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Conservation value of small meadows in a forest-dominated landscape assessed for ground beetles (Coleoptera: Carabidae)

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Abstract: Man-made small game meadows in forest-dominated landscapes may become important refuge habitats for invertebrates under the currently observed severe decline of grasslands characterized by low land-use intensity. We studied the ground beetle community of 24 small meadows that are used as grazing grounds for red deer (*Cervus elaphus*) in the sub-montane and montane zone of the Black Forest National Park. Our aim was to assess the conservation value of these meadows by focusing on species of conservation concern, typically threatened species. We were further interested in how soil properties, habitat type, elevation, and size of the meadows influence the carabid community. We found 52 carabid species covering a broad range of habitat preferences. Carabid species richness increased with smaller meadows, because the species pool was complemented by forest-inhabiting species. Nutrient-poor meadows hosted more species than wet meadows. The number of open-habitat species was affected by habitat type but not by elevation or any other variable tested. We found one endangered species and five species that can be considered near threatened according to the regional and national red lists. The conservation value of the studied meadows in a forested landscape is currently relatively small for ground beetles compared to other open habitats in the same area. However, small meadows in the montane zone of mid-mountain ranges may play an important role for biodiversity under ongoing changes of climatic conditions when the distribution of lowland species shifts towards higher elevations.

Keywords: game meadows; strictly protected forest; habitat islands; invertebrates; grassland management

Zusammenfassung

Extensiv genutztes Grünland ist stark von Intensivierung und alternativer Flächennutzung bedroht.

Wildwiesen als Beispiel für extensiv genutzte Wiesen in Waldlandschaften könnten wichtige Rückzugsräume für Wirbellose sein, wenn der Verlust an extensiv genutztem Grünland anhält. Wir haben Laufkäfer in 24 kleinen Wildwiesen in der submontanen und montanen Zone des Nationalparks Schwarzwald untersucht. Dabei war das Ziel, diese Wildwiesen hinsichtlich ihres Wertes für den Natur- und Artenschutz anhand der naturschutzfachlich wertgebenden Arten zu evaluieren. Weiterhin sollte der Einfluss der Bodeneigenschaften, des Habitattyps, der Höhenlage und der Größe der Wildwiesen auf Laufkäfergemeinschaften untersucht werden. Wir konnten 52 Laufkäferarten mit einem breiten Spektrum von Wald- und Offenlandarten nachweisen. Die Artenzahl war auf kleinen Wildwiesen größer, da kleine Wiesen häufiger von Waldarten genutzt werden. Nasswiesen waren weniger artenreich als Magerwiesen. Die Zahl der Offenlandarten wurde nur durch den Habitattyp aber durch keine andere getestete Variable beeinflusst. Wir konnten eine gefährdete und weitere fünf Arten der Vorwarnliste nachweisen. Verglichen mit anderen

Lebensräumen im Gebiet des Nationalparks besitzen Wildwiesen einen eher geringen Wert für Laufkäfer. Jedoch können in Zukunft insbesondere höher gelegene Wiesen bedeutsam für Arten werden, die aufgrund des Klimawandels ihre Populationen in tieferen Lagen verlieren.

1 Introduction

Land-use changes and the intensification of grassland management has led to a decline of extensively used grassland and to a dramatic change in species composition in recent decades (Dengler et al. 2014, Immoor et al. 2017). One specific type of extensively used grassland that is still very common in Central Europe is small meadows in forest-dominated landscapes. Small meadows in forests commonly do not suffer from land-use intensification, serve as grazing grounds for wild animals, and are thus often used for hunting. These meadows have been established for different purposes and they require management, including mowing, grazing and fertilizer application to retain their open nature. In the strictly protected non-intervention zones of National Parks they will face more or less rapid succession, and nutrient-poor open habitat will likely be lost. Small meadows in forests have rarely been subject to biodiversity research in Central Europe, although small forest gaps are expected to occur more frequently under natural disturbance regimes than larger patches in forests. These small forest gaps are preferentially used by ungulates for foraging rather than closed forest (Kuijper et al. 2009). Red deer (*Cervus elaphus*) spent seven times longer in forest gaps than in closed forest, which shows that small meadows in a forest-dominated landscape influence foraging behavior, thus affecting browsing pressure on tree regeneration.

