



# The higher abundance of host plant and suitable management recommended as the important elements in the conservation of *Phengaris (Maculinea) teleius* (Bergsträser, 1779) (Lepidoptera: Lycaenidae) in the Hradné lúky SAC meadows (Slovakia)

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Received: 3 April 2024 / Accepted: 4 October 2024 / Published online: 20 November 2024  
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## Abstract

This article presents a study of the isolated population of the scarce large blue butterfly, which is facing a significant threat in the meadows of the central part of Slovakia. The main objective of this study was to evaluate the effect of management, the presence of great burnet (*Sanguisorba officinalis* (L.)), and the host ants on the abundance of *Phengaris teleius* in the Hradné lúky Special Area of Conservation (SAC) in Slovakia. The study area was divided into six study plots. The abundance of *S. officinalis* host plant and ant communities, with emphasis on host ants (*Myrmica scabrinodis* (Nylander, 1846) and *M. rubra* (Linnaeus, 1758)), were analysed at each study plot. A generalized linear model (GLM) identified the significant relationships among three variables. Specifically, a relationship was confirmed between the number of *P. teleius* individuals and the abundance of the host plant *S. officinalis*, as well as between the number of *P. teleius* individuals and the current type of management at the specific biotope. The most important conservation recommendations regarding this study have been presented. Implications for insect conservation: Our results indicate that in the protection of *P. teleius*, it is important to support the abundance of *S. officinalis* as highly as possible. In addition, we confirm that targeted management with the absence of mowing in the critical phase of the year, especially in the *Molinia* meadows, is important for maintaining a healthy butterfly population.

**Keywords** Host ants · Host plant · Endangered species · Scarce large blue · Species conservation

## Introduction

In recent decades, the populations of many insect species have been heading towards extinction (Diamond 1989; Cardoso et al. 2020), while a biodiversity crisis is imminent (Singh 2002; Driscoll et al. 2018). The drivers of biodiversity decline are diverse (Sanchez-Bayo and Wyckhuys 2019). Habitat change, degradation, or loss caused by the

absence of management (and subsequent secondary succession) or intensification of agriculture (e.g., fertilization, drainage, use of pesticides) are major threats for many butterfly species of open habitats (van Swaay et al. 2010; Samways et al. 2020). The butterflies represent a typical group of insects suffering from landscape change and have been recognised as good indicators of habitat degradation and loss (Erhardt and Thomas 1991).

One such species, the scarce large blue butterfly (*Phengaris teleius* (Bergsträser, 1779)) is closely associated with human activity, since proper landscape management is crucial for its thriving (Van Langevelde and Wynhoff 2009; Popovic et al. 2014). Moreover, its life cycle depends particularly on the host plant *Sanguisorba officinalis* (L.) (Thomas 1984) and the limited group of host ant species from the genus *Myrmica* (such as *Myrmica scabrinodis* Nylander, 1846 and *Myrmica rubra* (Linnaeus, 1758) (Witek et al. 2010; Wynhoff et al. 2011; Tartally et al. 2019).

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All of these predictors (suitable management, host ants, host plant) are intertwined in a close relationship (Johst et al. 2006; Wynhoff et al. 2011). Additionally, they are essential for the development of *P. teleius*, which, due to its relatively complex bionomy, also predisposes this species to arduous coping with global change (van Swaay et al. 2010). For this reason, the scarce large blue butterfly, and its habitats are highly protected in Europe by Annexes II, IV of the Habitats Directive (European Commission 1992 Council Directive 92/43/EEC) and Annex II of the Bern Convention (Council of Europe 1982). *P. teleius* is also protected in Slovakia (Ministry of the Environment of the Slovak Republic 2003; Annexes 4b, 6a, 6b). It is classified as vulnerable (VU) in the Red Data Book of European Butterflies (van Swaay et al. 2010) and an endangered (EN) species in Slovakia (Kulfán and Kulfán 2001). The conservation value of *P. teleius* is further emphasised by the fact that it was recognised as a flagship species for the conservation of butterflies (Settele and Kühn 2009), but unfortunately this fact does not guarantee its effective protection in many localities (Kajzer-Bonk and Nowicki 2022). This species is also subjected to protection within the Hradné lúky Special Area of Conservation (SAC) meadows, where its viable population was recorded. However, this population is isolated and faces several factors, such as management, a lack of flowering host plants and host ants, as well as climate change (a likely factor), which may contribute to its poor condition. The ongoing LIFE project is meant to help set up appropriate measures to support the current population at this unique locality.

