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RESEARCH NOTE

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Management impacts on three reptile species (*Vipera ursinii*, *Lacerta agilis*, *Lacerta viridis*) in sandy grasslands in Hungary: Mowing should be avoided

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Abstract

Understanding the factors that determine the abundance of populations is of key importance in conservation biology, ecology, and biogeography. For grassland-associated species, such as the Hungarian meadow viper (*Vipera ursinii rakosiensis*), habitat management is particularly important. We aimed to study the effects of the three most common types of grassland management (grazing, mowing, and mowing + grazing) on the abundance of reptile species in meadow viper habitats in Kiskunság National Park, in Hungary. We surveyed grasslands repeatedly ($n = 15$ occasions) for reptiles in one autumn and one spring season in three 1-ha quadrates per grassland management type. We recorded all reptiles and their activity related to operative temperatures and analyzed data by n-mixture models. All reptile species known to occur in the habitats were observed during the surveys, but only the green lizard, sand lizard, and Hungarian meadow viper reached the minimum number of observations required for detailed analyses. Grazing had a strong positive effect on the abundance of Hungarian meadow vipers and sand lizards, while both mowing and mowing + grazing rotation had a negative effect. None of the grassland management types affected green lizard abundance. Our results suggest that grazing is the ideal type of grassland management for the endangered Hungarian meadow viper and the sand lizard. Mowing and mowing + grazing should be replaced by grazing to ensure the effectiveness of habitat management for conservation and to maintain healthy populations of grassland-associated reptile species.

KEYWORDS
abundance, conservation, grazing, mowing, n-mixture

1 | INTRODUCTION

Grassland biomes are affected by macroclimatic factors (e.g., continental climate) as well as several biotic and other abiotic factors, such as drought-induced fires and megaherbivores, which prevent the persistence of a sustained woody plant community and canopy cover and promote grasslands biomes (Anderson, 2006; Paruelo et al., 1999). The persistence and productivity of grasslands are strongly influenced by the biodiversity of the habitat (Tilman et al., 1996); the most diverse and species-rich ecosystems are also the most stable and longest persisting (Tilman et al., 2006). Grassland habitats are characterized by slower decomposition, which can lead to organic matter accumulation, making temperate grasslands ideal for arable farming. As a result, these habitats have suffered the most significant declines compared to other biomes (Deák et al., 2016).

Research by Grime (1973) has shown that species-rich grassland communities with at least 20 herbaceous species per square meter reach maximum diversity under moderate disturbance and stress. This result is compatible with the intermediate disturbance hypothesis (IDH) which predicts competitive exclusion among plant species without external disturbance (Armstrong & McGehee, 1980). Thus, some degree of disturbance, such as phytomass removal by grazing animals, and burning or removal of the competitive plant species, can positively affect grassland diversity (Belsky, 1992). The species richness of semi-natural grasslands is significantly higher in those habitats where grazing or mowing is applied, compared to abandoned, unmanaged grasslands, where the overdominance of a few species is usual (Willems, 1983). In addition to the less diverse species composition, there is a succession tendency towards the gradual emergence and spread of woody vegetation, which leads to a total structural and functional change in the area (Falińska, 1999).

Spatially extensive grassland management was practised in ancient times and although its role has declined, the tradition has survived and is still practised, especially in the temperate zone of Eurasia. Moderate grazing can maintain grasslands in good condition, as it helps to control the spread of invasive species and woody vegetation, thereby maintaining grassland diversity, which is also in the interest of farmers (Isselstein et al., 2005). Besides herding, mowing it is still necessary to produce winter feed for grazing animals. This practice was traditionally applied by hand, but the use changed in the mid-20th century and mechanical mowing became widespread. Even though mowing with machines is more effective, it means greater damage to the ecosystem (e.g., by soil compaction and direct killing of animals).

The effects of annual mowing and grazing generally support the preference for grazing over mowing for conservation purposes. However, it is important to note that in certain situations and for specific species, particularly plants, mowing has been demonstrated to be the preferred management approach (Tälle et al., 2016). When applying low to moderate grazing pressure (<0.5 animal units/ha) and annual rotation in grazed area units, plant species diversity in grasslands shows an increase compared to annual mowing. On the other hand, continuous overgrazing has a worse effect on grassland diversity than conventional mowing (Vadász et al., 2016).