Semi-natural grasslands are in general relatively species-rich (Vessby et al. 2002). Arthropods contribute significantly to grassland biodiversity (Tscharntke & Greiler 1995). One of the best known arthropod groups in terms of ecology and dis-

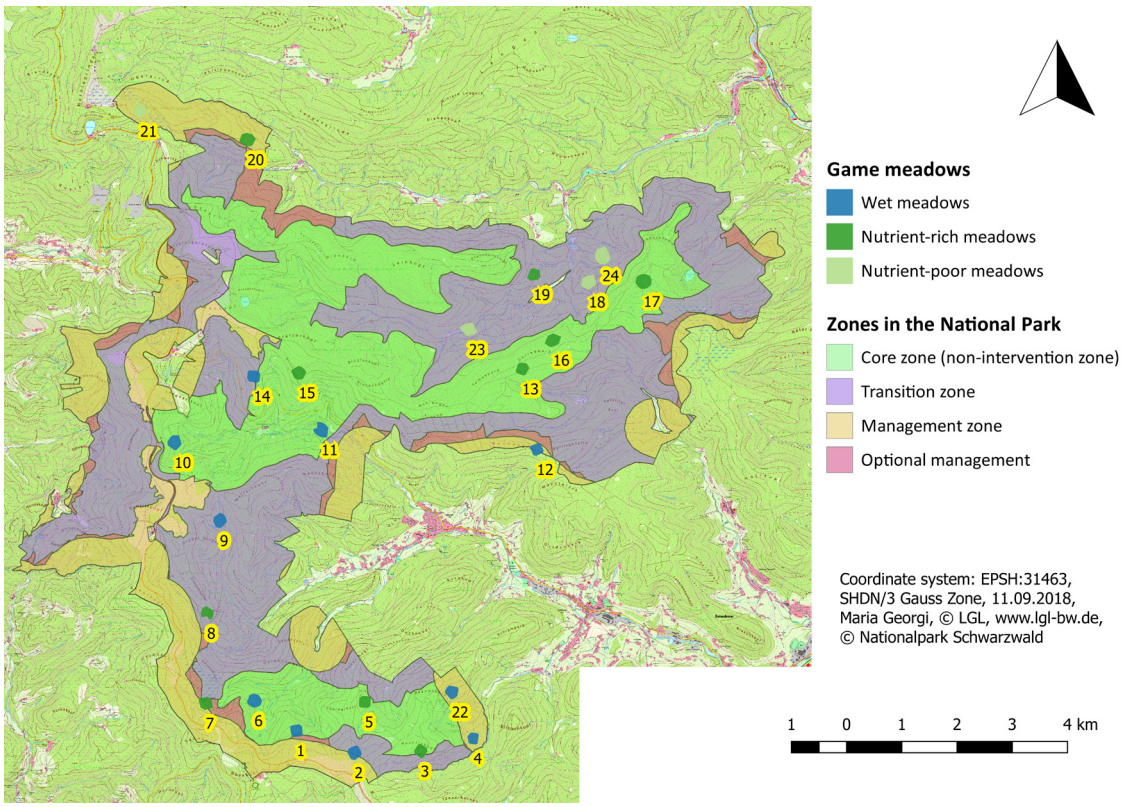

Fig. 1: Locations of the small meadows studied in the Black Forest National Park showing their habitat type and their position in the different zones of the National Park.

Tab. 1: Habitat type, area, elevation, and soil characteristics of the 24 meadows studied in the Black Forest National Park.