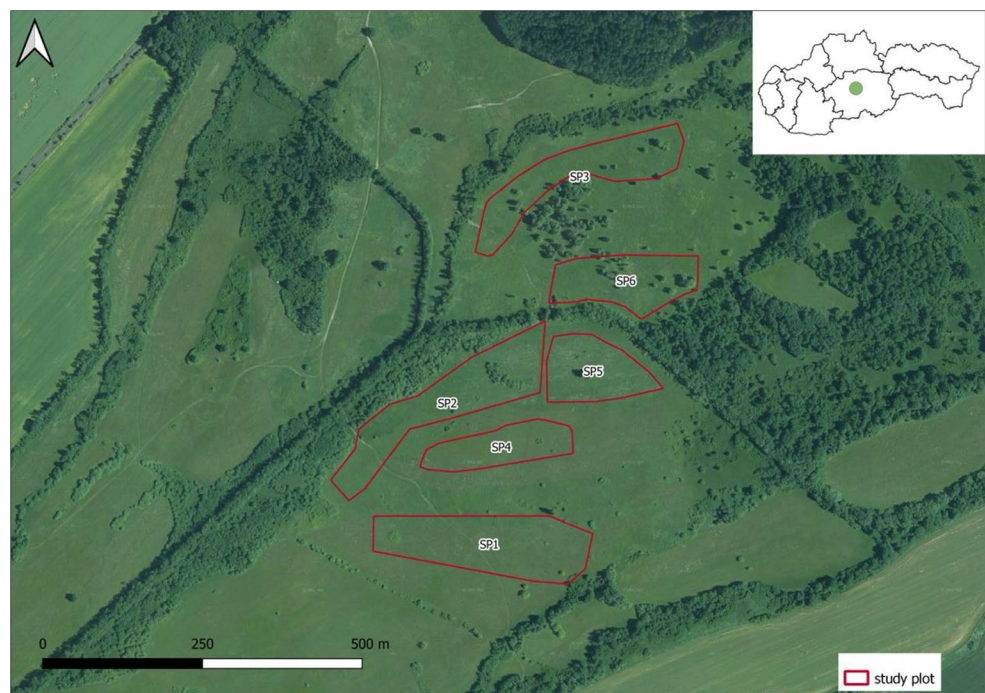
The main objective of this study was to evaluate the influence of selected predictors, the abundance of the host plant (*S. officinalis*), the abundance of host ants (*Myrmica* spp.), and the management practices in specific biotopes on the presence and population status of *P. teleius* in Hradné lúky SAC. We worked with the hypothesis that the suitable management with the absence of mowing during the critical time of butterfly development should support the healthy state of host plants and host ants necessary for thriving of *P. teleius* at the study area.

## Materials and methods

### Study area

The study was carried out in the Hradné lúky SAC meadows (Government of the Slovak Republic 2023), which is a part of the Protected Landscape Area (PLA) Poľana, located in the middle of Slovakia in Central Europe (Fig. 1). This locality is characterised by the presence of important habitats and biotopes for *P. teleius*, such as Lowland hay meadows (6510) and especially *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (6410) (Jasík and Dítě 2017; Government of the Slovak Republic 2023). The habitats provide suitable conditions for the host plant *S. officinalis*, which indicates that the biotope or part of it represents the ecological optimum of the taxon (Chytrý et al. 2021). The Hradné lúky SAC covers an area of 59.64 ha, of which 11.66 ha comprises the known occurrence of *P. teleius*, including an emphasis on the dominance of wet *Molinia*

**Fig. 1** Study area with the selected study plots (SP1 – SP6) in Hradné lúky SAC selected for the study of influence of the management, host plant and host ant on the abundance of *P. teleius*



meadows, which were selected for research of the scarce large blue butterfly (Table 1). In recent years, the area has been managed by a local agricultural company. There are no abandoned meadows, and the population of *P. teleius* is isolated. Management of the selected study area, as well as conservation of *P. teleius* is one of the goals of the ongoing LIFE project (LIFE19 IPE/SK/000003 LIFE- IP NATURA 2000 SVK).

Six study plots (SP1 – SP6) were established (Table 1) to study the impact of selected predictors (management in combination with vegetation cover, host plant and host ants) on the abundance of *P. teleius* in this area (Fig. 1).

## Sampling

Zigzag walks (Kadlec et al. 2012; Jakubikova and Kadlec 2015) were performed to monitor *P. teleius* adults, where a single walk on the study plot lasted 50 min. The number of encountered *P. teleius* individuals per minute was recorded in a form. The study plots were traversed between 9:30 and 16:30 at a constant pace (approximately 3 km/h) under suitable weather conditions (sunny day, low cloud cover, no precipitation, wind speed up to 5 m/s, temperature above 17 °C) (Kadlec et al. 2012). The observations proceeded towards the nearest study plots to avoid double counting as much as possible. The scarce large blue butterflies were observed during the flight period of adults (July 14; July 19; July 24; August 3; August 10) in 2022. Except for July 19 (without SP1, SP4) and August 3 (without SP4), butterflies were counted in all plots during individual visits with counting sequences randomly changed. The butterflies were not marked.

