic areas (Stoppa & Sforna 1995; Stoppa 1996). The area consists of an extensive forested area, with a great variety of flora, almost intact and well-preserved habitats and bears a great number of plant and animal species.

Methods

The occurrence of data in the Reserve was gathered through 1) field sampling over a period of seven months; 2) literature data using the Italian CkMap (Balletto *et al.* 2007) continuously updated by EB; and 3) citizen science data from the platform iNaturalist.

Field surveys have been carried out by the authors every two weeks from April to October 2022 in 90 plots (50 x 50 m) in five macro-areas within the Reserve's Core and Buffer areas. The plots were chosen by selecting an equal number of micro-habitats between grassland and woodland plots at different altitudes (Fig. 1B and 1C).

The data from iNaturalist were checked by the authors based on uploaded photographs before inclusion in the dataset. We followed the recent taxonomy proposed by Wiemers *et al.* (2018) and updated by Dapporto *et al.* (2022) for European species. Each data gathered from iNaturalist was attributed to the closest cell of CkMap (UTM cells of 10 x 10 km) using the *earth.dist* R function of the "fossil" R package (Vavrek 2011) and the combined dataset created (total dataset) was used for the analyses.

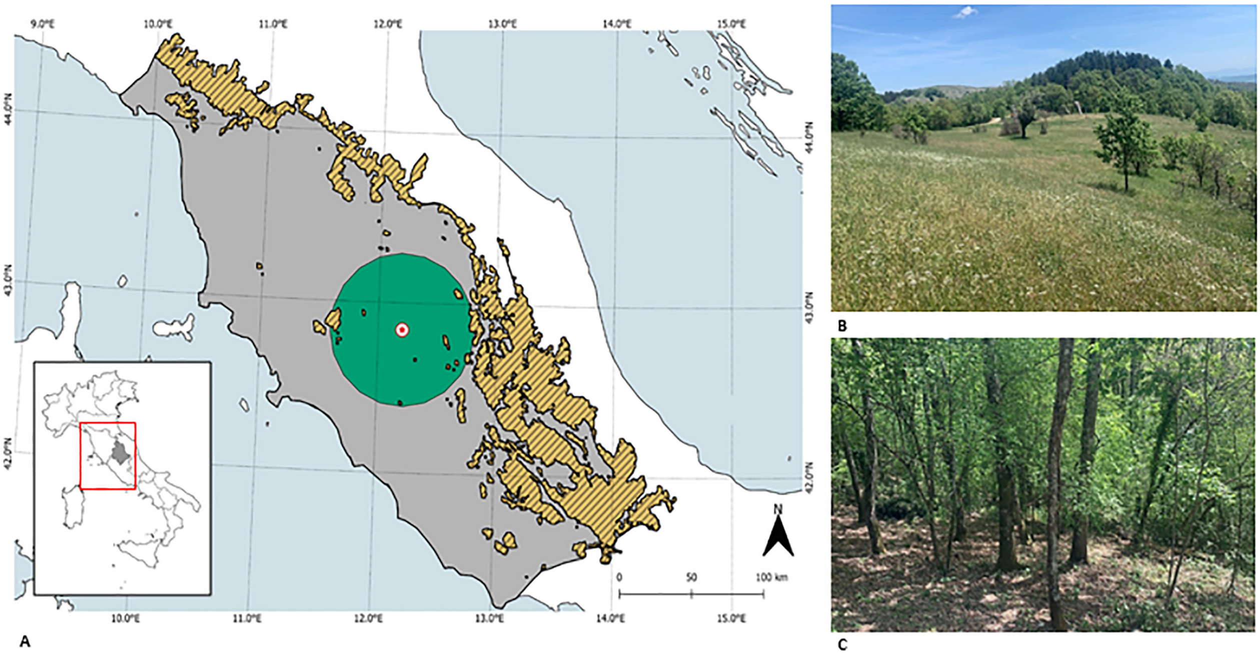

Figure 1. (**A**) The study area. The Monte Peglia is represented by a red star icon inside the circle of 50 km ray (green circle). Grey polygon represents the similar altitude areas in Central Italy used to calculate the species richness. The Apennines Mountain chain excluded from the analyses is represented in dark yellow. Typical grassy (**B**) and woody (**C**) areas inside the Reserve. Photos by ©Giulia Simbula.

