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ORIGINAL ARTICLE

Habitat of *Carabus zawadzkii* (Coleoptera: Carabidae) in the Eastern Carpathians

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Key words. Carabid assemblages, habitat relationship, conservation status, seasonal dynamics, management measures, Natura 2000

Abstract. This paper provides an analysis of the rare and important Natura 2000 species *Carabus zawadzkii* in terms of its ecological niche, conservation status and relationship with other *Carabus* species in carabid assemblages. Published sources are inconsistent in defining the habitats in which this species occurs. Therefore, a large part of this paper is dedicated to identifying the relationship of *Carabus zawadzkii* with particular non-forest habitats based on field research conducted in 2011–2013. The results revealed an unexpected affinity of this species for non-forest habitats in addition to the know relationship with forest habitats. Further analysis, using additional field data collected over the period 2013–2021, also focused on the assessment of the current conservation status of this rare species. Overall, the population of this species seems stable; however, to improve its conservation status it requires particular management measures. Important conservation measures include periodic extensive mowing of mountain hay meadows. This species' seasonal dynamics provides important information for nature conservationists. It is important to carry out research on this species in May, when it is most active. Presented results provide the most comprehensive overview of the ecological preferences and occurrence of this important and very rare Carpathian species.

INTRODUCTION

Although the genus *Carabus* (family Carabidae) is one of the most famous in the order of beetles (Coleoptera), our knowledge of many species in this group is relatively poor. The genus is highly diverse, with 135 species of the genus *Carabus* recorded in Europe (Turin et al., 2003). Of these, seven are listed in Annex II of the Habitats Directive, namely *Carabus olympiae* Sella, 1855, *Carabus menetriesi pacholei* Sokolář, 1911, *Carabus hampei* Küster, 1846, *Carabus hungaricus* Fabricius, 1792, *Carabus (variolosus) nodulosus* Creutzer, 1799, *Carabus variolosus* Fabricius, 1787 and *Carabus zawadzkii* Kraatz, 1854. A significant part of the population of *Carabus zawadzkii* occurs in the Slovak Republic, where there are 20 subgenera, 26 species and 34 geographical varieties of this genus (Hůrka, 1996; Müller-Motzfeld, 2004; Skoupý, 2004; Farkač, 2011). In Annex II of the Habitats Directive (HD), which focuses on species for which their habitats need protection, three species (*Carabus hungaricus*, *Carabus variolosus* and *Carabus zawadzkii*) are listed as present in Slovakia (Ambróz et al., 2011). Although *Carabus zawadzkii* is a protected species in both Europe and nationally (Natura 2000 network, monitoring schemes, 6-yearly reporting under Article 17 of HD, research projects, etc.), knowledge of its distribution, conservation status and general relationship with carabid assemblages is poor, both in Europe and Slovakia.

Ecology

This beetle is endemic to the east and middle Carpathians. From a European perspective it is a very rare species. It is found in southeastern Poland, eastern Slovakia, west-

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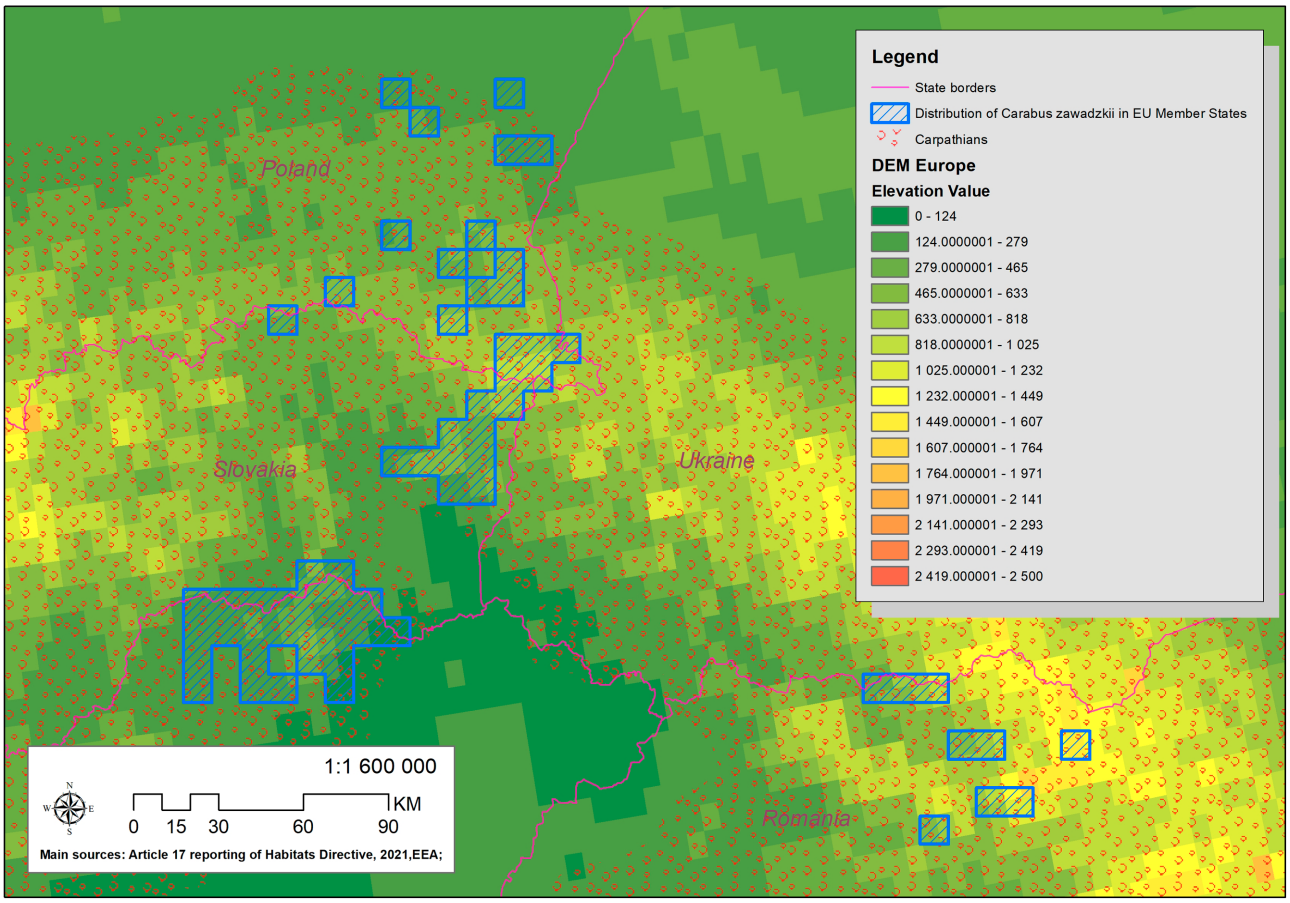

Fig. 1. Recent distribution of *Carabus zawadzkii* in EU Member States based on art. 17 HD reporting (EEA, 2021).

ern Ukraine, north-eastern Hungary and northern Romania (Figs 1, 2). In Poland it occurs in the Bieszczady mountains and their foothills. The north-western border of its range is in Poland. There are 7 sites known in Poland where it is found in small numbers (Pawlaczyk et al., 2004). The first information from Poland in the year 1991 related to its occurrence was based on one specimen caught on 11th of July 1974. Specimens from several sites are in the collections of the Museum and Institute of Zoology of the Polish Academy of Sciences in Łomno near Warsaw. In Poland this species, is found mainly in meadows and rotten stumps and lying logs. Due to the lack of specific data, it was previously not classified as a native beetle (Burakowski et al., 2000). Over the last two decades there was only one confirmed record for the year 2011 (BioMap diversity, 2022). It is also found very rarely in Slovakia and only in north-eastern Slovakia (especially Vihorlat mountains, Ondavská and Laborecká highlands, Bukovské and Čergov mountains) (Olšovský, 2015). In Romania, Barloy & Prunar (2012) document its occurrence in 15 localities in the Maramureş and Bistriţa Năsăud districts. There are two confirmed localities in Ukraine, namely Dilove and Bogdan in the Maramureş mountains and Podpula Mts respectively (Barloy et al., 2014). Putchkov (2011, 2012) documents the occurrence of two subspecies in the Ukrainian Carpathian range: *C. zawadskyi seriatissimus* Reiter, 1896, in the Carpathian moutains, and *C. zawadskyi zawadskyi* Kraatz, 1854, in the Carpathian foothills. In older literature on its occurrence in the Ukrainian Carpathians, this species is listed as 2 subspecies, *C. zawadskyi zawadskyi* Kraatz, 1854 and C. *zawadskyi ronayi* Csiki, 1905 (Kryzhanovskij, 1983; Kryzhanovskij et al., 1985). Also, 3 specimens of *Carabus zawadzkii* were collected in the 19th Century in Galicia, currently on the border between Poland and Ukraine, which are now deposited in the Natural History Museum of Sibiu Entomological Collections (Muntean et al., 2020).

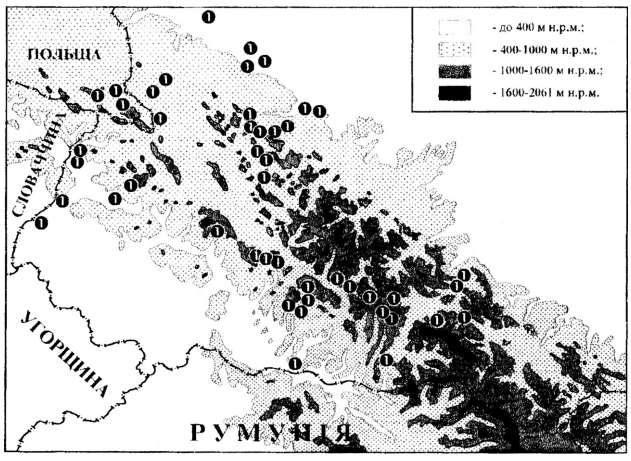

Fig. 2. Distribution of *Carabus zawadzkii* in Ukraine, indicated by black dots marked with Fig. 1 (Rizun, 2003).