	Habitat type	Sand [%]	Silt [%]	Clay [%]	Carbon [g/kg]	Nitrogen [g/kg]	pH	Area [m²]	Elevation [m]	Humus quality
1	Wet meadow	82.1	10.2	7.1	34.5	2.6	5.4	2.740	895	Mor
2	Wet meadow	63.9	18.8	17.2	41.4	3.4	5.5	3.325	944	Mor
3	Nutrient-rich meadow	84.5	9.1	6.4	24.3	1.9	4.5	2.269	905	Mor
4	Wet meadow	79.4	9	11.3	38.2	2.7	4.7	1.305	718	Mor
5	Nutrient-rich meadow	78.6	13.6	7.9	59.4	4	6.5	2.209	863	Mor
6	Wet meadow	79.6	8.2	12.1	55.9	3.8	4.5	3.248	766	Mor
7	Nutrient-rich meadow	83.6	7.6	8.5	80.3	5.4	4.6	2.718	860	Mor
8	Nutrient-rich meadow	74.6	15.1	9.4	42.8	3.2	4.9	1.858	861	Mor
9	Wet meadow	79.4	10.5	10.1	31.2	2.3	4.3	2.980	839	Mor
10	Wet meadow	76.5	11.8	11.6	32.9	2.5	5	3.731	910	Mor_Moder
11	Wet meadow	57.8	23.3	17.9	38.3	3.5	4.3	4.952	666	Moder
12	Wet meadow	64	17.7	18.3	36.7	2.8	5.8	1.953	860	Mor_Moder
13	Nutrient-rich meadow	69.7	16.7	13.6	37.6	3.1	4.6	1.932	932	Mor_Moder
14	Wet meadow	77.6	13.7	8	38.3	3	4.8	3.086	934	Mor_Moder
15	Nutrient-rich meadow	85.2	8.8	6.1	50.6	3.4	4.6	2.880	968	Mor
16	Nutrient-rich meadow	79.8	12.3	7.6	28	1.5	6.7	2.384	904	Mor
17	Nutrient-rich meadow	83.5	11.4	5.1	65.4	3.5	6.1	6.281	936	Mor
18	Nutrient-poor meadow	70.1	15.6	13.7	28	2.3	4.8	3.889	712	Moder
19	Nutrient-rich meadow	69.7	19.1	11.3	28.3	2.5	4.4	2.141	711	Moder
20	Nutrient-rich meadow	70.3	14.6	15	32.8	2.7	4.4	3.295	853	Mor_Moder
21	Nutrient-poor meadow	86.6	10.6	2.8	28.5	1.8	3.9	2.233	1.005	Mor_Moder
22	Wet meadow	84.2	9.8	6	32.6	2.1	4.8	2.933	800	Mor
23	Nutrient-poor meadow	92.3	4.4	3.3	33.3	2.7	5.1	3.215	650	Moder
24	Nutrient-poor meadow	64.6	18.4	17	42.5	3.3	5	7.678	700	Moder

tribution is that of the ground beetles (Kotze et al. 2011). Carabids are sensitive to disturbance intensity in grasslands, showing decreasing species richness and abundance at high disturbance levels, and are thus suitable indicators for grassland management intensity (Rainio & Niemelä 2003). On the other hand, they are also sensitive to shrub encroachment which is expected after management ceases (Schirmel et al. 2014b). We used carabids as a model group to assess the conservation value of small meadows in the forest-dominated landscape of the Black Forest National Park and we aimed to answer the following questions: 1) Do small meadows in a forest matrix represent a valuable habitat for threatened ground beetles? 2) How do soil properties, habitat type, and elevation affect the ground beetle community in small meadows?

