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Botanical Evaluation of the Two-Year-Old Flower Strip with Analysis of the Local Carabidae Population: Case Study

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Abstract: Flower strips (FSs) are an effective way to support the sustainable development of agricultural land. Properly managed FS on agricultural fields provide stable habitats for local arthropod populations, but over the years, it can be colonized by plants from the soil seed bank and then become a nuisance to surrounding crops. The aim of this study was to assess the botanical composition of FS in one year after establishment and to analyze the local population of Carabidae, most of which are predatory. Inventory of flowering plants in situ was made regularly from the beginning of June to the end of July, while beetles were collected in mid-July and August. It was found that plant species from the sown seed commercial mixture continued to dominate in the second year, but the proportion of species from the soil seed bank was also noted, ranging from 7.41% to 39.88%. It was concluded that *Trifolium pratense* L. and *Chrysanthemum leucanthemum* L. should be particularly recommended for strip sowing in the observed habitats. The species diversity (H′) of Carabidae was higher in the FS than in the cultivated fields. However, when comparing the Shannon–Wiener index for wheat and FS, regardless of time observation, no significant differences were noted. The most abundant ground beetle in the FS was *Harpalus rupees*, a universal predator that also feeds on weed seeds. Significantly fewer species and individuals of Carabidae were found in the alfalfa field than in the FS and wheat fields. The number of Carabidae was significantly higher in August than in July.

Keywords: FS durability; biodiversity; Carabidae; preferences to habitats; organic farming; common agricultural policy

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1. Introduction

Due to the ever-increasing amount of land under cultivation, agricultural practices are becoming more intensive. However, many agricultural practices put pressure on the environment, resulting in the loss of many wild plant and animal habitats [1]. Modern agriculture is becoming increasingly industrialized, and the area of arable land is constantly increasing. Acquisition of new agricultural land remains the main cause of deforestation, which is a result of the growth of the world's population and growing consumer needs. As a result of deforestation, local climatic conditions change, which causes the productivity of soil obtained from the forest to decline rapidly in the short term [2]. In and around agricultural fields, on the farm, there are living organisms that interact with each other and form a quasi-ecosystem of the farm, consisting of cultivated plants, wild plants, herbivorous organisms (e.g., plant pests) and natural enemies of pests. In the field, we have not only pests that can damage crops but also our allies that, by destroying harmful species, often allow us to eliminate or reduce chemical treatments. In natural and agricultural communities that have been altered by human activity, there are also species that are theoretically less important but also play a role in the ecosystem. Supporting biodiversity is, therefore, a tool for maintaining ecological balance and enhancing ecosystem services, which contribute to the provisioning (e.g., food, biomass, water) and regulating services (e.g., maintaining air quality, regulating the water cycle, biological pest control, reducing erosion, etc.). One of the tools to support biodiversity on farmland, which is often poor in wild biodiversity due to the excessive use of chemical pesticides, is FS [3].

Flower strips (FSs) are strips of abundantly flowering plants that attract beneficial insects and provide habitat for various groups of organisms in the agroecosystem. This is an effective way to increase the biodiversity of the agroecosystem and provide ecosystem services [4]. The main purpose of their establishment is to enrich the fauna of agricultural fields with various beneficial organisms that will reduce the population density of herbivorous insects (crop pests) [3,5–7]. Fields cultivated in organic systems or with FSs have a more diverse flowering plant species composition and are, therefore, more attractive to insects than conventional fields and have floral resources used by insects that provide ecosystem services [8].

Our presented research focused on the analysis of carabid beetles occurring there, which constitute the most numerous group of beetles. Due to their large size, high mobility, and huge appetite, they are among the most effective beneficial insects, significantly reducing the number of plant pests from various taxonomic groups. Some of them, such as *Zabrus tenebrioides* (Goeze) or e. g. numerous species of the *Amara* or *Harpalus* genus, are herbivorous, and also most of them (with the exception of *Z. tenebrioides*), both in the larval and adult stages, lead a predatory lifestyle, hunting other insects and small snails [9–11]. Carabidae are valuable bioindicators in many ecosystems [12–14]. In natural systems, they are important indicators of pollution; in agroecosystems, they are important as biological control agents. They can eat large quantities of weed seeds, with the size and strength of their mandibles and the thickness of the seed coat probably influencing which seeds they can control. The consumption of unwanted seeds by beneficial insects has economic value. Some species are almost exclusively predatory, but many are omnivorous. This expanded dietary range has important implications for pest and weed seed management [12]. They usually hunt their prey at night and remain motionless during the day under fallen leaves, under rocks, and in other shaded hiding places [9]. Only a few species of carabids climb herbaceous plants and trees; they are typical inhabitants of the surface layers of soil and litter and play an important role in the transformation of organic matter. Unfortunately, they are sensitive to anthropogenic influences, including pesticides, and cannot develop in many habitats close to humans [14–16], so a more friendly way of managing farmland is sustainable rather than intensive agriculture. To mitigate biodiversity loss, agri-environmental management is introduced, the effectiveness of which may be moderated by landscape structure and land use intensity [16]. Results of Favarin et al. [17] showed that the number of arthropods belonging to various functional groups is influenced by structural and functional factors of the FS. While the abundance of chewing herbivores and terrestrial saprophages was more related to the functional characteristics of FS (e.g., plant nutritional value), the abundance of parasitoids and pollinators was related to the structural characteristics of plant communities (plant cover). Diversification of agriculture by sowing FS in fields can increase biodiversity and the richness of the ecosystems around us. FS enriches the fauna of agricultural land with species that are economically useful, both animals that limit the density of pest populations and pollinators [18,19].

As shown by Scheper et al. [20], the success of agri-environmental schemes (AES) on arable land depends largely on ecological factors, being most effective when implemented in structurally simple, resource-poor landscapes dominated by cropland, where they readily create large ecological contrasts.

The aim of this study was to evaluate the FS in the second year after its establishment in Central Europe without any maintenance treatments and to analyze the local population of carabid beetles occurring there and in the fields immediately adjacent to the FS in order to justify if FS is an effective strategy in biodiversity conservation on agricultural fields possible to implement in a short period of time.

