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Impact of Land Use on Peat Soil Elemental Content and Carabidae and Plant Species Composition and Abundance

Katarzyna Szyszko-Podgórska [1,*], Żaneta Szweda [2], Marcin Świątek [2], Joanna Ukalska [3], Krzysztof Pietrasz [2], Magdalena Pietrasz [2], Paweł Wilk [4], Paulina Orlińska-Woźniak [4], Ewa Szalińska [5], Tomasz Rokicki [6], Sebastian Tylkowski [7] and Roman Niżnikowski [2]

1 The Institute of Environmental Protection—National Research Institute, Słowicza 32, 02-170 Warsaw, Poland
2 Institute of Animal Sciences, Warsaw University of Life Sciences—WULS, 02-787 Warsaw, Poland; zaneta_szweda@sggw.edu.pl (Ż.S.); marcin_swiatek@sggw.edu.pl (M.Ś.); k.pietrasz@gmail.com (K.P.); roman_niznikowski@sggw.edu.pl (R.N.)
3 Laboratory of Dendrometry and Forest Productivity, Department of Forest Management Planning, Dendrometry and Forest Economics, Institute of Forest Sciences, Warsaw University of Life Sciences, Nowoursynowska 159, 02-776 Warsaw, Poland; joanna_ukalska@sggw.edu.pl
4 Institute of Meteorology and Water Management—National Research Institute, Podleśna 61, 01-673 Warszawa, Poland; pawel.wilk@imgw.pl (P.W.); paulina.wozniak@imgw.pl (P.O.-W.)
5 Environment Protection Department, AGH University of Krakow, Mickiewicza 30, 30-059 Krakow, Poland; eszalinska@agh.edu.pl
6 Management Institute, Warsaw University of Life Sciences—WULS, 02-787 Warsaw, Poland; tomasz_rokicki@sggw.edu.pl
7 Department of Forest Sciences, University of Lodz Branch in Tomaszów Mazowiecki, 97-200 Tomaszów Mazowiecki, Poland; sebastian.tylkowski@uni.lodz.pl
* Correspondence: katarzyna.podgorska@ios.edu.pl

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Abstract: This study, conducted in 2020–2022, was designed to determine the impact of livestock grazing on habitat biodiversity and *Carabidae* beetles. Two research plots (a meadow and a pasture) were established on a farm in the village of Otapy, located in the agricultural catchment area of the Nurzec River in Eastern Poland. They were located next to each other so that they would possess the same set of atmospheric phenomena and processes shaped by the physical and geographical characteristics of the area. The study showed that the pasture was the richest in terms of the magnesium and calcium contents, while the meadow had significantly higher levels of phosphorus and zinc. The study also showed some differences in the abundance and species composition of plants and animals. The meadow had higher biodiversity, while the pasture was dominated by grasses. A disparity in the abundance of individual species was also presented. The study indicated the preference of individual species for particular forms of land use. *Anisodactylus binotatus*, *Harpalus rufipes* and *Poecilus cupreus* were most abundant in the meadow, while *Carabus granulatus* and *Pterostichus melanarius* were mostly represented in the pasture. The number of species, on the other hand, was the same. Our research concluded that proper landscape management through different uses affects plant and beetle diversity and soil element content.

Keywords: carabidae; plant biodiversity; livestock grazing; land use; elements Ca, Mg, P, Zn, C and N

1. Introduction

Currently, there is a strong decline in biodiversity. Studies conducted throughout Europe are increasingly reporting a very high homogenization of communities as a result of the loss of local species, a reduction in the biomass of native populations and the dominance of species that can tolerate anthropic disturbances [1]. Consequently, a drastic large-scale decrease in insect fauna has been reported [2–6]. This is assumed to be a multifactorial problem, involving different biotopes and plant diversity, soil characteristics and human activities (area management). Nevertheless, in practice, we still do not know the extent of this issue or its ecological consequences [7]. Humans, through their extensive economic activities (agriculture, industry, infrastructure and water reclamation), intensively affect the appearance and condition of the natural environment. As a result, this leads both to the displacement of many native species from the altered environments and the permanent isolation of groups of many of them, dramatically increasing the chances of their extinction. Among other things, grasslands are being intensively transformed, which can result in a decline in or loss of plant diversity [8]. A good example of this is the constantly growing pressure to increase livestock production [9], the consequence of which can be overgrazing, which degrades the soil. A number of previous studies [10,11] have shown that overintensive pastures have low species diversity, with a dominance of plants that tolerate grazing or trampling [12]. However, it is important to note that properly managed grazing can reduce competition for access to light, and therefore allow for more diverse plant species to grow. In addition, it provides plants with a necessary dose of natural fertilizer, contributing to (i) an increase in organic matter content, (ii) improvements in the abundance of soil nutrients necessary for soil microorganisms (iii) and, consequently, a positive effect on soil-forming processes. Soil elemental content, plant diversity, insect diversity and land use are mutually correlated [13]. Plant diversity is considered a major determinant of diversity at higher trophic levels, although this finding is still not well supported by more recent investigations [14]. The knowledge of how land use strategies affect invertebrate species diversity is also still poorly understood, limiting the ability to predict how the loss of such diversity may affect the ecosystem [7]. Meanwhile, due to predation, invertebrates play an important role in the formation and cycling of organic matter in the ecosystem in both larval and imago forms [15]. In addition, by fragmenting organic residues, they accelerate their colonization by microorganisms and subsequently by saprophagous animals [16]. Soil animals, excreting undigested food in the form of feces containing various humus substances, play a key role in the movement of organic material deep into the soil [16]. The current study was performed in the agricultural catchment of the Nurzec River (Eastern Poland), where no similar biodiversity study has been conducted before. The area, which is unique in the context of Central Europe, is characterized by an exceptional structure of agricultural land. The meadows and pastures that dominate the landscape are located in peat areas that stretch along the river, creating a natural buffer zone between other types of land use, mainly agricultural. Such an arrangement not only ensures the protection of the environment, but also enables the preservation of a specific ecosystem. The lack of previous research on biodiversity and, in particular, beetles in the area has been an important knowledge gap. Since carabid beetles are a key group of insects that perform important ecological functions, their presence and diversity can indicate the health of the ecosystem. This research provides an understanding of the impact of agriculture on peatland ecosystems and an assessment of the extent to which meadows and pastures act as a buffer to agricultural land.

Therefore, the aim of the presented research was to demonstrate the influence of the form of land use (meadow and pasture) on the elemental content of the soil, as well as the abundance and species diversity of plants and ground beetles.

2. Materials and Methods

2.1. Study Area

The research was conducted in the catchment area of the Nurzec River (Eastern Poland). The area is characterized by meadows and pastures, located mostly on peat soils stretching along watercourses, forming a buffer zone between the river and areas intensively used for agriculture. The farm where the study was carried out is located in the village of Otapy (the middle part of the Nurzec River catchment area). The settlement is located in Podlaskie Voivodeship, Bielsk County, Brańsk Community (Figure 1). The neighbourhood, mainly due to the small amount of industrialization and urbanization, and the proximity of reserves, landscape parks and Natura 2000 areas, is considered the cleanest region in Poland. The area of the farm is 39.65 hectares and consists of 39 plots of land. The farm is engaged in crop and livestock production.