2 Material and Methods

2.1 Study area

We sampled ground beetles in 24 different meadows within the southern part of the 10,000 ha large Black Forest National Park (Fig. 1 and 2). Selection of meadows was done within a project dealing with plant-pollinator interactions and related management options (Georgi et al. in preparation). Most of these meadows were established around 30 to 50 years ago for different purposes, e.g. hay making, as seed nurseries, and for hunting. Some of the meadows were established 150 years ago or are part of the montane heathlands ("Grinden") which have developed due to agricultural practices dating back to the 15th century. The area of the meadows studied ranged in area from 1,000 to 8,000 m² and were located between 650 and 1005 m a.s.l. (Table 1). Most of the meadows are characterized by low pH values (Lower Trias solid rock) and relatively wet conditions. Soils are poor in nutrients and are typically Podsols, Cambisols, or Gleysols (IUSS working group for WRB 2015). Annual precipitation in the area is around 2,000 mm and mean annual temperature is 5 to 6 °C. The studied meadows were roughly classified into three habitat types based on a vegetation survey: wet meadows ("Nasswiese und waldfreier Sumpf"), nutrient-poor meadows ("Wirt-

Tab. 2: Species sampled in 24 meadows in the Black Forest National Park. Extinction risk is listed for both Germany and Baden-Württemberg. The number of recorded individuals and their frequency over the 24 meadows are given. * = Not threatened, NT = Near Threatened, EN = Endangered.

Species	Red list status Germany	Red list status Baden-Württemberg	Individuals	Frequency
Abax ovalis (Duftschmid, 1812)	*	*	6	2
Abax parallelepipedus (Piller & Mitterpacher, 1783)	*	*	3	1
Abax parallelus (Duftschmid, 1812)	*	*	1	1
Acupalpus flavicollis (Sturm, 1825)	*	*	1	1
Agonum muelleri (Hbst., 1784)	*	*	28	11
Agonum sexpunctatum (L., 1758)	*	*	5	3
Agonum viduum (Panzer, 1796)	*	*	16	5
Amara aenea (De Geer, 1774)	*	*	2	1
Amara communis (Panzer, 1797)	*	*	17	11
Amara convexior Stephens, 1828	*	*	5	1
Amara kulti Fassati, 1947	*	*	1	1
Amara lunicollis Schiodte, 1837	*	*	28	14
Amara nitida Sturm, 1825	EN	EN	1	1
Amara ovata (F., 1792)	*	*	1	1
Amara plebeja (Gyllenhal, 1810)	*	*	1	1
Anisodactylus binotatus (F., 1787)	*	*	27	14
Bembidion lampros (Hbst., 1784)	*	*	77	13
Bembidion mannerheimii C.R. Sahlberg, 1827	*	*	22	6
Bembidion properans (Stephens, 1828)	*	*	3	2
Carabus auronitens F., 1792	*	*	2	2
Carabus monilis F., 1792	NT	*	4	2
Carabus nemoralis O.F. Muller, 1764	*	*	74	12
Carabus violaceus L., 1758	*	*	5	4
Cicindela campestris L., 1758	*	*	4	2
Clivina fossor (L., 1758)	*	*	100	17
Dyschirius globosus (Hbst., 1784)	*	*	68	13
Harpalus affinis (Schrank, 1781)	*	*	1	1
Harpalus laevipes Zetterstedt, 1828	NT	NT	1	1
Harpalus latus (L., 1758)	*	*	7	4
Harpalus rufipes (De Geer, 1774)	*	*	1	1
Limodromus assimilis (Paykull, 1790)	*	*	1	1
Loricera pilicornis (F., 1775)	*	*	12	5
Microlestes minutulus (Goeze, 1777)	*	*	1	1
Molops elatus (F., 1801)	*	*	1	1
Molops piceus (Panzer, 1793)	*	*	2	2
Nebria brevicollis (F., 1792)	*	*	128	13
Notiophilus palustris (Duftschmid, 1812)	*	*	1	1
Oodes helopioides (F., 1792)	*	NT	1	1
Poecilus versicolor (Sturm, 1824)	*	*	442	20
Pterostichus aethiops (Panzer, 1796)	*	*	11	6
Pterostichus burmeisteri Heer, 1838	*	*	2	2
Pterostichus diligens (Sturm, 1824)	NT	NT	4	1
Pterostichus melanarius (Ill., 1798)	*	*	8	3
Pterostichus nigrita (Paykull, 1790)	*	*	43	9
Pterostichus oblongopunctatus (F., 1787)	*	*	4	3
Pterostichus rhaeticus Heer, 1837	*	NT	6	4
Pterostichus strenuus (Panzer, 1796)	*	*	40	17
Pterostichus vernalis (Panzer, 1796)	*	*	53	15
Synuchus vivalis (Ill., 1798)	*	*	2	1
Trechus obtusus Erichson, 1837	*	*	22	13
Trichotichnus laevicollis (Duftschmid, 1812)	*	*	1	1
Trichotichnus nitens (Heer, 1837)	*	*	1	1