The loss of grassland habitats has been accompanied by a decline in populations of grassland-associated animal species and a decreasing number of rare and specialist species as agriculture intensifies (Hilpold et al., 2018). Many species found in grasslands have been pushed to the brink of extinction over the last century, but thanks to the increasing conservation efforts in the last decades, there are examples of successful conservation projects in the case of some species, including the imperial eagle (*Aquila heliaca*), the red-footed falcon (*Falco vespertinus*), and the great bustard (*Otis tarda*) (Faragó et al., 2014; Fehérvári et al., 2012; Kovács et al., 2008). The main steps of these projects are usually extensive monitoring, tracking of tagged individuals, estimation of population sizes and restoration of habitats to their presumed original condition suitable for them.

One of Europe's most endangered vertebrates, the Hungarian meadow viper (*V. ursinii rakosiensis*) is also a grassland specialist species, which was historically common in the steppes of the Pannonian basin (Mizsei et al., 2018; Móré et al., 2022). As a consequence of agricultural intensification, most of its habitats were converted to arable croplands, thus the Hungarian meadow viper's distribution range shrunk drastically. Moreover, the remaining populations also suffered a significant decline due to the intensified grassland utilization and excessive predation pressure (Móré et al., 2022; Péchy et al., 2015). At present, only a few small, isolated populations remain in the Hanság, Kiskunság, and Transylvanian plain areas (Mizsei et al., 2018). Thanks to the ongoing, Hungarian meadow viper LIFE project conducted since 2004, the habitats were extended and national parks implemented viper-friendly grassland management measures in several areas. In addition, declining populations were reinforced with individuals from ex situ breeding or restored populations at sites were the species gone extinct in the past (Péchy et al., 2015). However, there is still lack of evidence what kind of management can be considered as viper-friendly.

It is essential that conservation interventions are evidence-based (Sutherland et al., 2004), as habitat restoration and other conservation efforts that are not based on proven scientific knowledge may only create sub-optimal habitat for the species of conservation concern or have a different effect than expected or no effect at all (Cromsigt et al., 2012). Relatively little information is available on the habitat selection of the Hungarian meadow viper, therefore, it is essential to have as detailed and in-depth knowledge to ensure that grassland restoration and management would be carried out in the most optimal way. The aim of the study was to investigate the effects of the most common practices of grassland exploitation regimes in Natura2000 sites on the abundance of reptile populations in Hungarian meadow viper habitats in the Upper Kiskunság region.

2 | METHODS

2.1 | Sampling design

The sampling areas were designated in nine grassland patches in the "Felső-Kiskunság-Turjánvidék" Natura 2000 (HUKN20003) priority conservation area of Kiskunság National Park. The studied patches can be divided into three groups according to grassland management: grazing, mowing, and rotational grazing + mowing (mown in early or mid-summer, grazed afterwards). In both mowing management, mowing was done by mechanized hayfield mowers. In each of the patches, we randomly placed a quadrat of 1 ha (100 × 100 m) to be surveyed (Figure 1). The quadrats were split to four 50 × 50 m subplots for the statistical analysis.

2.2 | Data collection

We surveyed reptiles through counts repeated 15 times in the vegetation period in each of the designated survey quadrats. Surveys were conducted between 7 am and 6 pm in both survey periods. Surveys were carried out between 10–15 September 2019 (autumn 2019) and 16 April to 1 June 2020 (spring 2020) on days with suitable weather conditions for the activity of the reptile species being surveyed. We surveyed the quadrats by walking along east–west oriented straight lines located 10 m apart from each other, which resulted in a total surveyed distance of 1100 m per quadrat per occasion. The position of the sightings was recorded using the Locus GIS 1.1.0 Android application along with the access route in a smartphone. For each reptile sighting, we recorded the species, age and sex category (juvenile, subadult, adult male, and adult female), exact time, and coordinates of the observed animals. In the study sites four lizard (*Podarcis tauricus*, *Lacerta agilis*, *Lacerta viridis*, and *Zootoca vivipara*) and three snake species (*Coronella austriaca*, *Natrix natrix*, and *V. ursinii*) occur.

Because temperature fundamentally influences the activity of reptiles, we also measured operative temperature during the surveys. Operative temperature (t_o) is the ambient temperature that is available to the individual at different times during thermoregulation (Shine & Kearney, 2001).