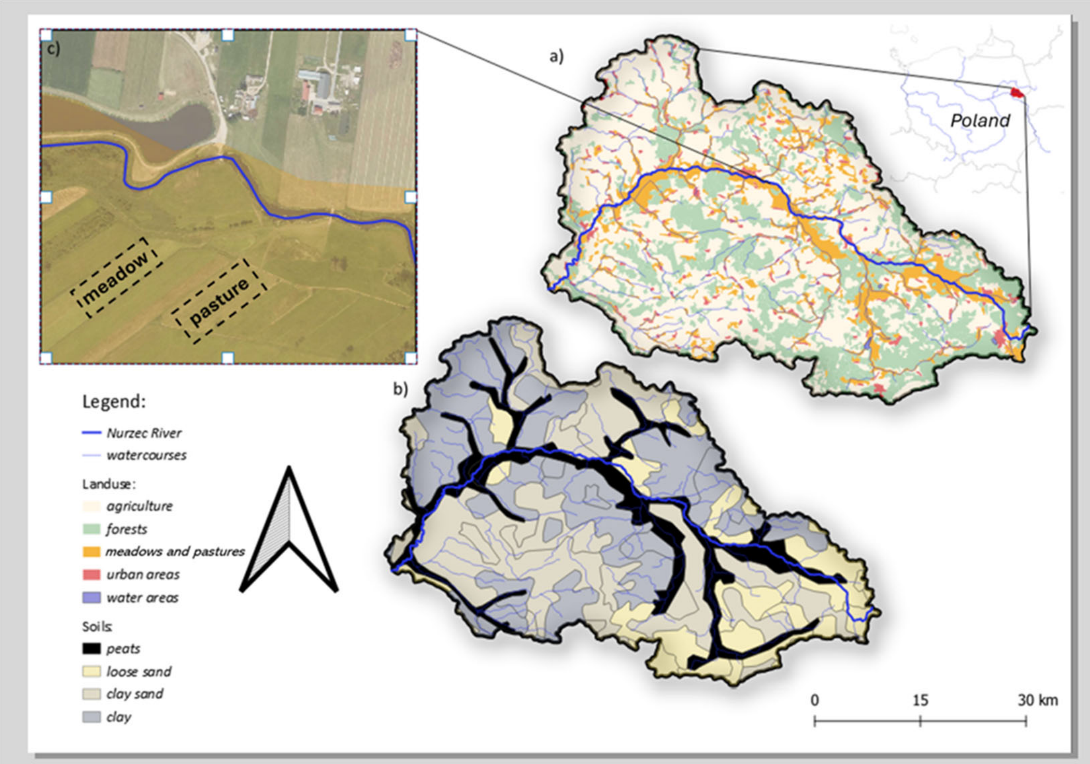

Figure 1. Location of the Nurzec River drainage basin used for the study, along with: (**a**) land uses, (**b**) soil types and (**c**) land use types (meadow and pasture) in the described studies.

2.2. Methodology of the Study

The methodology included the selection of appropriate research areas, sampling and three types of research, conducted in accordance with the diagram presented in Figure 2.

In the study area, two study plots of 1.5 hectares were selected that differed in use: pasture and meadow. These plots were adjacent to each other, characterized by the same hydrometeorological and geomorphological conditions. In the examination covering the years 2020–2022, the pasture was grazed by sheep (from May to September) while the meadow was unused and mowed once a year. Soil sampling was conducted in each of the analyzed years in the following months: May, July and September. In each plot, fie sampling points were randomly determined. At each point, five individual samples were taken using the field method (using an Egner stick, at a depth of 0–20 cm at each measurement point). The combination of individual samples constituted a representative sample for the study plot. The collected soil material was used for macro- and micronutrient determinations. Total nitrogen was determined using the PN-EN 16169:2012 methodology [17]. Metal determinations were made using a calibrated Varian Vista Pro ICP-AES (Varian Inc., Mulgrave, VIC, Australia) analyzer in accordance with the BL-PB-10 test procedure. Prior to that, the sample was microwave-mineralized with a reaction mixture called aqua regia (HNO_3 1:3 HCl). Total and organic carbon was determined using an automatic TOC carbon analyzer with the SSM-5000A attachment for solid samples, in compliance with the BL-PB-17 procedure [18]. The samples of plant material used for analysis were collected in line with Rozycki's agrotechnical method [19], using a $1m^2$ frame from randomly selected sites in the study area (five samples were collected from each plot). The analyzed plants were divided into two systematic groups, dicotyledons and monocotyledons, in order to identify changes in plant diversity and species dominance depending on the degree and type of land use. Quantitative and species surveys of beetles were also conducted on both types of land use in May–September by installing 21 STN traps on each site (Figure 3), characterized by the constant size of the opening, guaranteeing the collection of individuals of similar body size. The trap consisted of a 330 mL jar filled with glycol and dug into the ground. The jar was equipped with a funnel with an outlet of 1.2 cm to prevent vertebrates from falling in and a canopy to protect its contents from precipitation. The period and length of beetle collection were determined by the beetles' seasonal activity [20]. Each year in September, all captured beetles were fished out of the traps, and then collectively, for each year and a given study plot, counted and identified at the species level. Identification and naming were carried out in accordance with the system proposed by Freude et al. [21].

