Review

Endangered Butterflies and their Conservation: the Decline of *Parnassius apollo* and *Phengaris spp.* in Europe and Slovenia

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Abstract:

This article addresses the alarming global decline in insect biomass and biodiversity and the decline of European butterfly populations, more notably in Slovenia. Between 1989 and 2016, a 76% decrease in insect biomass raises concerns for ecosystems reliant on pollinators and intricate food webs. Butterfly populations, echoing this decline, witnessed a 50% reduction between 1976 and 2021. Key contributors, including habitat loss, chemical pollution, and climate change, necessitate urgent conservation efforts. Focusing on the Apollo (*Parnassius apollo*) and genus *Phengaris*, the study emphasises the threats posed by global warming and habitat loss. Swift and comprehensive conservation measures are crucial to ensure the survival of these iconic species, moreover recognizing butterflies as "umbrella species" that safeguard broader ecosystems.

Keywords: Butterflies, Decline, *Phengaris*, *Parnassius apollo*, Biodiversity, Conservation

1. Introduction

Insects have a crucial role in ecosystems around the globe. For the past few decades there has been an alarming decline in insect biomass. Between the years 1989 and 2016 the insect biomass declined for more than 76% (Hallmann et al., 2017). Loss of insect biomass and diversity is certain to affect the ecosystems negatively, as insects are crucial in many food webs and in the role of pollination (Müller et al., 2023; Hallmann et al., 2017). One of the most recognizable, well-known, and remarkable groups of insects are butterflies (Lepidoptera). It is composed of day butterflies (Rhopalocera) and moths (Heterocera). While butterflies are comprised of about 17.500 species (Smithsonian, n. d. - a), most of the species in the order Lepidoptera are moths with more than 160.000 species (Smithsonian, n. d. - b). Butterflies serve as an important environmental indicator as they react hastily to changes in the environment, as their presence does not follow vegetation-based indicators (Dennis et al., 2003). As the population of insects has dwindled over time, a parallel decline has been observed in the population of butterflies. It is estimated that between the years 1976 and 2021 overall numbers of butterflies decreased by around 50% (Warren et al., 2021). Further studies have concluded that butterfly numbers started decreasing long ago, with a 80% decline between the years 1890 and 1940 (Warren et al., 2021). Main factors that contribute to the rapid decline are habitat loss, chemical pollution, and climate change (Warren et al., 2021).
The aim of this article is to shed light on the factors of rapid decline and how they affect butterfly populations in Slovenia and conservation programs that have and are helping butterfly populations.

2. Biology of the butterfly

2.1. Adaptations to specific habitat

When assessing the endangerment level of a particular species, significant consideration is given to its degree of specialism (generalism). Two terms are widely used: specialists and generalists. Species described as specialists are often confined to specific ecological parameters and are more susceptible to change, whereas generalists whose ecological niche is broader are less vulnerable and thus better cope with ongoing environmental shifts. In a stable environment, specialists typically outperform generalists. This is due to the additional expenses of generalists linked with utilising multiple resources and developing expensive adaptations to cope with fluctuating environmental conditions (Dapporto & Dennis, 2013; Richmond et al., 2005). Current conditions, influenced by human interference, are far from stable and therefore specialised species are impacted to a greater extent. Several characteristics like number of suitable host plants and nectaring flowers, mobility index, voltinism (number of broods per year) and many others are considered when assessing how specialised a certain species is (Dapporto & Dennis, 2013). It is worth noting that employing either the term specialist or generalist for classifying a species might not yield the most precise characterization, as there clearly exists a continuum between the two extremes. Some species can be specialists for some resources and generalists for others (Dapporto & Dennis, 2013).

2.2. Grassland indicator

The European Grassland Butterfly Indicator program represents the collective population trend of 17 selected grassland species. Initiated in 1990 and ongoing, it has identified substantial butterfly declines across Europe, with published data extending until 2020. When interpreting these findings, it is important to realise that at the start of the monitoring lower population coverage was available and that butterfly populations fluctuate significantly from year-to-year. The number of transects is also limited. With new countries joining and new data becoming available, trends can change and differ from previous versions of the indicator. The indicator shows a linear decline of 36% in the last ten years in Europe, with the 2020 value being significantly lower than the start value (van Sway, et al. 2022).

