INTENSIVE MOWING EFFECT OF ONE PATCH ON THE METAPOPULATIONS OF TWO *PHENGARIS* SPECIES*

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In the second half of the 20th century, change of land use in the name of intensive agriculture was one of the most important factors caused significant loss of butterfly diversity in Europe. *Phengaris nausithous* and *Phengaris teleius* belong among the flagship species associated with wet meadows and are directly threatened by the intensive agriculture practises or management abandonment. Due to their very specific lifecycle, they are closely linked to their habitats and appropriate mowing management on their patches is thus crucial for their survival. Our research took place in Dolní Labe, Děčín, Czech Republic, on 16 patches and has been performed using Mark-Release-Recapture since 2009. This paper will illustrate how intensive mowing management, applied on only one of the patches, which forms only 9.4% of total locality size, can influence the entire local *Phengaris* metapopulation. The selected patch was intentionally mowed in the middle of flight season annually for four years. Even though, no significant effect was identified after the first year of study, after the second and third seasons, there was evidence of population decline of both studied species.

Mark-Release-Recapture, land use management, Lepidoptera, conservation

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INTRODUCTION

Cultural landscape and agricultural lands are historically changing. In the past centuries, these lands were used at a low intensity with minimal use of fertilizers, agrochemicals, and other external inputs (Beaufoy et al., 1995; Barthel et al., 2013). However, agricultural policy in Europe has changed during the second half of the 20th century and intensive agriculture began to play a main role (Kovacs-Hostyanszki et al., 2016). The factors directly connected with these changes subsequently caused the loss of semi-natural habitats, high-input arable farming and grassland management, increased fertilizers and pesticides use as well as cessation of the traditional farming methods (Benton et al., 2003). Moreover, the change of agricultural management also led to general loss of biodiversity throughout Europe (Kleijn et al., 2008; Geiger et al., 2010; Uchida, Ushimaru, 2014). Biodiversity of numerous species has decreased primarily due to patch destructions or other irreversible changes performed on these meadows (Sala et al., 2000; Sutcliffe et al., 2015).

Butterflies form an important part of species, which have been significantly affected by the above mentioned changes of natural habitats. Large-scale land use changes have resulted in serious declines of many butterfly species in recent decades and currently they are among the most endangered insects worldwide (Thomas et al., 2004; van Swaay et al., 2006). Regarding the impact on butterfly populations, intensive agriculture and especially intensive mowing have been identified as the main inappropriate management interventions (Bubova et al., 2015).

In the last century, the agricultural management of meadows was characterized by extensive land use, which is generally known as 'traditional' management. Smallholder farming with limited technical possibilities maintained a diverse mosaic of flowering meadows and extensive grazing hillside, which were

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mowed in different times (Balmer, Erhardt, 2000; Morris, 2000; Konvicka et al., 2005; Uchida, Ushimaru, 2015). Rotational mosaic mowing management, usually complemented by extensive grazing (Saarinen, Jantunen, 2005; Farruggia et al., 2012), is one of the most appropriate management strategies for butterflies (Bubova et al., 2015).

Despite the fact that traditional farm products have become very fashionable in recent years, there have been only few such farms. Most of agricultural lands are currently managed by agricultural cooperatives or commercial companies. In order to optimize profit, the meadows are mowed all over the place at once, with the most intensive mowing runs from May to September (Korosi et al., 2014), which unfortunately corresponds with the flight season of almost all meadow butterfly species (Thomas, 1984). Inappropriate mowing management has negative effects on availability of the nectar sources for butterflies' imagoes and also decreases the number of host plants available for oviposition (Johst et al., 2006; Wynhoff et al., 2011). Intensive agricultural and mainly intensive mowing is thus a real threat to the two typical meadow butterfly species, *Phengaris nausithous* (Bergsträsser 1779) and *P. teleius* (Bergsträsser 1779). Blue butterflies of genus *Phengaris* Doherty 1891 (syn. Maculinea Van Eecke 1915) are regarded as flagships of grassland conservation and useful indicators of insect species richness (Thomas, Settele, 2004). In the European Red List of Butterflies, the studied species are considered 'Vulnerable/Near Threatened' (van Swaay et al., 2010). Both species are characterized by highly specialized myrmecophilous and monophagous life cycles (Nowicki et al., 2015), when they feed exclusively on the single host plant *Sanguisorba officinalis*. Females of *Phengaris* species oviposit their eggs into the head of the host plants. Larvae start their development by feeding on seeds in the flower heads of the host plant. After 3–4 weeks, when they reach their last, fourth instar, they descend to the ground, where they need to be found and subsequently adopted by suitable *Myrmica* host ant workers. The workers take *Phengaris* larvae to the anthill, where they feed on the ant brood, overwinter, and finish the development. Adult butterflies hatch and fly from early July to mid-August (Thomas, 1984, 1995).