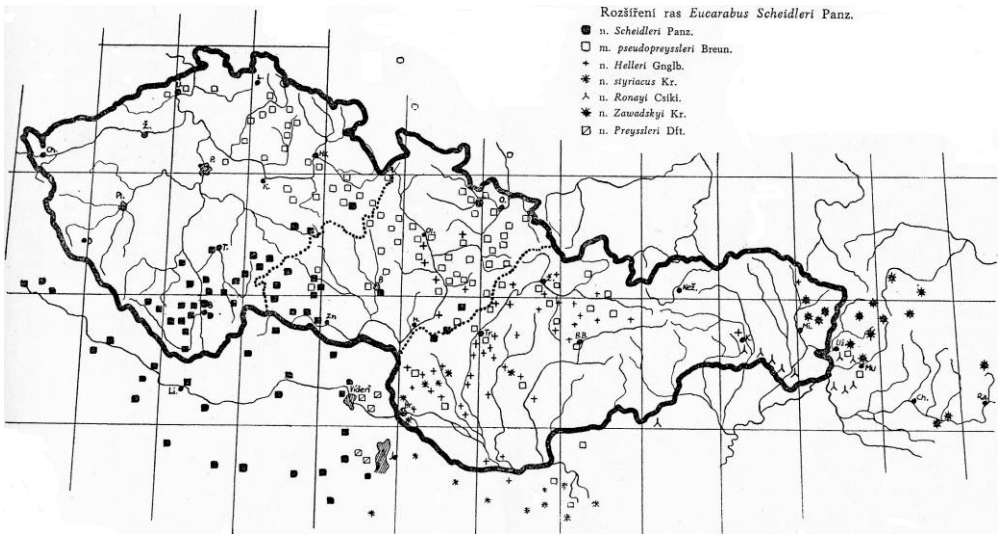

Fig. 3. Historical distribution of *Carabus zawadzkii* in Czechia and Slovakia (Niedl, 1957).

There is relatively little published information on its habitat preferences and distribution. Art. 17 reporting according to HD defines this species as follows: "It lives predominantly in forests and forest margins of hills and mountains, but it also occurs in river valleys, both in riparian forests and in wet meadows". In Romania it is reported by Barloy & Prunar (2012), particularly the subspecies *Carabus (Morphocarabus) scheidleri zawadzkii seriatissimus* Reiter, 1896. Its habitats are classified as forests or forest edges, or bushes at the boundaries of meadows in the vicinity of semi-permanent brooks. Based on its occurrence in the Poloniny region of Slovakia it is classified as a forest species (Jászay, 2001). Only one expert considers this species to be one that inhabits foothills, lower mountain

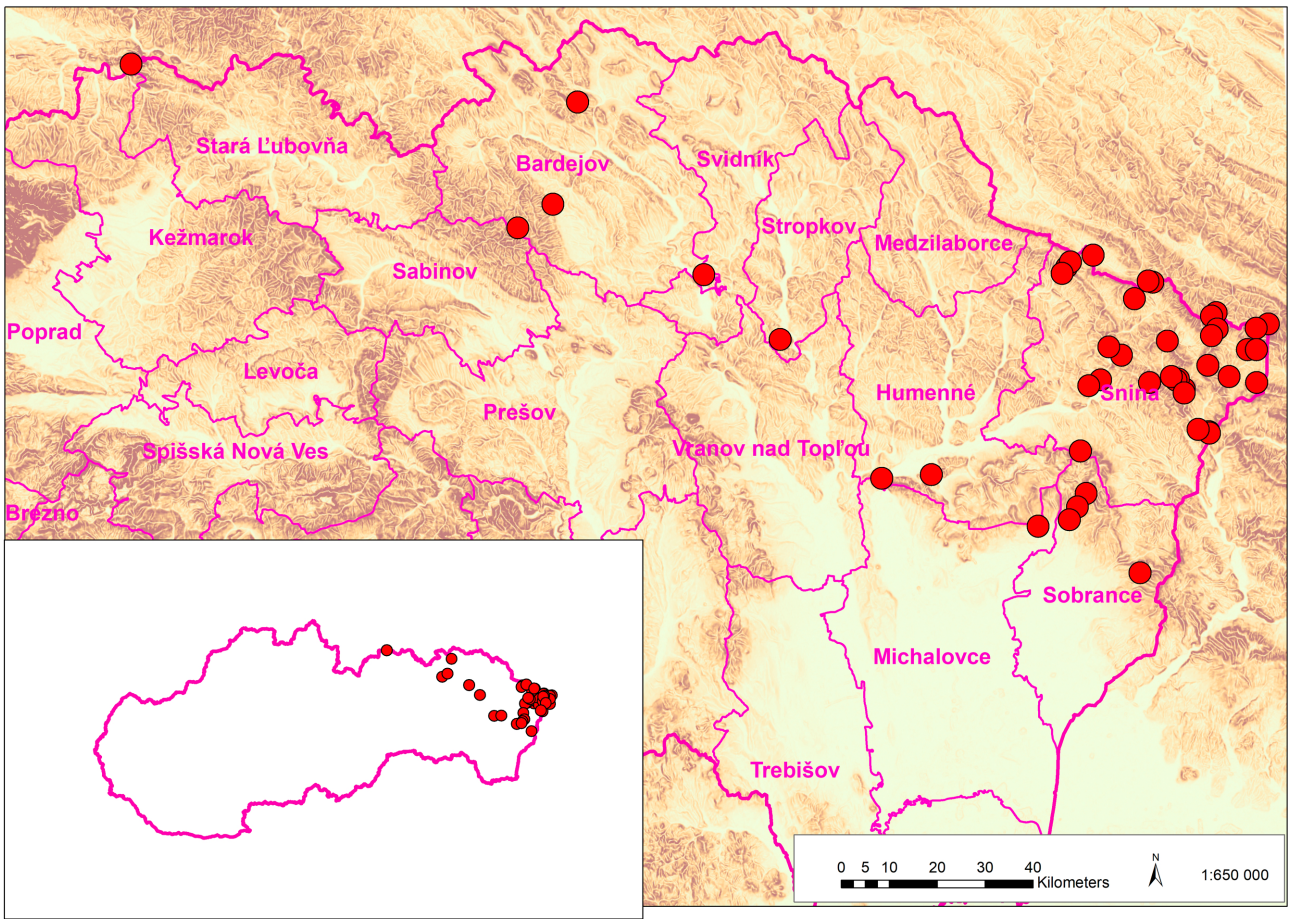

Fig. 4. Inventory of the field data confirming presence of *Carabus zawadzkii*.

Table 1. Results of the inventory research of *Carabus zawadzkii* (MC – method of collection, PT – pitfall traps, IC – individual collection).