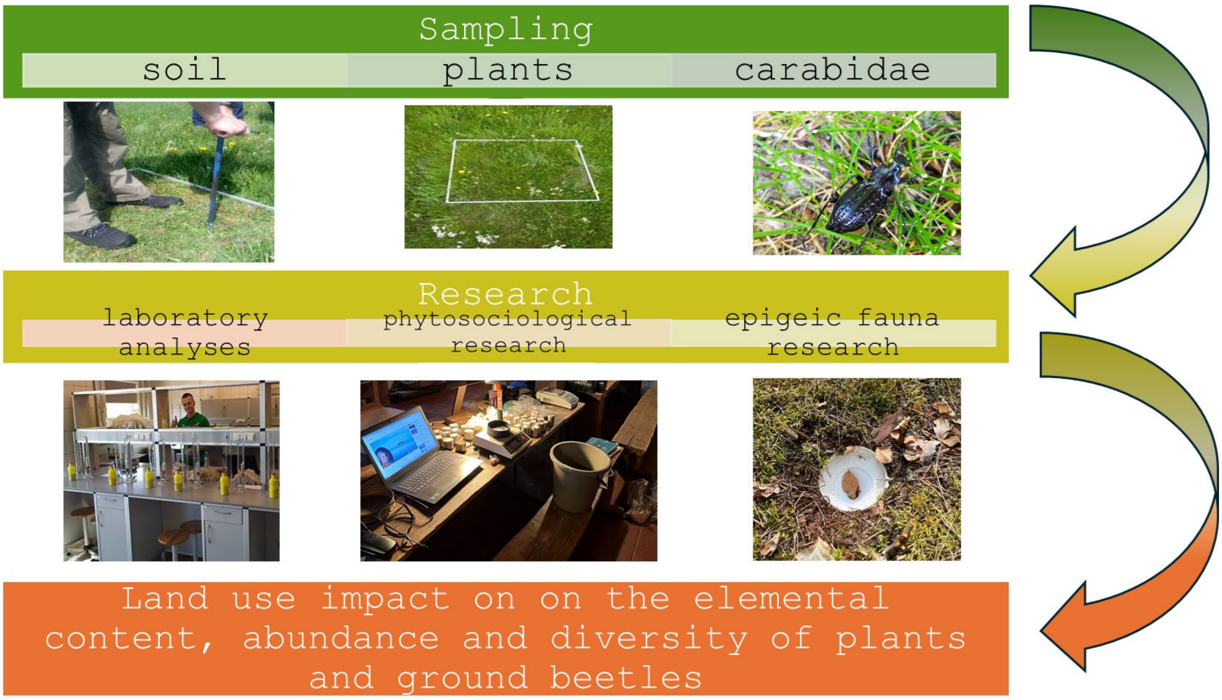

Figure 2. Experimental design diagram.

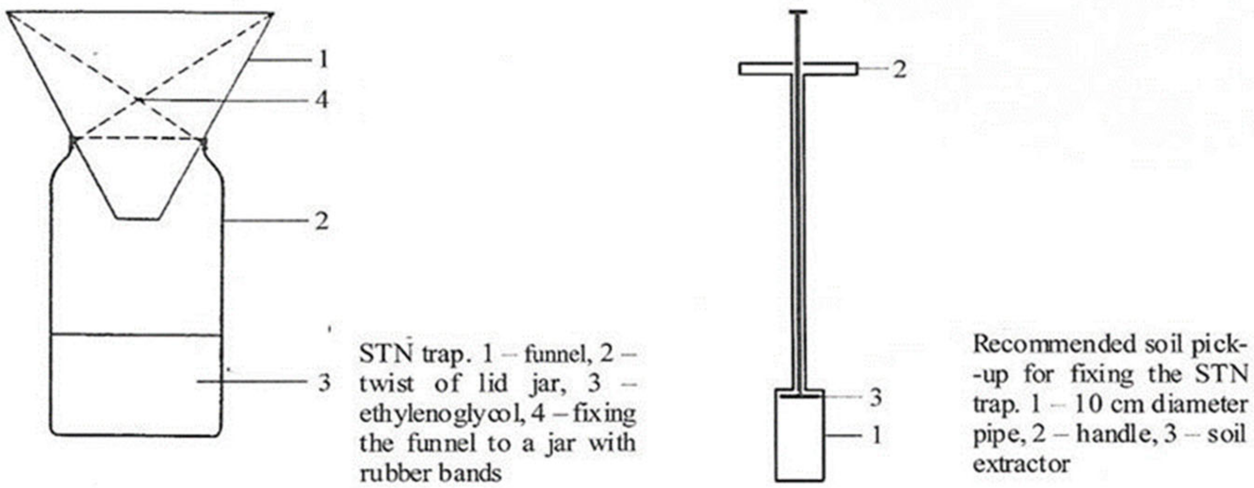

Figure 3. Schematic of the STN trap, along with the soil sampling, used for installing this trap according to Szyszko 1985 [22].

2.3. Statistical Analysis

The variation in soil element content among the studied environments and years was examined using two-factor analysis of variance according to the full model with interaction, where the fixed effects were the form of use (FU) and year of observation (Y). For significant model effects, pairwise comparisons were made between means with Tukey's post-hoc test. The botanical composition and diversity of the plant material were analyzed, as well as its trend. The variation in plant occurrence, depending on the form of use and year of observation, was examined using gradient analyses. Multivariate analyses were performed by treating each form of use (i.e., grassland and pasture) in the study year (2020, 2021 and 2022) as separate environments. Unconstrained unimodal ordination (CA) was used, taking the maximum proportion of each species for analysis. Poisson generalized linear models (GzLM) were used to examine the variation in the abundance of ground beetles in the studied environments and years. For species occurring yearly in both studied environments, a full two-factor model was used, with the following effects: form of use (FU), year (Y), FU $\times$ Y and log function as the link function. For beetle species that did not occur every year in each form of use, but for which zero values appeared once or twice (*Harpalus rufipes*, *Poecilus cupreus*, *Poecilus versicolor*), a zero inflated Poisson model with two main factors, FU and Y, was used, but without an interaction effect (due to the lack of convergence of the full model). For two species that were found in one or two survey years (*Amara communis* and *Calathus fuscipes*), it was only possible to compare abundances between the forms of use (FUs). For very rare species, it was not possible to test the significance of differences in the number of individuals between FU and Y. The significance of the model effects was evaluated by the Wald χ^2 test for a type 3 analysis. For significant model effects, pairwise comparisons were made between the least-square means with Tukey's post-hoc test. Gradient analyses were also used to examine the variability in carabid beetles' occurrence in relation to environmental variables in the forms of use and years studied. A redundancy analysis (RDA) was performed considering the environmental variables of total nitrogen (Nt), carbon content (TOC), Zn content and number of plant species (N_plant). Analyses of variance were performed using SAS/STAT® 14.3 software [23] using the soil element variation (GLM) and beetle species diversity analyses (GENMOD) procedures, while gradient analyses and the graphs created from them were performed using CANOCO 5 software [24].

3. Results

3.1. Peat Soil Elemental Content

Based on the analyses, there was a significant effect of land use form on the content of Ca, Mg, P and Zn in the soil (Table 1). The contents of Mg and Ca were significantly higher in soil from pasture compared to soil from meadow, while the contents of P and Zn were considerably higher in samples from meadow. There was no significant effect of land use form on the other elements in the soil.

The content of Cu and Zn in the soil changed in the years studied (Table 1). The amount of both elements was significantly higher in 2020 than in 2022, and, in the case of Zn, 2020 levels were also higher than in 2021. The amount of other elements did not differ between years on average. There was also no significant location*year interaction.

In terms of the content of total carbon (TC), the studied land uses did not differ, but significant differences occurred between the years of the study. TC content was higher in 2020 and 2021 than in 2022. There was no effect of land use form on organic carbon content, although this conclusion is at the limit of significance ($p = 0.058$). In contrast, there were some major differences between the study years. TOC was higher in 2020 than 2022.

Table 1. Mean ± Standard Error (M + SE) content of tested elements in soil in the meadow and pasture in the years studied and the results of the analysis of variance (F statistic and *p*-value in parentheses) for the two-factor linear model with interaction. Means with the same lowercase letters within a row are not significantly different at $p \leq 0.05$.