2. Materials and Methods

2.1. Study Area

The study area consisted of a 6 m wide and 100 m long flowering strip established in the spring of 2021 between a field of alfalfa (*Medicago satvia*) and a field of wheat (*Triticum aestivum*), where no chemical pesticides or synthetic nitrogen fertilizers were used, at the Experimental Station in Winna Góra (52.209963, 17.433402) located in western Poland (see Figure 1).

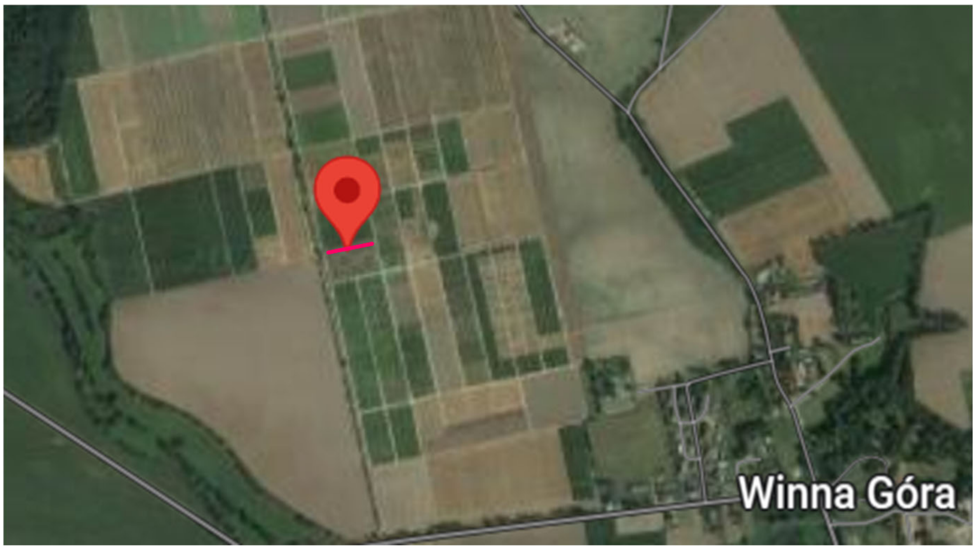


Figure 1. Location of the flower strip in question (own study based on Google map, 2025, red line—flower strip).

It was sown with a commercial mixture *Bees' universe* Toraf (available on the market) containing seeds of 30 species of undemanding annual, biennial and perennial plants with high nectar and pollen yield (Table 1). The seeds were sown to a depth of 1 cm and then rolled. The strip is located on average good arable soils in a very good rye complex (wheat-rye), in valuation class IIIb, and made of silty clay sands. The FS has not been mowed or treated with pesticides.

Table 1. Plants sown as a commercial mixture observed in 2021.

No.	Species	Family	Month of Flowering	Life Cycle
		Commercial Mixture		
1	*Calendula officinalis* L.	Asteraceae	June–September	annual
2	*Centaurea cyanus* L.		July–September	annual
3	*Chrysanthemum leucanthemum* L.		June–September	perennial
4	*Coreopsis tinctoria* Nutt.		July–October	annual
5	*Cosmos bipinatus* Cav.		July–October	annual
6	*Echinacea purpurea* (L.) Moench		June–September	perennial
7	*Guizotia abyssinica* (L. f.) Cass		August–September	annual
8	*Borago officinalis* L.	Boraginaceae	June–August	annual
9	*Echium creticum* L.		July–September	annual
10	*Echium plantagineum* L.		June–October	annual
11	*Echium vulgare* L.		June–October	biennial
12	*Phacelia tanacetifolia* Benth.		May–June	annual
13	*Gypsophila elegans* M.Bieb.	Caryophyllaceae	June–August	perennial
14	*Lotus corniculatus* L.	Fabaceae	May–August	perennial
15	*Lupinus angustifolius* L.		June–September	annual
16	*Melilotus albus* Medik.		June–October	biennial
17	*Melilotus officinalis* (L.) Pallas		July–October	biennial
18	*Trifolium incarnatum* L.		May–September	annual
19	*Trifolium pratense* L.		May–September	perennial
20	*Vicia sativa* L.		May–August	annual
21	*Dracocephalum moldavicum* L.	Lamiaceae	July–August	annual
22	*Melissa officinalis* L.		June–September	perennial
23	*Origanum majorana* L.		June–November	annual
24	*Salvia officinalis* L.		May–June	perennial
25	*Linum usitatissimum* L.	Linaceae	June–August	annual
26	*Mirabilis jalapa* L.	Nyctaginaceae	June–September	annual
27	*Oenothera paradoxa* Hudziok	Onagraceae	July–October	biennial
28	*Papaver rhoeas* L.	Papaveraceae	May–August	annual
29	*Fagopyrum acutatum* (Lehm.) Mansf. ex K.Hammer	Polygonaceae	July	annual
30	*Nigella sativa* L.	Ranunculaceae	May–September	annual

2.2. Botanical Studies

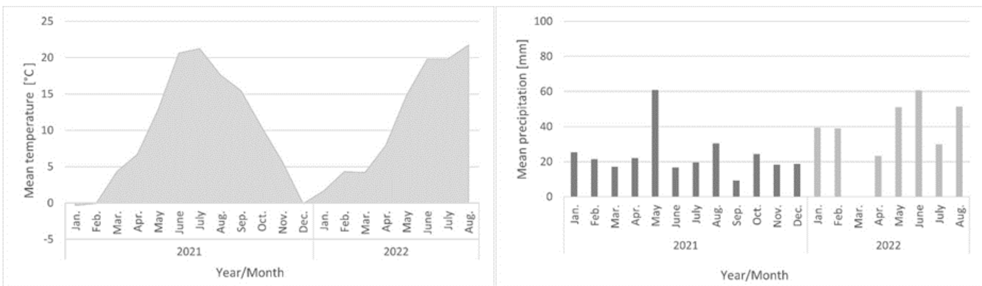
Species richness and abundance of blooming plants were recorded from 8 June to 26 July 2022. The species richness and abundance of individual plant species flowering at a given date were noted. Observations (inventories) were made five times: on 8 June, 5 July, 12 July, 20 July and 26 July. Abundance was quantified, with all floristic observations made by the same person. Inventories of plants in the FS were made randomly in a metal frame measuring 0.5 m x 0.5 m along the entire length of the strip, with 5 samplings along the entire length of the strip at each observation date. Due to their usefulness/attractiveness for arthropods, the number of plants currently flowering—in full bloom (per 0.25 m^2) was counted, and in the case of rhizome species, such as the Trifolium genus, inflorescence shoots were counted. Both species from the sown mixture and from the soil seed bank were recorded, and their percentage of the total number of flowering plants was also calculated. In addition, the number of species of currently flowering plants and the color of their inflorescences was determined each time during the observations, as this is one of the factors affecting their attractiveness to arthropods and should be taken into account when planning the plant composition intended for the FS.