Evaluation of Potential Extinctions upon Time Series

To evaluate the degree of possible number of species lost after a given period in the Monte Peglia Reserve, we calculated the Potential-Extinction-upon-Time-Series (PETS) with the following equation introduced by Labadessa *et al.* (2021):

$$PETS = \frac{\sum_{i=1}^{n} last\ year - last\ occ_i}{\sum_{i=1}^{n} \left(last\ year - first\ occ_i\right) + 1}$$

Where $first\ occ_i$ and $last\ occ_i$ are the year of the first and of the last observation of the species *i* respectively and *last year* is the last year of sampling activities (equal for all species and 2022 in this study); *n* is the number of species occurring in the community. Practically, the PETS algorithm measures the mean completeness of the time series since last record of each species observed in a community.

A list of all species recorded in the Reserve was compiled showing their first and last sighting. The time series for each species was reported in a graph (Fig. 2) where the y-axis represents the species ordered considering their last sighting whilst the x-axis shows the years when the species were observed in the reserve.

Rare species

A grid of 0.2 x 0.2 longitude and latitude was created. We then identified all the UTM cells having their centre closer than 50 km from the centre of the Reserve (12.2 longitude and 42.8 latitude in decimal degrees) (Fig. 1A, green circle). The rare species in this area are those species occurring in the lowest 25% quantile of spatial abundance (Fattorini *et al.* 2013; Ohlemüller *et al.* 2008). We verified which of these rare species were also recorded in the Reserve.

Species richness

We created a polygon delimited from north to south by Cinque Terre and Circeo national parks, from east to west by the Apennines Mountain chains and the coast (Fig. 1A grey area). In order to calculate and compare species richness of the Reserve with areas of similar altitude, we selected all occurrences in 10 x 10 km UTM squares from the total dataset included in the polygon except the ones from the Apennines.