3. Apollo (*Parnassius apollo*)

3.1. Description

One of Europe's most iconic butterflies, belonging to the family Papilionidae, is the Apollo (*Parnassius apollo*) (Linneaues, 1758) (**Figure 1**). The Apollo is a medium sized butterfly, with 50–80 mm wingspan and great flying capabilities (Brommer & Fred, 1999). It is a butterfly with rounded, chalky white wings, with grey markings, black spots, and red spots with a lighter smaller spot in the centre on the hindwings. The Apollo expresses sexual dimorphism, with male and female having different patterns on fore and hindwings. It has more than 200 (Todisco et al., 2010) subspecies through its territory with the variation in size and wing shape, pattern, the density and intensity of grey markings and black spots, while hindwings always contain the striking red spots. The Apollo was widely distributed from Europe to Asia, although its range has been declining because of loss of habitat. Their populations are often isolated (Collins & Morris, 1985).

Figure 1. **a)** *Parnassius apollo*. **b**) *Sedum album,* host plant of *P. apollo.* Photo: Luka Šturm (with permission)

3.2. Habitat and ecology

The Apollo is a relic of the glacial epoch (Collins & Morris, 1985). The butterfly is found in ranges from 500–2400 m, generally above 1000 m in S Europe (Tolman & Lewington, 2008). It inhabits diverse, rocky, subalpine regions that are not only rocky but also in proximity to deeper soils, that are able to support nectar-rich plants for imagos to feed on (Tolman & Lewington, 2008). The Apollo is univoltine, overwintering in the egg stage. Caterpillars of the Apollo feed exclusively on stonecrops (*Sedum* spp.) (Collins & Morris, 1985), principally *Sedum album* and less often on *Sedum telephium* (Tolman & Lewington, 2008). The larval host plant thrives in dry, rocky outcrops which aren't suitable for nectar-rich plants, therefore the resources for the imago and its larval phase are segregated spatially (Brommer & Fred, 1999).

3.3. Decline of the Apollo

The Apollo was and still is prized by many insect collectors, especially the more lucrative subspecies. Over-collecting isolated populations can easily bring them to extinction. However, over-collecting is not the main factor driving the rapid decline (Collins & Morris, 1985).

Studies have shown that the Apollo is temperature sensitive and 35% of the populations moved northward by 35-50km in the span of a few decades. Populations in the lowland habitats have been in serious decline because of the aforementioned factors, moreover it has been discovered that the Apollo is unable to exist in ranges below 850m in southern

France and appearing earlier as a consequence of global warming. Unpredictable weather has shown to have devastating effects on the populations of the Apollo, especially when its populations are smaller. Such small populations often experience inbreeding and as a result of that higher mortality because of occurrence of deformations. Natural forest expansion is directly limiting and fragmenting the habitat of the Apollo as it prefers open, sunny habitats as are abandoned grasslands in early successional stages. One of the ways that suitable habitats are formed is through forest fires, which can reshape a forest into a grassland. One of the factors of the habitat reduction is abandonment of livestock pasture, as it allows for shrub and forest succession to take place. The impact of predators and parasites is negligible on the decline of the Apollo (Nakonieczny et al., 2007).

Loss of habitat due to human interference is one of the most pressing challenges for the Apollo. Forest management and intensive farming have led to severe shrinkage of its habitat and consequently its numbers. To negate deforestation as a consequence of the industrial revolution many countries started afforestation with the intent to replenish and help the local ecosystems. With the introduction of foreign tree species (spruce and pine) that increased soil acidity, before-present plant species were unable to thrive and create an environment suitable for the Apollo. The afforestation played a major role in fragmentation and isolation of Apollo habitats. Open mines, settlements, roads and quarries effect and any other profound land transformations have a negative impact on the species. Moreover, pollution plays a crucial role in the rapid decline of the Apollo (Nakonieczny et al., 2007).