2.3. Survey of Carabidae

An inventory of carabids in the FS and adjacent organic fields was made. It provided a preliminary picture of their diversity both in the FS and in the adjacent fields, i.e., in the alfalfa and wheat fields. The beetles were collected twice, once in mid-July and once in August. The material was caught in ground traps filled with preservative liquid (70% ethylene glycol with a drop of liquid detergent to minimize surface tension) in five samples at each date and location. Traps were placed in the center of the FS, with each trap 20 m apart. Traps were similarly placed in adjacent fields.

2.4. Location and Weather Conditions

In order to determine the variable environmental factors important for the wintering of plants, meteorological data from the Winna Góra Experimental Station (52.205194, 17.449223) were used in the period from January 2021 to August 2022. The average air temperatures in periods III–VIII in 2021 and 2022 were similar, amounting to 13.90/14.73 °C (Figure 2a). These were warm years; in March each year, the average air temperature was higher than the climatological norm for Poland, similar to June and July and the autumn and winter months—from October to February [21]. Precipitation was measured using a Hellmann rain gauge (mm). The average annual sum of precipitation for the region where the FS was located (western Poland) was 284.00/407.50 mm for 2021 and 2022, respectively, and was lower than the long-term value of 523 mm [22]. Monthly averages are shown in Figure 2b. Considering the average of the months of greatest water demand, 2021 was dry, and 2022 had more rainfall (Figure 2b).



(**a**) (**b**)

Figure 2. Average air temperature (**a**) and precipitation (**b**) in the year of establishing the FS (2021) and in the year of observation (2022).

2.5. Statistical Analysis

The results were statistically processed using the Statistica 12.0 program (StatSoft Polska, Kraków, Poland). Prior to the analysis, the Shapiro–Wilk test for normal distribution was performed. In the case of data with a normal distribution, the results were statistically processed using a one-way and two-way analysis of variance, and the means were compared using the unprotected Fisher's Least Significant Difference (LSD) test at a significance level of $\alpha = 0.05$. For data that did not have a normal distribution, the Kruskal–Wallis test was performed, a non-parametric equivalent to one-way ANOVA (Kruskal–Wallis one-way analysis of variance by ranks). Multiple comparison tests were performed. For comparisons of arthropod data that deviated from the normal distribution, the Mann–Whitney U test was used. To compare species diversity between the FSs and the alfalfa and winter wheat fields, the Shannon–Wiener index was used, calculated with the program PAST 4.03 [23].

3. Results

3.1. Botanical Studies

In 2021, plants sown as a commercial mixture were inventoried, and all species that should be flowered were noted (Table 1). The assessments were based on 25 inventories. In 2022, only 25 flowering plant species were noted, 12 plant species from the commercial mixture and 13 species came from the soil seed bank (Table 2). Many botanical families were observed among the soil seed bank plants, most of them from the Asteraceae family (Table 2).

Table 2. Plants emerging from the soil seed bank and the percentage (%) of flowering plants in the FS, one year after establishment (2022).

No.	**Species**	**Family**	**Month of Flowering**			**Life Cycle**	
			Soil Seed Bank				
1	*Chenopodium album* L.	Amaranthaceae	June–October			annual	
2	*Anthemis arvensis* L.	Asteraceae	May–October			annual/perennial	
3	*Artemisia vulgaris* L.		July–September			perennial	
4	*Matricaria chamomilla* L.		May–August			annual	
5	*Tripleurospermum maritimum* (L.) W.D.J. Koch		June–September			annual	
6	*Myosotis arvensis* (L.) Hill	Boraginaceae	May–August			annual	
7	*Capsella bursa-pastoris*	Brassicaceae	May–October			annual	
8	*Raphanus sativus* L. *var. oleiformis* Pers.		May–October			annual	
9	*Silene vulgaris* (Salisb.) Sm.	Caryophyllaceae	May–September			perennial	
10	*Geranium pusillum* L.	Geraniaceae	April–October			annual	
11	*Plantago lanceolata* L.	Plantaginaceae	May–September			perennial	
12	*Rumex crispus* L.	Polygonaceae	June–August			perennial	
13	*Viola tricolor* L.	Violaceae	May–October			annual	
No.	Species	Color of Inflorescences	Date of Inventory (2022)				
			8 June	5 July	12 July	20 July	26 July
			Commercial Mixture				
1	*Calendula officinalis*	orange	0.48	0.00	0.00	0.86	2.13
2	*Centaurea cyanus*	white/pink/blue/violet	31.43	17.59	4.17	6.03	8.51
3	*Chrysanthemum leucanthemum*	white/yellow	15.71	1.85	2.98	2.59	0.00
4	*Coreopsis tinctoria*	pink	0.00	0.00	5.95	18.10	4.26
5	*Echium vulgare*	violet	1.43	3.70	1.19	1.72	8.51
6	*Gypsophila elegans*	white	9.05	0.00	0.00	0.00	0.00
7	*Melilotus albus*	white	0.00	0.00	2.38	3.45	6.38
8	*Melilotus officinalis*	yellow	0.95	1.85	1.19	0.00	0.00
9	*Trifolium incarnatum*	dark pink	8.10	0.00	0.00	0.00	0.00
10	*Trifolium pratense*	pink	9.52	67.59	41.07	56.90	38.30
11	*Papaver rhoeas*	red	0.00	0.00	1.19	0.86	0.00
12	*Fagopyrum acutatum*	white/pink	8.10	0.00	0.00	0.00	0.00
			Soil Seed Bank				
1	*Chenopodium album*	green	0.00	0.00	1.19	0.00	0.00
2	*Anthemis arvensis*	white/yellow	0.00	0.00	23.81	0.00	0.00