Orographic unit	Cadastre	Habitat	MC	Collection date	Latitude	Longitude	Males	Females	Expert	Number of specimens
Bukovské vrchy	Hlboké	beech forests	PT	1.6.1999–3.8.1999	49.16083333	22.17805556	4♂♂	7♀♀	Jászay	11
Bukovské vrchy	Hlboké	beech forests	PT	26.5.2000–3.8.2000	49.16083333	22.17805556	5♂	10♀♀	Jászay	15
Bukovské vrchy	Hlboké	pastures	PT	15.10.1999–26.5.2000	49.16722222	22.185		2♀♀	Jászay	2
Bukovské vrchy	Kalná Roztoka	beech forests	PT	27.5.1999–30.7.1999	49.01944444	22.33305556		2♀♀	Jászay	2
Bukovské vrchy	Kalná Roztoka	beech forests	PT	22.10.1999–25.7.2000	49.01944444	22.33305556		1♀	Jászay	1
Bukovské vrchy	Kolbasov	wet meadows and fens	PT	4.5.1995–18.7.1995	49.01194444	22.39777778		1♀	Jászay	1
Bukovské vrchy	Kolbasov	mesophilic meadows	PT	1.5.1995–18.7.1995	49.02361111	22.3875		1♀	Jászay	1
Bukovské vrchy	Kolbasov	mesophilic meadows	PT	17.5.2000–26.7.2000	49.02222222	22.38277778	4♂♂	6♀♀	Jászay	10
Bukovské vrchy	Kolbasov	mesophilic meadows	PT	26.7.2000–27.10.2000	49.02222222	22.38277778		2♀♀	Jászay	2
Bukovské vrchy	Kolbasov	alder forests	PT	7.6.1999–18.8.1999	49.02694444	22.37416667		1♀	Jászay	1
Bukovské vrchy	Kolbasov	xerothermic meadows	PT	7.6.1999–18.8.1999	49.00666667	22.39777778		4♀♀	Jászay	4
Bukovské vrchy	Nová Sedlica	alder forests	IC	24.5.1994	49.06	22.51666667		1♀	Jászay	1
Bukovské vrchy	Runina	beech forests	IC	13.6.1994	49.07027778	22.36694444	1♂		Jászay	1
Bukovské vrchy	Zboj	beech forests	PT	1.6.1995–7.8.1995	49.10527778	22.45833333	6♂♂	13♀♀	Jászay	19
Bukovské vrchy	Osadné	pastures	PT	15.10.1999–26.5.2000	49.15333333	22.16944444	1♂		Jászay	1
Bukovské vrchy	Osadné	pastures	PT	26.5.2000–3.8.2000	49.15333333	22.16944444	1♂		Jászay	1
Bukovské vrchy	Ruské	wet up to mesophilic meadows	PT	23.6.2000–24.7.2000	49.1425	22.33888889		3♀♀	Jászay	3
Bukovské vrchy	Ruské	wet meadows and fens	PT	30.10.2000	49.12222222	22.305		2♀♀	Jászay	2
Bukovské vrchy	Ruský Potok	beech forests	PT	7.6.1995–10.8.1995	49.04027778	22.44222222	1♂	1♀	Jászay	2
Bukovské vrchy	Stakčín	xerothermic oak forests	PT	27.5.1999–30.7.1999	49.0225	22.24194444		1♀	Jászay	1
Bukovské vrchy	Stakčín	xerothermic oak forests	PT	26.7.2000–9.9.2000	49.0225	22.24194444		1♀	Jászay	1
Bukovské vrchy	Stakčín	xerothermic meadows	PT	21.10.1999–11.5.2000	49.01555556	22.21944444	5♂♂	5♀♀	Jászay	10
Bukovské vrchy	Stakčín	xerothermic meadows	PT	11.5.2000–25.8.2000	49.01555556	22.21944444	3♂♂	3♀♀	Jászay	6
Bukovské vrchy	Stakčín	xerothermic meadows	PT	25.7.2000–9.10.2000	49.01555556	22.21944444	1♂	1♀	Jászay	2
Bukovské vrchy	Starina	xerothermic meadows	PT	1.5.1995–18.7.1995	49.05305556	22.28055556		1♀	Jászay	1
Bukovské vrchy	Starina	abandoned meadows and pastures	PT	11.5.2000–25.7.2000	49.06305556	22.25722222	1♂	3♀♀	Jászay	4
Bukovské vrchy	Zboj	wet meadows and fens	PT	11.6.1999–20.8.1999	49.01944444	22.53388889	7♂♂	22♀♀	Jászay	29
Bukovské vrchy	Osadné	wet meadows and fens	PT	26.5.2000–3.8.2000	49.17583333	22.22722222		1♀	Jászay	1
Bukovské vrchy	Uličˇ	oak-hornbeam forest	PT	26.7.2000	48.95916667	22.44416667	1♂	3♀♀	Jászay	4
Bukovské vrchy	Uličˇ	oak-hornbeam forest	PT	21.9.2000	48.95916667	22.44416667	1♂	7♀♀	Jászay	8
Bukovské vrchy	Uličˇ	margin of oak-hornbeam forest and meadows	PT	26.7.2000	48.9575	22.44527778	1♂	8♀♀	Jászay	9
Bukovské vrchy	Nová Sedlica	margin of beech forest and mountain meadows	PT	24.4.2002–1.10.2002	49.09138889	22.55583333	1♂	4♀♀	Jászay	5
Nízke Beskydy	Bardejovské Kúpele	firb-eech forest with maple	PT	1.8.2010–5.9.2010	49.36277778	21.26111111		1♀	Jászay	1
Nízke Beskydy	Bardejovské Kúpele	fir-beech forest with maple	PT	1.7.1986	49.36277778	21.26111111	1♂	1♀	Jászay	2
Pieniny	Červený Kláštor	wet meadows and fens	IC	June 1987	49.40916667	20.42472222		1♀	Jászay	1
Čergovské vrchy	Olejníkov	beech forests	IC	30.5.1998	49.20888889	21.14972222		1♀	Jászay	1
Nízke Beskydy	Brezov	field	IC	29.6.1998	49.15166667	21.49805556	1♂	1♀	Jászay	2
Čergovské vrchy	Šiba	fir-beech forest with maple	IC	19.6.1955	49.23805556	21.21555556	1♂		Jászay	1
Ondavská vrchovina	Valkov	beech forest	IC	23.7.1973	49.07222222	21.64083333		1♀	Jászay	1
Ondavská vrchovina	Valkov	beech forest	IC	20.6.1975	49.07222222	21.64083333	1♂		Jászay	1
Ondavská vrchovina	Valkov	beech forest	IC	1.7.1976	49.07222222	21.64083333	1♂		Jászay	1
Bukovské vrchy	Zboj	margin of beech forest and mountain meadows	IC	20.6.1994–23.8.1994	49.10527778	22.45833333	4♂♂	12♀♀	Jászay	16
Bukovské vrchy	Nová Sedlica	mesophilic meadows	IC	24.4.2002–1.10.2002	49.08611111	22.53305556	1♂♂	2♀♀	Jászay	3
Bukovské vrchy	Nová Sedlica	beech forest	IC	10.7.2019	49.06000315	22.53333733			Bednařík	1
Bukovské vrchy	Ruské	mesophilic meadows	IC	10.7.2019	49.14389204	22.33056033			Bednařík	7
Bukovské vrchy	Ruské	mesophilic meadows	IC	20.6.2018	49.14389204	22.33056033			Bednařík	6
Bukovské vrchy	Zboj	beech forest	IC	28.7.2020	49.10111403	22.44944842			Bednařík	1
Bukovské vrchy	Zboj	beech forest	IC	4.7.2017	49.10111403	22.44944842			Bednařík	1
Bukovské vrchy	Zboj	beech forest	IC	29.7.2020	49.08500300	22.46000439			Bednařík	4
Bukovské vrchy	Zboj	beech forest	IC	2.7.2017	49.08500300	22.46000439			Bednařík	5
Bukovské vrchy	Ruské	mesophilic meadows	IC	9.6.2017	49.14389204	22.33056033			Bednařík	1
Vihorlatské vrchy	Brekov	mesophilic meadows	IC	23.5.2015	48.90143437	21.83138423			Gabzdil	1
Vihorlatské vrchy	Brekov	mesophilic meadows	IC	3.6.2015	48.90143437	21.83138423			Gabzdil	1
Vihorlatské vrchy	Brekov	mesophilic meadows	IC	4.6.2015	48.90143437	21.83138423			Gabzdil	1
Vihorlatské vrchy	Brekov	mesophilic meadows	IC	24.5.2015	48.90143437	21.83138423			Gabzdil	1
Vihorlatské vrchy	Brekov	mesophilic meadows	IC	15.6.2015	48.90143437	21.83138423			Gabzdil	1
Vihorlatské vrchy	Brekov	mesophilic meadows	IC	16.6.2015	48.90143437	21.83138423			Gabzdil	1
Vihorlatské vrchy	Jasenov	abandoned meadows and pastures	IC	16.6.2015	48.90610916	21.92446931			Gabzdil	1
Vihorlatské vrchy	Jasenov	abandoned meadows and pastures	IC	15.6.2015	48.90610916	21.92446931			Gabzdil	1
Vihorlatské vrchy	Jasenov	abandoned meadows and pastures	IC	4.6.2015	48.90610916	21.92446931			Gabzdil	1
Vihorlatské vrchy	Jasenov	abandoned meadows and pastures	IC	3.6.2015	48.90610916	21.92446931			Gabzdil	1
Vihorlatské vrchy	Jasenov	abandoned meadows and pastures	IC	24.5.2015	48.90610916	21.92446931			Gabzdil	1
Vihorlatské vrchy	Jasenov	abandoned meadows and pastures	IC	23.5.2015	48.90610916	21.92446931			Gabzdil	1
Vihorlatské vrchy	Vyšná Rybnica	beech forest	IC	26.5.2007	48.88301121	22.21465301			Potocký	3
Vihorlatské vrchy	Vyšná Rybnica	beech forest	IC	26.5.2007	48.88301121	22.21465301			Potocký	3
Vihorlatské vrchy	Remetské Hámre	beech forest	IC	25.5.2007	48.86634235	22.19799692			Pelikán	2
Východoslovenská pahorkatina	Remetské Hámre	mesophilic meadows	IC	10.7.1992	48.85041342	22.18299050			Jendek	1
Východoslovenská pahorkatina	Remetské Hámre	mesophilic meadows	IC	3.6.1994	48.85041342	22.18299050			Jendek	1
Bukovské vrchy	Zboj	mesophilic meadows	IC	26.6.1993	49.02669736	22.48233337			Jendek	1
Bukovské vrchy	Uličˇ	mesophilic meadows	IC	1.6.1994	48.96178201	22.42409781			Jendek	1
Bukovské vrchy	Uličˇ	mesophilic meadows	IC	29.6.1993	48.96178201	22.42409781			Jendek	1
Vihorlatské vrchy	Koňuš	beech forest	IC	12.7.1992	48.78491696	22.31546043			Jendek	1
Východoslovenská pahorkatina	Remetské Hámre	mesophilic meadows	IC	15.6.1997	48.85041342	22.18299050			Jendek	1

meadows, well-lit forests with glades and edges of forests near meadows with extensive management and with plenty of natural hiding places (Olšovský, 2015). Its occurrence in the first half of the 20th century in the former Czechoslovakia and in surrounding countries are summarized by Niedl (1957), where this species is referred to 2 subspecies of *Carabus scheidleri*, namely *C.s. zawadskyi* and *C.s. ronayi.* This species is reported in eastern Slovakia and also in Hungary and Ukraine (Figs 3, 4).

Taxonomy

There are very few studies on the taxonomy of this species and most of them indicate it is problematic in terms of its various subspecies (Barloy et al., 2014). Zawadzkii's ground beetle was a species with unclear taxonomic status in the past. For specialists on Carabidae, it is only a subspecies of Scheidler's ground beetle (*Carabus scheidleri* Panz.) in the Western Carpathians, which is widespread in Central Europe. Also, in the last Catalogue of Palearctic Coleoptera (Löbl & Löbl, 2017) it is a subspecies of Scheidler's ground beetle as *Carabus scheidleri zawadzkii* (according to Annex II of HD it is *Carabus zawadzkii*). *Carabus scheidleri zawadzkii seriatissimus* Reiter, 1896 recorded from Romania and Ukraine is on the other hand in the Catalogue of Palearctic Coleoptera listed as separate subspecies *Carabus scheidleri seriatissimus* (Löbl & Löbl, 2017) and *zawadzkii* is not mentioned. However, there are experts who recognize it as a completely separate species. From the point of view of European legislation, the process of declaration of Natura 2000 sites is based on the Habitats Directive, where under the listed name *Carabus zawadzkii* there are currently *Carabus scheidleri zawadzkii zawadzkii*, *Carabus scheidleri zawadzkii ronayii* and *Carabus scheidleri seriatissimus* (listed also by some experts as *Carabus scheidleri zawadzkii seriatissimus*, *Carabus zawadzkii seriatissimus*) and this understanding is accepted in the present paper.

Aim of the research

The aim of this research is to use field data to clarify the species' niche in terms of its association with mainly non-forest habitats and identify what management measures will better maintain or improve the conservation status of *Carabus zawadzkii.* Forest habitats are already confirmed habitats of this species and not the main focus of this research although it also includes some findings related to forest ecosystems. A significant part of the research is also dedicated to determining the most appropriate monitoring methods for assessing the seasonal dynamics of this species. An additional aim is to present a comprehensive overview of the distribution of this important and very rare Carpathian species for which there is currently very little information.

