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## The decline of the charismatic *Parnassius mnemosyne* (L.) (Lepidoptera: Papilionidae) in a Central Italy national park: a call for urgent actions

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### Abstract

Here we report the strong decline of a population of the endangered species *Parnassius mnemosyne* (Linnaeus, 1758) (Lepidoptera: Papilionidae) in the National Park of Foreste Casentinesi, Monte Falterona and Campigna (Italy). We compared historical presence data (before 1969) with current data from two years of monitoring (2018–2019) and provided evidence of a drastic reduction in the number of sites inhabited by the species. A preliminary assessment suggested that the population of *P. mnemosyne* occurring in the Park is limited to a few individuals. We argue that the population of this iconic and charismatic butterfly is at the verge of extinction in this National Park, probably because of a combination of habitat loss (i.e. decrease in size and number of areas of open grassland on the mountain belt) and climatic changes. Being one of the few populations of *P. mnemosyne* in the Northern Apennines, the implementation of protection measures is a high conservation priority. Several other butterfly species on the Italian mountains that are facing the same survival challenges would also benefit from the establishment of conservation actions aimed at improving habitat quality for *P. mnemosyne*. Present article is meant to call for action researchers, stakeholders, and especially decision-makers in order to increase the efforts to upturn the evident decline in abundance of this population.

**Key words:** biodiversity conservation, butterflies, habitat loss, habitat management, Lepidoptera, Parnassinae

### Introduction

Italy is the European country that hosts the richest butterfly fauna, with 290 species of the approximately 500 species of the Papilionoidea superfamily existing in Europe (Bonelli *et al.* 2018; Wiemers *et al.* 2018). A recent assessment at the species level based on the IUCN criteria showed that only 6.4% of species are threatened (Critically Endangered, Endangered and Vulnerable), and an additional 5.7% is Near Threatened, which might suggest a good overall conservation status of the Italian butterflies (Bonelli *et al.* 2018). However, the large variety of environments that determines such a rich fauna is mirrored by high heterogeneity in the conservation status of different populations across the country. Indeed, some populations of a given species, whose conservation status has been evaluated as

Least Concern at a country level, may be under high risk of extinction. Besides, due to the heterogeneity of the genetic structure of many butterfly species in the Mediterranean areas (Cesaroni *et al.* 1994; Todisco *et al.* 2010; Patricelli *et al.* 2013; Dapporto *et al.* 2019), these populations often represent crucial genetic lineages, e.g. *Erebia* spp. from the Apennines (Dapporto *et al.* 2019). This creates a complex and patchy landscape of conservation status for the Italian butterfly fauna (Bonelli *et al.* 2011, 2018; Scalercio *et al.* 2014; Dapporto *et al.* 2017) which requires special attention to local urgencies and assessments of the conservation status carried out separately for different areas.

A clear-cut example of the heterogeneous conservation status of butterflies in Italy is represented by many mountainous species, which show a very good conservation status over the Alps, while are characterized by declining populations over the Apennines (Scalercio *et al.* 2014; Bonelli *et al.* 2018). Indeed, the Apennines host rather isolated and unconnected populations of *Erebia* spp. and *Parnassius* spp. For example, *Parnassius apollo* (Linnaeus, 1758) has a restricted distribution in Sicily and Calabria, with only two recognized populations (Bonelli *et al.*, 2018), *Erebia pandrose* (Borkhausen, 1788) is known to be present only in a small area at the top of Monti della Laga (Cupedo 2007) and the recently rediscovered population of *Erebia gorge* (Hbner, 1804) on Monte Pollino is at the verge of extinction (Piazzini & Favilli, 2020). The relictual status and the limited distribution range of these highly fragmented and small populations make them particularly threatened by habitat loss and climate change (Gratton *et al.* 2008; Todisco *et al.* 2010; Bonelli *et al.* 2018).