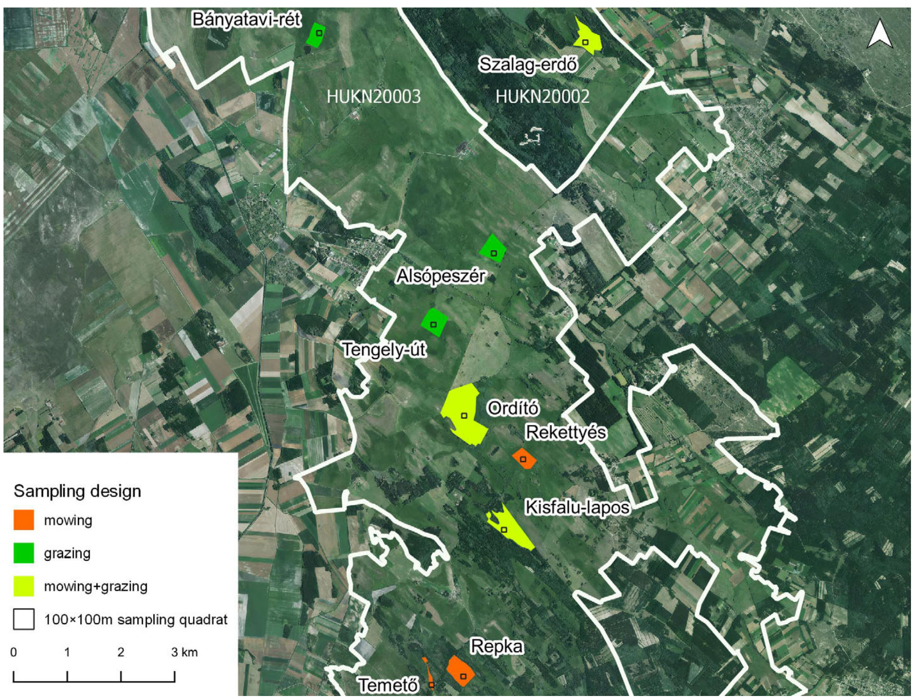

FIGURE 1 Location of the surveyed sites.

The t_o cannot be calculated from commonly measured meteorological data because it is influenced by radiation, surface temperature, wind speed, humidity, animal shape, and heat absorption, in addition to air temperature (Kearney & Porter, 2019). To measure t_o, we used two copper tube thermometers per quadrat, equipped with an iButton DS1921G-F5# Thermochron temperature logger, which recorded the operative temperature values at 5-min intervals. Data on operative temperature were retrieved from the logger for each survey occasion.

2.3 | Data analysis

The effect of management type on abundance was investigated using n-mixture models (Dénes et al., 2015; Royle, 2004). We fitted separate models for the three species studied (*V. ursinii*, *L. agilis*, and *L. viridis*), but their structure was identical. The explanatory variable in the detection submodel was the mean of the t_o during the survey, while the explanatory variable in the abundance submodel was management, that is, the type of grassland management as a factor variable. The models were built and run in the unmarked package of R (Fiske & Chandler, 2011). For each species, Poisson, zero-inflated Poisson (ZIP), and negative binomial (NB) error distribution models were constructed, from which the model with the best AIC value was selected (Fiske & Chandler, 2011; Kéry, 2018). Interpretation of the effect of management types was done following the suggestions of Hopkins (2022).

3 | RESULTS

We recorded a total of 15 observations of the Hungarian meadow viper, the primary study species, only during the autumn surveys, and we recorded 855 green lizard ($n = 151$ in autumn, $n = 695$ in spring) and 846 sand lizards ($n = 614$ in autumn, $n = 695$ in spring) observation (Figure S1). In addition, we also detected two grass snakes (*N. natrix*), two smooth snakes (*C. austriaca*), two Balkan wall lizards (*P. tauricus*), and five common lizards (*Z. vivipara*). The number of observations was sufficient for statistical modeling only for the Hungarian meadow viper, the green lizard and the sand lizard, thus, we excluded the other species from further analyses. The mean observation number across surveys was 0.027 for Hungarian meadow viper, 0.28 and 1.28 for sand lizard, and 1.14 and 0.45 for green lizard, for autumn and spring, respectively.

For Hungarian meadow vipers, the best-fitting model was the ZIP error distribution model (Table 1). Viper

TABLE 1 AIC values of n-mixture models fitted to the study species observation data using three different mixtures.