MATERIALS AND METHODS

Study area

Carabus zawadzkii and carabid assemblages were studied in the Slovakian part of the Eastern Carpathians. This study is mainly an inventory of the non-forest habitats of this species and an assessment of its conservation status.

Inventory

This part of the research was carried out mainly at the end of the last century and first years of the present century with the aim of collecting data on the distribution of the epigeic fauna especially the species of community interest (Natura 2000 species) including *Carabus zawadzkii*. Only a few records are available for the period since 1955 and 1970s. An overview of the localities where *Carabus zawadzkii* occurs is presented in Table 1 and Fig. 4. Sampling was carried out mainly by using formalin pitfall traps without bait, which is identical with that described in subchapter "Sampling". This was supplemented by collecting specimens. Most of the specimens of *Carabus zawadzkii* collected were deposited in the Šariš Museum of Entomological Collections (Bardejov, Slovakia).

Table 2. Survey of the 20 studied non-forest habitat localities in NP Poloniny, and categorization of their generalized habitat type.

Code	Locality	Cadaster	Altitude	Longitude and latitude (WGS 84)		Types of habitats
R1	Ruské 1	Ruské	910	49°8.646′	22°21.228′	mountain meadows
R2	Ruské 2	Ruské	622	49°8.225′	22°20.466′	mountain meadows
R3	Ruské 3	Ruské	568	49°7.970′	22°20.443′	mountain meadows
R4	Ruské 4	Ruské	570	49°7.786′	22°20.466′	mesophile meadows
R5	Ruské 5	Ruské	535	49°7.453′	22°20.475′	mesophile meadows
R6	Ruské 6	Ruské	504	49°7.225′	22°20.444′	nitrophilous ruderal plant communities
R7	Ruské 7	Ruské	548	49°6.873′	22°20.440′	mesophile meadows
R8	Ruské 8	Ruské	482	49°6.652′	22°20.418′	wet meadows and fens
R9	Ruské 9	Ruské	454	49°6.398′	22°20.412′	nitrophilous ruderal plant communities
R10	NNR, Pod Ruským 10	Veľká Poľana	439	49°6.229′	22°20.031′	wet meadows and fens
St11	Starina 11	Starina	374	49°2.729′	22°14.944′	abandoned meadows
Pr12	Príslop 12	Príslop	514	49°2.345′	22°19.240′	Intensively-used mesophile meadows
Pr13	Príslop 13	Príslop	508	49°2.352′	22°19.252′	mesophile meadows with specific management
To14	Topoľa 14	Topoľa	362	49°1.562′	22°21.184′	Intensively-used mesophile meadows
To15	Topoľa 15	Topoľa	359	49°1.544′	22°21.164′	mesophile meadows with specific management
Bz16	NR Bzaná 16	Kolbasov	375	49°0.843′	22°22.637′	mesophile meadows
Ko17	Kolbasov 17	Kolbasov	302	49°0.431′	22°22.997′	wet meadows and fens
Se18	Nová Sedlica 18	Nová Sedlica	427	49°2.554′	22°31.155′	wet meadows and fens
Se19	Nová Sedlica 19	Nová Sedlica	428	49°2.574′	22°31.213′	abandoned meadows
Se20	Nová Sedlica 20	Nová Sedlica	433	49°2.560′	22°31.202′	mesophile meadows

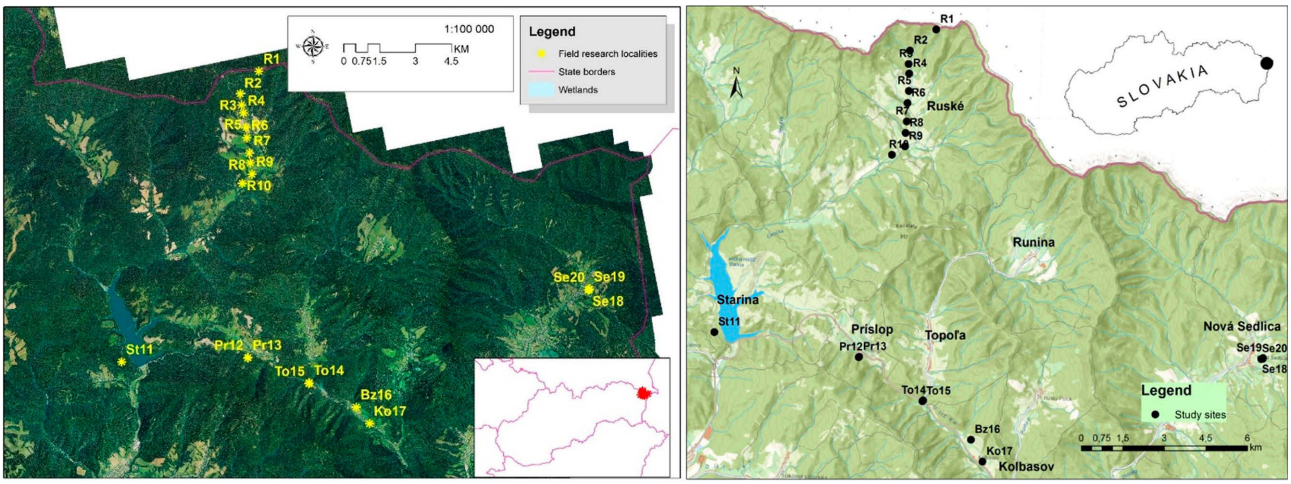

Fig. 5. Area and localities studied in eastern Slovakia in 2011–2013 projected on satellite images (left) and map of land cover (right).

Research on non-forest habitats

Our chosen model area was the Poloniny National Park, which extends over a large part of the Bukovské mountains and includes a small area in Slovakia, located in the eastern part, on the borders with Poland and Ukraine. The topography of the area is mainly mountaineous, with a more or less rugged relief of the flysch zone and dominance of deciduous forests only in the eastern part, with mixed forests here and there.

The landscape in the area is typically Carpathian and the localities studied were chosen for their similarity with other places in the known range of *Carabus zawadzkii*. According to Bezák (2010), meadow ecosystems currently cover about 10% of the area. These are mainly typical mountain meadows, which are located on the main ridges of the Bukovské mountains. In addition to mountain meadows, various non-forest ecosystems are also present: pastures; moist, mesophilic, ruderal, xerothermic and permanent grasslands; and other types of non-forest habitats. The research was carried out at 20 localities, with 7 types of non-forest habitats characteristic of the Eastern Carpathians (Table 2 and Fig. 5).

Localities studied: "Mountain meadows"

The mountain meadows studied are Ruské 1 (R1), Ruské 2 (R2) and Ruské 3 (R3). R1 is a typical mowed mountain meadow belonging to the *Nardo strictae-Agrostion tenuis* alliance. Depending on the time since last mowing, they were at different successional stages. Tree species coverage is rather low, but species composition changes over time (Ružičková & Halada, 2002; Halada et al., 2004). There was a fire at this site in the spring of 2012. R2 and R3 are meadows belonging to the *Calamagrostion arundinacae* alliance. The communities of this association primarily occur at high altitudes, but also occur secondarily at low altitudes in areas free of forest due to grazing. In the Bukovské mountains, the occurrence of communities of this association are secondary and occur on the main ridge and sides of high ridges at altitudes above 800 m (Ružičková & Halada, 2002; Halada et al., 2004). The R2 site was not mown during the study period and that at R3 was mown once.

"Wet meadows and fens"

Wet meadows and bogs occur at Ruské 4 (R4), Ruské 8 (R8), National Nature Reserve (NNR) Pod Ruským 10 (R10), Kolbasov 17 (Ko17) and Nová Sedlica 18 (Se18). These are moist meadow habitats with a relatively stable groundwater level, where the soil surface is rarely completely dry. All were created by human activity. They belong to the *Calthion* alliance. All areas are mown once a year (Ružičková & Halada, 2002; Halada et al., 2004). The Se18 locality is a peat meadow belonging to the *Caricion lasiocarpae* alliance. At Pod Ruským (R10) there are natural communities of moist waterlogged meadows and wetlands on the floodplain of the Cirocha River. The overall character of the vegetation is that of tall wetland plants typical of swamp and wetland communities.

"Mesophilic meadows"

The mesophilic meadows studied are those at Ruské 5 (R5), Ruské 7 (R7), Kolbasov – Nature Reserve (NR) Bzaná 16 (Bz16) and Nová Sedlica 20 (Se20). These meadows are at middle mountain locations and in lowlands on nutrient rich or fertilized soils. They belong to the alliance *Arrhenatherion elatioris*. Typical *Arrhenatherion* meadows are currently extremely rare in the area studied, with only the subtype with red fescue present (Ružičková & Halada, 2002; Halada et al., 2004). Locations R5, R7, Bz16 and Se20 were mown once a year. Nature reserve Bzaná (Bz16) is a rich mesophytic meadow and shrub community with a south-western exposure.

"Intensively used mesophilic meadows"

The localities Príslop 12 (Pr12) and Topoľa 14 (To14) are non-forest habitats. They are intensively-used mesophilic meadows at middle mountain locations and lowlands on nutrient rich or fertilized soils. They belong to the alliance *Arrhenatherion elatioris*. The areas surveyed were mown twice a year.

"Mesophilic meadows with specific management"

The localities Príslop 13 (Pr13) and Topoľa 15 (To15) are non-forest habitats of this type. These are mesophilic meadows at mid mountain locations and in lowlands belonging to the *Arrhenatherion elatioris* alliance, which are similar to the previous type, but importantly unlike them in terms of biodiversity and are managed in a specific way (e.g. use of only organic fertilizers, limits on the dosage thereof, etc.) as specified in the document "Rural Development Program SR 2007–2013" (Ministry of Agriculture of SR, 2010). The funds for their protection and management are provided by higher subsidies than for intensively used meadows. The areas surveyed were mown once a year.