schaftswiese mittlerer Standorte mager"), nutrient-rich meadows ("Wirtschaftswiese mittlerer Standorte fett"). Wet meadows are characterized by mesotrophic to eutrophic wet conditions with a large proportion of sedges and rushes. Nutrient-poor meadows are characterized by species-rich vegetation and are usually not treated with fertilizers. Nutrient-rich meadows are largely covered by grasses and were mostly treated with fertilizers until 2012. However, nutrient availability in soil did not differ significantly among habitat types and can be considered as nutrient-poor irrespective of habitat type (Eichenseer 2018).

2.2 Sampling

Ground beetles were sampled twice to cover their main activity period in the study area: mid-May to mid-June and mid-September to mid-October 2017. Unpublished data from other locations within the Black Forest National Park show that this rather short sampling interval is suitable to reach nearly 90 % sampling coverage in terms of species. Short sampling intervals have been successfully used in similar habitats by other studies (Schirmel et al. 2014a). We used five pitfall traps per meadow filled with 50 % propylene glycol and a few drops of scentless soap to reduce surface tension.

A relatively high level of precipitation in our study area was measured in May (sum = 126 mm) and June (166 mm) 2017 while temperatures where higher than the long-term mean. Mean temperature in May was 8.2 °C and in June 11.7 °C. September 2017 was relatively cold (mean temperature = 8.7 °C) and dry (precipitation sum = 39 mm). Climate in October 2017 was near to the long-term mean.

All material was sorted and preserved, but only carabids were identified to species level (Müller-Motzfeld 2006). Reference specimens are held in the beetle collection of the Black Forest National Park.

Soil samples were taken in September and October 2017 (Eichenseer 2018). Mixed samples from six different subplots within each meadow were taken by drilling up to 10 cm into the soil. At each subplot we took five drill samples resulting in 30 soil samples which were then combined to make one sample per meadow. Samples were then dried for one week in an oven at 40 °C. We analyzed carbon and nitrogen concentrations with a CNS analyzer and calculated the C/N ratio (range: 10.9 – 18.7). Soil acidity was measured with a glass electrode in $CaCl_2$ (0.01 M). pH values ranged between 3.9 and 6.5. Proportions of sand (2 mm – 0.063 mm), silt (63 µm – 2 µm) and clay (<2 µm) in the soil were used to describe the soil texture (Table 1).

2.3 Statistical analysis

Generalized linear models (GLM) were used to test the influence of soil properties, habitat type, meadow size, and elevation on ground beetle species richness. Bivariate correlations between environmental variables were tested before a full model was built. Strong correlations ($r_{spearman} > 0.7$) were found for sand, silt, and clay content. We deleted silt and clay content from further analysis because of the reciprocal correlation with sand content. AIC-based stepwise backwards selection of variables was performed to reduce model complexity. Species were classified into four different habitat guilds (forest, wetland, open habitat, generalist) based on their regional habitat preferences in the south-western mountain ranges of Germany (GAC 2009). A specific conservation value of small meadows in a forest matrix is most likely for species inhabiting open habitats. For this reason we also used GLMs to test the influence of environmental variables on the abundance of species with a preference for open habitats. We transformed abundance into log-scale (log+1) to meet the basic assumptions of the statistical model.