Table 2. *Cont.*

No.	Species	Family	Month of Flowering			Life Cycle	
3	*Artemisia vulgaris*	green/yellow	0.00	0.00	0.00	4.31	4.26
4	*Matricaria chamomilla*	white/yellow	0.00	7.41	4.76	0.00	0.00
5	*Tripleurospermum maritimum*	white/yellow	0.00	0.00	0.00	0.00	25.53
6	*Myosotis arvensis*	blue	0.00	0.00	0.00	0.86	0.00
7	*Capsella bursa-pastoris*	white	8.10	0.00	0.00	0.00	0.00
8	*Raphanus sativus*	white	0.00	0.00	5.95	0.00	0.00
9	*Silene vulgaris*	white/pink	0.00	0.00	1.79	3.45	0.00
10	*Geranium pusillum*	violet	4.29	0.00	0.00	0.00	0.00
11	*Plantago lanceolata*	green/white	0.00	0.00	0.60	0.00	2.13
12	*Rumex crispus*	green/white/pink	0.00	0.00	1.79	0.86	0.00
13	*Viola tricolor*	violet/white/yellow	2.86	0.00	0.00	0.00	0.00

Among the flowering plants of the commercial mix, several species dominated, especially *Trifolium pratense* (Fabaceae) with its pink inflorescences, *Chrysanthemum leucanthemum* (Asteraceae) and *Centaurea cyanus* (Asteraceae) (Table 2). At the beginning of July, *T. pratense* accounted for more than half (67.59%) of the flowering plants.

Among the flowering plants from the soil seed bank, *Anthemis arvensis* (23.81% on 12 July) and *Tripleurospermum maritimum* (25.53% on 26 July) from the Asteraceae family had the highest proportion (Table 2).

The time of intense flowering of the plants in the FS was the beginning of June (Table 3). The dominant one was *Centaurea cyanus* (Asteraceae), which came from the commercial mix, with different colors of inflorescences: from white, through pink and blue to dark purple. It represented 31.43% of all flowering plants at that time (Table 2). The second species in terms of abundance was *Chrysanthemum leucanthemum*, belonging to the same family, with white ligulate and yellow tubular flowers (15.71%), and *Capsella bursa-pastoris* (8.10%) from the soil seed bank. The proportion of other species was low. One month later (at the beginning of July), *C. cyanus* was still a very abundant flowering species in the FS (17.59%), but *T. pratense* was clearly dominant and remained so until the end of the observation (Table 2). Plants flowering in the flower strip from early June to late July are shown in Figure 3.

Table 3. The number of flowering plants will depend on the date of observation (2022).

Date of Inventory	$\bar{x}$ (SD)	Me * (Min./Max.)	Mean Rank	Kruskal-Wallis Test (4, N = 25)
8 June	38.60 (±12.89)	38.00 (25.00/60.00)	19.30 a **	H = 14.498 p =0.0059
5 July	21.60 (±5.95)	20.00 (14.00/29.00)	12.00 ab	
12 July	33.60 (±8.31)	35.00 (23.00/46.00)	18.00 a	
20 July	23.20 (±10.19)	25.00 (11.00/36.00)	12.20 ab	
26 July	9.60 (±2.24)	11.00 (6.00/12.00)	3.50 b	
Test statistics	χ^2 = 8.974	df = 4		p = 0.0617
Significant difference		1–5		3–5

* Me—median, ** Mean marked with the same letters do not differ significantly at α = 0.05.


(**a**) (**b**) (**c**) (**d**) (**e**)

Figure 3. Flowering plants in the FS, from early June to late July 2022 ((**a**)—8 June, (**b**)—5 July, (**c**)—12 July, (**d**)—20 July, (**e**)—26 July).

The flowering strip was dominated by plants from the sown commercial mix (Figure 4), which accounted for 60.12% (12 July) to 92.59% (5 July). The proportion of flowering plants that came from the seed bank in the soil varied, depending on the observation date, from 7.41 to 39.88%. The largest number of them was noted in mid-July (Figure 5). In general, the species diversity of the FS was not high, depending on the date of observation, from 3.4 to 7 species (in the first half of July), most of them coming from the sown mixture (originally containing 30 species). The largest number of species coming from the soil seed bank has been observed since mid-July (Table 2, Figure 5).

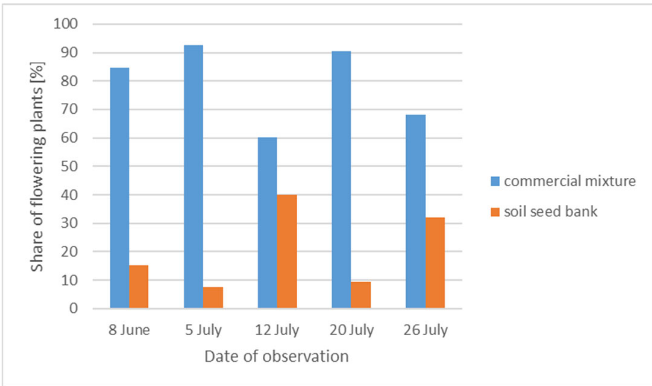


Figure 4. The percentage of flowering plants in the FS (2022), depending on the date of observation (from the commercial mixture and the soil seed bank).