According to the European, Mediterranean and Italian IUCN Red List there is no immediate risk of extinction for most butterfly species. However, the population trend is considered as decreasing for 31%, 26% and 9% of the species assessed at European (485 species), Mediterranean (462) and Italian level (283) respectively (van Swaay *et al.* 2010; Numa *et al.* 2016; Bonelli *et al.* 2018). Unfortunately, in most cases detailed information about population distribution and abundance is so limited that it is not possible to predict future local extinctions, but in a few cases the existence of historical records, coupled with recent data gathered through monitoring schemes, allow to assess population declines and thereby forecast local extinctions in the near future. In such cases, it becomes possible and urgent to protect the populations, primarily by reducing the loss of suitable habitats.

It is the case of *Parnassius mnemosyne*, a charismatic and regionally declining West Palearctic butterfly. In continental Europe, the species inhabits forest steppes, sparse forests and especially forest clearings. It is a univoltine and oligophagous species (feeding on *Corydalis* species, such as *C. cava* (L.) Schweigg. & Körte, *C. solida* (L.) Clairv. and *C. intermedia* (L.) Mérat), with adults flying from mid-May to end-June in Europe. It overwinters at the egg stage, sometimes as very young larvae, in Spring larvae feed on different species of *Corydalis* (Fumariaceae), which are generally adapted to humid, fertile soils and usually grow at forest margins (Konvička & Kuras 1999; Meglécz *et al.* 1999; Bergström 2005; Valimaki *et al.* 2005; Konvička *et al.* 2006; Bonelli *et al.* 2016).

The population trend of *P. mnemosyne*, a species evaluated as Near Threatened (NT) in Europe and Least Concern (LC) at Mediterranean and Italian level, is considered “decreasing” at European and Mediterranean level, but “stable” in Italy. The risk of extinction for *P. mnemosyne* has been assessed in 28 out of the 32 European countries in which the species occurs (Maes *et al.* 2019). A decline in the distribution or population size higher than 30% was reported in Bosnia and Herzegovina, Germany, Latvia and Ukraine while a lower decline (6–30%) was evaluated in Albania, Austria, Belarus, Czech Republic, France, Hungary, Romania and Switzerland. In contrast, in Italy the population trend was assessed as stable based on the few data available for the Alpine populations, which are usually locally abundant (but see also Bonifacino *et al.* 2017; Rossi *et al.* 2018). Nevertheless, several populations of *P. mnemosyne* in the central Apennines are decreasing likely because of forest recolonization or climate change. However, evidence for such a trend is generally missing due to the lack of long-term monitoring initiatives in Italy. For this reason, improvements in monitoring schemes could profoundly affect future reports.