We used non-metrical dimensional scaling (NMDS, k = 2) to test the impact of soil properties, habitat type, meadow size, and elevation on community composition. To test true resident communities, we deleted species that were represented by singletons and used only species with minimum two individuals in the total catch (36 of 52 species). Community dissimilarity was calculated using Bray-Curtis distances.

All statistical analyses were performed in R 3.3.3 (R-Core-Development-Team 2017).

3 Results

We sampled 1,298 individuals of 52 different carabid beetle species in the 24 meadows (Table 2). The majority of individuals were open habitat specialists (20 species, 627 individuals) followed by eurytopic species (8 species, 434 individuals). Forest specialists comprised only 121 individuals (15 species) and wetland specialists were found with 116 individuals (9 species).

Tab. 3: Generalized linear models (Poisson) explaining total species richness of ground beetles in 24 meadows of the Black Forest National Park.

Species richness	Full model (Null deviance=30.5, residual deviance=20.2)			Final model (Null deviance=30.5, residual deviance=22.0)		
	Coefficient	SE	P	Coefficient	SE	P
Intercept	3.250	0.936	<0.001	2.482	0.179	<0.001
Elevation	-0.000	0.001	0.529			
Habitat[rich_meadow]	0.284	0.142	0.046	0.250	0.138	0.071
Habitat[poor_meadow]	0.364	0.196	0.063	0.427	0.180	0.017
Area [ha]	-0.780	0.560	0.164	-0.845	0.492	0.086
Sand content [%]	0.001	0.010	0.928			
C/N ratio	0.007	0.051	0.893			
pH	-0.115	0.109	0.291			

Individuals of *Poecilus versicolor* represented 34% of the total catch. The most frequent species were *P. versicolor* (20 of 24 meadows), *Clivina fossor* and *Pterostichus strenuus* (both 17 meadows).

Overall species richness ranged from 5 to 19 across meadows and was affected by habitat type and meadow size (28 % explained deviance). Richness increased with smaller meadows, and nutrient-poor meadows hosted more species than wet meadows (Table 3). The number of eurytopic species was positively related to overall species richness ($r_{spearman}$ = 0.78, p<0.001).

Open habitat specialists represented between 0 and 89 % of the total catch per meadow (mean = 43 %). Species preferring open habitats (627 of 1,298 individuals) were affected by habitat type, i.e. wet meadows contained less open-habitat species than both nutrient-poor and -rich meadows (Table 4, 50 % explained deviance). There was no effect of meadow size on open-habitat species. Measured soil properties and elevation did not influence species richness.

NMDS showed only weak discrimination of species and sites (stress = 0.23). Community composition was influenced by meadow size (ADONIS, p = 0.066) and habitat type (p = 0.004).

In total, we recorded six species (17 individuals) of conservation concern (Table 2). Five species are listed as Near Threatened in Germany and/or Baden-Württemberg. In addition, *Amara nitida* is classified as endangered for Baden-Württemberg and Germany (Trautner et al. 2006).

Discussion

Ground beetles were mainly affected by habitat type and meadow size. Soil properties and elevation had no direct impact on the sampled communities. Small meadows were inhabited by a mixture of generalists and open-habitat species. There were fewer forest specialists in larger meadows, resulting in higher species richness in small meadows. This is in contrast to butterflies in fragmented grassland habitats (Steffan-

Tab. 4: Generalized linear models explaining abundance of ground beetles with a preference for open habitats. Beetles were sampled in 24 meadows of the Black Forest National Park.