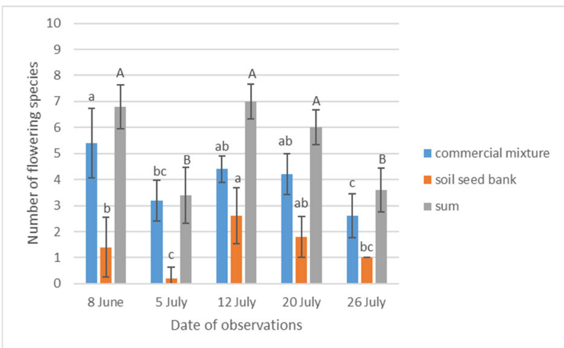


Figure 5. Number of flowering species in the FS, depending on the inventory date (for mixture and soil seed bank); based on one-way ANOVA, means with same letters are not significantly different at $\alpha = 0.05$.

Echium vulgare deserves special attention. Although its percentage share in the total number of flowering plants was not large (8.51% at the end of July), the size of the entire plants and the number of individual flowers, of which there are a lot, meant that insects, mainly bumblebees, visited it very willingly (Table 2, Figure 6).

Figure 6. *Echium vulgare* with intensely colored flowers (5 July), which also stand out from the background of the FS due to their height (2022).

3.2. Survey of Carabidae

A total of 40 species of carabid beetles were observed. The most abundant species were *Harpalus rufipes*, *Dolichus halensis* and *Calathus fuscipes* (1482, 169 and 120 individuals, respectively). In August, *H. rupifes* was most abundant in the wheat field and the FS (528 and 451 individuals, respectively), representing 78.22% and 62.21% of all carabid beetles collected at that time. The species found in the FS were dominated by those that feed on seeds of various plants, including weeds and other invertebrates. Particularly noteworthy is the presence of *Anchomenus dorsalis*, a predatory species specialized in hunting aphids (Table 4).

Table 4. Number of individuals (IS) of beetles and their proportion (%) of the total number of carabid beetles in the FS and in adjacent fields of different crops to the strip, depending on the date of inventory (2022).

Species	Site (Preferences to Habitats) Alfalfa Field				FS				Wheat Field			
	July		August		July		August		July		August	
	IS	[%]	IS	[%]	IS	[%]	IS	[%]	IS	[%]	IS	[%]
Agonum muelleri (Herbst)	0.00	0.00	0.00	0.00	2.00	1.49	0.00	0.00	3.00	1.69	0.00	0.00
Amara aenea (De Geer)	1.00	1.10	1.00	0.27	5.00	3.73	2.00	0.28	5.00	2.82	12.00	1.78
Amara aulica (Panz.)	0.00	0.00	0.00	0.00	2.00	1.49	17.00	2.34	4.00	2.26	0.00	0.00
Amara bifrons (Gyll.)	0.00	0.00	0.00	0.00	5.00	3.73	1.00	0.14	1.00	0.56	0.00	0.00
Amara lunicollis (Schiödte)	0.00	0.00	0.00	0.00	1.00	0.75	1.00	0.14	0.00	0.00	1.00	0.15
Amara plebeja (Gyll.)	0.00	0.00	0.00	0.00	1.00	0.75	1.00	0.14	1.00	0.56	0.00	0.00
Amara similata (Dej.)	0.00	0.00	0.00	0.00	3.00	2.24	5.00	0.69	6.00	3.39	2.00	0.30
Anisodactylus binotatus (F.)	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.14	0.00	0.00	0.00	0.00
Bembidion lampros (Herbst)	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.14	0.00	0.00	1.00	0.15
Bembidion properans (Steph.)	7.00	7.69	1.00	0.27	11.00	8.21	0.00	0.00	10.00	5.65	2.00	0.30
Bembidion quadrimaculatum (L.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.13	2.00	0.30
Calathus ambiguus (Payk.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.56	2.00	0.30
Calathus erratus (Schalb.)	0.00	0.00	10.00	2.67	6.00	4.48	15.00	2.07	2.00	1.13	13.00	1.93
Calathus fuscipes (Goeze)	2.00	2.20	40.00	10.67	7.00	5.22	36.00	4.97	3.00	1.69	32.00	4.74
Calathus melanocephalus (L.)	1.00	01.10	2.00	0.53	1.00	0.75	3.00	0.41	1.00	0.56	1.00	0.15
Calathus rotundicollis (Dej.)	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.14	0.00	0.00	0.00	0.00
Clivina fossor (L.)	1.00	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.15
Dolichus halensis (Schaller)	5.00	5.49	5.00	1.33	7.00	5.22	147.00	20.28	1.00	0.56	4.00	0.59
Harpalus affinis (Schalb.)	0.00	0.00	4.00	01.07	0.00	0.00	2.00	0.28	9.00	05.08	18.00	2.67
Harpalus anxius (Duft.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.44
Harpalus froelichii (Sturm)	2.00	2.20	3.00	0.80	3.00	2.24	4.00	0.55	0.00	0.00	1.00	0.15
Harpalus griseus (Panz.)	4.00	4.40	0.00	0.00	5.00	3.73	3.00	0.41	1.00	0.56	7.00	01.04
Harpalus luteicornis (Duft.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.56	0.00	0.00
Harpalus distinguendus (Duft.)	2.00	2.20	0.00	0.00	0.00	0.00	1.00	0.14	4.00	2.26	0.00	0.00
Harpalus rufipes (De Geer)	55.00	60.44	300.00	80.00	59.00	44.03	451.00	62.21	89.00	50.28	528.00	78.22
Harpalus signaticornis (Duft.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	1.69	19.00	2.81
Harpalus smaragdinus (Duft.)	2.00	2.20	0.00	0.00	0.00	0.00	0.00	0.00	6.00	3.39	7.00	01.04
Harpalus tardus (Panz.)	2.00	2.20	0.00	0.00	1.00	0.75	1.00	0.14	0.00	0.00	0.00	0.00