"Nitrophilous ruderal plant communities"

Two localities, namely Ruské 6 (R6) and Ruské 9 (R9), are of this type. These are nitrophilic ruderal fringe communities outside settlements, belonging to the *Galio-Alliarion* alliance (R6) and

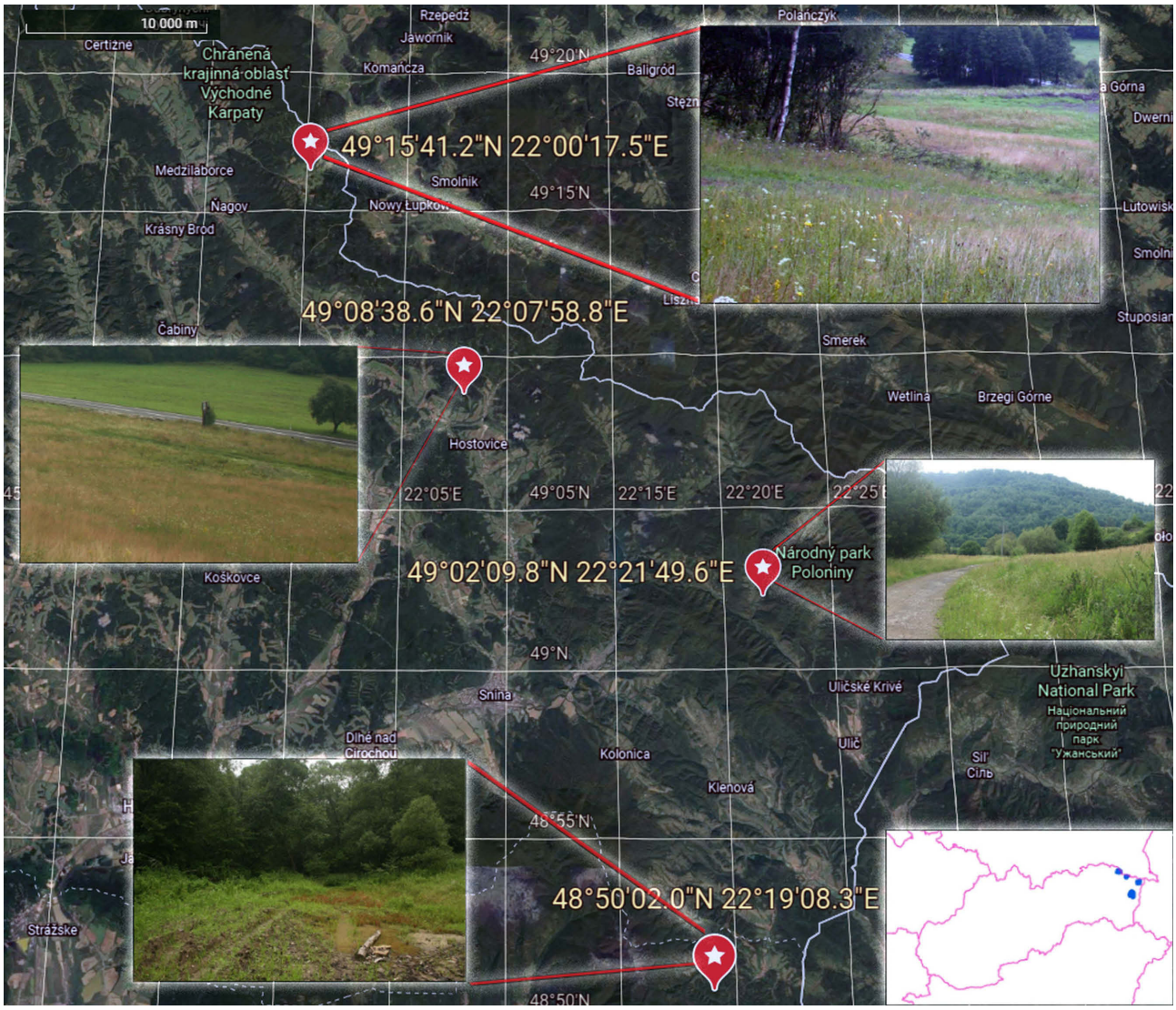

Fig. 6. Plots monitored for assessing the conservation status of *Carabus zawadzkii* during field visits in 2013–2021.

the *Aegopodion podagrariae* alliance (R9), association *Chero-phylletum aromatici*. There was a fire at locality R9 in 2013.

"Abandoned meadows"

The localities Starina 11 (St11) and Nová Sedlica 19 (Se19) include abandoned meadows. St11 is an unmown acid meadow with a fluctuating water regime influenced by groundwater from the Starina reservoir. It belongs to the alliance *Caricion lasiocarpae*. It is at succession stage of moist thistle and Filipendula meadows of the *Polygalo-Cynosurenion* alliance. These meadows are more species-rich with a unique species composition (Ružičková & Halada, 2002; Halada et al., 2004). Se19 is an unmown degraded meadow belonging to the alliance *Calthion palustris*.

Analysis of the distance of the localities from forest habitats

Since the preference of *Carabus zawadzkii* for forest habitats is mentioned by several authors, it is necessary to determine the distance of the areas studied from the nearest forest when determining and confirming a possible relationship with other habitats (in our case non-forest habitats). Distance is especially important in terms of determining the extent to which nearby forest ecosystems can affect the occurrence of this species. For this purpose, a GIS analysis of the distance of the localities studied from the nearest forest habitats was carried out. This analysis was performed in Arc GIS 10.1 using the NEAR function, which measures the shortest distance to specified elements (in this case, polygons of forest habitats). Based on the recorded distances of the 20 localities the average value of the distance of all areas from forest habitats was calculated.

Sampling

Field research was conducted over a two-year period: June 2011–June 2013. Pitfall traps were used to catch beetles of the genus Carabus (Coleoptera) especially *Carabus zawadzkii*. At every locality a line of 5 pitfall traps (plastic cups of 10 cm diameter and 0.5 l capacity) were set at 5 m intervals and monitored on a regular basis.

Diversity of *Carabus* assemblages recorded in the habitats at the localities studied

Diversity was evaluated using three parameters: number of taxa, α-diversity, Shannon index of diversity (H) and Pielou index of equitability (J).

Evaluation of ecological factors and gradients

For determining the statistical significance of the relationships of LEV (landscape environment variables) with the distribution of *Carabus* beetles at the localities studied, we used a Monte-

Table 3. List of species of *Carabus* recorded, their abundance and dominance, and summary of the results of the field research (2011–2013).

Species	No. of records	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total no. of individuals	Dominance (%)
Carabus arcensis Herbst, 1784	75	7	1	6		14	14	6	11	5	1	62				3	4			62	10	206	14.7
Carabus auronitens Fabricius, 1792	3		2	1																		3	0.2
Carabus cancellatus Reitter, 1896	74	164	100	75	1	2	4	6		4					2		1		1	4		364	26
Carabus convexus Fabricius, 1775	21					6	2	1		1	1			1		14	3				1	30	2.1
Carabus coriaceus Linnaeus, 1758	66	1			4	4	6	4	8	39	7	1			2	7		6	5	2	2	98	7
Carabus glabratus Paykull, 1790	3			2		1	1	1														5	0.4
Carabus granulatus Linnaeus, 1758	54			5	3	5	20		19	5	26				6			1	1			91	6.5
Carabus intricatus Linnaeus, 1758	3		2											1							1	4	0.3
Carabus irregularis Fabricius, 1792	3						1	1	1													3	0.2
Carabus linnaei Panzer, 1812	5						4			1											1	6	0.4
Carabus obsoletus Sturm, 1815	45	45	23	12	1	1	3			1		8	3							12	4	113	8.1
Carabus sylvestris Panzer, 1793	1								1													1	0.1
Carabus ulrichii Germar, 1824	35		1	1				6	2			51			5		1			1	2	70	5
Carabus variolosus Fabricius, 1787	17		2		2				14		1					4			28	1		52	3.7
Carabus violaceus Linné, 1758	120	20	5	21	16	55	56	17	23	26	11	3	3						2			258	18.4
Carabus zawadszkii Kratz, 1854	38	14	11	6	5	1	8	1				2	7	32			3			4	1	95	6.8
Total no. of individuals		251	147	129	32	89	119	43	79	82	47	127	13	34	15	28	12	7	37	86	22	1399	100
Dominance (%)		17.9	10.5	9.2	2.3	6.4	8.5	3.1	5.6	5.9	3.4	9.1	0.9	2.4	1.1	2	0.9	0.5	2.6	6.1	1.6	100	
No. of species		6	9	9	7	9	11	9	8	8	6	6	3	3	4	4	5	2	5	7	8		

Carlo permutation test (Ter Braak & Šmilauer, 2018; Šmilauer & Lepš, 2014) of the full model, with 1999 iterations. Software CANOCO5 was used for this purpose. A significance level of $\alpha = 0.05$ was used to test the parameters of the variables. Results for all of the 20 localities studied were tested. Species richness and Shannon's index were calculated using the statistical package in MS Excel.

To evaluate the significance of the carabid assemblages at the localities we used sample averages (number of individuals at a locality / total number of species), counts (number of species at the localities), recount (number of species at a locality / total number of species), variance (sample variance), total (sum of specimens), N2 (Simpsons index = 1 / Σ(pi)2), H´ (Shannon entropy = –∑ pi * lnpi), H´max (log number of species in samples) and evenness (sample H´ / log (N) ratio). These data were exported from the Canoco5 program using the menu Statistics of compositional table (Šmilauer & Lepš, 2014). We chose ordination methods based on the greatest lengths of the environmental gradient (lengths of gradient = SD units) as described by Šmilauer & Lepš (2014).