Abundance of species preferring open habitats (log+1)	Full model (Null deviance=35.0, residual deviance=15.5)			Final model (Null deviance=35.0, residual deviance=17.4)		
	Coefficient	SE	P	Coefficient	SE	P
Intercept	0.910	3.014	0.766	1.817	0.288	<0.001
Elevation	0.001	0.002	0.644			
Habitat[rich_meadow]	1.554	0.461	0.004	1.470	0.408	0.002
Habitat[poor_meadow]	2.042	0.665	0.007	2.159	0.539	<0.001
Area [ha]	1.651	1.756	0.361			
Sand content [%]	0.008	0.034	0.808			
C/N ratio	-0.173	0.169	0.322			
pH	0.231	0.359	0.529			

Dewenter & Tscharntke 2000, Liivamaegi et al. 2014). Carabids are more affected by land use than other epigeic invertebrates (Dauber et al. 2005). The habitat type of our meadows is most likely influenced by management in terms of fertilizer treatment and mowing regime. Although we found no influence of C/N-ratio on carabids, there was a significant impact of habitat type. This can perhaps be attributed to management in the past or to the water availability. Soil water content is known to have a strong influence on specialized species and is positively linked to overall species richness (Irmler 2006).

Fig. 2: Example of a small game meadow in the Black Forest National Park.

Open habitats such as small meadows increase habitat diversity and thus increase the species diversity in a forest-dominated area. This is particularly important if meadows are heavily grazed by herbivores such as red deer which has a positive effect on the number of plant species (Schütz et al. 2003). The meadows studied here, however, were established by humans and are managed to keep them open. Those meadows located in the non-intervention zone of a Central European National Park face rapid succession in the near future because they will no longer be managed. At present, the studied small meadows are of limited value for ground beetle conservation. We found only one threatened species *Amara nitida,* a characteristic species of hay meadows (Habitats Directive Habitat types 6510 and 6520) which is threatened by intensive grassland management and shrub recovery following management abandonment (Trautner 2017). *A. nitida* is endangered in Baden-Württemberg and represents one of the focal species for practical conservation planning (Geissler-Strobel et al. 2006). The species was recorded in the management zone of the Black Forest National Park. Particularly threatened ground beetles are negatively affected by high management intensity (Irmler 2006). Here we recommend no fertilizer treatment and low intensity mowing. The relatively rich vegetation (34 vascular plants) in this meadow will also benefit from this recommendation.

One of the small nutrient-poor meadows with high sand content in soil (86 %) and low pH (pH = 3.9) was inhabited by *Oodes helopioides* and *Pterostichus diligens,* which are both species of conservation concern. This was the only record of these two species during our investigation. Although the meadow is located at 1,005 m a.s.l. in the non-intervention zone of the National Park we see no threat for both populations as a result of the upcoming management abandonment. Both species prefer wet habitats, and the water regime will not be affected by lack of management in this specific case. Two meadows were colonized by *Carabus monilis*, a eurytopic species that is widely distributed and locally abundant in Baden-Württemberg (Trautner 2017). However, the current distribution in the federal state shows a large distribution gap in the northern Black Forest and a smaller gap in the southern Black Forest. These gaps are probably related to high elevation. Our records at 700 m and 968 m a.s.l. are the first records in the northern Black Forest. Possible range expansion of this species into higher elevations can be tracked within our permanent plot monitoring system in the Black Forest National Park. There are more than 200 permanent monitoring plots distributed over the 10,000 ha large National Park at elevations ranging from 500 m to more than 1,000 m a.s.l.

We summarize that small meadows in a forest-dominated landscape may host ground beetle species of conservation concern, but the conservation value for

ground beetles is currently relatively small compared to other open habitats such as montane heathlands in the management zone of the Black Forest National Park. There are more than six threatened ground beetle species recorded from the montane heathlands in the Black Forest National Park (Buse et al. 2018). However, the relative conservation value of small game meadows is expected to be higher in landscapes with large proportions of intensively used arable fields and only a small proportion of extensively used grassland. Small meadows in the montane zone of mid-mountain ranges may play an important role for biodiversity under changing climatic conditions when lowland species shift their distribution towards higher elevations. The potential conservation value might then vary for different organism groups, and probably be higher for insects because they typically shift their distribution limits faster than plants (Bässler et al. 2013, Roth et al. 2014). For current management it is recommended not to use fertilizers so as to retain nutrient-poor conditions under a medium disturbance regime in these meadows (Dengler et al. 2014).

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