		AIC		
		Poisson	Negative-binomial	Zero-inflated Poisson
Vipera ursinii	Autumn	122.9866	124.9866	**122.8229**
Lacerta agilis	Autumn	522.8489	**522.4593**	524.3272
	Spring	1268.333	**1266.333**	1268.333
Lacerta viridis	Autumn	952.5802	**950.5801**	952.5801
	Spring	655.7097	638.1121	**630.3827**

Note: Bold values indicate lowest AIC, which models are presented in the results.

density was significantly positively influenced by grazing (estimate 3.8 ± 1.1 individuals/ha, $z = 3.49$, $p = .0005$). Mowing and mowing + grazing had non-significant negative effects on viper density. In the autumn survey, the density of the Hungarian meadow viper was 25.5 ± 5.66 individuals/ha in quadrats of grazing management, and only 2.25 ± 0.44 individuals/ha in quadrats with mowing + grazing rotation, and it was not found at all in quadrats with mowing management (Figure 2). The mean detection probability of the Hungarian meadow viper was 0.004 ± 0.0001, and the t_o had a significant negative effect on viper detectability (estimate $= -0.096 \pm 0.096$, $z = -2.67$, $p = .0075$). Because no Hungarian meadow vipers were detected in the spring of 2020, we did not conduct analyses for this species.

For sand lizards, the best-fitting models were the NB error distribution models in both the autumn and the spring periods (Table 1). In the autumn survey, sand lizard density was positively influenced by grazing (estimate $3.61 \pm$ (SE) 0.84 individuals/ha, $z = 4.28$, $p < .0001$). Mowing and mowing + grazing had a non-significant negative effect on sand lizard density. In the autumn, sand lizard density was 34.87 ± 10.9 individuals/ha in the grazed quadrats, 6.32 ± 7.12 individuals/ha in the mowing + grazing quadrats, and 0 individuals/ha in the mown quadrats (no individuals found; Figure 2). The mean detection probability of the sand lizard in the autumn period was 0.02 ± 0.0001, and the t_o had a significant positive effect on lizard detectability (estimate $= 0.028 \pm 0.012$, $z = 2.40$, $p = .0166$). In the spring, grazing management had a significantly positive effect on species density (estimate $1.45 \pm$ (SE) 0.24, $z = 5.98$, $p < .0001$). Sand lizard density was 7.79 ± 5.83 individuals/ha in grazed quadrats, 4.31 ± 2.99 individuals/ha in mowing + grazing quadrats, and 1.04 ± 0.01 individuals/ha in mown quadrats (Figure 2). The mean detection probability of the sand lizard in the spring period was 0.414 ± 0.0006, and the

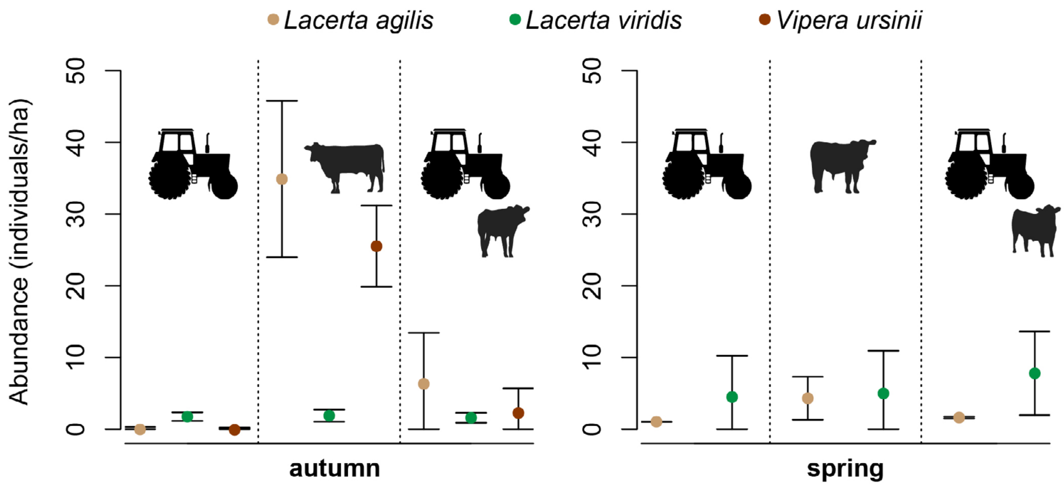

FIGURE 2 Abundance estimates (mean ± 95% CI) of the study species on mowing, grazing, and mowing + grazing management sites by the two survey seasons analyzed.

t_o did not have a significant effect on sand lizard detectability in the spring.

For green lizards in the autumn period, the best-fitting model was the NB error distribution model (Table 1). All three grassland management types had a positive but non-significant effect on green lizard density. In the autumn, green lizard density was 1.89 ± 0.83 individuals/ha in grazed quadrats, 1.59 ± 0.68 individuals/ha in mown quadrats, and 1.74 ± 0.59 individuals/ha in mown + grazed quadrats (Figure 2). The mean detection probability of the green lizard in the autumn period was 0.638 ± 0.0002, and we also found a positive non-significant relationship between detection probability and t_o. In the spring, the best-fitting model was the ZIP model for green lizards (Table 1). All three grassland management types had a negative but non-significant effect on green lizard density. In the spring, green lizard density was 4.98 ± 5.94 individuals/ha in grazed quadrats, 4.48 ± 4.75 individuals/ha in mown quadrats, and 7.79 ± 5.83 individuals/ha in mown + grazed quadrats (Figure 2). The mean detection probability of the green lizard in the spring period was 0.11 ± 0.0003, and a significant positive effect was found of t_o on detection probability (estimate = 0.056 ± 0.015, $z = 6.65$, $p = .0003$).