Table 4. *Cont.*

Species	Site (Preferences to Habitats) Alfalfa Field				FS				Wheat Field			
	July		August		July		August		July		August	
	IS	[%]	IS	[%]	IS	[%]	IS	[%]	IS	[%]	IS	[%]
Harpalus pumilus (Sturm)	0.00	0.00	0.00	0.00	1.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00
Harpalus xanthopus (Schaub.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.15
Anchomenus dorsalis (Pont.)	0.00	0.00	0.00	0.00	0.00	0.00	11.00	1.52	0.00	0.00	0.00	0.00
Loricera pilicorns (F.)	2.00	2.20	0.00	0.00	2.00	1.49	1.00	0.14	0.00	0.00	0.00	0.00
Microlestes minutulus (Goeze)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00	3.95	0.00	0.00
Poecilus cupreus (L.)	0.00	0.00	1.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poecilus lepidus (Leske)	0.00	0.00	2.00	0.53	1.00	0.75	1.00	0.14	15.00	8.47	14.00	02.07
Poecilus versicolor (Sturm)	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.28	0.00	0.00	0.00	0.00
Pterostichus melanarius (Ill.)	3.00	3.30	6.00	1.60	5.00	3.73	16.00	2.21	1.00	0.56	3.00	0.44
Syntomus foveatus (Geoff.)	0.00	0.00	0.00	0.00	3.00	2.24	0.00	0.00	1.00	0.56	0.00	0.00
Trechus quadristriatus (Schrank)	0.00	0.00	0.00	0.00	1.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00
Zabrus tenebrionides (Goeze)	2.00	2.20	0.00	0.00	2.00	1.49	1.00	0.14	0.00	0.00	1.00	0.15
Individuals Species (Σ)	91.00		375.00		134.00		725.00		177.00		675.00	

Comparing the species richness of Carabidae in the FS with the adjacent crop, it was found that both in July and August, the Shannon–Wiener index in the FS was higher than in the alfalfa and the wheat field (Figure 7). The obtained result turned out to be statistically significant for the comparison of flower strip vs. alfalfa (Mann–Whitney U test: $U = 16.5$; $p = 0.009$), indicating that this index was higher for FS, but compared the Shannon–Wiener index for wheat and FS, regardless on time observation, no significant differences were noted.

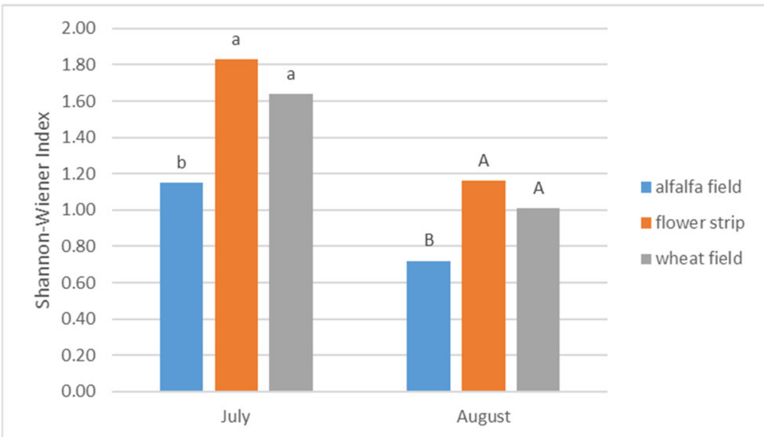


Figure 7. Shannon–Wiener Index (H') depending on habitats and month of observation (2022). A different case of letters refers to the time of inventory.

Regarding the number of species observed, the analysis of variance showed that July and August did not differ significantly by month:mean 8.60 and mean 8.67, respectively (Figure 8). Regardless of the month of observation, there were significantly fewer species in the alfalfa field than in the FS and in the wheat field. In July, the number of species in the alfalfa field was not statistically different from that in the wheat and FS, but in August, significantly more species were noted in the FS and wheat field (10.80 and 10.60, respectively) than in the alfalfa field (4.60). The habitat of wheat plants was similarly attractive to carabidae as FSs (Figure 8, Table 5).

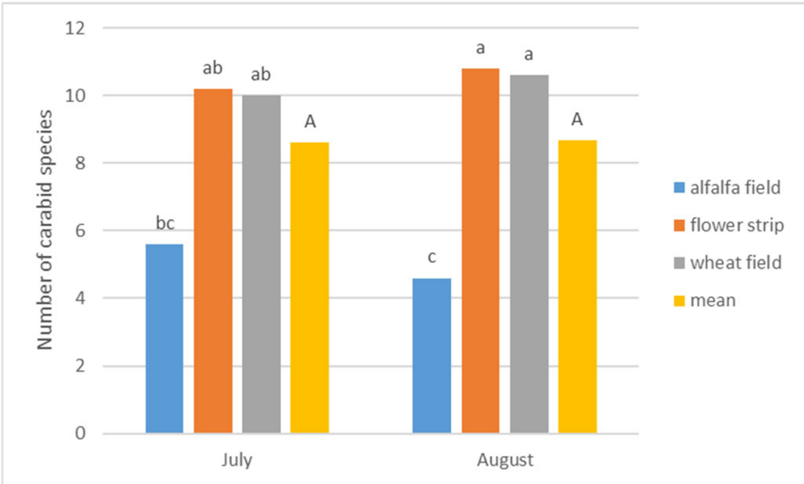


Figure 8. The mean number of carabid species, depending on habitats and month of inventory (2022); one-way ANOVA, mean marked with the same letters do not differ significantly at α = 0.05. Capital letters refer to the mean number in a month regardless of habitat.

Table 5. The number of carabid beetles, depending on habitats (2022).

Habitats	$\bar{x}$ (SD)	Me * (Min./Max.)	Mean Rank	Kruskal-Wallis Test (2, N = 30)
Alfalfa Field	46.60 (±63.34)	22.00 (4.00/210.00)	11.45	H = 3.213
Flower Strip	85.90 (±74.45)	50.50 (20.00/215.00)	17.90	p = 0.2006
Wheat Field	85.20 (±82.09)	55.00 (4.00/249.00)	17.15	
Test Statistics	χ^2 = 3.20	df = 2		p = 0.2019
Significant difference				not significant

* Me—median.

The mean number of ground beetle individuals caught in the different habitats, regardless of month, was significantly lower in the alfalfa field. Regardless of habitat, there were many more individuals in August (118.3) than in July (26.8) (Table 6).