Element	Form of Use FU			Year Y				FU × Y
	Meadow	Pasture	F (*p*)	2020	2021	2022	F (*p*)	F (*p*)
Ca [g/kg s.m.]	151 ± 5.9 b	193 ± 11.6 a	10.3 (0.008)	160 ± 9.3 a	180 ± 19.8 a	175 ± 12.5 a	0.8 (0.455)	0.8 (0.472)
Mg [g/kg s.m.]	1.01 ± 0.05 b	1.28 ± 0.08 a	6 (0.03)	1.15 ± 0.04 a	1.13 ± 0.13 a	1.15 ± 0.12 a	0 (0.978)	0.3 (0.729)
Na [g/kg s.m.]	246 ± 15.8 a	253 ± 18 a	0.1 (0.788)	267 ± 17 a	249 ± 10.4 a	233 ± 29.5 a	0.6 (0.588)	0.2 (0.805)
K [g/kg s.m.]	809 ± 58.8 a	781 ± 83.3 a	0.1 (0.809)	718 ± 43.6 a	868 ± 55.7 a	799 ± 133.4 a	0.6 (0.557)	0.2 (0.865)
P [g/kg s.m.]	8.98 ± 1.15 a	3.74 ± 0.45 a	19 (0.001)	7.17 ± 1.49 a	5.19 ± 0.71 a	6.72 ± 2.16 a	1 (0.398)	1.5 (0.269)
Cu [g/kg s.m.]	2.22 ± 0.27 a	1.91 ± 0.18 a	1.7 (0.218)	2.53 ± 0.11 a	2.22 ± 0.29 ab	1.45 ± 0.21 b	7 (0.01)	1 (0.404)
Zn [g/kg s.m.]	26.6 ± 1.9 a	15.8 ± 1.8 a	34 (<0.001)	26.6 ± 2.7 a	18.2 ± 1.6 b	18.8 ± 3.9 b	8.4 (0.005)	1.7 (0.231)
TC [% s.m.]	27.1 ± 1.3 a	25.7 ± 1.5 a	1.6 (0.226)	30.1 ± 0.5 a	27.4 ± 1.4 a	21.7 ± 0.7 b	18.5 (<0.001)	0.3 (0.77)
TOC [% s.m.]	23.2 ± 1.1 a	20.3 ± 1.2 a	4.4 (0.058)	24 ± 0.9 a	22.1 ± 1.9 ab	19.2 ± 0.5 b	4.2 (0.041)	0.6 (0.549)
N_og [mg/kg s.m.]	2.12 ± 0.16 a	1.82 ± 0.14 a	2.5 (0.137)	2.3 ± 0.23 a	1.93 ± 0.14 a	1.68 ± 0.07 a	3.6 (0.061)	0.2 (0.804)

3.2. Plant Species Composition and Abundance

Phytosociological work recorded 15 species of vascular plants belonging to 11 families (Table 2). The dicotyledonous class dominated, represented by 11 species from 9 families. Comparing the three research seasons, the differences between the uses, in terms of the number of plant species, are small. Greater species diversity was shown in the meadow. This type of land use was characterized by the highest biodiversity in 2020 (14 plant species) and a similar number of species in the other two seasons (13 in 2021 and 12 in 2022). The pasture was characterized by lower biodiversity in 2020 and 2021, where 10 and 9 species were recorded, respectively. On the other hand, in 2022, the most species were recorded, namely 13. Both study plots (except 2020) showed a slight decrease in the number of recorded species as the growing season progressed. Differences will appear, however, in the percentage coverage of the plot by monocotyledonous and dicotyledonous classes according to use. Of the monocotyledonous plants, *Festuca rubra* and *Holcus lanatus* occurred in almost every season and in every land use type, as did *Carex nigra*. Of the dicotyledonous class, it was *Trifolium repens* that occurred in almost every sample tested.

The species that were only inventoried in the meadow were *Plantago lanceolata*, *Achillea millefolium*, *Angelica sylvestris* and *Filipendula ulmaria* (except for the July pasture sample of 2022). *Urtica dioica*, on the contrary, was a species that was inventoried only in the pasture. In addition, *Urtica dioica* along with *Angelica sylvestris* were species that appeared only once in all the samples taken. The analysis of the floristic composition of the land use types studied showed that the pasture was dominated by grasses, almost in every season, and they accounted for about 80% or more of the total. The meadow was more floristically diverse, with the proportion of plants from the monocotyledonous class ranging from 42 to 77%, with only two samples that were significantly higher: September 2021, at 89.4%, and September 2022, at 96.0%. Of the plants from the monocotyledonous class, *Festuca rubra* had the highest proportion in most samples, except for 2022, where *Poa pratensis* or *Carex nigra* had the highest percentage.

The highest share of plant species from the dicotyledonous class was recorded in the 2020 and 2021 seasons, and it was almost twice as high as in 2022. *Angelica sylvestris* (28.9%) and *Plantago lanceolata* (20.7%) obtained the highest percentage covers in the meadow in 2020, while *Plantago lanceolata* (19.8%) and *Ranunculus acris* (17.5%) had the highest scores in 2021. In 2022, on the other hand, there was no dominance of a single species, and *Plantago lanceolata* had the largest share, with 8.5% coverage.

In the diagram of Figure 4, the pastures are on the left, with pasture p2021 separated from the others along the second axis of the ordination. The meadows are on the right, with m2020 separated along the second axis of the ordination. The form of land use, as well as the year of study, differentiates the occurrence of individual plant species. *Angelica sylvestris* is closely associated with the meadow in 2020 (m2020), *Holcus lanatus*, *Festuca rubra* and *Taraxacum officinale* with the meadow in 2021 (m2021), and *Ranunculus acer* with the meadow in 2022 (m2022). *Poa pratensis* shows a clear association with pasture in 2020 (p2020), and *Trifolium repens* with pasture in 2022 (p2022).

Table 2. Floristic composition of the sward of the studied plots throughout the study period (species with a share of more than 5% of land cover during at least one point in the study period) [%]: m—meadow; p—pasture.