We used 11 environmental variables to define the ecological characteristics of a site: altitude, vegetation cover (E1%), abandoned meadows, building rubbish, mowed meadows and type of vegetation (coded as 6 dummy variables: *Nardo strictae-Agrostion tenuis*, *Calamagrostion arundinaceae*, *Calthion*, *Arrhenatherion elatioris*, *Galio-Alliarion*, *Caricion lasiocarpae*). We tested the statistical significance ($p\alpha = 0.05$) of the null hypothesis (environmental factors do not affect the species groupings) using a Monte Carlo permutation test with 499 permutations. The success of the analysis was measured by the value of the coefficient of determination (R^2) and its adjusted value R^2_{adj}, which considers sample size and number of variables. We tested the simple effects, which summarize the independent effects of all the explanatory variables, and conditional effects, which summarize the conditional (partial) effect of each predictor. We verified the tightness of the mutual relationship (correlation) with environmental factors using the nonparametric Spearman correlation coefficient in the Statistika.cz program (StatSoft, 2004). For this verification we used the correlation matrix in Canoco5 (log file, $p_\alpha = 0.05$). We evaluated The strength of the linear bond was evaluated using the r coefficient and the categories proposed by Conelly (2012): strength of correlation $r < 0.2$ slight, $r = 0.2$–04 low, $r = 0.4$–0.7 moderate, $r = 0.7$–0.9 high, $r > 0.9$ very high.

Monitoring – conservation status

In order to assess the conservation status, specific field visits were carried out in the period 2013–2021 (Fig. 6) and additional data collected in 2011–2013. The plots monitored were visited repeatedly in order to record quantitative and qualitative data using a standardized method (Saxa et al., 2015). This method was based primarily on monitoring abundance using animal traps distributed along a transect (5 traps at 5 m intervals) and recording parameters related to the quality of the species' habitat, future prospects, threats and pressures. At 4 plots selected for monitoring *Carabus zawadzkii*, 20 field visits were made. All the plots monitored were in non-forest habitats, mostly habitats in hay meadows.

The conservation status based on individual parameters and overall assessment were divided into 3 categories: favourable (FV), unfavourable-inadequate (U1) and unfavourable-bad (U2).

Evaluation of the species' conservation status using this categorization is based on the evaluation of these parameters:

(a) Quality of the population at a locality
(b) Quality of the habitat at a locality
(c) Future prospects of the species' habitat at a locality

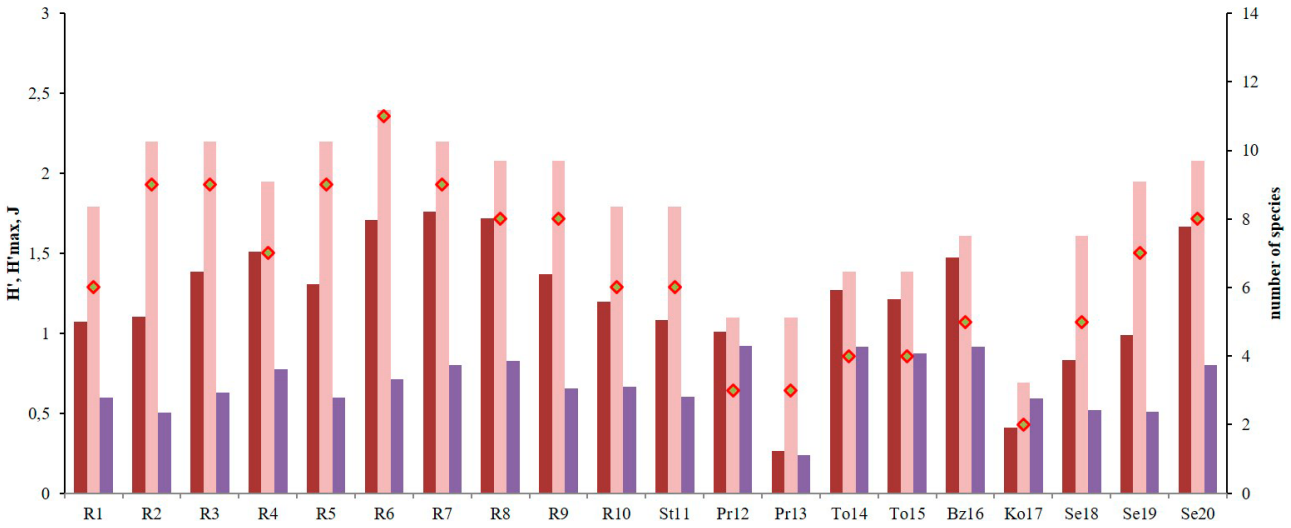

Fig. 7. Number of species (burgundy), Shannon index of diversity (pink) and Pielou index of equitability of the plots studied (lilac colour).

These three parameters were evaluated. For each parameter and category of status, the percentage values were estimated on the basis of an expert assessment during short field visits (two days visits per year). The process by which this data was used to assess the overall status of the individual parameters was as follows.

The overall status for a particular parameter, a, b or c, is favourable when the following values are achieved:

– favourable ≥ 85% of assessments are favourable, or favourable when ≥ 70% of assessments are favourable and no assessements are unfavourable-bad.

The overall status for a particular parameter is unfavourable-bad when the following values are achieved:

– unfavourable-bad assessments are ≥ 50% of the total assessments.

All other combinations of percentages result in an unfavourable-inadequate status of the given parameter.

This assessment of parameters was followed by a joint evaluation of all assessed parameters, which combines the results of the evaluations of all the parameters. The parameter which scored the worst determines the total assessment at the locality level. So, where all three parameters are favourable (FV), the overall conservation status at the locality is also assessed as favourable (FV). If one or more parameters are assessed as unfavourable-bad (U2), the overall conservation status at the locality is assessed as unfavourable-bad (U2). All other combinations result in an unfavourable-inadequate conservation status (U1). This method of assessment was used separetly for each plot monitored. The overall approach and assessment were based on the standardized conservation status assessment reported for Slovakia (Janák et al., 2015). After the calculations at the locality level, the final conservation status was defined on the basis of the number of FV, U1 and U2 assessments. The parameter which occurred most often was recorded as the conservation status. In addition, the average % for the quality of the population, quality of the habitat and future prospect was calculated as a mean value for the assessments of all 20 field visits.

RESULTS

Inventory of the samples of *Carabus zawadzkii*

There are 73 records of *Carabus zawadzkii* recorded by experts in the period from 1976–2020 (Table 1). Based on the prevalence of records (41 vs. 29) and abundance (118 vs. 96 specimens) this species mainly occurs in non-forest habitats (Table 4). It is evident that this species also occurs in forest habitats. In forest habitats *Carabus zawadzkii* is recorded occuring in beech forests, fir-beech forests, alder forests, thermophilous oak and oak-hornbeam forests (Table 4). In the case of forest habitats, it is possible that the edges of the forests are also suitable as at Babličke in oak-hornbeam forest, during the same period of time, this species was more numerous in traps at the edge of the forest than in those located in the forest (9 vs. 4 specimens).

Number of species of *Carabus* recorded in non-forest habitats

During the period 2011–2013, a total of 1399 individuals of the genus *Carabus* belonging to 16 species, were recorded in seven non-forest habitats (Table 3). The most numerous species in non-forest habitats in the area studied were the 3 eudominant species, *Carabus cancelatus* (26.02%), *Carabus violaceus* (18.44%) and *Carabus arcensis* (14.72%). Five *Carabus* species were dominant in the area studied. Of the Annex II HD species, two were

Table 4. Inventory of the presence of *Carabus zawadzkii* in particular habitats.

Habitat	No. of observations	No. of specimens
Forest habitats ∑	29	96
alder forests	2	2
beech forest	12	24
beech forests	8	52
fir-beech forest with maple	3	4
oak-hornbeam forest	2	12
xerothermic oak forests	2	2
Margin of forest and meadows ∑	3	30
margin of beech forest and mountain meadows	2	21
margin of oak-hornbeam forest and meadows	1	9
Non-forest habitats ∑	41	118
abandoned meadows and pastures	7	10
field	1	2
mesophilic meadows	19	42
pastures	3	4
wet meadows and fens	5	34
damp mesophilic meadows	1	3
xerothermic meadows	5	23
Total	73	244

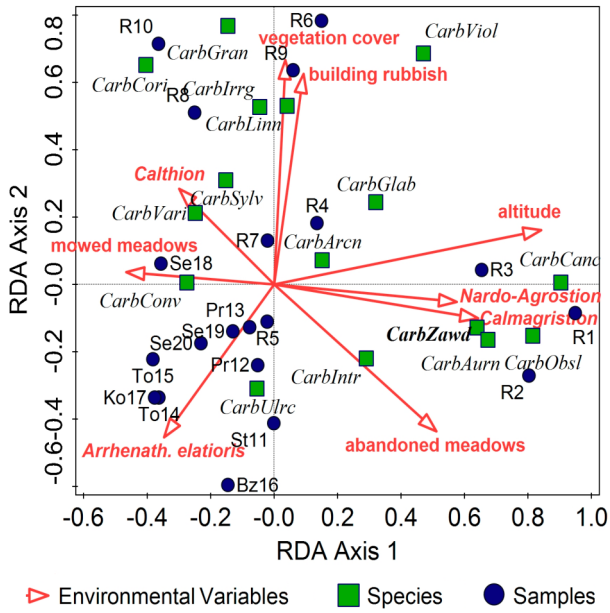

Fig. 8. Redundancy analysis (RDA) of the relationship between species occurrence and non-forest habitats.

relatively numerous, *Carabus variolosus* being eudominant and *Carabus zawadzkii* dominant in the samples.

Biodiversity

The carabid assemblages in the samples were evaluated in terms of species richness, diversity and equitability (Fig. 7). The highest number of species was recorded in nitrophilous ruderal plant communities (R6), with 11 species. High values of the diversity index were recorded in habitats at localities R7 and R8, and the highest value of equitability at localities Pr12, To14, To15 and Bz16 (above 0.9). The carabid assemblages recorded at locality Pr13 had the lowest equitability value (0.24) due to the low number of identified species and of the eudominant *Carabus zawadzkii*. The lowest number of species (2 to 3 species) was recorded in the meadow communities at Príslop (Pr12 and 13) and wet meadow at Kolbasov (Ko17).

Detailed statistics and calculated indexes of Average, Count, Relative Count, Variance, N2, H′, H′max and Evenness for individual localities are in Table S1.