Four small sampling quadrats (25 m<sup>2</sup>, square = 5 × 5 m) were randomly established at each study plot (SP1 – SP6) to observe the presence of host plants and host ants. The abundance of the host plant *S. officinalis* was obtained as the number of plant shoots per 25 m<sup>2</sup> sampling quadrat. The number of shoots were used as a predictor because the number of flower heads were limited in the sampling quadrats during the year 2022 as we shall discuss later.

The abundances of the anthills of different species (the number of nests) were monitored at the same sampling

quadrats (25 m<sup>2</sup>, square = 5 × 5 m). Ants and their anthills were searched for exactly 15 min (standardized across all sampling quadrats) to compare the results across the study plots. The observation was performed by disturbing the soil with a knife, which exposed the anthills and prompted individual worker ants to emerge on the soil surface. The presence of ant species and the abundance of their nests were recorded (Wynhoff et al. 2011). At least three worker individuals from each nest were collected for later identification in the laboratory using the works of Czechowski et al. (2012) and Seifert (2018).

The presence and specifics of “targeted” or “non-targeted” management, especially in regard to the *P. teleius* population, has also been studied. The “non-targeted” management was defined as the mowing of vegetation during June to mid-September, and it was highly associated with lowland hay meadows biotope (SP1, SP4), which resulted in the absence of flowering plants (especially *S. officinalis* in this case). The mowing was done with a tractor mower twice during the vegetation season. In contrast, “targeted” management was characterised by the absence of anthropogenic activity during the critical part of the year for the development of *P. teleius*, from June to mid-September and specifically in *Molinia* meadows (SP2, SP3, SP5, SP6). In recent years, these plots are also mulched after mid-September, coupled with the removal of plant biomass.

## Data analysis

A generalized linear model (GLM) with a quasi-Poisson error structure (due to overdispersion) was used for the analysis. The number of *P. teleius* per visit was used as the dependent variable along with three independent variables: management in specific biotope = targeted vs. non-targeted, the abundance of host plants, and the number of anthills of host ants. The Akaike information criterion (AIC) was used to select the model that best fits the data. Moreover, the Analysis of Deviance was used to compare individual models. The statistical significance of the predictors was based on F-statistics. The Spearman correlation coefficient was used to study the relationships between ant species. The analyses and visualisation of the results were carried out

**Table 1** Characterisation of the study plots (SP1 – SP6) in Hradné lúky SAC used to explore the effect of management, host plant, and host ant presence on the abundance of *Phengaris teleius*

|                     | SP1    | SP2    | SP3    | SP4    | SP5    | SP6    |
|---------------------|--------|--------|--------|--------|--------|--------|
| Area [ha]           | 2.75   | 2.58   | 2.03   | 1.23   | 1.40   | 1.66   |
| Altitude [m a.s.l.] | 438.01 | 438.09 | 446.16 | 440.42 | 445.60 | 447.80 |
| Biotope             | 6510   | 6410   | 6410   | 6510   | 6410   | 6410   |
| Management          | NT     | T      | T      | NT     | T      | T      |

SP1, SP2, SP3, SP4, SP5, SP6 – study plots; 6510 – Lowland hay meadows with the alliance *Arrhenatherion elatioris* Luquet 1926, 6410 – *Molinia* meadows on calcareous, peaty, or clayey-silt-laden soils with the alliance *Molinion caeruleae* Koch 1926; Management – NT = not-targeted - mowing of vegetation during June to mid-September, T = targeted - the absence of anthropogenic activity during the critical part of the year for the development of *P. teleius*;

**Fig. 2** The number of *Phengaris teleius* individuals (A) and *S. officinalis* per 25 m<sup>2</sup> (B) at individual study plots (SP1 – SP6) recorded during the research in Hradné lúky SAC

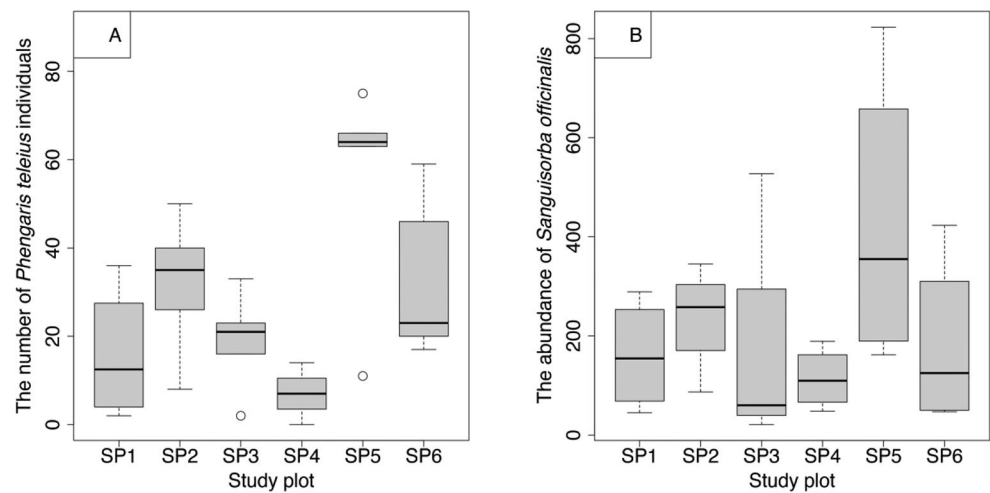


**Table 2** The abundance of ant nests at individual study plots with their overall dominance (D) recorded during the research in Hradné lúky SAC