To support the only hostplant abundance during the flight season, it is essential to apply optimal management on the meadows with *Phengaris* occurrence. Mowing once a year or mowing every other year is reported to be the most appropriate management (Johst et al., 2006). Timing of meadows mowing is very important as well; the first cut should be ideally performed in May, which allows the food-plant recovery before the flight season beginning (Dierks, Fischer, 2009). The grass on meadows mowed in spring should be harvested no later than June 15th. Later mowing poses the risk that the host plants will not grow enough to be available for first hatched adult butterflies. In autumn, it is ideal to cut meadows during the later half of September. From this time, it is certain that all larvae have been already adopted in the anthills (Elmes, Thomas, 1992). In a study on *Phengaris* butterflies, Konvicka et al. (2005) consider mosaic and rotation mowing using rotatory grass mowers set up on higher cutting length (to avoid damaging ant hills) as the best management. In the Czech Republic, these species exclusively inhabit wet meadows, very often neighbouring large rivers. Patches along the Labe River in the Děčín area form such a locality. Since 2009, populations of both sympatric *Phengaris* species have been monitored by mark-recapture-recapture sampling at 17 patches (see Fig. 1) at this locality (data from patches No. 1–16 were used for the purpose of this study). The present research aims to reveal local population characteristics in dependence on meadow management performance. This paper describes the effect of intensive mowing management performed on one patch on a local *P. nausithous* and *P. teleius* metapopulation system. To the best of our knowledge, the influence of targeted mowing on butterflies has not been investigated before.

MATERIAL AND METHODS

Study area and experimental design

The experiment complies with current laws of the Czech Republic.

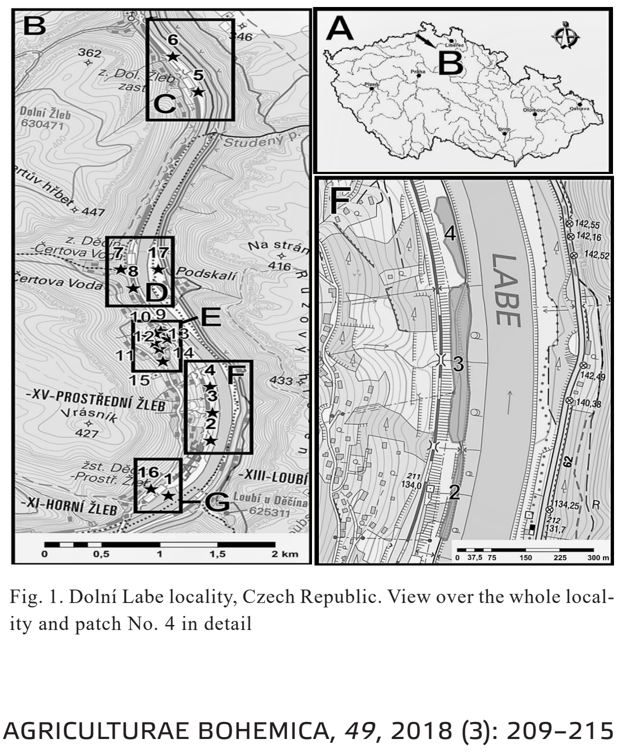

Fig. 1. Dolní Labe locality, Czech Republic. View over the whole locality and patch No. 4 in detail

Table 1. Areas of *Sanguisorba officinalis* patches at Dolní Labe, Czech Republic