3.4. Protection of the Apollo

To conserve the Apollo and its habitat many actions have taken place. It was the first invertebrate to be included in Appendix II of Convention on International Trade in Endangered Species (CITES) (Collins & Morris, 1985). It is also included in the Bern Convention and European Union (EU) Habitats Directive and EU regulation of trade of fauna and flora (European Environment Agency, n. d.). In many countries active efforts have been taken to conserve their habitat with shrub and tree removal in areas where larvae or imagos were present. Many countries monitor populations, and some have reintroduced the species in parts where it was extinct. Inside the EU the butterfly and its habitat is protected under the Natura 2000 project. This is of big importance in Slovenia, as there are yearly transect monitorings. Preserving the Apollo's habitat is of great importance as it also protects the complex plant and animal communities living in such habitats and serves as an "umbrella species" for the whole ecosystem (Nakonieczny et al., 2007).

3.5. Apollo in Slovenia

Sadly, the numbers of imagos have been on a sharp decline as in line with the rest of Europe. In Slovenia we face significantly bigger problems as our base population is much smaller than in other countries due to lack of habitat. The numbers of adult Apollos counted in transects has dwindled by more than 90% in the last 8 years (Zakšek et al., 2023). Currently there are no active programs in Slovenia dedicated to protecting and conserving the Apollos habitat as it isn't prioritised as much as other wetland butterflies.

4. Genus *Phengaris*

4.1. Description

Within the Lycaneidae family, the genus *Phengaris* stands as one of the most extensively researched and studied due to its unique and fascinating life cycle (Thomas et al., 1989; Nowicki et al., 2007). Four European species are currently recognised: *Phengaris alcon* (Denis and Schiffermüller, 1775); *Phengaris arion* (Linnaeus, 1758); *Phengaris teleius* (Bergsträsser, 1779) and *Phengaris nausithous* (Bergsträsser, 1779) (**Figure 2**) (Wiemers et al., 2018). All four species are also present in Slovenia (Verovnik et al., 2012). The genus is thought to have evolved in the steppes of central Asia (Als et al., 2002;

Sibatani et al., 1994), so that the European *Phengaris* species were pre-adapted to survive and spread in traditional European agricultural landscapes. Their existence in Western Europe is currently threatened with extinction, likely attributable to recent alterations in land use practices (Als et al., 2002; Kljun et al., 2016). In Europe, *Phengaris* butterflies occur in 37 countries with northernmost populations in Finland while southernmost populations reside nearby in the Asian part of Turkey (Oliveira et al., 2013). Their status is deemed to be stable in only seven countries (Oliveira et al., 2013; Wynhoff, 1998).

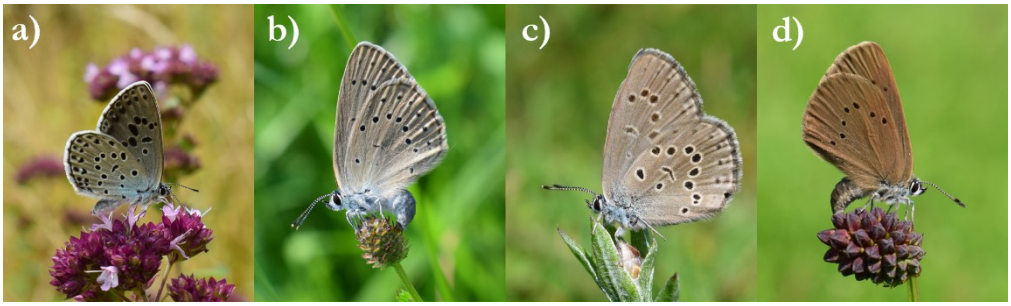

Figure 2. **a**) *Phengaris arion* on its host plant *Origanum vulgare*. **b**) *Phengaris teleius* on its host plant *Sanguisorba officinalis*. **c**) *Phengaris alcon.* **d**) *Phengaris nausithous* on its host plant *Sanguisorba officinalis.* Photo: Luka Šturm (with permission)

4.2. Habitat and ecology

Phengaris species live across various vegetation types, typically found in relatively poor soil. As a result, *P. teleius* and *P. nausithous* occur in wet grasslands, *P. arion* occupies dry grasslands, and *P. alcon* inhabits moist heaths and bogs. Within these habitats, mentioned species predominantly reside in isolated populations with minimal migration or dispersal tendencies (Oliveira et al., 2013).