| Species                          | Study plot |     |     |     |     |     | D [%] |
|----------------------------------|------------|-----|-----|-----|-----|-----|-------|
|                                  | SP1        | SP2 | SP3 | SP4 | SP5 | SP6 |       |
| <i>Formica cunicularia</i>       | 0          | 0   | 1   | 0   | 1   | 0   | 2.00  |
| <i>Lasius flavus</i>             | 7          | 9   | 9   | 22  | 21  | 2   | 69.31 |
| <i>Lasius niger</i>              | 0          | 1   | 3   | 0   | 2   | 1   | 6.93  |
| <i>Lasius platythorax</i>        | 0          | 2   | 0   | 1   | 0   | 2   | 4.95  |
| <i>Myrmica rubra</i>             | 0          | 1   | 1   | 0   | 0   | 4   | 5.94  |
| <i>Myrmica scabrinodis</i>       | 4          | 0   | 0   | 0   | 2   | 2   | 7.92  |
| <i>Tetramorium cf. caespitum</i> | 0          | 0   | 2   | 0   | 0   | 0   | 1.98  |

using R software (R Core Team 2023) and by running AICmodavg, sciplot, and sjPlot packages.

## Results

A total of 782 individuals of *P. teleius* were recorded during the research. The median value of the number of butterflies varied across individual study plots, with the highest number in the SP5 study plot (Fig. 2A). The average abundance of *S. officinalis* is similar among all study plots, with the SP5 plot being characterised by the highest median (Fig. 2B).

During the research, seven species of ants were recorded. The abundance of their nests at different study plots with the information about their dominance is indicated in Table 2. The anthills of the host ants *M. rubra* (5.94%) and *M. scabrinodis* (7.92%) were not dominant throughout the study area, but these species dominated SP6 at which they made up more than 50% of the recorded anthills (Fig. 3). Overall, *M. scabrinodis* was the second and *M. rubra* the fourth most dominant species in the study area of Hradné lúky SAC. *Lasius flavus* (69.31%) represented eudominant species (Table 2; Fig. 3).

The Spearman correlation coefficients between the numbers of ant nests at individual sampling plots are given in Table 3. The relationship between the dominant species

*Lasius flavus* and *L. niger* and the ants from *Myrmica* genus were preferably analysed. In this sense, the significant ( $p < 0.001$ ) negative correlation ( $r = -0.64$ ) between *Myrmica rubra* and *Lasius flavus* is indicated. On the other hand, *M. rubra* positively correlated with the species *Lasius platythorax* ( $r = 0.62$ ). *Myrmica scabrinodis* did not correlate significantly with other ant species.

The impact of targeted management in combination with biotope, the abundance of host plant (*S. officinalis*), as well as host ants (*M. scabrinodis*, *M. rubra*) was tested using a generalized linear model (Table 4). The final selected model with the best AIC contained all the studied variables. The results indicate that the targeted management ( $p = 0.0021$ ) and the abundance of *S. officinalis* ( $p = 0.0059$ ) had a significant impact on the number of individuals of the scarce large blue butterfly.

The positive relationship (according to the GLM) between the number of individuals of *P. teleius* and the abundance of *S. officinalis* is depicted in Fig. 4. The number of scarce large blue butterflies continually increased with the increase in average number of *S. officinalis*.

The relationship between the abundance of *P. teleius* and the management practices at individual types of biotopes in Hradné lúky SAC is given in Fig. 5. The higher number of butterflies was typical for *Molinia* meadows with targeted management (without mowing during the vegetation season

**Fig. 3** The dominance of the anthills of all observed ant species (A) and the abundance of anthills of *Myrmica* species (B) at individual study plots (SP1 – SP6) recorded during the research in Hradné lúky SAC; For\_cun – *Formica cunicularia*, Las fla – *Lasius flavus*, Las\_nig – *Lasius niger*, Las\_pla – *Lasius platythorax*, Myr\_rub – *Myrmica rubra*, Myr\_sca – *Myrmica scabrinodis*, Tet\_cae – *Tetramorium cf. caespitum*