Patch No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Area (m^2)	5 406	285	6 216	7 588	19 084	13 850	622	3 567	1 296	1 596	1 693	569	6 255	140	5 983	6 471	80 621

The study area Dolní Labe (50.8137756N, 14.2248814E) is situated in North Bohemia, Czech Republic, near the town of Děčín. This area is typical for metapopulation systems formed by spatially separated local populations within mosaic landscapes (Nowicki et al., 2014). The study area is composed of 16 patches sizing 140–19 084 m^2 (80 621 m^2 in total) (Table 1) and the maximum distance between the patches is 5.21 km (Fig. 1). The blue butterflies monitoring at Dolní Labe was launched in 2008, starting with only six patches. Therefore, this season was not included in the results. In 2009, the monitoring was extended to 10 newly discovered patches with *Phengaris* butterflies occurrence. Both species were monitored using mark-recapture-recapture method (MRR) for the next eight years (2009, 9/7–19/8; 2010, 9/7–12/8; 2011, 8/7–5/8; 2012, 14/7–10/8; 2013, 5/7–15/8; 2014, 3/7–18/8; 2015, 6/7–14/8; 2016, 7/7–12/8). Butterflies were captured with entomological nets, individually marked with numbers written on the underside of their left hind wing using permanent markers, and immediately released at place of capture. Marking was realised on a daily basis, weather permitting (e.g. no precipitation), from 9:00 to 17:00. Each captured specimen was marked with a unique number. Sex, weather, behaviour, and places of capture were recorded. To evaluate the effect of intensive management on one patch on the local metapopulation, patch No. 4 was selected because of its location in the centre of Dolní Labe locality (Fig. 1) and because, based on results obtained during 2009–2012, the *Phengaris* populations here were characterised as relatively stable. The No. 4 patch size is 7588 m^2, i.e. almost 10% of the total patch area of *Sanguisorba officinalis* at Dolní Labe locality. In 2013–2016, this patch was intentionally mowed at times inappropriate for blue butterflies – in the middle of the flight season (dates: 2013, 12/8; 2014, 27/7; 2015, 26/7; 2016, 6/7).

Data analysis

Various population characteristics and real population size $\hat{N}_{total}$ were determined using the MRR method (White, Burnham, 1999). The obtained data were then evaluated separately for both *P. nausithous* and *P. teleius* for all flight seasons considered. Based on these data, the negative effect of intensive mowing at inappropriate dates on the *Phengaris* populations could be revealed. Data on the population size provided by the MRR method were processed using MARK 8 software. Cormack-Jolly-Seber type constrained models were applied according to the procedure described by Nowicki et al. (2005). To predict $\hat{N}_{total}$ for the next 2017 flight season, fixed nonlinear regression with prediction dependent variable was used. Statistical analyses for both *Phengaris* butterfly species were then run in program STATISTICA, Version 13.2. The significance level α = 0.05 was selected for all the tests performed.