Table 6. The number of carabid beetles depends on the date of inventory (2022).

Habitats	Month	
	July	August
Alfalfa Field	18.20 b	75.00 a
Flower Strip	26.80 b	145.00 a
Wheat Field	35.40 b	135.00 a
Mean	26.80 B	118.33 A

One-way ANOVA: average marked with the same letters do not differ significantly at α = 0.05.

4. Discussion

Many conservation practices have multiple effects on soil conditions, arthropod diversity, and plant nutrition and health. FSs on agricultural land are one such practice. It is worth noting that plants from FSs can help protect the soil from water and wind erosion. Plants can also improve soil structure by increasing water and air permeability, which can promote better crop health in nearby fields [24]. Annual flower strips may be easier for farmers to establish because their location can be changed each year, but then agricultural work carried out on the removed annual strip does not provide conditions and opportunities for overwintering for arthropods, including predators [25], such as Carabidae. Properly managed perennial FS can offer a more stable habitat, contributing to increasing local arthropod populations. However, over the years, they may lose most of their properties and floral values [26] because grass begins to dominate, making them less attractive to many species. However, Pankanin–Franczyk and Bilewicz–Pawinska [26] reported that some predator species can occur in grass communities, indicating that grass communities can also play an important role in the agroecosystem in maintaining the stability of phytophagous and predator systems.

During our observations, one year after the establishment of the FS, no spontaneous grass species were observed, which can be an increasing problem in the future. The FS was very compact and the plants flowered profusely (Figure 5). Similar results were obtained on another evaluated perennial strip (about 70 km away from this one) in the same growing season, located on a similar type of soil, where the proportion of grasses was marginal [24].

May and June are usually the most intense flowering months for plants in the FS [25,26]. In the study by Favarin et al. [17], commercially sown species in the FS represented 44% of all plant species, with an average of 92.46 (±5.85)% of the total cover, and spontaneous species 6.84 (±0.72)%. On our collected dates, 6 to 15 plant species flowered simultaneously, the majority of which came from the sown mixture (53.33–83.33%). The percentage of flowering plants from the mixture in the total number of flowering plants was much higher (60.12–92.59%) than that of plants from the soil seed bank (7.41–39.88%), but it is worth remembering that spontaneously emerging species (considered as weeds) can successfully colonize emerging gaps in the flowering strip, ensuring an increase in biodiversity [27,28].

Several species dominated, with particular emphasis on *T. pratense* of the Fabaceae family (Table 2). Ouvrard [29] and Favarin et al. [17] also recorded the largest number of plants from this family, which provide large amounts of both pollen and nectar to arthropods and are desirable in FS [30]. *T. pratense* has high soil and water requirements [31]. The FS was located on average good arable soils, and although the weather conditions in 2022 seemed inappropriate for its proper development, especially in spring (Figure 4), *T. pratense* flowered profusely and was the dominant plant in the strip almost throughout the observation period (Table 2). *Trifolium incarnatum*, although it has lower water and soil requirements than *T. pratense* [31], constituted a small proportion (8.10%) of the flowering plants and only in the initial period (Table 2). However, this species is very sensitive and can become extinct, which was the case during our observations. *T. incarnatum* flowered profusely, making up an average of 70.5% of all flowering plants in May, and was recommended for sowing in perennial FS. Our observations confirm the strong influence of environmental conditions on the success of FS establishment and the high probability of the need for reseeding in subsequent years.

At the beginning of June, in the FS, a high share of flowering plants (31.43%) was *Centaurea cyanus* (cornflower), which bloomed throughout the entire observation period. Dobrzański [32] states that it is characterized by a broad ecological optimum, which may appear in various periods of the growing season, regardless of weather conditions. Although it is characterized by high nectar yield [33] and is often recommended for mixtures intended for FS, Marczewska-Kolasa et al. [34] indicate that the proximity of cornflower seeds may significantly influence the reduction of the fresh weight of the above-ground parts of some cereals.

Chrysanthemum leucanthemum at the beginning of June accounted for 15.71% of flowering plants. In the study by Antkowiak et al. [27] in another FS, this species was also a component of the commercial mixture, but its percentage share in the total number of flowering plants was less than half. It is a perennial plant that reproduces both by seeds, germinating throughout the growing season, and by shallow rhizomes, spreading quickly [35]. According to Babicki [36], *C. leucanthemum* plays an important role in maintaining the balance of the ecosystem. Spiders often use it as a hunting ground, and the flowers attract numerous beneficial insects, the larvae of which feed on aphids. As Reddy et al. [35]

pointed out, chrysanthemum essential oil has antifungal, antimutagenic and antibacterial properties. It is limited, among others, the growth of Alternaria sp., *Aspergillus flavus* and *Pythium ultimum* (reduction > 80%). These properties seem to be particularly valuable in relation to fungal spores, which are carried by the wind and sometimes can cause huge losses in agriculture. Haouas et al. [37] described the insecticidal effect of methanol extracts of chrysanthemum flowers and leaves on *Tribolium confusum*. It seems reasonable to include it in seed mixtures intended for FSs for this reason and to create a source of raw material to make extract used to protect grain yield in storage. Also, the essential oil of *T. pratense* has antimicrobial and antifungal properties [38], which constituted a large share of flowering plants in the FS from the beginning of July until the end of the observations (Table 2, Figure 3) while being an important host plant for bumblebees pollinating crops. The use of plants that secrete strong essential oils could additionally support crops adjacent to FSs in good phytosanitary conditions.