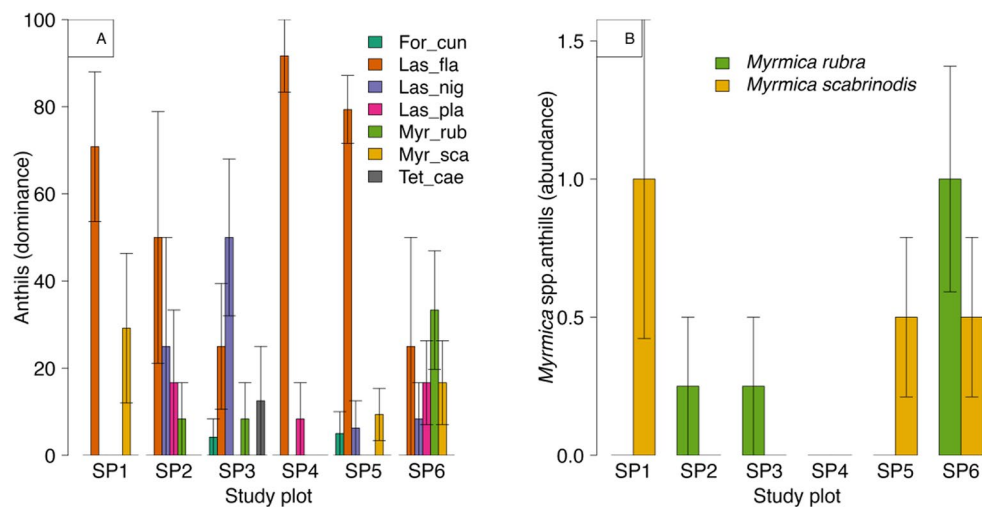


**Table 3** Correlation (Spearman coefficient) between the abundance of ant nests at individual sampling plots

|                                  | Myrmica scabrinodis | Myrmica rubra | Lasius niger | Lasius flavus | Formica cunicularia | Lasius platythorax |
|----------------------------------|---------------------|---------------|--------------|---------------|---------------------|--------------------|
| <i>Myrmica rubra</i>             | 0.12                |               |              |               |                     |                    |
| <i>Lasius niger</i>              | 0.06                | 0.15          |              |               |                     |                    |
| <i>Lasius flavus</i>             | -0.13               | -0.64***      | -0.41*       |               |                     |                    |
| <i>Formica cunicularia</i>       | -0.17               | -0.15         | 0.24         | -0.06         |                     |                    |
| <i>Lasius platythorax</i>        | -0.03               | 0.62**        | -0.25        | -0.42*        | -0.13               |                    |
| <i>Tetramorium cf. caespitum</i> | -0.12               | -0.11         | -0.12        | 0.00          | -0.06               | -0.09              |

Significance codes: < 0.001\*\*\*; < 0.01\*\*; < 0.05\*. Computed correlation used the spearman method with listwise deletion

**Table 4** The generalized linear model (GLM) indicated the relationship between the abundance of *Phengaris teleius*, the management, the host plants and the host ants in Hradné lúky SAC

|                                | Df | Deviance | Resid. Df | Resid. Dev | F       | Pr(> F) |    |
|--------------------------------|----|----------|-----------|------------|---------|---------|----|
| Management and Biotope         | 1  | 112.284  | 25        | 352.38     | 12.0703 | 0.0021  | ** |
| <i>Sanguisorba officinalis</i> | 1  | 85.827   | 24        | 266.56     | 9.2262  | 0.0059  | ** |
| Host ants                      | 1  | 17.32    | 23        | 249.23     | 1.8619  | 0.1856  |    |

Management and Biotope – the combination of management and biotope; either favourable management on *Molinia* meadows or unfavourable management on lowland hay meadows; *Sanguisorba officinalis* – the average abundance of host plant per 25 m<sup>2</sup>, Host ants – the average abundance of *Myrmica scabrinodis* and *Myrmica rubra* anthills per 25 m<sup>2</sup>; Resid. Df – Residual degrees of freedom, Resid. Dev – Residual Deviance, Significance codes: < 0.001\*\*\*; < 0.01\*\*; < 0.05\*

that promote the flowering of *S. officinalis*, accompanied by mulching and vegetation removal in the autumn).

## Discussion

It has been shown that the scarce large blue butterfly (*P. teleius*) strongly depends on the relationships with host plants (e.g., Nowicki et al. 2007), host ants (e.g., Wynhoff et al. 2011), and their habitat (e.g., Thomas 1984; Nowicki et al. 2009; van Langevelde and Wynhoff 2009). Our study also indicated the influence of meadow management in combination with suitable habitat and the abundance of the host plant *S. officinalis* in Hradné lúky SAC.