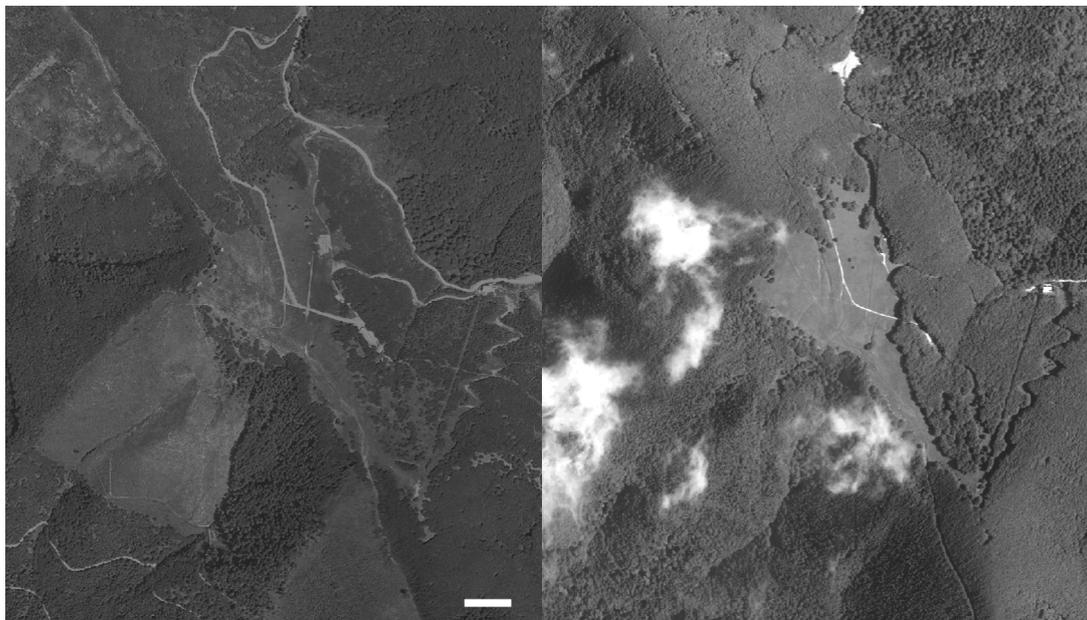
The present article shows that the population of *P. mnemosyne* (Fig. 1a) inhabiting the National Park of Foreste Casentinesi, Monte Falterona and Campigna (hereafter PNFC), in the Italian Northern Apennines, is facing such a decline and similar threats. The PNFC is a very crucial area for the conservation of the Northern Apennines biotas, being one of the two national parks existing in this territory and hosting the precious Riserve Naturali Statali Foreste Casentinesi, that are among the few primary beech forests in Europe (Sabatini *et al.* 2018; UNESCO 2020). The area of the Park is very rich in butterfly species, with 107 species recorded (Dapporto *et al.* 2004; Piazzini & Favilli 2016). In particular, four Habitats Directive butterflies of high conservation interest have been recorded: *Parnassius mnemosyne*, *Maculinea (Phengaris) arion* (Linnaeus, 1758), *Euphydryas aurinia* (Rottemburg, 1775) and *Zerynthia cassandra* (Geyer, [1828]). The rich biodiversity and uniqueness of the National Park attracted great naturalistic interest in the last century, with a wealth of faunistic expeditions that allowed to obtain a detailed knowledge of the fauna and the flora of the territory. Thanks to the eminent naturalist Pietro Zangheri, valuable data of butterfly species occurrence have been available since the 60s for the Romagna region (Zangheri 1966). Other occurrence data have been published

in following years (Fiumi & Camporesi 1988; Dapporto *et al.* 2004). However, these two main sources only reported the sites where the species have been observed without indications about the dates of collection and the number of observed individuals. More recent studies indicated more detailed collection data (Piazzini & Favilli 2016). In the Apennines, *P. mnemosyne* inhabits mainly areas of open grasslands surrounded by forests (Fig. 1b), at high altitude (Leonetti *et al.* 2019). In the PNFC, where the maximum altitude is 1658 m a. s. l., the alpine belt does not exist due to the low elevation of the peaks, and the climax community is represented by forests (mainly *Fagus* spp.).

Thus, within the Park, the species is confined to areas of open grasslands in the highest mountain ridge. Moreover, in the last 70 years, the Park territory has been subjected to conspicuous forest recolonization of open areas, mainly caused by the abandonment of the summit pastures, which resulted in the drastic reduction of areas of open grasslands (Fig. 2). In parallel to this reduction, and possibly because of increasing temperatures, some of the sites where the species was recorded by Zangheri in 1969, were not confirmed in recent times (Piazzini & Favilli 2016). In this view, a preliminary assessment of *P. mnemosyne* conservation status was performed.



**Figure 1.** On the left, *Parnassius mnemosyne* adult butterfly: the individual 8.2 marked and released at site Porcareccio. The species is listed in the Annex IV of the European Habitats Directive and it is considered as Near Threatened in the Red List of European butterflies. On the right, the typical habitat where *P. mnemosyne* can be found in the territory of the National park of the Foreste Casentinesi, Monte Falterona and Campigna (photo credit: F. Barbero).