Carabus zawadzkii in non-forest habitats

This species was recorded more frequently in non-forest habitats. The species was recorded at most localities (13 of the 20 localities studied) and in all types of non-forest habitats. The results indicate that in addition to other habitats this species regularly occurs abundantly in mountain meadows and was recorded in all the mountain meadows studied (Table 3).

It was most abundant at Pr13, which is one of the 2 managed sites (Table 3). Thirty-two individuals were recorded here over 2 years. A relatively high abundance of this species (7 individuals) was also recorded at Pr12, but it is 4.5 times less than at Pr13. It is interesting that these localities had low α-diversities and therefore *Carabus zawadzkii* was subject to little competition. In contrast, the lowest frequency of occurrence of *Carabus zawadzkii* was recorded in wet habitats and was recorded at only one of the 5 wetland sites studied. The presence in this type of habitat is probably accidental, because it was recorded only once and at the edge of wetland habitat R4, possibly due to a marginal effect. The wetland at R4 is relatively small and the composition of the invertebrates caught by the lateral trap and pitfall traps was possibly affected by extensively-used meadows located close by. Based on these results we assume that this species avoids wetland habitats.

The unimodal analysis of the response (species) data provided a gradient value of 2.7 SD units, which indicates a linear method (Redundancy analysis) should be used. The analysis of the relationship (Fig. 8) between non-forest habitats and occurrence of the studied species suggests a connection between *Carabus zawadzkii* and extensively-managed mountain meadows that are mown once a year, or even less frequently, with the presence of some degree of secondary succession. Occurrence of this species was also recorded in uncultivated meadows that had not been mown for a long time, although in these areas the abundance of this species was very low. Based on these findings, we conclude that this species prefers extensively-farmed mountain meadows (apart from forest habitats) and that the population declines with time since they were last mowed. On the other hand, there was a low abundance of this species in ruderal and forest areas. The preferred plant communities in non-forest habitats included the phytocenological alliances *Nardo strictae-Agrostion tenuis* and *Calamagrostion arundinacae*. We recorded similar habitat preferences (only occasionally mown or unmown) for the species *Carabus auronitens*, *Carabus intricatus*, *Carabus obsoletus* and *Carabus cancelatus*.

Table 5. Unimodal analysis of response (species) data. IF – inflation factor; p bold – statistically significant variables ($p < 0.005$); simpl – simple effects; condi – conditional effects.

Variables	IF	Explains % simpl/condi	pseudo-F simpl/condi	Pvalue simpl/condi	Pvalue (adj) simpl/condi
Altitude	4.52	22.9/22.9	5.3/5.3	0.002/0.002	**0.018/0.018**
Calamagrostion arundinaceae	4.07	14.4/4.8	3.0/1.4	**0.018**/0.202	0.162/1.000
Abandoned meadows	10.19	12.2/11.1	2.5/3.1	**0.024/0.006**	0.216/0.054
Nardo strictae-Agrostion tenuis	6.51	10.9/3.2	2.2/1.0	0.068/0.462	0.612/1.000
Arrhenatherion elatioris	7.83	9.7/5.3	1.9/1.5	0.082/0.144	0.738/1.000
Vegetation cover (E1%)	2.69	8.6/9.0	1.7/3.1	0.106/**0.006**	0.954/0.054
Building rubbish	3.23	8.6/4.3	1.7/1.3	0.118/0.224	1.000/1.000
Mowed meadows	12.36	7.7/2.7	1.5/0.8	0.200/0.558	1.000/1.000
Calthion	4.95	5.4/6.0	1.0/2.0	0.394/0.118	1.000/1.000
Galio-Alliarion	0.00	–	–	–	–
Caricion lasiocarpae	0.00	–	–	–	–

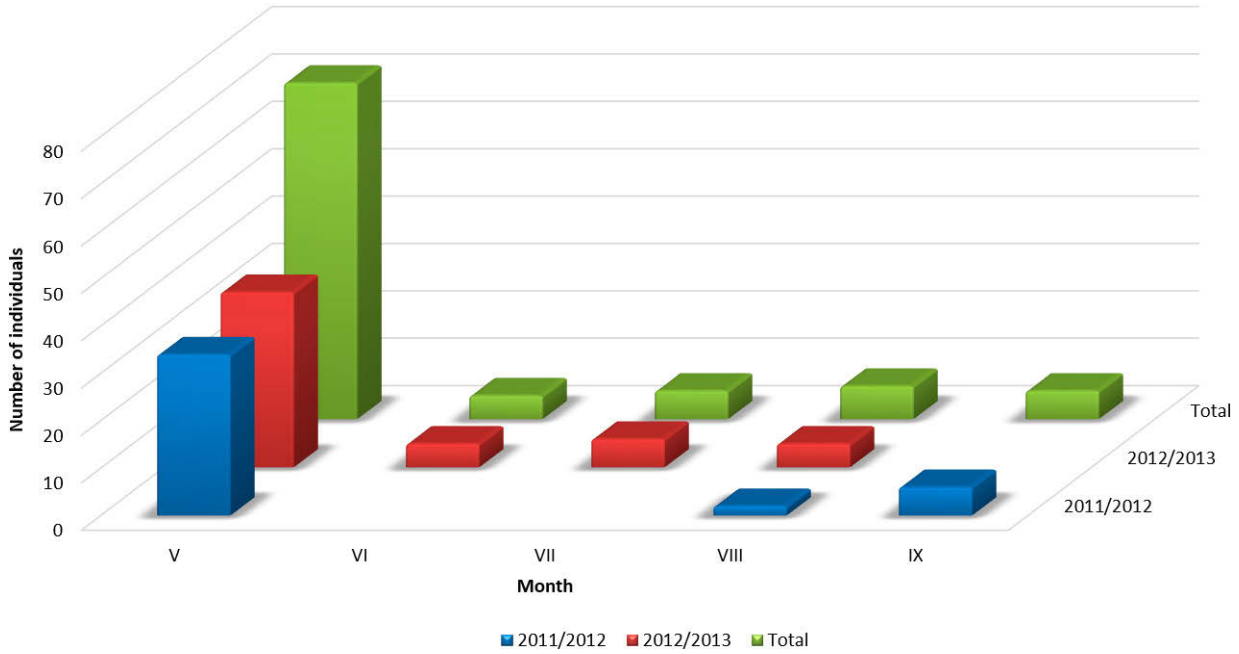

Fig. 9. Seasonal dynamics of *Carabus zawadzkii* in non-forest habitats in the period of 2011–2013.

The vegetation cover factor and ruderal communities (building rubbish) are highly positively correlated (Spearman's r = 0.76) and cover is a statistically significant factor. The vegetation types *Calamagrostion arundinaceae* (dominant tall grass in meadows at Poloniny) and *Nardo strictae-Agrostion tenuis* (r = 0.92) also correlate positively. *Calamagrostion arundinaceae* correlates very strongly and statistically significantly with the mowed meadow factor (r = –0.92).

The unimodal analysis of the response (species) data provided a gradient value of 2.7 SD units, which indicates a linear method (Redundancy analysis) should be used. The species table includes 16 species of *Carabus* recorded at over 20 localities and 59.7% zero values, i.e a particular species was not present at a particular location. Of the selected factors, the vegetation types *Galio-Alliarion* and *Caricion lasiocarpae*, were not included in the analysis as they are correlated with other factors. The remaining factors constrained by the RDA model explain 69.29% of the variability of the species data (explanatory variables account for 60.41%). The adjusted value after Benferroni correction is relatively high at 41.65% (adjusted explained variation is 24.78%). The values of the simple and conditional effects of the Monte Carlo permutation test of the null hypothesis are presented in Table 5.

Based on these results it seems that this species, as previously suggested, has a wider ecological niche (Table 6) and is also able to some extent to survive in highly anthropically-disturbed habitats (nitrophilous ruderal communities).

The ordination analysis shows that *Carabus zawadzkii* prefers abandoned meadows at high altitudes with tall vegetation (*Calamagrostis arundinacea*). Mowed meadows, bogs and moist herbaceous communities (*Calthion*) are less suitable habitats, as these factors negatively correlate with the 1st ordination axis, p = 0.002. The vegetation cover factor positively correlates with the 2nd ordination axis, p = 0.024.

NEAR analysis provided information on the distance of research plots in non-forest habitats from the nearest forest habitats. The results indicate that the average distance of the research plots from forest was 225 m. Based on these findings the occurrence of specimens in non-forest habitats is not occasional or random. Although the dispersal ability of this species can play a role in its distribution in non-forest areas, its confirmed presence at a high number of non-forest localities is significant and that this species has broad ecological niche, which includes both non-forest and forest habitats. Detailed calculation of the distances is presented in Table S2.

Table 6. Presence and frequency of *Carabus zawadzkii* in non-forest habitats.

Habitat	No. of localitiess	No. of individualss	No. of records of *Carabus zawadzkii* at locality	Frequency of occurrence at locality (%)	Average no. of individuals caught / locality
Mountain meadows	3	31	3	100	10.33
Wet meadows and fens	5	5	1	20	1
Mesophilic meadows	4	6	4	100	1.5
Intensively used mesophilic meadows	2	7	1	50	3.5
Mesophilic meadows with specific management	2	32	1	50	16
Nitrophilous ruderal plant communities	2	8	1	50	4
Abandoned meadows	2	6	2	100	3

Fig. 10. Average assessments of the quality of the habitat, quality of the population, future prospects and overall assessments of conservation status of *Carabus zawadzkii* based on field visits (n = 20).

The most common accompanying species of *Carabus*

According to Olšovský (2015), the most common accompanying carabid species are *Carabus violaceus violaceus*, *Carabus glabratus glabratus*, *Carabus obsoletus* and *Carabus nemoralis nemoralis*. Based on the results of our field study, the most common accompanying species of *Carabus* in non-forest habitats are *Carabus obsoletus*, *Carabus cancellatus* and *Carabus arcensis*. *Carabus zawadzkii* has a negative, and statistically significant, correlation with *Carabus ulrichii*. *Carabus violaceus*, one of the most common species, seems to prefer different types of habitat.