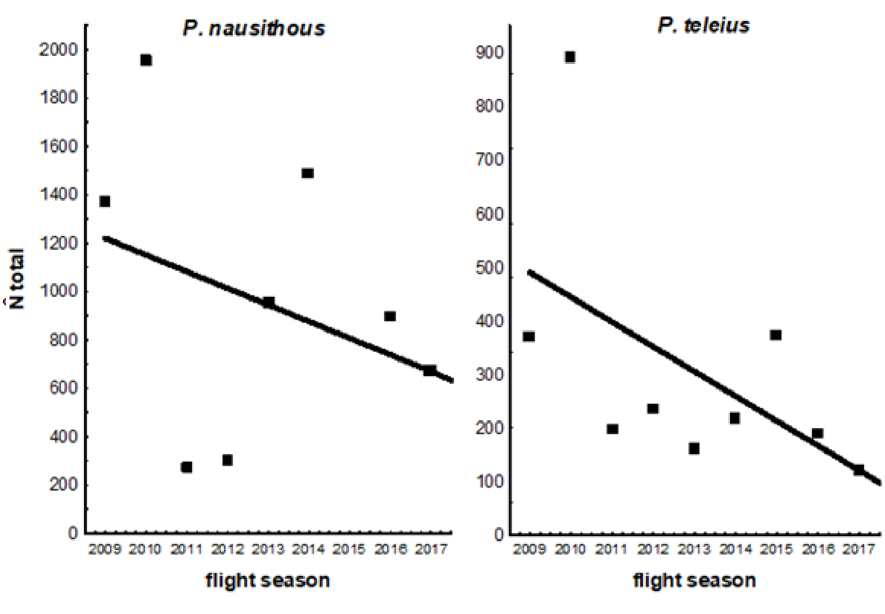

Fig. 2. Prediction of population size for 2017 flight season and time line for *P. nausithous* and *P. teleius* at Dolní Labe, Czech Republic

Models used for calculation: (1) model (.)(.): *P. nausithous* in flight seasons 2009, 2011, 2013, 2015 and *P. teleius* in flight seasons 2009, 2010, 2011, 2012, 2013, 2014, 2015; (2) model (g)(.): *P. nausithous* in flight season 2012 and *P. teleius* in flight season 2016; (3) model (.)(g): P. nausithous in flight season 2016; (4) model (.)(t): *P. nausithous* in flight season 2014; (5) model (.)(t): *P. nausithous* in flight season 2010

RESULTS

Population size $\hat{N}_{total}$ was estimated using the program MARK with the selection of the best-fit model for each individual flight season. The models best calculating the population size in flight seasons 2009–2015 were published by B u b o v a et al. (2016) (Fig. 2). For *P. nausithous* in flight season 2016, the φ(.)p(g) model (with equal daily survival and capture probability differing between sexes) was selected. For *P. teleius* the φ(g)p(.) model (with varying daily survival differing between sexes and equal capture probability) was used. Statistical analysis-based prediction of time line suggested for the expected population size $\hat{N}_{total}$ for the flight season 2017 at investigated locality was 669 individuals for *P. nausithous* and 119 individuals for *P. teleius*. The confidence level then ranged –503/1842 individuals for *P. nausithous* and –317/557 individuals for *P. teleius* (Table 2). In the light of this analysis, population decline of both species is estimated to be continued in the next season (Fig. 2).

Table 2. Prediction of 2017 time line for *P. nausithous* and *P. teleius* at Dolní Labe, Czech Republic

	Prediction 2017	–95% CL	+95% CL
P. nausithous	669	–503	1842
P. teleius	119	–317	557

CL – confidence level

DISCUSSION

The negative impact of land management on butterflies was previously described by many authors. Since butterflies can inhabit various habitats, they also have different survival requirements. High abundance of host plants and various mosaic meadows are decisive factors for grassland butterflies survival. Intensive agriculture and mowing are known as factors causing significant plant diversity decrease (C o l e et al., 2015). For instance, significantly higher egg densities were found on early mowed meadows than on those mowed later (in summer) (D o l e k, G e y e r, 1997). Therefore, abandonment of the intensive mowing management could positively affect the total number of butterfly species on meadows (K r u e s s, T s c h a r n t k e, 2002).

Many butterfly species are currently threatened by intensive land management (for their review see B u b o v a et al., 2015). *Phengaris arion* in Great Britain could be considered as an example; during 20 years of intensive land management, the sward structure was altered from being tall and dense to the edge of extinction (T h o m a s et al., 1998a; W e t t s t e i n, S c h m i d, 1999). The uniform machine mowing of entire areas with two cuts per year led in the Czech Republic to extinction of the species *Colias myrmidone* from the White Carpathians (K o n v i c k a et al., 2008).

A metapopulation consists of spatially separated populations of the same species, which mutually communicate in some way. *Phengaris* butterflies, with the fragmented system of local habitat patches with sometimes experience local extinctions and colonisations, and the dynamics of populations inhabiting these patches appear fairly independent from one another (N o w i c k i et al., 2005), thus belong among typical representatives of such a system. Habitat is reported to be the crucial effect influencing a metapopulation system (B e n d e r et al., 1998). The progressive destruction of patches in the landscape has wide and non-trivial implications for the persistence of metapopulation systems (B a s c o m p t e, S o l e, 1996). Inappropriate management causes that the patch is temporarily unsuitable to serve as habitat for the associated species. However, in contrast to irreversible habitat loss, these patches could regenerate and thus be subsequently re-colonized by individuals from other sub-populations. In the light of this, persistence of species with long-range dispersal is more likely than that of sedentary species (J o h s t et al., 2002) such as *Phengaris* butterflies.