Plant Species	2020						2021						2022					
	V		VII		IX		V		VII		IX		V		VII		IX	
	m	p	m	p	m	p	m	p	m	p	m	p	m	p	m	p	m	p
Festuca rubra (Linnaeus, 1753)	52.1	30.2	31.6	60.5	27.3	65.5	24.8	56.3	28.5	41.5	59.6	55.1	46.3	31.5	12.6	21	1.7	43.3
Poa pratensis (Linnaeus, 1753)		0.5			1.3		5.1	21.6	4.8	20	17.6	11.1	9.31	8.2	27.7	40.5		46
Holcus lanatus (Linnaeus, 1753)	23.7	62.3	8.5	14.9	20.2	13.9	14.5	11.9	5.5	3.7	12.2	7.2	13.5	9.3	7.7	6.5		10.1
Family *Poaceae*	75.8	93	40.1	75.4	48.8	79.4	44.4	89.8	38.8	65.2	89.4	73.4	69.1	49	48	68	1.7	99.4
Carex nigra (Reichard, 1778)	0.9	3.6	1.9	14.1	1.8	19.5	8.2	4.2	15.7	24.9		24.1	4.5	38.5	21.7	13	94.3	
Family *Cyperaceae*	0.9	3.6	1.9	14.1	1.8	19.5	8.2	4.2	15.7	24.9		24.1	4.5	38.5	21.7	13	94.3	
Class monocotyledons—total	76.7	96.6	42	89.5	50.6	98.9	52.6	94	54.5	90.1	89.4	97.5	73.6	87.5	69.7	81	96	99.4
Taraxacum officinale (Weber and Wiggers)	6.1	1.6			1.8		8.5	0.7	0.8	3.1	0.9		2.2		2.5			0.1
Achillea millefolium (Linnaeus, 1753)	2.2		1.8		6.9		1.7		3.5		0.9		0.4		3.4			
Family *Asteraceae*	8.3	1.6	1.8		8.7		10.2	0.7	4.3	3.1	1.8		2.6		5.9			0.1
Filipendula ulmaria (Maximowicz, 1879)			2.8		8.4		2.7		0.8						0.5	1.1		
Family *Rosaceae*			2.8		8.4		2.7		0.8						0.5	1.1		
Ranunculus repens (Linnaeus, 1753)			0.7	1.3			0.9	1.2	7.4	1.4	2.1	0.1	4	0.5			0.7	0.2
Ranunculus acris (Linnaeus, 1753)	5	0.7	6.5		4.8		17.5		2.1				3	0.9	7.2	2.6		
Family *Ranunculaceae*	5	0.7	7.2	1.3	4.8		18.4	1.2	9.5	1.4	2.1	0.1	7	1.4	7.2	2.6	0.7	0.2
Rumex acetosa (Linnaeus, 1753)	1	3.62	2.2	2.2			8.7	0.2						0.4		0.3		
Family *Polygonaceae*	1		2.2	2.2			8.7	0.2						0.4		0.3		
Trifolium repens (Linnaeus, 1753)	0.3	0.2	0.3	4.7	0.3	0.8	1.1	1.2	3.3	5.1	1.2	2.1	1	0.2	5.3	0.4		
Family *Fabaceae*	0.3	0.2	0.3	4.7	0.3	0.8	1.1	1.2	3.3	5.1	1.2	2.1	1	0.2	5.3	0.4		
Veronica chamaedrys (Linnaeus, 1753)	1.5		3.7		6.1	0.3	1.7		4.5	0.1	1.2	0.2	5.3			3.3	0.8	0.2
Family *Scrophulariaceae*	1.5		3.7		6.1	0.3	1.7		4.5	0.1	1.2	0.2	5.3			3.3	0.8	0.2
Plantago lanceolata (Linnaeus, 1753)	4.1		8.8		20.8		2.9		19.7		1.4		2.2		8.5		2.2	
Family *Plantaginaceae*	4.1		8.8		20.8		2.9		19.7		1.4		2.2		8.5		2.2	
Angelica sylvestris (Linnaeus, 1753)			28.9															
Family *Apiaceae*			28.9															
Urtica dioica (Linnaeus, 1753)																11.1		
Family *Urticaceae*																11.1		
Class dicotyledons—total	20.2	2.5	55.7	8.2	49.1	1.1	45.7	3.3	42.1	9.7	7.7	2.4	18.1	2	27.4	18.8	3.7	0.5

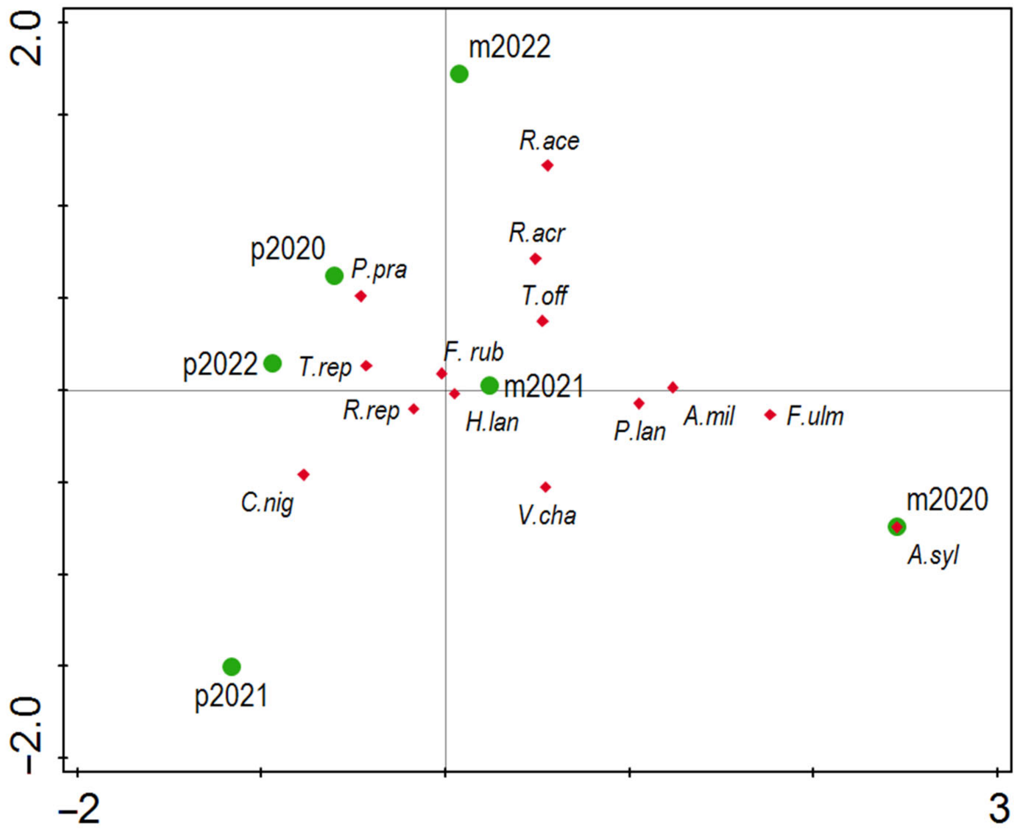

Figure 4. Ordination plot Correspondence Analysis (CA) for the study sites (green circles: p—pasture; m—meadow) and plant species (red diamond: uppercase letter—genus name; lowercase letters—first three letters of the species name).

3.3. Carabidae Species Composition and Abundance

Within the framework of the 2020–2023 epigeic fauna survey, a total of 2420 individuals of carabid beetles belonging to 19 species were caught in both analyzed land use types. The most abundant species turned out to be *Pterostichus melanarius*, with 1549 individuals caught. The next most numerous species were *Poecilus cupreus*, *Carabus cancellatus*, and *Carabus granulatus*, of which 269, 174 and 157, respectively, were caught. Fourteen species of beetles were each recorded in the pasture and meadow. These two grasslands were also characterized by the same dominant species in terms of the number of individuals. The species *Pterostichus melanarius* was most abundant in both the meadow and the pasture. In contrast, it was observed that individuals of *Poecilus cupreus* and *Anisodactylus binotatus* clearly preferred the meadow, while those of *Carabus granulatus* and *Pterostichus melanarius* were more abundant in the pasture. In all likelihood, it can be said that the form of land use influenced the numbers of these species.