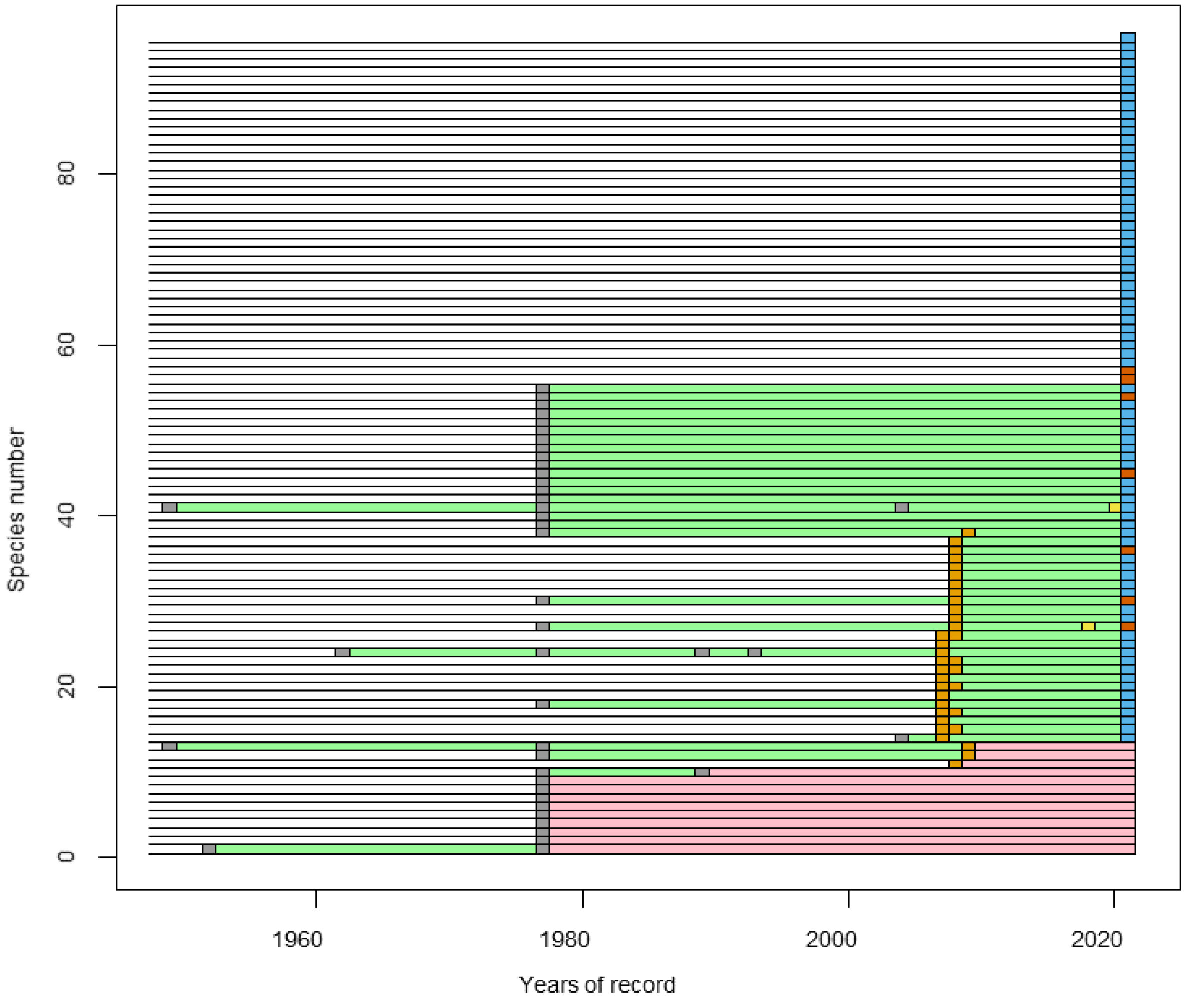

Figure 2. The PETS graph illustrates the time series for each species recorded in the Monte Peglia Reserve. Species are reported on the y-axis from 1 to 96, ordered like in Table 1 from those recorded in older times (bottom) to those recorded more recently (top). Grey squares represent the observations without a date included with the year of the publication. Orange squares represent dated literature data, yellow squares iNaturalist data, blue squares sampling data from authors and red squares data belonging to more than one source. The green area represents the sector of time series confirmed, while the red area in the bottom-right part of the graph is the potential for extinction (unconfirmed sector of time series).

Results

Evaluation of Potential-Extinction-upon-Time-Series

We listed 96 species recorded in the Monte Peglia UNESCO Biosphere Reserve between 1952 and 2022 (Table 1). Papers published between 1952 and 2005 did not show precise collection dates (grey squares) contrary to data published between 2008 and 2010 (orange squares) (Fig. 2). We gathered 9 occurrence data from iNaturalist (yellow squares) between 2019 and 2022, mostly overlapping (red squares) with our sampling activities data of 2022 (blue squares) (except for *Hipparchia fagi* and *Argynnis paphia*). In particular, a total of 55 species were recorded in literature: among them 10 (18.2%) were not recorded since 1978 to 1990, one (*Euphydryas aurinia*) since 2009 and 2 (3.63%) since 2010 (*Cupido alcetas, Libythea celtis*) (Table 1). In the sampling activities of 2022, all species from CkMap (but those thirteen) and iNaturalist were confirmed, and 39 species were recorded for the first time in the reserve (Table 1).

The fraction of potential extinctions was represented by a missing area (red area in Fig. 2) of 23.54% of the total length of time series (red plus green area in Fig. 2).

Table 1. The 96 species recorded for the Monte Peglia UNESCO Biosphere Reserve (in the same order of Fig. 2). The first and last years when the species have been recorded, the frequency in the region cells and the status as rare as well as species included in the Habitat Directive (HD) are also provided. Species marked with asterisk (*) were not confirmed in 2022. First = First sighting; Last = Last sighting; Occ. cells = Occupied cells; HD= Habitat Directive