The obtained results indicate possible impact of inappropriate management (intensive mowing) of one populous patch (but forming only one tenth of the total area of all patches) on the whole local metapopulation system of *P. nausithous* and *P. teleius*. During four flight seasons (2013–2016), intensive mowing management was intentionally applied on patch No. 4 at Dolní Labe, Czech Republic. The population size in these flight seasons fluctuated (Table 3), but the prediction of the time line showed decreases in butterflies for the following season 2017 (Fig. 2). The population size decline is not expected to be very high, especially considering the calculation is influenced by high population peaks in 2010 (Fig. 2), so the confidence levels have high interval which could probably be caused by the significant differences between the flight seasons displayed in Table 2. On the other hand, the decline trend is evident. Negative impacts of inappropriate mowing leading to reduction or extinction of *P. teleius* population were reported before. For instance, reintroduced populations of this species in the Netherlands were severely reduced by the wrong date of mowing, which was performed shortly after the peak of flight season (W y n h o f f, 1998). In Flanders, Belgium, intensive agriculture including mowing management changes led to *P. teleius* extinction in 1980 (M a e s, V a n D y c k, 2001). On the other hand, P o p o v i c et al. (2014), who studied the distribution of *P. teleius* in Northern Serbia in 2013, found out mowing in July as a suitable time for local populations. The highest abundance of adult butterflies was determined on patches mowed during June and July. However, their work was based on results from just one season, therefore they also recommend mosaic management as

Table 3. Population size $\hat{N}_{total}$ of *P. nausithous* and *P. teleius* at Dolní Labe, Czech Republic in flight seasons 2009–2016 (calculated by MARK software)

$\hat{N}_{total}$	2009	2010	2011	2012	2013	2014	2015	2016
P. nausithous	1370	1952	273	298	952	1486	602	896
P. teleius	368	889	196	233	160	215	371	187

Models used for calculation: (1) model (.)(.): *P. nausithous* in flight seasons 2009, 2011, 2013, 2015 and *P. teleius* in flight seasons 2009, 2010, 2011, 2012, 2013, 2014, 2015; (2) model (g)(.): *P. nausithous* in flight season 2012 and *P. teleius* in flight season 2016; (3) model (.)(g): *P. nausithous* in flight season 2016; (4) model (.)(t): *P. nausithous* in flight season 2014; (5) model (.)(t): *P. nausithous* in flight season 2010

appropriate for *P. teleius*. Regarding long-term studies, the influence of inappropriate meadow management on *Phengaris* populations is also evident from a 15-year MRR monitoring in Přelouč, Czech Republic published by Vrabec et al. (2017).

Based on our results, mowing in the middle of flight season appeared as inappropriate for *Phengaris* species at Dolní Labe. Even though in the first season, when mowing was performed at wrong date, no negative impact was detected; the negative impact over the whole metapopulation size was proved during next two seasons. The negative effect of intensive agriculture and mowing on *P. nausithous* and *P. teleius* was not manifested immediately, but after two years, with significant loss of local metapopulation abundance. This phenomenon could be explained by possible extension of development in the host ant colony, when e.g. Thomas et al. (1998b) revealed that 75% of larvae of the related species *Phengaris alcon rebeli* extended their development up to 22 months.

CONCLUSION

Despite the fact that inappropriate management was applied to only one patch (9.4% of total *S. officinalis* patches area) and for quite a short time (4 years), the declines of *P. teleius* as well as *P. nausithous* metapopulations were evident. On the other hand, it is clear that occasional mowing on inappropriate dates may not endanger local populations. Finally, it should be noted that even though the performance of this research could imbalance the local *Phengaris* populations, the knowledge of especially dispersal behaviour in the case of inappropriate management or patch destruction, may be a crucial parameter which could contribute to increased efficiency in protection of these species. Further research is thus needed.

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