The proper management of open habitats that are suitable for *P. teleius* implies that mowing should be avoided during the growing phase of the host plant (*S. officinalis*),

particularly from mid-June to mid-September (Johst et al. 2006; Grill et al. 2008; Nowicki et al. 2009; Wynhoff et al. 2011). Correct timing of mowing is necessary for the preservation of the vital population of *P. teleius*, whereas frequent mowing can have a negative impact on its reproductive success and egg laying (Johst et al. 2006; Grill et al. 2008; Nowicki et al. 2009; Popović et al. 2014). Our results confirmed that the ‘traditional’ mowing regime (twice per year with the second cut shortly before the flight period) is unfavourable for *P. teleius* populations (Johst et al. 2006). In addition, the mowing of vast areas of open habitats limits the migratory abilities of the species, which is able to spread up to a distance of 5 km based on Mark Release Recapture studies (Nowicki et al. 2005; Van Langevelde and Wynhoff 2009). On the other hand, mowing can promote dispersal of individuals that are not well-adapted to dispersal (as shown in Popović and Nowicki 2023). Nevertheless, scarce large

**Fig. 4** The significant positive relationship (according to the GLM) between the number of individuals of *Phengaris teleius* and the average abundance of *Sanguisorba officinalis* per 25 m<sup>2</sup> (the dark grey zone represents the confidence intervals)

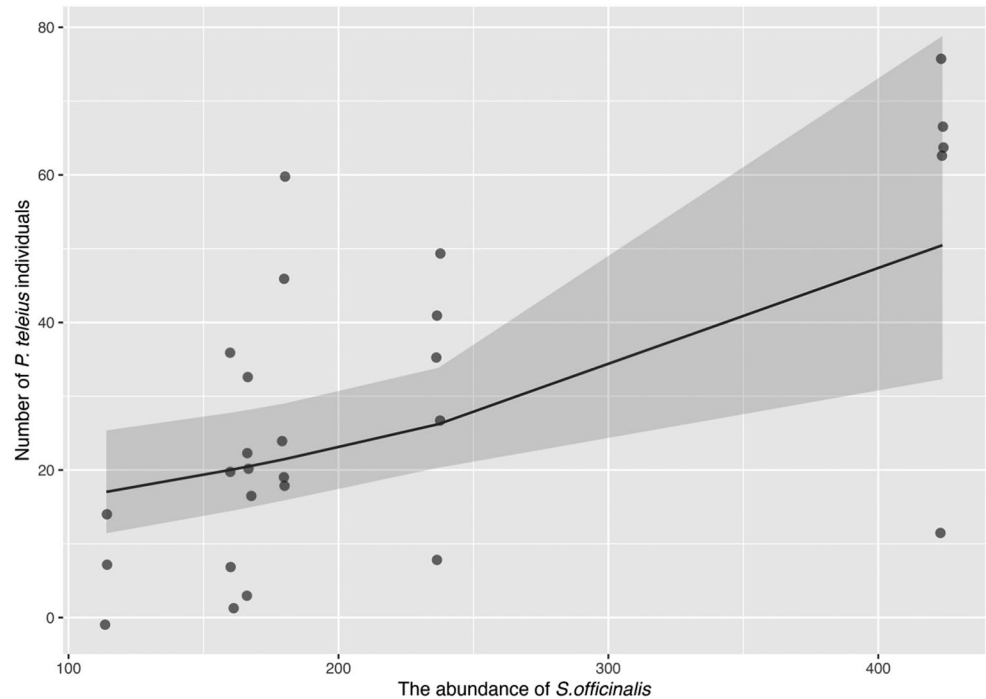
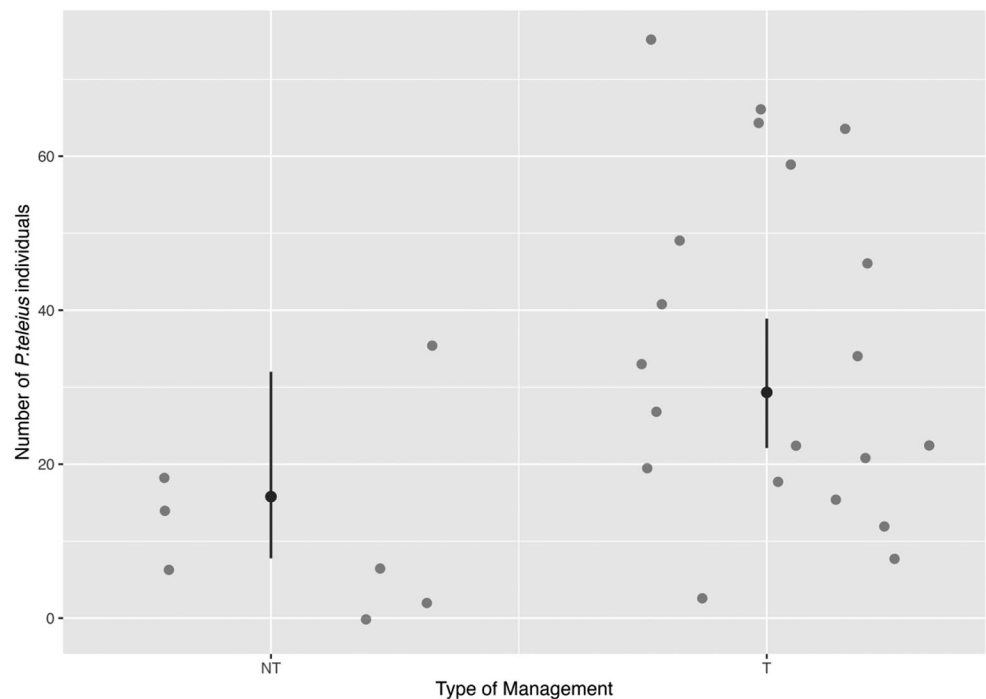