Species	First	Last	Occ. cells	Rare/HD
Chazara briseis (Linnaeus, 1764)*	1953	1978	9	-
Pieris mannii (Mayer, 1851)*	1978	1978	13	-
Hamearis lucina (Linnaeus, 1758)*	1978	1978	8	-
Lycaena thersamon (Esper, 1784)*	1978	1978	8	-
Thecla betulae (Linnaeus, 1758)*	1978	1978	4	rare
Polyommatus dorylas (Denis & Schiffermüller, 1775)*	1978	1978	5	rare
Fabriciana niobe (Linnaeus, 1758)*	1978	1978	4	rare
Carcharodus baeticus (Rambur, 1839)*	1978	1978	1	rare
Hyponephele lupina (Costa, 1836)*	1978	1978	7	-
Gegenes nostrodamus (Fabricius, 1793)*	1978	1990	3	rare
Euphydryas aurinia (Rottemburg, 1775)*	2009	2009	9	-
Cupido alcetas (Hoffmansegg, 1804)*	1978	2010	18	-
Libythea celtis (Laicharting, 1782)*	1950	2010	15	-
Zerynthia cassandra (Geyer, 1828)	2005	2022	26	HD
Pieris rapae (Linnaeus, 1758)	2008	2022	47	-
Colias alfacariensis Ribbe, 1905	2008	2022	21	-
Leptidea sinapis (Linnaeus, 1758)	2008	2022	34	-
Cupido minimus (Fuessly, 1775)	1978	2022	13	-
Aricia agestis (Denis & Schiffermüller, 1775)	2008	2022	40	-
Polyommatus icarus (Rottemburg, 1775)	2008	2022	53	-
Melitaea cinxia (Linnaeus, 1758)	2008	2022	32	-
Melitaea didyma (Esper, 1778)	2008	2022	46	-
Limenitis reducta Staudinger, 1901	2008	2022	45	-
Melanargia arge (Sulzer, 1776)	1963	2022	26	HD
Pararge aegeria (Linnaeus, 1758)	2008	2022	38	-
Lasiommata megera (Linnaeus, 1767)	2008	2022	53	-
Iphiclides podalirius (Linnaeus, 1758)	1978	2022	65	-
Callophrys rubi (Linnaeus, 1758)	2009	2022	30	-
Melitaea phoebe (Denis & Schiffermüller, 1775)	2009	2022	32	-
Papilio machaon Linnaeus, 1758	1978	2022	49	-
Pieris napi (Linnaeus, 1758)	2009	2022	42	-
Euchloe ausonia (Hübner, 1804)	2009	2022	22	-
Colias crocea (Geoffroy, 1785)	2009	2022	46	-
Glaucopsyche alexis (Poda, 1761)	2009	2022	34	-
Lysandra bellargus (Rottemburg, 1775)	2009	2022	33	-
Vanessa cardui (Linnaeus, 1758)	2009	2022	40	-
Lasiommata maera (Linnaeus, 1758)	2009	2022	38	-
Polyommatus escheri (Hübner, 1823)	1978	2022	16	-
Vanessa atalanta (Linnaeus, 1758)	1978	2022	38	-
Polygonia egea (Cramer, 1775)	1978	2022	20	-
Charaxes jasius (Linnaeus, 1767)	1950	2022	16	-
Pontia edusa (Fabricius, 1777)	1978	2022	28	-
Favonius quercus (Linnaeus, 1758)	1978	2022	17	-
Leptotes pirithous (Linnaeus, 1767)	1978	2022	30	-
Celastrina argiolus (Linnaeus, 1758)	1978	2022	30	-
Pseudophilotes baton (Bergsträsser, 1779)	1978	2022	19	-
Lysandra coridon (Poda, 1761)	1978	2022	14	-
Polyommatus thersites (Cantener, 1835)	1978	2022	17	-
Nymphalis polychloros (Linnaeus, 1758)	1978	2022	30	-
Boloria dia (Linnaeus, 1767)	1978	2022	13	-
Melitaea celadussa Fruhstorfer, 1910	1978	2022	22	-
Brintesia circe (Fabricius, 1775)	1978	2022	27	-
Hipparchia statilinus (Hufnagel, 1766)	1978	2022	17	-
Issoria lathonia (Linnaeus, 1758)	1978	2022	34	-

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Table 1. (Continued)