The larvae of all species exhibit a high level of specialisation by briefly feeding on a specific plant. The host plants differ between species: *P. teleius* and *P. nausithous* use exclusively *Sanguisorba officinalis* (Kőrösi et al., 2012; Oliveira et al., 2013), *P. arion* uses *Thymus* spp. and *Origanum vulgare* and *P. alcon*, uses *Gentiana pneumonanthe* as its main host plant (Oliveira et al., 2013).

After the phytophagous stage is over they spend 11–23 months underground, acting as social parasites within colonies of *Myrmica* ants (Thomas & Schönrogge, 2019). Various species of *Phengaris* engage in parasitic relationships with usually one or two different ant species, depending on the region and habitat they occur in (Oliveira et al., 2013). With such complex and specialised life cycle big challenges must be overcome for success in complete development. The first is the selection of the right host plant, preferably in the vicinity of host ants (Dyck et al., 2000; Oliveira et al., 2013). The second challenge arises after the larva reaches 4th instar, when it drops to the ground and awaits the adoption by specific host ants. Foraging worker ants of a particular species mistake the *Phengaris* larvae for their own brood, due to chemical mimicry, and carry them to their nests (Oliveira et al., 2013). It is key that the ants do not recognise them as impostors. When these butterflies lay their eggs in ant nests that are not of the suitable host species, the ants quickly identify the hatched caterpillars as impostors, as they are unable to mimic the necessary cues or signals to deceive the ants. In such instances they do not manage to leave the nest alive (Thomas et al., 1989).

4.3. Decline of the genus Phengaris

Because of the complex and specialised foremost mentioned lifecycle the butterflies of the genus are highly susceptible to environmental changes and have suffered severe declines in Europe. For example in the Netherlands four of the *Phengaris* species occurred at the beginning of the century, but in the seventies all but one became extinct. *P. arion* went extinct from the United Kingdom (UK) in 1979 (Wynhoff, 1998; Oliveira et al., 2013).

One of the main factors contributing to the rapid decline of the Large blue butterflies is the direct habitat loss caused by human activities. In a recent study spanning roughly two decades a nearly 15% decrease in total habitat area has been detected (28.8 ha of the original area exceeding 200 ha was lost). Two thirds were lost through conversion to built-up areas complemented by abandonment that resulted in vegetation overgrowth and the disappearance of host plants (Kajzer-Bonk & Nowicki, 2023). The study was conducted near Krakow in Poland monitoring populations of *P. teleius* and *P. nausithous* and their habitat. The estimated loss of butterflies in vanished patches was considerable in both investigated species, oscillating around several hundred to thousands of adult individuals per year (Kajzer-Bonk & Nowicki, 2023).

The problem of abandonment of patches by farmers has also become apparent. It results in increased vegetation height providing cover and a subsequent loss of microclimates suitable for ants, whose nests support the Large Blue butterflies (Oliveira et al., 2013). Overgrowing may also cause the reduction in available host plants, also resulting in diminishing butterfly populations. An often problem when talking about overgrowth are invasive plant species which frequently colonise new environments as a result of human activities. One of the most notable ones are goldenrods (*Solidago* spp.), which In Central Europe, have become dominant in up to 90% of former grasslands, leading to the creation of homogenous habitat (Kalarus, 2023). The sizes of local populations of the *P. teleius* and *P. nausithous* butterflies were both lower in patches with higher goldenrod cover (Kalarus, 2023).

Another issue affecting large blue butterflies is the improper meadow management, particularly mowing at inappropriate times. If the latter occurs during the flowering of host plants and flight period of the adults (July-September) it prevents imagos from accessing nectar sources. More importantly it prevents females from accessing suitable locations for egg-laying if host plants are not there (Oliveira et al., 2013).