**Fig. 5** The significant relationship (according to the GLM) between the number of *Phengaris teleius* individuals and management at individual biotopes (T=targeted management on *Molinia* meadows, NT=non-targeted management on lowland hay meadows). Confidence intervals are shown as lines



blue butterfly is known as mostly settled species that rarely abandon their home patches (Thomas 1984; Nowicki et al. 2007; Popović et al. 2017). Therefore, proper management of habitats surrounding the patches, including biocorridors in the landscape, are important for survival of its meta-population (Nowicki et al. 2005). In this regard, favourable changes in management practices can significantly improve its migration rate, the state of its habitat, as well as other

specific ecological requirements critical for its persistence (Wynhoff et al. 2017), and thus preventing smaller isolated populations from extinction (Nowicki et al. 2005; Popović et al. 2014). Therefore, we recommend less intensive mowing on a smaller spatial scale (Popović et al. 2014) as well as rotational mowing schemes (Nowicki et al. 2009) performed in autumn after the flight period in the studied area (Johst et al. 2006; Grill et al. 2008). Extensive appropriate

management of the lowland hay meadows around *Molinia* meadows and support of landscape connectivity has the potential to increase the area of occurrence of *P. teleius* at this locality and help its migration in search of the most suitable conditions for reproduction and development.

Incorrect management performed by mowing in the flowering period of *S. officinalis* removes the flower heads on which the scarce large blue butterflies lay eggs (Wynhoff et al. 2011). This is even more true for our study locality, where flower heads are likely a limited resource, since their low number were recorded during the flying period of butterflies (only 34 flower heads on all sampling quadrats – see Material and methods). A few unfavourable years like this (yr. 2022 was extremely dry at this locality) with incorrect management could have a very negative influence on the population of butterflies. The population of *P. teleius* is strongly dependent on regularly mown wet meadows with the presence of *S. officinalis* host plants. Moreover, our study indicates that not only the presence of *S. officinalis*, but also its higher abundance, is essential for maintaining a good state of the butterfly population. This was likely the main reason for the high abundance of *P. teleius* on SP5, where the average number of *S. officinalis* shoots is much higher compared to other study plots (424 shoots per 25 m<sup>2</sup> compared to the second most abundant study plot SP2 with 237 shoots per 25 m<sup>2</sup>). The number of host plants significantly affects butterfly abundance (the results can be compared with Nowicki et al. 2007; Dierks and Fischer 2009). As a consequence, because our results underscore the importance of maximizing host plant abundance within the occupied area, we recommend supporting sufficiently-high abundances of *S. officinalis* by the targeted management (mowing in early autumn with the removal of plant biomass) so that the presence of the plant ceases to be the main limiting resource for the populations of scarce large blue butterflies (Witek et al. 2010; Popović et al. 2014), emphasizing the importance of other factors. Therefore, the increase in host plant availability tends to translate into a higher carrying capacity of the habitat, which is especially beneficial in species with narrow diet breadths, low mobility, and habitat specialists (Dennis et al. 2013; Curtis et al. 2015). As long as food plants and host ant species of *P. teleius* are present, the butterflies may continue to resist both global and local changes, while also facing climate change, habitat fragmentation (Garcia et al. 2024), and unfavourable years.

Not only the host plants, but also the host ants should be present at suitable habitats for the scarce large blue butterfly (Witek et al. 2010; Wynhoff et al. 2011, 2017). Our results did not confirm any significant effect of the *Myrmica* species on the population of *P. teleius*. However, we are fully aware that the presence of host ants in the proximity of *S. officinalis* is also indispensable for the population of *P. teleius*