Species	First	Last	Occ. cells	Rare/HD
Hipparchia semele (Linnaeus, 1758)	1978	2022	16	-
Hipparchia fagi (Scopoli, 1763)	2022	2022	15	-
Argynnis paphia (Linnaeus, 1758)	2022	2022	44	-
Anthocharis cardamines (Linnaeus, 1758)	2022	2022	31	-
Gonepteryx rhamni (Linnaeus, 1758)	2022	2022	25	-
Gonepteryx cleopatra (Linnaeus, 1767)	2022	2022	18	-
Coenonympha pamphilus (Linnaeus, 1758)	2022	2022	51	-
Lycaena tityrus (Poda, 1761)	2022	2022	25	-
Lycaena phlaeas (Linnaeus, 1761)	2022	2022	29	-
Pyrgus malvoides (Elwes & Edwards, 1897)	2022	2022	13	-
Boloria euphrosyne (Linnaeus, 1758)	2022	2022	9	-
Polygonia c-album (Linnaeus, 1758)	2022	2022	27	-
Ochlodes sylvanus (Esper, 1777)	2022	2022	26	-
Spialia sertorius (Hoffmansegg, 1804)	2022	2022	11	-
Erynnis tages (Linnaeus, 1758)	2022	2022	11	-
Pyrgus sidae (Esper, 1784)	2022	2022	3	rare
Aporia crataegi (Linnaeus, 1758)	2022	2022	37	-
Pieris brassicae (Linnaeus, 1758)	2022	2022	47	-
Maniola jurtina (Linnaeus, 1758)	2022	2022	49	-
Brenthis daphne (Denis & Schiffermüller, 1775)	2022	2022	20	-
Satyrium ilicis (Esper, 1779)	2022	2022	26	-
Thymelicus sylvestris (Poda, 1761)	2022	2022	18	-
Thymelicus lineola (Ochsenheimer, 1808)	2022	2022	13	-
Coenonympha arcania (Linnaeus, 1761)	2022	2022	23	-
Thymelicus acteon (Rottemburg, 1775)	2022	2022	18	-
Aglais urticae (Linnaeus, 1758)	2022	2022	14	-
Fabriciana adippe (Denis & Schiffermüller, 1775)	2022	2022	11	-
Melanargia galathea (Linnaeus, 1758)	2022	2022	37	-
Carcharodus alceae (Esper, 1780)	2022	2022	18	-
Heteropterus morpheus (Pallas, 1771)	2022	2022	8	-
Aglais io (Linnaeus, 1758)	2022	2022	24	-
Satyrium acaciae (Fabricius, 1787)	2022	2022	15	-
Satyrus ferula (Fabricius, 1793)	2022	2022	8	-
Pyronia cecilia (Vallantin, 1894)	2022	2022	10	-
Pyronia tithonus (Linnaeus, 1771)	2022	2022	14	-
Carcharodus floccifera (Zeller 1847)	2022	2022	5	rare
Hesperia comma (Linnaeus, 1758)	2022	2022	3	rare
Lampides boeticus (Linnaeus, 1767)	2022	2022	19	-
Pyrgus armoricanus (Oberthür, 1910)	2022	2022	7	-
Plebejus argus (Linnaeus, 1758)	2022	2022	16	-
Cupido osiris (Meigen 1829)	2022	2022	7	-
Pyrgus onopordi (Rambur, 1839)	2022	2022	5	rare

Rare species

In total, we found 132 species in the area identified by a ray of 50 km around the Reserve. We identified 31 rare species (Table 2), based on the number of 0.2 x 0.2 cells where they were recorded. Some of them represent mountain species that could be found above 1000 m of altitude. Among these rare species, 9 were also documented in the Monte Peglia Reserve but 5 (*Fabriciana niobe, Polyommatus dorylas, Thecla betulae, Carcharodus baeticus, Gegenes nostrodamus*) were last recorded between 1978 and 1990, and 4 (*Carcharodus floccifera*, *Hesperia comma, Pyrgus onopordi*, *Pyrgus sidae*) were observed for the first time by the authors in 2022 (Table 2).

Species Richness in the region and data completeness

Species richness in 10 km x 10 km UTM cells show a range from 1 to 122 species (mean±SE= 34.4±1.3). Most of the cells (97.2 %) compared to Monte Peglia Reserve ones show a lower species richness (blue dots in Fig. 3A). The Reserve with a total number of 96 species (57 historical and citizen science data, and 39 sampling from 2022) falls into the 96th percentile (Fig. 3).

Table 2. List of 31 rare species over the wide region around the Reserve (50 km ray).