For the entire species, significant differences in the abundance of carabid beetles were found between forms of use and years studied, and there was a significant FU × Y interaction (Table 3). In 2020 and 2021, the total number of individuals of all species of *Carabidae* was significantly higher in the pasture than in the meadow, while in 2022, the trend was reversed. Comparing the number of individuals in the meadow in different years, it can be noted that 2021 had a significantly lower abundance of beetles than in the other years. In the case of the pasture, the number of beetles was significantly higher in 2020 than in subsequent years of observation (Table 4).

Table 3. Results of the Wald test by type 3 analysis, using Wald χ^2 and *p*-values (in parentheses), examining the effect of form of use (FU) and year (Y) on the occurrence of Carabidae.

Carabidae	**Form of Use (FU)**	**Year (Y)**	**FU × Y**
All *Carabidae* (species)	4.43 (0.035)	58.79 (<0.001)	20.17 (<0.001)
Carabus cancellatus (Illiger, 1798)	2.35 (0.125)	25.92 (<0.001)	12.2 (0.002)
Anisodactylus binotatus (Fabricius, 1787)	14.22 (<0.001)	21.92 (<0.001)	12.74 (0.002)
Pterostichus melanarius (Illiger, 1798)	90.12 (<0.001)	195.67 (<0.001)	170.64 (<0.001)
Carabus granulatus (Linnaeus, 1758	7.92 (0.005)	24.93 (<0.001)	28.94 (<0.001)
Harpalus rufipes (De Geer, 1774)	4.88 (0.027)	7.14 (0.028)	- [1]
Poecilus cupreus (Linnaeus, 1758)	32.43 (<0.001)	56.39 (<0.001)	-
Poecilus versicolor (Sturm, 1824)	12.33 (<0.001)	8.33 (0.004)	-
Amara communis (Panzer, 1797)	0.64 (0.424)	-	-
Calathus fuscipes (Goeze, 1777)	2.71 (0.1)	-	-

[1] No value means that the model did not account for this effect because the analyzed species did not occur in the given form of use/year.

Table 4. Mean ± SE for the number of individuals of the studied species of *Carabidae* in the meadow and pasture in the studied years. Means with the same lowercase letters within a column or means with the same uppercase letter within a row for a species are not significantly different at $p \leq 0.05$.

	Year	**Meadow**	**Pasture**	**Mean**
All *Carabidae* (species)	2020	433 ± (20.8) aB	533 ± (23.1) aA	480.4 ± (15.5) a
	2021	294 ± (17.1) bB	361 ± (19) bA	325.8 ± (12.8) c
	2022	436 ± (20.9) aA	363 ± (19.1) bB	397.8 ± (14.1) b
	mean	381.5 ± (11.4) A	411.8 ± (11.8) A	
Anisodactylus binotatus	2020	33 ± (5.7) bA	4 ± (2) bB	11.5 ± (3) b
	2021	48 ± (6.9) aA	21 ± (4.6) aB	31.7 ± (4.2) a
	2022	11 ± (3.3) cA	14 ± (3.7) aA	12.4 ± (2.5) b
	mean	25.9 ± (3.3) A	10.6 ± (2.1) B	
Carabus cancellatus	2020	31 ± (5.6) aA	22 ± (4.7) bA	26.1 ± (3.6) b
	2021	47 ± (6.9) aA	40 ± (6.3) aA	43.4 ± (4.7) a
	2022	7 ± (2.6) bB	27 ± (5.2) abA	13.7 ± (2.9) c
	mean	21.7 ± (3.2) A	28.7 ± (3.1) A	
Carabus granulatus	2020	30 ± (5.5) aA	10 ± (3.2) cB	17.3 ± (3.2) b
	2021	28 ± (5.3) aA	52 ± (7.2) aB	38.2 ± (4.5) a
	2022	2 ± (1.4) bB	35 ± (5.9) bA	8.4 ± (3) b
	mean	11.9 ± (3) B	26.3 ± (3.4) A	
Pterostichus melanarius	2020	225 ± (15) bB	452 ± (21.3) aA	318.9 ± (13) a
	2021	23 ± (4.8) cB	185 ± (13.6) cA	65.2 ± (7.2) b
	2022	401 ± (20) aA	263 ± (16.2) bB	324.8 ± (12.9) a
	mean	127.6 ± (9.5) B	280.2 ± (10) A	
Harpalus rufipes	2020			6.2 ± (1.9) a
	2021			3.2 ± (1.6) ab
	2022			1.2 ± (0.7) b
	mean	5.5 ± (1.4) A	1.6 ± (0.9) B	
Poecilus cupreus	2020			43.6 ± (6.3) b
	2021			90.4 ± (7.1) a
	2022			1.3 ± (0.9) c
	mean	26.8 ± (6.4) A	11 ± (3.1) B	
Poecilus versicolor	2020			23.7 ± (3.5) a
	2021			-
	2022			11.9 ± (2.4) b
	mean	10.8 ± (2.3) B	25.9 ± (3.6) A	
Amara communis	mean	2 ± (1.4) A	4 ± (2) A	
Calathus fuscipes	mean	12 ± (3.5) A	5 ± (2.2) A	

Similarly, for most of the species analyzed, with the exception of *Carabus cancellatus* and *Amara communis*, there were significant differences between the number of individuals in the meadow and pasture (Tables 3 and 4) between the years of study, and a significant FU × Y interaction. The analysis of the occurrence of *Carabus cancellatus* in individual plots showed significant differences between the years, while there were no significant differences between forms of use. (Tables 3 and 4).

The RDA results for all species (Figure 5) show that the analyzed variables, such as the number of plant species (N_plant), organic carbon (TOC2), total nitrogen (Nt2) and, to a lesser extent, zinc (Zn2), indicate a positive correlation. The size of the arrows of the environmental variables Nt, Zn and TOC, and their alignment along the horizontal axis of ordination, indicate that organic carbon and total nitrogen determined the occurrence of beetles. The abundance of species on the right side of the graph of *Anisodactylus binotatus*, *Poecilus cupreus*, *Harpalus rufipes*, *Carabus nemoralis*, *Pterostichus niger* and *Amara anthobia* showed a positive correlation with all environmental variables. In contrast, *Amara communis*, *Carabus granulatus*, *Calathus fuscipes* and *Carabus cancellatus* arrows are orthogonal to the N_plant arrow and showed no correlation with this variable, while there is a positive correlation (not very strong) with the other variables. In contrast, the abundance of species located in the lower left corner showed a negative correlation. As the organic carbon and the total nitrogen content increased, so did the number of individuals of *Harpalus rufipes*, *Poecilus cupreus* and *Anisodactylus binotatus*, while the number of *Pterostichus melanarius* and *Poecilus versicolor* decreased. The abundance of beetles in the pasture also showed a negative correlation with all environmental variables in all years of study. A positive correlation was shown by the abundance of beetles in the meadow in 2020 and 2021, while 2022 revealed no significant correlation with all environmental variables.