**Figure 2.** An example of the habitat loss driven by a decrease in areas of open grassland on the mountain ridge in the PNFC; aerial photographs of the area “Burraia” in 1963 (left) and in 2016 (right): a remarkable difference in the size of the open area can be noted. White bar=100 m; aerial photos from Cartografia Tecnica Regionale-SITA-Regione Toscana.

## Material and methods

Surveys to assess the presence and abundance of *P. mnemosyne* were carried out during 2018 and 2019. In 2018, during the flight peak of the species (23–30 June), we performed daily walking transects (Pollard & Yates 1993) in all the areas of the mountain ridge where the species was reported in 1969. Each area was sampled at a constant pace from side to side so that the entire area was covered once and only once (Scalercio 2002) (under this protocol, the observation time depends on the size of each area). The same area was surveyed again using the same protocol every two weeks between the 1st of June to the end of July 2019 (average maximum daily temperature during the period of sampling were 16.8 °C in 2018 and 18.3 °C in 2019, as recorded by the closest meteorological station of the Tuscany regional meteorological network: Camaldoli site ([TOS10000610]; <http://www.sir.toscana.it/>)). This sampling allowed to quantify the presence and the abundance of *P. mnemosyne* during the whole flight period, thus confirming the preliminary data obtained the previous year.

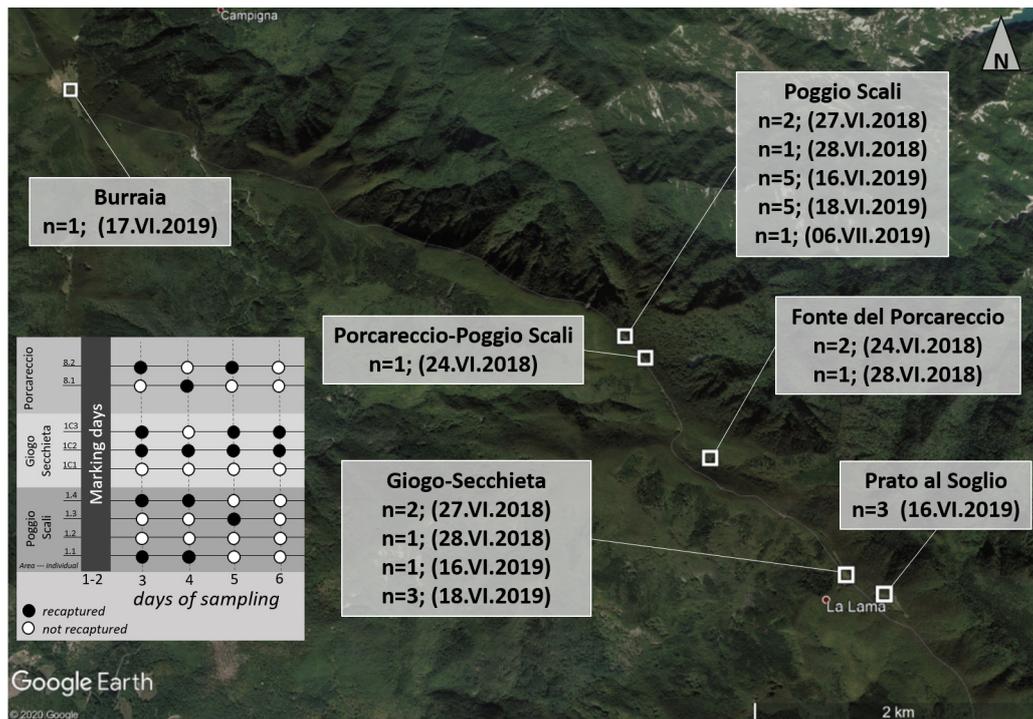
A more detailed population assessment was carried out in 2018. During the peak of the flight season (23–28 June), we carried out a preliminary Mark-Release-Recapture (MRR) study by individually marking on the wings all the encountered *P. mnemosyne* individuals.