(Wynhoff et al. 2008, 2011, 2017). In addition, our results may have been affected by several factors and limitations. The first and probably the most important reason for the lower abundance/absence of host ants (especially at study plot SP4) may lie in inefficient methodology. The combination of soil disturbance with the application of pitfall traps could provide us better information not only about the abundance of *Myrmica* species (Patricelli et al. 2011), but about the entire ant community (Schlick-Steiner et al. 2006). In addition to methodological limitations, other causes are also considered, such as source-sink dynamics (Timus et al. 2017) that could be promoted by mowing (Popović and Nowicki 2023) or inappropriate management of the meadows (Wynhoff et al. 2011). Weather conditions (Grill et al. 2008) and competition with other ant species (Wynhoff et al. 2011, 2017) can also play a role. The weather in 2022 was exceptionally warm and dry, which was indicated by the absence of typical surface water on the *Molinia* meadows, a habitat that is adapted to significant fluctuations in the groundwater level during the growing season (Šuvada et al. 2023). Inappropriate habitat conditions could lead *Myrmica* ants to rapidly abandon their nests, which was previously recorded even during a single season (Mouquet et al. 2005). Furthermore, competition with other species of ants, such as *Lasius niger* and *Lasius flavus*, may play an important role in the presence, distribution, and colonisation of habitat by *Myrmica* ants (Dauber and Wolters 2004; Wynhoff et al. 2011). *L. niger* is often mentioned as a competitor of *Myrmica* ants (e.g., Wynhoff et al. 2011, 2017) and the abundance of *Myrmica scabrinodis* often decreases with the increase of *L. niger* and *L. flavus* in the response to mowing (Dauber and Wolters 2004; Grill et al. 2008). *L. flavus* was the most dominant species in our study, which may indicate the presence of unsuitable conditions for *Myrmica* ants and high competition with them. A negative correlation of *L. flavus* was confirmed in the relation to *Myrmica rubra*, which prefers warm and moist habitats (Wynhoff et al. 2011), such as dump meadows, woodland edges, river banks, and cool grasslands (Wardlaw et al. 1998). *L. flavus* is more thermophilous and its workers build large nests. Therefore, similarly to the *Myrmica* species, it may be sensitive to disturbances with direct effect (e.g., nest destruction – mowing) or indirect effect (e.g., changes in vegetation structure) (Wynhoff et al. 2011). The significant correlation between the presence of *M. scabrinodis* and other species was not confirmed. This is a widely distributed *Myrmica* species (Elmes and Wardlaw 1982) and possibly a major host for *P. teleius* (Thomas et al. 1989). *M. scabrinodis* often occurs in open habitats characterised by short vegetation (Wynhoff et al. 2011) and tolerates habitats of widely varying conditions (Elmes and Wardlaw 1982). It is slightly more thermophilous than *M. rubra* (Wynhoff et al. 2011),

but these species often occur sympatrically (Wardlaw et al. 1998). Moreover, it should be mentioned that the plant biomass was not removed at the SP3, SP5, SP6 study plots in previous years. This may negatively influence the diversity of ant species that are associated with habitats of limited vegetative cover (Grill et al. 2008). *Myrmica* ants require habitats with dense vegetation and a herb layer that alleviate extreme microclimatic conditions. If these requirements are met, they are able to compete with the early colonising pioneer ant species (Wynhoff et al. 2011). All of these factors likely act synergically and could lead to a low abundance of the sampled ants. Moreover, the results may have also been affected by the relatively small sample size of *M. scabrinodis* and *M. rubra*.

Our study has some limitations, and the results must be supported by further research in the future. First, scientific design is not optimal, being more observational than experimental and with sample size limited by the available area in Hradné lúky. It represents a landscape-scale ecological study, where several factors (the small area of suitable habitat, plots are relatively close to each other, private land ownership, difficulties to set up the appropriate habitat management) influenced our ability to set up an optimal design. Therefore, the management practice (mowing and mulching) and habitat type (lowland hay meadows and *Molinia* meadows) could not be studied separately. Finally, 15 min of sampling of ants was likely not sufficient to document the dynamics of host ant species, as we discussed before.

Despite these facts, based on the results from GLM model, we cautiously state that supporting the highest possible abundance of host plants in the habitats of *P. teleius* is one of the essential recommendations for the conservation of this species. In addition, the absence of mowing from June to mid-September with one late mowing/mulching per year and with a plant biomass removal in *Molinia* meadows would likely lead to a more suitable habitat and larger population of scarce large blue butterflies in Hradné lúky. The fact that only a limited number of host plants were able to flower in the sampling quadrats in 2022, and the number of *Myrmica* ants were insufficient, represents strong arguments for urgent species conservation in Hradné lúky SAC.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s10841-024-00640-w>.

**Acknowledgements** The authors would like to express their gratitude to Dr. Juraj Holec for creating a map using GIS, to Ing. Peter Potocký from CHKO Polana for providing information on the management of Hradné lúky, to Dr. Hubert Žarnovičan for the valuable consultations in the field of phytocology. We also thank Michael Jerry Sabo for improving the English.

**Author contributions** R.M.: Conceptualization, data collection, methodology, data analysis and data visualisation, writing – original draft,

review and editing; P.K. and B.L. and J.R.: Data collection; A.P.: Data collection & data analysis; J.B.: Data collection, writing – review and editing. All authors have read and agreed to the published version of the manuscript.

**Funding** Funding was provided by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic, VEGA Grant No. 1/0372/24 and monitoring of endangered species was supported by the project LIFE19 IPE/SK/000003 LIFE- IP NATURA 2000 SVK. Open access funding provided by The Ministry of Education, Science, Research and Sport of the Slovak Republic in cooperation with Centre for Scientific and Technical Information of the Slovak Republic

**Data availability** The data presented in the study are available on request from corresponding author.

## Declarations

**Animal ethics** Not applicable.

**Competing interests** The authors declare no competing interests.

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