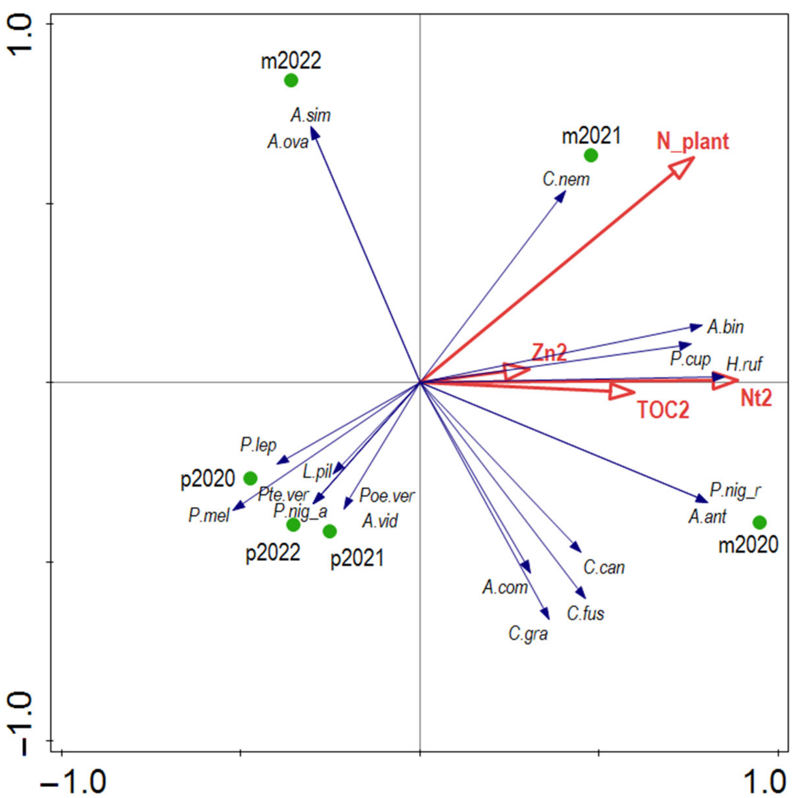

Figure 5. Redundancy analysis (RDA) ordination plot of beetle groupings (blue arrows: uppercase letters—genus name; lowercase letters—first three letters of the species name. Exceptions: Poe.ver—*Poecilus versicolor*; Pte.ver—*Pterostichus vernales*; P.nig_a—*Pterostichus nigirita*; P.nig_r—*Pterostichus niger*) against gradients of environmental variables (red arrows) for the study sites (green circles: p—pasture; m—meadow). For a list of all the species that were caught, see Appendix A.

4. Discussion and Conclusions

The diversity of ecosystems in landscape is a key factor in habitat diversity, which, in turn, affects species diversity [25]. Both inter- and intra-ecosystem diversity are essential for maintaining sustainable populations [26–30]. Carabid beetles respond to changes in the landscape at both the macro- (landscape) [31] and micro-habitat (soil conditions) levels [32]. They are also used as indicators of changes in soil conditions, such as soil contamination or soil preparation techniques [33–35].

Individual insect species, especially phytophages, have complex interactions with plants, and these, in turn, depend on soil properties and human ecosystem management practices. Plants act as mediators between animals and soil [36]. They also play a crucial role in inter-soil and aboveground interactions, which affect biodiversity [37]. Soil properties have a major impact on these patterns, not only in the context of soil fauna [38]. The habitat management practices exert a considerable influence on the communities of arthropod species, including ground beetles. The integration of the theoretical and experimental aspects of ecology with the practical knowledge of managers is vital for effective biodiversity conservation [39]. Grasslands, especially those under moderate human influence, can be very species-rich areas.

The integration of theoretical and practical knowledge is important for effective arthropod conservation in these areas [40,41]. The response of plants and animals to anthropogenic disturbances is one of the key areas of conservation research and the biggest challenge facing researchers. Animals react to the loss of their natural habitats with changes in their abundance and distribution, which can eventually lead to migration or even extinction. Despite many studies indicating a decline in species diversity following land use changes, this aspect is still being debated [42]. Undoubtedly, the impact of landscape management on the occurrence of plant and animal species, as well as soil chemistry, depends on the specific activities undertaken in a given area.

Although studies have not focused on the response of biodiversity to grazing in a given season, many researchers indicate that human activities show significant inter-annual variability in habitats [43–46]. The response of plant diversity to grazing can vary according to species and degree of phylogenetic diversity, which may be due to differences in initial conditions or the response to resources such as water, heat, nitrogen, carbon–nitrogen (C:N) ratio, pH and overlapping ecological niches [43]. The effect of grazing on plant and soil microbial communities can also vary by grassland type and grazing seasons. This may be related to changes in nitrogen availability due to grazing, the ratio of available nitrogen to phosphorus and soil moisture [44]. In addition, the season—cold or warm—can affect plant communities, soil bacteria and fungi, and their effects on the same microbial taxa can vary in both magnitude and direction [44]. Also, studies conducted to date have shown that the timing of grazing during cold and warm seasons can affect how different elevations store nutrients. Grazing can increase differences in nutrient accumulation between areas of different elevations, suggesting that human activities can alter the spatial patterns of grassland ecosystems. This means that grazing, especially in a seasonal context, can have long-term effects on these ecosystems, affecting their diversity and functioning [46].

Soil is one of the most important factors affecting the suitability of a habitat, due to the ability of micro- and macro-elements to penetrate the vegetation. On the other hand, soil macrofauna is a prominent indicator of soil quality due to its sensitivity to changes resulting from farming operations [16]. Nutrient availability is determined by the soil's physicochemical parameters [47,48], which affect plant growth and development [49], as well as the occurrence of soil fauna. The research described in this article revealed differences in the elemental content of soil in the two land use types studied. The content of particular elements was in agreement with the results of a previous study in this area [50], where the overall results of geochemical indices (geochemical index (I_{geo}) and enrichment factor (EF)) demonstrated low levels of soil contamination by the studied elements. A comparison of the land use types in terms of the content of the elements studied in the soil demonstrated significant disparity with regard to magnesium, calcium, phosphorus and zinc.

Magnesium stimulates the development of the root system and activates the processes responsible for the uptake of minerals from soil. It also influences the better utilization of nitrogen, potassium and phosphorus, and its content has a significant impact on the condition, resistance and development of plants. Phosphorus is crucial in the early growth period, after winter, when elemental uptake is limited due to low soil temperatures. Zinc, on the other hand, plays an important metabolic role in plant growth and development, and is therefore called an essential trace element or micronutrient [51]. Both of these elements also have a beneficial effect on the root system, providing a better start for the plant and faster recovery after winter. Calcium is an important element for plant cell structure. It is also crucial in cell signaling, participating in plant responses to environmental stimuli. Calcium deficiency leads to problems with new cell development and can cause plant deformities. Nitrogen is crucial for plant growth and vitality. Nitrogen deficiency leads to stunted growth, and general plant weakness. Excess nitrogen, on the other hand, can lead to overly lush vegetative growth at the expense of flowering and fruiting [52]. Carbon is the basic element of all organic compounds in plants, is the main source of energy for plants and provides the basis for building their structures. Each element has different roles, and the balance between them is crucial for optimal plant development. A lack or excess of any of these elements can lead to health problems and growth disorders.