## Results and Discussion

Over the two years, we were able to confirm the presence of *P. mnemosyne* at only five sites (Table 1, Fig. 3), out of the eight investigated sites, thus the species was not recorded at three previously known sites on the mountain ridge, i.e. Monte Falco (43.8769 N, 11.7130 E; 1654 m a.s.l.), Passo della Calla (43.8595 N, 11.7448 E; 1299 m a.s.l.) and Prato alla Penna (43.8124 N, 11.8301 E; 1249 m a.s.l.) (Zangheri 1966; Fiumi & Camporesi 1988). The population size observed in the last two years is also very small. A maximum of nine specimens was recorded in a single day across all sites (Table 1, Fig. 3). The small population size was further confirmed by preliminary Mark-Release-Recapture (MRR) study in 2018. The total number of marked butterflies was nine in the first two days, with several recapture events in the following days (Fig. 3). Therefore, our data suggest that the charismatic population of *P. mnemosyne* in the PNFC is limited to a very small number of individuals every year. In the Sila National Park, where the species is not apparently subjected to immediate threats, 26 individuals had been observed in optimal habitats during one single monitoring session (Leonetti *et al.* 2019). Similarly, in the Natural Park of The Maritime Alps, where the species was monitored according to the national guidelines for Habitats Directive species (Bonelli *et al.* 2016), from 1 to 10 individuals were counted in 400m-transects (30 minutes) at every monitoring sessions from June to July (Bonelli *et al.* unpublished data).

**Table 1.** Results of the transect sampling performed on the mountain ridge between Monte Falco and Prato alla Penna, in 2018 and 2019. The number of individuals observed each day of sampling is reported for each area.

Area	Latitude	Longitude	Altitude (m a.s.l.)	Date	Observed individuals
Fonte del Porcareccio	43.83608	11.79604	1390	24.VI.2018	2
Porcareccio Poggio Scali	43.84293	11.79035	1484	24.VI.2018	1
Giogo Secchieta	43.82821	11.80769	1381	27.VI.2018	2
Poggio Scali	43.84489	11.78858	1514	27.VI.2018	2
Fonte del Porcareccio	43.83608	11.79604	1390	28.VI.2018	1
Giogo Secchieta	43.82821	11.80769	1381	28.VI.2018	1
Poggio Scali	43.84489	11.78858	1514	28.VI.2018	1
Giogo Secchieta	43.82821	11.80769	1381	16.VI.2019	1
Poggio Scali	43.84489	11.78858	1514	16.VI.2019	5
Prato al Soglio	43.82686	11.81124	1345	16.VI.2019	3
Burraia	43.86500	11.73000	1472	17.VI.2019	1
Giogo Secchieta	43.82821	11.80769	1381	18.VI.2019	3
Poggio Scali	43.84489	11.78858	1514	18.VI.2019	5
Poggio Scali	43.84489	11.78858	1514	06.VII.2019	1



**Figure 3.** Aerial map of the area investigated, with the results of the transect sampling (boxes report the number of individuals observed in each area, for each sampling event) and the results of the preliminary Mark-Release-Recapture (MRR) study performed in 2018: *P. mnemosyne* individuals were individually collected and marked during the first two days of sampling in each of the three areas surveyed; black circles indicate the day in which each individual was recaptured, white circles indicate that the individual was not recaptured.