Spatial distribution

The spatial distribution of this species was uneven (Table 7) as it was often only caught by one or two of the five pitfall traps set at 9 localities. A more even spatial distribution was recorded at St12, where similar numbers of this spe-

Table 7. Spatial distribution of catches in traps at localities of *Carabus zawadzkii*.

Loc.	Habitat	No. of individuals 2011/2012	No. of individuals 2012/2013	Number of positive traps	Code of trap	No. of sampless
R1	mountain meadow	10	4	2	2 / 5	3
R2	mountain meadow	11		2	2/3/4	3
R3	mountain meadow	6		2	3/5	3
R4	wet meadow/fen	5		1	5	1
R5	mesophilic meadows	1		1	1	1
R6	nitrophilous plant ruderal communities	7	1	3	1/2/4	4
R7	mesophilic meadow		1	1	2	1
St11	abandoned meadow		2	2	3/5	2
Pr12	intensively-used mesophilic meadow		7	5	1/2/3/4/5	6
Pr13	intensively-used mesophilic meadow	5	27	4	2/3/4/5	7
Bz16	mesophilic meadow	2	1	1	1/3	3
Se19	abandoned meadow		4	3	1/4/5	3
Se20	mesophilic meadow		1	1	1	1
Total		47	48			37

cies (1 or 2 individuals) were caught by all 5 traps. This is a locality where the grass was mown twice a year. In contrast, the neighbouring locality was extensively used (occasionally mowed) and this species was caught by all but one trap, but the number captured varied significantly, from 1 to 23. The differences in the evaluated periods 2011–2012 and 2012–2013 are interesting. While in the period 2011–2012 this species was mainly recorded in the Cirocha basin, at high altitudes, in the following year it was significantly more often caught by traps located in the Ulička valley (low altitude). It is likely that the population density varies from year to year and the factors that cause this need to be investigated. Overall, the total number of individusls caught in both periods was almost the same, which indicates that the population in the area is stable, though not large. A study of the dispersal of *Carabus hungaricus* (Elek et al., 2014) indicates that its spatial distribution is influenced by its movement, which is locality dependent. The average distances moved by males and females at each of the localities ranges between 47 and 207 m (Elek et al., 2014). Dispersal of *Carabus zawadzkii* needs further study, however the average distance moved is likely to be similar to that of *Carabus hungaricus*.

Sesonal dynamics

Seasonal activity of *Carabus zawadzkii* in both years was concentrated in May, when almost 73% of the individuals were recorded (Fig. 9). From the end of September to the end of October and during the winter period (November to end of April), no individuals were caught. In the other months (June to the end of September) very few individuals were caught. The period of activity coincides with their reproductive period. The beetles had one marked period of activity that extended from the end of April to end of May and very few were caught from end of May to end of September.

Conservation status

The conservation status was assessed based on the results of 20 field visits to 4 plots (Fig. 10). The average quality of their habitat and future prospects were assessed as mostly unfavourable (39% U1 and 16% U2). The average quality of the population was assessed as 69% unfavourable (29% U1 and 40% U2), with only 31% assessed as FV. Overall, 14 field visits resulted in an assessment of unfavourable – inadequate (U1) and 6 unfavourable – bad (U2). The overall conservation status is therefore assessed as unfavourable – inadequate (U1).

The most frequently recorded threat to non-forest habitats is that of insufficient mowing and abandonment of traditional management practices as this species is most abundant in those non-forest habitats that are frequently mown.

DISCUSSION

As there is very little information on *Carabus zawadzkii* this study provides new findings on its relationship with forest and non-forest habitats and important information on its seasonal dynamics. This research did not focus on the composition of the population (age structure and reproductive characteristics) so in the future it would be interesting to study the whole life-cycle of this species.

The results presented are important for conservation agencies and organizations that are responsible for monitoring this species as it should enable them to optimize the use of funds for the collection of field data. For instance, the monitoring method currently used in Slovakia is based on recording individuals of this species living under stones and by monitoring every locality using baited non-lethal pitfall traps during the period 1st of May to 15th of October. The number of visits per year is set at 3, and the second and third visit should follow no later than 3 days after the previous visit. With such monitoring it is possible that sites are visited at the wrong time of year resulting in wrong conclusions. Therefore, based on our results, we suggest that monitoring should be carried out mainly in May. As sampling over such a short period of time provides little and potentially unreliable information we suggest that in-addition to intensive monitoring during the whole of the period of activity in May the number of field visits should be increased in order to increase the reliability of the data.

In addition this study defines the habitat in which this species normally lives. Previous studies indicate it lives mainly in forest habitats, but this study indicates it is also abundant in non-forest habitats including human-modified and disturbed habitats (intensively used meadows, abandoned meadows and pastures, nitrophilous ruderal plant communities, etc.). A similar wide ecological niche is also proposed by Andorkó & Kádár (2009) for a closely related species *Carabus scheidleri*. It is likely that the mosaic-like landscape in the Eastern Carpathians, with its open and also afforested parts, meets the habitat requirements of this important European species.

This habitat should be the choice for the location of monitoring plots in both forest and non-forest ares in future attempts to map this species' distribution.

According to the official data based on art. 17 HD reporting (EEA, 2021), the population size and trends of this species in Poland are unknown. In Slovakia, the population size is currently estimated at 1000 to 5000 individuals (probably underestimates) and its occurrence is based on 196 1 × 1 km grids, but the trend in population and distribution of this species are unknown. In Hungary, it occurs in 81 1 × 1 km grids, conservation status is listed as favourable and trends are classified as stable, however there is no detailed information on its population size and therefore most probably the results are based only on the judgement of experts rather than on recently collected field data. In Romania, both the trend in and population size of this species are unknown and the population based 1000 1 × 1 km grids is very likely to be an overestimate as there are only a few records for a few localities. Based on this information it is clear that our knowledge of this species is inadequate and the assessment of its conservation status in the 27 EU states is questionable and should be improved/corrected in the future.

Lack of data is a general problem and clearly there is a need to gather new information from across the entire

Carpathian range. For example, information on the recent distribution of this species in Ukraine comes only from very limited set of localities (Barloy et al., 2014) and its distribution is based only on old data (Rizun, 2003).

CONCLUSION

There is little and in some cases contrary information on the ecology of the rare species *Carabus zawadzkii*. This research contributes by presenting information regarding its ecological niche. *Carabus zawadzkii* is a species of European interest and is listed in Annex 2 of the HD (a species for which a Natura 2000 protected area is declared), which makes the need for research and new knowledge even more pressing. The results presented indicates that it evident that *Carabus zawadzkii* not only occurs in forest, but also in non-forest habitats. They also indicate a need for EU member states to adopt more appropriate monitoring systems and establish more monitoring plots based on these new findings, especially in Slovakia, Romania, Hungary and Poland. The results also provide important information for improving the management and conservation status of this species. Particular attention should be paid to the implementation of appropriate measures at Natura 2000 sites where this species is protected, as well as in other areas where this species occurs naturally. Regarding suitable management regimes in non-forest habitats, extensive mowing seems to be the most beneficial and in fact seems to be the most important factor for the survival of this species in addition to the presence of adequate forest ecosystems. This study also provides insights into the seasonal dynamics, showing that it is most active in May, followed by July. Despite the improvement in the knowledge of this protected species provided by this study, it is necessary to do further research on its distribution and ecology.

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Table S1. Statistics of the localities studied.

Locality	Average	Count	RelCount	Variance	Total	N2	H´	H´max	Evenness
R1	15.69	6	0.38	1708.63	251	2.13	1.07	1.79	0.60
R2	9.19	9	0.56	622.56	147	2.02	1.10	2.20	0.50
R3	8.06	9	0.56	351.53	129	2.64	1.38	2.20	0.63
R4	2.00	7	0.44	16.53	32	3.28	1.51	1.95	0.78
R5	5.56	9	0.56	187.33	89	2.40	1.31	2.20	0.60
R6	7.44	11	0.69	199.60	119	3.65	1.71	2.40	0.71
R7	2.69	9	0.56	20.10	43	4.43	1.76	2.20	0.80
R8	4.94	8	0.50	59.13	79	4.89	1.72	2.08	0.83
R9	5.13	8	0.50	123.05	82	2.97	1.37	2.08	0.66
R10	2.94	6	0.38	47.40	47	2.60	1.20	1.79	0.67
St11	7.94	6	0.38	367.66	127	2.47	1.08	1.79	0.60
Pr12	0.81	3	0.19	3.76	13	2.52	1.01	1.10	0.92
Pr13	2.13	3	0.19	63.58	34	1.13	0.26	1.10	0.24
To14	0.94	4	0.25	3.66	15	3.26	1.27	1.39	0.92
To15	1.75	4	0.25	14.73	28	2.90	1.21	1.39	0.87
Bz16	0.75	5	0.31	1.80	12	4.00	1.47	1.61	0.92
Ko17	0.44	2	0.13	2.26	7	1.32	0.41	0.69	0.59
Se18	2.31	5	0.31	48.63	37	1.68	0.83	1.61	0.52
Se19	5.38	7	0.44	237.58	86	1.84	0.99	1.95	0.51
Se20	1.38	8	0.50	6.52	22	3.78	1.67	2.08	0.80

Table S2. Near analysis – distance from forested area.

No_Locality	Locality	Distance (m)
1	Ruské	48.750648
2	Ruské	12.384648
3	Ruské	6.176147
4	Ruské	93.58314
5	Ruské	407.81009
6	Ruské	178.974959
7	Ruské	84.833214
8	Ruské	217.761442
9	Ruské	93.240244
10	Ruské-Sihla	138.036295
11	Starina	4.0021
12	Príslop	406.056335
13	Príslop	398.256858
14	Topola	255.144873
15	Topola	187.242871
16	Kolbasov-Bzaná	235.274163
17	Kolbasov	186.728874
18	N Sedlica	579.401034
19	N Sedlica	473.590534
20	N Sedlica	502.049774
Average distance from nearest forest habitat		225.464807