Our study showed that the pasture was the richest in terms of calcium and magnesium content, while the meadow had significantly higher phosphorus and zinc contents. Hence, it can be concluded with a high degree of probability that the form of land use resulting from human economic activity influences the elemental content of the soil [53–55] and, consequently, also the plant cover.

This conclusion is also supported by previous studies [56,57], which presented a positive effect of long-term grazing on C, N and P accumulation in the soil, while a negative effect was shown on phosphorus availability. In addition, grazing during the growing season promotes shallow nutrient stratification, while grazing during the rest of the year sequesters nutrients deep into the soil profile. The grazing period also affects plant regrowth due to an increase in the rate of fecal decomposition and faster nitrification in warmer weather. At the same time, when grazing is too intensive, it can lead to a reduction in biodiversity and plant cover. However, the short-term exclusion of grazing can benefit vegetation characteristics and enrichment in the short term [58].

Comparing the three research seasons, the highest plant species diversity was shown in the meadow, while the pasture was dominated by grasses, which had more than 80 percent cover. The lower taxonomic and functional diversity of plants and insects in intensive pastures compared to extensive hay meadows, as well as the strong differences in composition between the two grassland types, has also been confirmed by an earlier study conducted in the Opawskie Mountains, at the border between Poland and the Czech Republic [12]. In addition, the studies of plant species richness in relation to nitrogen (N) input as an indicator of land use intensity found that it was significantly negatively related to nitrogen input in the study plots [8]. Regarding our study areas, however, there was no major difference in nitrogen content, so it is not possible to conclusively determine whether nitrogen content affected plant occurrence.

In the case of beetles, in the results of this study, it is impossible to conclude which form of use determines the species richness of this taxonomic group of animals. This is probably conditioned by the caught species' characteristics and needs in relation to the environment [59]. On the other hand, an increase in the number of individuals of each species depending on the form of use was observed, with some species showing a clear preference. *Pterostichus melanarius* turned out to be the most abundant species, as was also found in related studies that analyzed the effect of land use on beetle occurrence [60–64]. The beetle assemblages from the three years of observation in the pasture and meadow overlapped to a large extent. The number of individuals was also similar. On the other hand, it was observed that, in the first two years of observation, the number of individuals was higher in the pasture, while in the last year, the number of species was higher in the meadow. Also, in the meadow, the last year of the study (2022) showed a significantly higher proportion of monocotyledonous species and a considerably lower proportion of dicotyledonous species than in previous years.

The study showed that individuals of the species *Anisodactylus binotatus*, *Harpalus rufipes* and *Poecilus cupreus* clearly preferred the grassland, while individuals of *Pterostichus melanarius*, *Carabus granulatus* and *Poecilus versicolor* were more numerous in the pasture. It can be concluded with a high degree of probability that the appearance of these species is determined by a certain form of land use, and through appropriate management actions, it is possible to influence their abundance. This is confirmed by previous studies, which indicated that the average species richness of beetles was significantly higher in mowed plots than in pasture plots, and the species composition differed radically between the two types of management. In addition, different species characteristics were demonstrated for mowed and grazed plots [62], and it was found that a higher fertilization intensity was the most important factor for higher species richness and had a significant effect on species composition in both habitats. The studies in Scotland found that ground beetles were captured in lower overall numbers in ungrazed plots [65], while in the Netherlands, the abundance and activity of individual beetles was lower in grazed open grassland than in ungrazed open grassland [66].

The possibility of controlling the abundance of a given population was determined in a study conducted on other taxonomic groups of animals. In the case of a study in France, opening the soil and vegetation structure and cutting and grazing increased the abundance of some ground beetles and other invertebrates. However, grazing seemed too intensive, as spider species richness decreased [67]. A study conducted in Austria on grasshoppers (*Orthoptera*) showed that the average number of species between mown and grazed areas was very similar, while they differed in terms of the number of individuals. The average abundance in grazed transects was about one-third lower than in mowed transects [68]. In a study carried out by Szyszko-Podgórska [59] on land with different economic uses, it was shown that the number of species did not differ much between mowed and unmowed fallow land.

In contrast, the occurrence of species varied considerably in terms of abundance. The highest abundance was recorded on fallow land mowed with exported biomass. The management practices in agricultural and forest ecosystems were also found to have a significant impact on the formation of beetle and butterfly communities. Large-scale management strategies are needed to effectively protect species diversity [59]. As one can observe, the management operations that are carried out affect the occurrence of animals in the environments we shape, and these actions can have a positive effect on a particular group of insects, as well as a negative effect on another. Therefore, it can be concluded that by shaping different forms of land use or creating mosaics, we influence species richness and abundance. By shaping the landscape, we therefore shape the habitat of the species found there. Through various actions, we can influence the growth of species that are desired by us or inhibit the undesirable ones.

Beetle species richness is going to reach its peak when mowed and grazed grasslands co-occur at low and high intensities [62] and is stimulated by a mosaic of grazing intensities. In addition, the abandonment of grazing [65] as well as mowing [69] can be detrimental to some biodiversity components. In order to understand the complex effects of management on beetles, it is important to properly quantify management intensity and distinguish between management types, as they have different effects on ground beetles [62]. Understanding this aspect allows for the well-conceived control of animal population dynamics. The research that was conducted highlights the complexity of the relationship between habitat diversity, ecosystems and species diversity. These findings are very likely to be relevant to conservation planning, ecosystem management and the development of sustainable land use strategies. Adopting a holistic approach that takes into account habitat diversity, interspecies interactions and the impact of management practices is key to effective biodiversity conservation.

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Appendix A

Table A1. List of Carabidae species in individual study plots in 2020–2023.

Carabidae Species	Meadow			Pasture			Total 2020–2022
	2020	2021	2022	2020	2021	2022	
Carabus cancellatus (Illiger, 1798)	x	x	x	x	x	x	174
Amara communis (Panzer, 1797)	x				x		6
Amara anthobia (A. Villa and G.B. Villa, 1833)	x						4
Anisodactylus binotatus (Fabricius, 1787)	x	x	x	x	x	x	131
Harpalus rufipes (DeGeer, 1774)	x	x	x	x		x	24
Poecilus cupreus (Linnaeus, 1758)	x	x	x		x		269
Poecilus versicolor (Sturm, 1824)	x		x	x		x	78
Pterostichus melanarius (Illiger, 1798)	x	x	x	x	x	x	1549
Calathus fuscipes (Goeze, 1777)	x			x		x	17
Pterostichus niger (Schaller, 1783)	x						2
Carabus granulatus (Linnaeus, 1758)	x	x	x	x	x	x	157
Carabus nemoralis (O.F. Müller, 1764)		x					1
Poecilus lepidus (*Pterostichus virens*) (Leske, 1785)				x			1
Agonum viduum (Panzer, 1796)					x		1
Amara similata (Gyllenhal, 1810)			x				1
Amara ovata (Fabricius, 1792)			x				1
Pterostichus vernalis (Panzer, 1796)						x	1
Loricera pilicornis (Fabricius, 1775)						x	1
Pterostichus nigirita (Paykull, 1790)						x	2
Total	433	294	436	533	361	363	2420

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