4.4. Protection of the genus Phengaris

Many actions have taken place to conserve the genus of the Large blue butterflies. P. *arion*, *P. teleius* and *P. nausithous* have all been included in European Union Habitats Directive App. II and IV and IUCN Red List of European Butterflies (van Swaay et al., 2010). All *Phengaris* butterflies are also included in the red lists of most European countries (Czekes et al., 2014; Kljun et al., 2016). Various reintroduction programs have taken place to assist with the declining *Phengaris* populations. These notably include the reintroduction of the *P. arion* in the UK in 1986 and reintroduction of *P. teleius* and *P. nausithous*, in the Netherlands in 1990. Both of these were classified as successful, as the populations have developed well and increased in numbers (Oliveira et al., 2013). A key consideration limiting the success of reintroductions is low habitat quality. Ensuring the long-term survival of these species critically hinges upon maintaining habitats that offer essential resources as mentioned earlier: flowering host plants available from July to September and the presence of suitable host ants (Kalarus, 2023; Nowicki et al., 2007).

4.5. Genus Phengaris in Slovenia

As previously mentioned, all four European species are found in Slovenia. Among them, *P. arion*, *P. nausithous*, and *P. teleius* have been under monitoring schemes as a part of Natura 2000 for over a decade. The outcomes of these monitoring programs consistently indicate an unfavourable population status for these species (Zakšek et al., 2023). While monitoring of *P. alcon* is not conducted annually, it holds an 'endangered' (EN) status and stands as one of the most rapidly declining butterfly species in Slovenia, as indicated by Verovnik et al. in 2012. It has vanished from significant portions of its range, potentially facing extinction in the Koroška region. Only a few scattered populations remain in the Štajerska, Gorenjska, and Bela krajina regions (Verovnik et al., 2012; Kljun et al., 2016).

Main factors that contribute to the endangerment of the genus in Slovenia are overgrowth of dry grasslands caused by their abandonment, excessive grazing, and too frequent mowing. Inappropriate timing of mowing, alongside with habitat fragmentation and

degradation due to intensification also pose serious threats to Slovenian populations (Verovnik et al., 2012; Zakšek et al., 2023).

5. Conservation

Butterfly conservation is carried out at several levels, from the programs founded by the EU to an individual's garden. The more that we realise the importance of biodiversity, the more we have to do to conserve it. Sadly, much of the damage we have done is practically irreversible, such as global warming, which the United Nations are trying to keep to a max + 1.5 degrees Kelvin (United Nations, n. d.). One of the core issues that many grassland butterflies face is too many grass cuttings through the summers. Studies have shown that delayed mowing and delayed first grazing has outstandingly positive effects for the invertebrate, plant and bird species studied (Dicks et al., 2020). For that reason, inside the European Union there have been stimuluses to defer the farmers from mowing too often and restrict overgrazing to protect Natura 2000 species (European Commissions, 2018). Removal and restriction of invasive species is also crucial as they can completely displace authentic species and prevent the growth of host plants (Kalarus, 2023). Of course, loss of habitat due to human interactions is unavoidable, but with careful road-planning and protection of endangered habitats it is possible to leave a smaller impact. With the reintroduction of controlled cattle grazing, it is possible to restore mountain pastures and provide much needed habitat for butterflies to thrive in (Nakonieczny et al., 2007).

Most of the aforementioned points require government-sided programs, but there are still many things an individual can do. One of the more vital steps is spreading awareness, as many people are not informed about the loss of biodiversity and insect biomass that is currently happening. Programs like the Big Butterfly Count, which is a UK-wide environment assessment survey, are bringing awareness of wildlife and butterfly protection to the public (Big Butterfly Count, n. d.). Moreover, many gardens can be transformed into adequate habitats for butterflies with the addition of nectar-rich and host plants for butterflies to develop (Teasdale, n. d.).

6. Conclusion

Among all the species on the decline it is important to remember that many others are as important as these two species. Species like Cranberry blue (*Plebejus optilete*) face similar issues as the Apollo, as it is also a glacial epoch and is facing serious decline in Slovenia. We mustn't forget about other wetland butterfly species, which are currently disappearing the most. One of the most indicative of them is False ringlet (*Coenonympha oedippus*), for whom we have special programs for restoration in Slovenia (Čelik, 2021). There are many generalists whose populations are also on a decline, but many of them are so prevalent that there isn't too much concern about their downfall yet, however we believe it is crucial to act accordingly and conserve their diverse habitats before it is too late. It is important to note that with the protection of many butterfly species that are so-called "umbrella-species" we protect many other species of animals and plants that are heavily specialised to that region.

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