A realistic candidate as the main responsible for the drastic reduction in *P. mnemosyne* occurrence and abundance in the Apennines is represented by habitat loss due to vegetation encroachment. Forest recolonization can indirectly affect butterflies by reducing open ridges and therefore also edges and clearings, which represent the ideal habitat for *P. mnemosyne* host plant, i.e. *Corydalis* spp. (Megléczy *et al.* 1999; Konvička *et al.* 2006). Additionally, an increase in canopy coverage could influence both adult females, that in the Mediterranean region preferentially lay eggs on irradiated plants (Bergström 2005), and the thermophilic immature stages. Indeed, larvae preferentially select host plants exposed to direct sunlight and pupal development is delayed in areas with higher canopy coverage (Välimäki & Itämies 2005). Together with the availability of the host plant, also climatic variables could play a role in shaping *P. mnemosyne* distribution (Settele *et al.* 2008). In the Apennines, *P. mnemosyne* only inhabits humid and cool environments in mountain-subalpine belts. This suggests that the foreseen climate change of the Mediterranean area, with increasing temperatures and reduced precipitations (Giorgi & Lionello 2008), might further reduce habitat suitability for southern populations. Indeed, at the European scale, *P. mnemosyne* has been considered at high risk of extinction due to climate change, and under at least one scenario of future climate changes, more than two thirds of the territory with currently suitable climate may no longer be available in 2080, with a special reference to the Apennine region (Settele *et al.* 2008).

Upsettingly, the decline in abundance of butterfly species in PNFC may not be limited to *P. mnemosyne*. Other species, such as *Lycaena virgaureae* (Linnaeus, 1758), *Satyrrium w-album* (Knoch, 1782), *Chazara briseis* (Linnaeus, 1764) and *Hyponphele lupina* (Costa, [1836]), previously observed by Pietro Zangheri on the Park mountain ridge, have not been confirmed in recent years (Dapporto *et al.* 2004; Piazzini & Favilli 2016). For this reason, we believe that *P. mnemosyne* may become a flagship species representing the endangered butterflies of areas of open grassland in the PNFC and, more extensively, of the entire Apennines. Since the species is listed in the Annex 4 of the Habitats Directive, suitable habitats for its survival should be protected and managed. Important actions for *P. mnemosyne* will thus be aimed at managing areas of open grassland in order not only to preserve, but even increase its favorable habitat, e.g. by creating woodland gaps and maintaining a mosaic of woodland and clearings by traditional low-intensity management as suggested by EU conservation guidelines and consequently favoring other butterfly species (van Swaay *et al.* 2012). Moreover, ad hoc studies on microhabitat preferences are necessary, in order to highlight which would be the best management action allowing to increase suitable patch abundance while at the same time

limiting the impact on the surrounding forest habitat. This is especially true for those species, such as *P. mnemosyne*, which rely on a single or very few host plant species. Indeed, promising conservation achievements for *P. mnemosyne* were obtained by Kuussaari and colleagues in Finland (Kuussaari *et al.* 2015).

A similar conservation framework has been carried out in Mediterranean insular meadows within the National Park of Tuscan Archipelago (Cini *et al.* 2019), to protect the highly endangered population of *Z. cassandra*. This work allowed the implementation of pinpoint small-scale sustainable management actions (through the cut of shrubs) that are likely to increase the oviposition rate of the butterfly.

The effects of conservation actions (e.g. in terms of population trends) should then be monitored by a Butterfly Monitoring Scheme. Nowadays, a few protected areas are applying the monitoring according to Article 17 of the Habitats Directive while a National Monitoring Scheme is currently under implementation for the fifth EU report (2019–2024). Moreover, Italy has recently joined the European Butterfly Monitoring Scheme (eBMS). These two monitoring schemes coupled with the many datasets available on the web (e.g. GBIF, iNaturalist) will give us a clearer picture of the actual conservation status of this charismatic species.

In this article, historical and current presence and abundance data of the butterfly *P. mnemosyne* in the PNFC were merged. These data are the first quantitative assessment of the population, performed with standard and replicable methods, which could be used to evaluate future changes in population sizes, and to implement ad hoc MRR studies, according to national monitoring guidelines (Bonelli *et al.* 2016). This article is explicitly made to ask decision-makers to promote the implementation of conservation actions to preserve the habitat of *P. mnemosyne*. From this perspective, this species could also represent a valuable umbrella species to protect the rich and peculiar butterfly community of one of the most important hotspots of biodiversity in the Northern Apennines in Italy.

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