Species	Occupied cells
Carcharodus baeticus	1
Carcharodus floccifera	5
Carcharodus lavatherae	4
Coenonympha dorus	4
Erebia meolans	1
Fabriciana niobe	4
Gegenes nostrodamus	3
Hesperia comma	3
Hipparchia hermione	3
Hyponephele lycaon	3
Iolana iolas	5
Lycaena alciphron	4
Lycaena virgaureae	2
Melitaea trivia	4
Nymphalis antiopa	4
Parnassius mnemosyne	2
Phengaris alcon	1
Polyommatus amandus	5
Polyommatus damon	1
Polyommatus daphnis	6
Polyommatus dolus	5
Polyommatus dorylas	5
Polyommatus eros	1
Pyrgus alveus	3
Pyrgus carthami	2
Pyrgus foulquieri	1
Pyrgus onopordi	5
Pyrgus serratulae	2
Pyrgus sidae	3
Satyrium spini	1
Thecla betulae	4

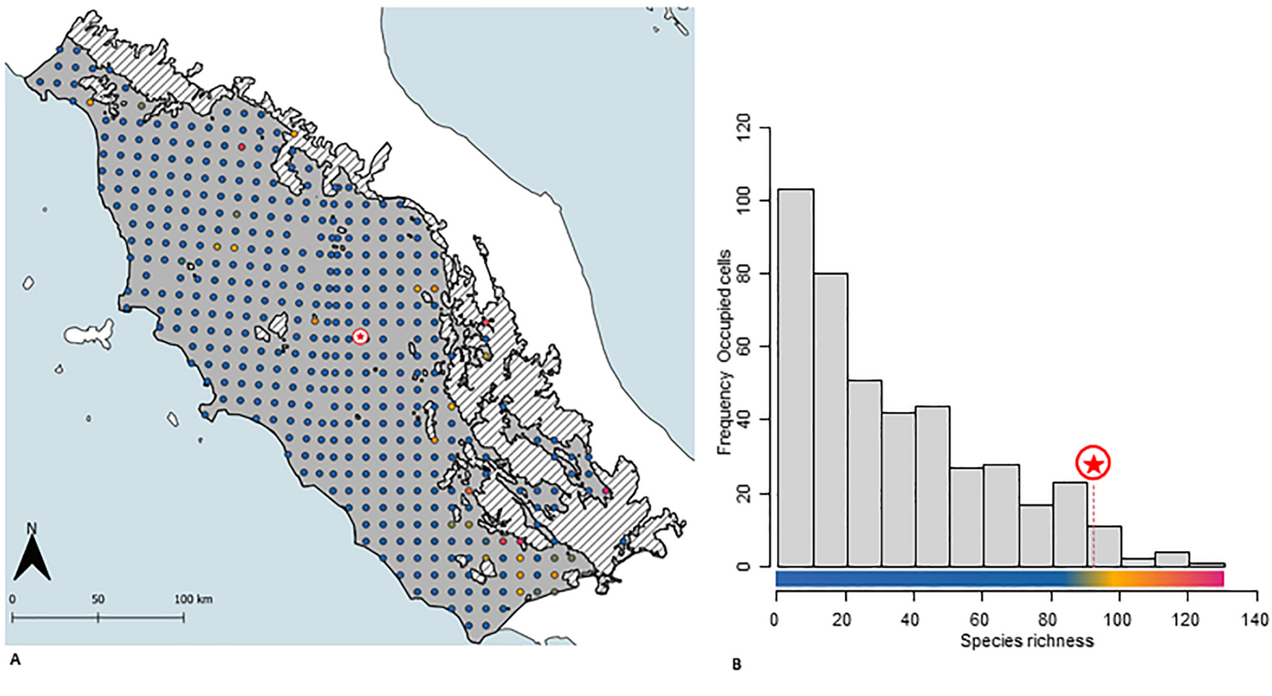

Figure 3. (**A**) Species richness of the cells inside the selected polygon without the Apennines, the cell colours are the same shown in the x-axis of the histogram; (**B**) histogram representing the frequency of species richness among the cells. The red star represents the Monte Peglia Reserve cell (96 species).