Important antagonists of pests in the environment of agricultural fields are many species of carabids whose populations can be supported with FSs [19,39]. In the study by Twardowski et al. [40], the presence of FSs in sugar beet cultivation had a positive effect on the number of carabids. However, more carabid species were identified in the uncultivated strip—plants that spontaneously appear from the soil seed bank—than in the strip with the sown mixture (consisting of *Phacelia tanacetifolia*, *Coriandrum sativum* and *Sinapis alba*), therefore the authors suggest leaving 1 m wide strip uncultivated to increase density Carabidae population. In the uncultivated strip, depending on the date of observation, 17–27 plant species were recorded, the most common being *Thlaspi arvense*, *Matricaria chamomilla*, *Chenopodium album*, *Amaranthus retroflexus*, *Polygonum persicaria* and *Euphorbia helioscopia*. In our research, 13 plant species were observed from the soil seed bank, with *Matricaria chamomilla* accounting for 7.41% of flowering plants at the beginning of July and *Chenopodium album* just 1.19% midway through this month. The largest share of self-sown flowering plants was observed in the first half of July (Table 2), and there were significantly more carabid beetles in August than in July (Table 6).

In the study by Kujawa et al. [19], as many as 46 species of carabids were observed in the FS, the most numerous of which was *Harpalus rufipes*, which accounted for 45.8%. Similar results were obtained in our own observations. *H. rupifes* was the highest in August in all habitats, the highest in the wheat field (528 individuals), in the FS (451 individuals), and the lowest in the alfalfa field—300 individuals (Table 5). Species of the Harpalus genus occur mainly in open landscapes. They are the most common beetles of field agrocenosis [41], and *H. rufipes* is a medium-sized, feeds on both plants and animals, flies well and recolonizes disturbed habitats very quickly [41]. Adults are active from spring to autumn. *H. rufipes* is a universal predator; like many other carabids, it eats a wide range of prey. It can make a significant contribution to reducing the occurrence of aphids and fly larvae, as well as snails such as *Deroceras reticulatum* [42]. Larvae in the third stage eagerly feed on seeds, especially grass seeds [39], which additionally helps to naturally minimize the risk of their excessive growth in the FS in the subsequent years of its use.

Even annual FS is quickly becoming local shelters for arthropods of a large variety, including enemies of crop insect pests [36]. In the study by Triquet et al. [43], some Carabidae species were recorded mainly or only in the FS already in the first year after establishment, with the density of *Poecilus cupreus* and *Pterostichus melanarius* being higher closer to the strip. In the study by Ditner et al. [39], *P. cupreus*, next to *H. rupifes* and *Bembidion quadrimaculatum*, was the most abundant beetle, with an average of 30% more carabid beetles in FS than outside them. There were also more spiders in the FS. In our research, 40 species of carabids were observed (Table 4), with the average number of carabid species in alfalfa field, wheat field and the FS 5.10, 10.50 and 10.50, respectively

(Figure 8). Even though the number of species was similar in the FS and in wheat fields, species diversity was higher in the strip than in wheat. The Shannon–Wiener index in the FS was higher in both months (1.83 and 1.16, respectively) than in the fields directly adjacent to it, in winter wheat (1.64 and 1.01) and in alfalfa (1.15 and 0.72). As the presented research results show, single individuals of *P. cupreus* were recorded only in the alfalfa field in August, and *P. melanarius* at all dates and locations, with the largest number in the FS (Table 4).

Kosewska et al. [44] found that plowing has a negative impact on the diversity of Carabidae, so leaving perennial FS without any cultivation seems to be much more beneficial for them than eliminating the annual strip every year. Skłodowski [45] reports that of the various ways of preparing the soil in clear-cuts and their management, the most positive effect on carabids is exerted by branches arranged in prisms on clear-cuts, which, in fact, protect the forest fauna of carabids and are a rescue for them, which can be analogously translated into long-term FS in intensively used fields, which become a real refuge for them. Plowing the soil causes the disappearance of some carabids living in open areas, especially full plowing, which means the complete destruction of dense vegetation cover and replacing it with a vast space not covered with plants. Spring soil cultivation may be harmful, especially for species of the spring development type, when fieldwork coincides with the period of larval maturation and pupation, e.g., *Pterostichus melanarius*. In the study by Twardowski et al. [40], the most numerous Carabidae species included *Harpalus rufipes*, *Anchomenus dorsalis*, *Poecilus cupreus* and species of the Bembidion genus. The species diversity of Carabidae was highest in the strips with plants from the soil seed bank. In our study, only single individuals of *P. cupreus* were recorded in an alfalfa field, and the genus Bembidion was represented by three species: *B. lampros*, *B. properans* and *B. quadrimaculatum.* There were more individuals of *B. properans*, more in July than in August, at all habitats (Table 4). The proper structure of agricultural land is a key element of a successful agricultural production system, but the structure of FSs can also influence the biodiversity of entomofauna of field crops and FSs. Our future could be largely determined by sustainable agriculture [46]. Alternative methods of controlling pests and diseases in agricultural crops are needed, including activities aimed at promoting biological conservation methods, which in turn are strengthened by, among other things, the introduction of FSs, which can perform various functions [2,18], including the creation of refuges for one of the most important groups of insects in agricultural fields, i.e., Carabidae. In order to encourage farmers to support these practices, it is necessary, first of all, to disseminate knowledge in the field of sustainable agriculture and to introduce financial instruments that will contribute to the gradual adaptation of these methods to the specificity of agricultural production and their development in the long term. The creation of friendly habitats for natural enemies of insect pests is a crucial element of sustainability in plant production. Interaction between insect plants and the search for attractive or repellent for Carabidae plants should be developed in the next study at the biochemical levels.

5. Conclusions

One year after the establishment of the FS, plant species from the commercial seed mix still predominated, but plants from the soil seed bank are a valuable complement to the emerging gaps in the FS, providing both a source of food and shelter for many arthropods living in the strip, including carabid beetles. *Trifolium pratense* and *Chrysanthemum leucanthemum* are particularly recommended for sowing in perennial FSs in Central Europe, as they flower profusely on moderately good arable soils under average hydrological conditions. The species diversity (H') of Carabidae was higher in the FS than in the cultivated fields, but no significant differences were found when comparing the Shannon–Wiener index for wheat and FS, regardless of month observation. The most abundant ground beetle in the FS was *Harpalus rupifes*, a universal predator that also feeds on weed seeds. Significantly fewer species and individuals of Carabidae were found in the alfalfa field than in the FS and wheat fields. The number of Carabidae was significantly higher in August than in July.

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