4 | DISCUSSION

Based on our results the density of both the Hungarian meadow viper and the sand lizard was positively influenced by grazing while mowing and mowing + grazing had a likely negative effect. These species are almost absent in mowed sites and have a low density in sites managed by mowing + grazing. The density of green lizards was not explained by the grassland management type. Taken together, these results suggest that grazing is the most appropriate type of grassland management for the studied reptile species.

The studied species are all sensitive to vegetation structure, and lizard species are also sensitive to the extent of vegetation cover (Mizsei et al., 2020). These habitat characteristics are all determined by the management of grasslands. Grazing is likely to result in a taller and more diverse vegetation structure, with a higher total cover compared to the less structured, the shorter vegetation resulting from mowing. Many studies from different biomes have found that grazing has a more positive effect on biodiversity and is more appropriate for species conservation than mowing (Tälle et al., 2016). For grassland habitat specialist reptiles such as the Hungarian meadow viper, there has been no previous study on the effects of grassland management, but our results demonstrate that grazing results in a more suitable habitat for both the grassland-associated viper and the sand lizard.

Structurally diverse grasslands can provide sufficient quality and quantity of hiding places (e.g., tussocks), thus increasing the chances of avoiding predation. In addition, thermoregulation is more efficient in grasslands with higher structural diversity, because they provide more opportunities for individuals to choose ideal basking spots. It is important to note that mowing did not have a significant positive effect on the abundance of any species. Although mechanical mowing can maintain and increase species diversity in temperate high-productivity grasslands as well as grazing can (Collins et al., 1998), our results do not corroborate this view. In addition, the density of sand lizards was also negligible in mown quadrats compared to other types of management that included grazing for at least part of the vegetation period.

A limitation of this study is that we surveyed only three spatial replicates per management type, which limits the potential for spatial extrapolation of the results. In addition, we surveyed only in two consecutive seasons, which is too low for assessing the changes in the density of the studied cryptic species. However, because management has been conducted unchanged for several years in each studied grassland patch, we believe that our results reflect the differences between management types. In the future, a fine-scale investigation of grazing is necessary to look at the effects of grazing pressure and cattle breeds on reptile abundance, and perhaps to compare the data with the effects of grazing by other livestock species. Similarly, mowing could be addressed in more detail by involving factors that might influence reptile density such as the type of mowing machinery used (Humbert et al., 2010), the height of the left-over stubble, the number of mowing occasions per year, the time since mowing, and the location and depth of ditches, burrows and other hiding places (Jellinek et al., 2014).

Our results suggest that to maximize reptile abundance, mowing and mowing + grazing management should be avoided and habitats should be grazed instead. Based on our knowledge of the current habitat of the Hungarian meadow viper and the results of this study, we expect that the species has not been able to adapt to the sudden disappearance of phytomass due to mowing. Furthermore, mowing can be a direct cause of mortality for vipers (pers. obs.) and other reptiles (Deák et al., 2021). Our results thus also confirm the empirical knowledge of conservationists, mainly national park rangers, that the viper is likely to disappear from mown grasslands in a relatively short time. Therefore, in order to ensure the long-term survival of this threatened subspecies, mowing should be discontinued in currently occupied and potential habitats and a switch to low intensity cattle grazing should be made wherever this has not been done.

AUTHOR CONTRIBUTIONS

Edvárd Mizsei and **Csaba Vadász** conceived the ideas and designed the methodology. **Edvárd Mizsei**, **Mátyás Budai**, **Attila Móré**, **Gergő Rák**, **Dávid Radovics**, **Barnabás Bancsik**, **Bálint Wenner**, and **Szabolcs Márton** collected data. **Edvárd Mizsei** and **Mátyás Budai** analyzed the data. **Edvárd Mizsei**, **Mátyás Budai**, **Zoltán Korsós**, and **Szabolcs Lengyel** led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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DATA AVAILABILTY STATEMENT

The data used for the analysis and the R scripts will be archived at the Zenodo repository (https://zenodo.org/records/10119157).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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