Discussion

In this study, we listed a total of 96 species for the Monte Peglia Unesco Biosphere Reserve and combined all available information about the butterfly fauna of the area. Approximately half of the species have been confirmed in the Reserve, however a considerable number of species (39) were found for the first time. Additionally, despite the massive and widespread sampling effort, we couldn't find 13 species, 10 of which have not been recorded since 1990. Within the 50-km radius of the Reserve, 9 of the 31 species classified as rare occur, 5 of them were among the 13 not recorded during the sampling activities of 2022.

The PETS index (fraction of the species absence over the time since the first observation) is an easy method to evaluate the degree in which a community appears eroded in time due to two possible causes: 1) extinction of species; 2) unavailability of occurrence data providing an inaccurate estimate of extinction. The latter possibility was confirmed in our work by the presence of a majority timely scattered and old literature records for the area. Although prior to this work the Monte Peglia Reserve butterfly occurrence had been poorly studied, the large portion of detected species in 2022 resulted in a low probability of extinctions in last decades (recorded confirmed species represent 76.46% of the total area of occurrence). The gross paucity of butterfly inventory data reported here could lead to a significantly biased dataset, indeed more often than not, faunistic data can be expected to suffer from the degree of species "appeal" (Troudet *et al.* 2017; Sánchez-Fernández *et al.* 2021) and the accessibility of the sampling sites (Girardello *et al.* 2019). Under these circumstances and similar constraints, it is well known that our knowledge of geographical distribution of butterflies remains taxonomically and geographically incomplete (Sánchez-Fernández *et al.* 2021). Accordingly, as it often occurs in poorly studied areas, literature data reported mainly rare species, while iNaturalist records were few and focused on large and striking butterflies. Consequently, many widespread and well-known species (i.e., *Pieris brassicae*, *Gonepteryx* spp. and *Maniola jurtina*) were recorded for the first time in our study. Despite the positive general trend in data accumulation of butterfly occurrence, there are still several spatial-temporal biases in inventory completeness especially at local level, suggesting that a great effort must be made to accumulate more data in these areas. An additional problem for historical data is linked to the lack of free accessible electronic databases (Girardello *et al.* 2019).

Regardless of the thorough investigation carried out fortnightly for seven months and the scarcity of historical data, the absence of 13 species during sampling activities in the Reserve may reflect once again sampling incompleteness and/or possible decrease or extinction. Further sampling efforts would be necessary to ascertain whether the apparent absence of the unrecorded species in the Reserve reflects actual local extinctions or is the result of insufficient survey effort. Based on our sampling, 8 of the 13 unconfirmed species (*Pieris mannii, Carcharodus baeticus, Gegenes nostrodamus, Thecla betulae, Cupido alcetas, Lycaena thersamon, Hamaeris lucina* and *Lybithea celtis*) typically occur within the Monte Peglia altitudes and could have been overlooked possibly because some of them are rare in the region forming very small populations, due to their late and/or short period of flight, their small sizes and/or their peculiar flight behaviour (i.e. tree tops). On the contrary, 5 unrecorded species (*Polyommatus dorylas, Euphydryas aurinia, Hyponephele lupina, Chazara briseis, Fabriciana niobe*) are spotted more frequently above 1000 m a.s.l. on Apennines, mostly in recent years after possible elevational upward shift of their range and could have undergone local extinction in the Reserve. For example, the distribution range of *C. briseis* has contracted considerably in the last decades (Kadlec *et al.* 2010) and, since most records from Northern Apennines predate 1990, it is likely locally extinct over most of this area (Balletto *et al.* 2007). *F. niobe* is nowadays found above 1000 m a.s.l. (Santorufo *et al.* 2021) in Central and Southern Italy with very few records reporting this species at lower altitudes (Scalercio 2001; Cagnetta *et al.* 2020).

In conclusion, our study represents a realistic snapshot of the butterfly community of the Monte Peglia Reserve. The checklist was updated and improved by our extensive sampling effort, so it now falls in the 96th percentile of the similar size and altitude range areas in central Italy. The butterflies of Monte Peglia Reserve can serve as a repeatable example to establish comprehensive occurrence datasets (massive field data coupled with literature and citizen science data) analysed with an objective evaluation of community erosion and rarity at regional scale. Mostly, the current snapshot will function as a perfect model to document in the future possible local extinctions of butterflies in a Mediterranean area.

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