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Changes in segetal flora in a selected habitat of southern Poland from 1993 to 2022. Part 1. Species richness and biodiversity

Zmiany flory segetalnej w wybranym siedlisku Polski Południowej w latach 1993–2022. Część 1. Bogactwo gatunkowe i różnorodność biologiczna

Abstract. The research aimed to assess changes in segetal flora richness and biodiversity in cereal crops in a selected habitat (Małopolska voivodship; southern Poland) from 1993 to 2022. The research material consisted of 65 phytosociological relevés representing selected years of the analyzed multiannual period. The total species richness and the average number of segetal species on individual fields slightly decreased. In the first year of the study (1993), the total number of species was 56, and the average number of species in the phytosociological relevé was 23. However, in the last year (2022), the total number of species was 55, while their average number was around 20. The proportion of monocotyledonous weeds in the total weed infestation constantly increased, from 10% in 1993 to 23% in 2022. The studied flora was dominated by short-lived species (especially therophytes) throughout the entire multiannual period. The Shannon-Wiener diversity index remained at a relatively similar level for many years – in 1993 it was 0.8, and in 2022 – it was 0.9, which generally indicates a constant diversity of the studied flora of fields. The Simpson dominance index showed a decreasing trend; in the first year of the study it was 0.4, and in the last year – less than 0.3.

Keywords: segetal weeds, agrophytocenosis, Shannon-Wiener diversity index, Simpson dominance index, Miechów Upland

INTRODUCTION

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The species richness and diversity of field flora are the result of a number of factors, including anthropogenic impacts, which deserve much more attention than they currently receive. In recent decades, significant changes in flora and segetal communities have been observed in Europe. Numerous researchers pointed to the reduction in biodiversity, the uniformity of phytocenoses, and even the possibility of losing some of the weed species (especially applies to annual species with a narrow ecological amplitude and low competitive abilities) [Baessler and Klotz 2006, Bomanowska 2006, Tyšer et al. 2009, Kapeluszny and Haliniarz 2010, Meyer et al. 2013, Richner et al. 2015, Dąbkowska et al. 2017, Skrajna 2021]. The increasing importance of intensive agriculture is indicated as the cause of transformations in flora and segetal communities, which is related, amongst other factors, to changes in land use, intensive mineral fertilization, reduced crop rotation and tillage, purification of seed material, and the widespread use of herbicides [Storkey et al. 2012, Dąbkowska et al. 2017, Feledyn-Szewczyk et al. 2020]. Other researchers indicated importance of arable weeds in the proper maintenance of agroecosystems [Marshall et al. 2003, Trzcińska-Tacik 2003]. The role of weeds as the basis of agricultural food webs and their significance for domestic and wild pollinators was also emphasized [Bretagnolle and Gaba 2015]. These factors mean there is an urgent need to address issues related to assessing changes and even protecting flora biodiversity in agricultural ecosystems, as suggested by many authors [Marshall et al. 2003, Feledyn-Szewczyk et al. 2020].

The basis for biodiversity analyses is the richness and diversity of species occurring in the studied area. The species richness of a plant community is most often measured by the number of species and taxonomic groups (genera, families) in a given area. The species diversity is expressed by the number of life forms, growth forms, taxonomic groups, and life strategies [Falińska 2004]. When assessing biodiversity, the number of species, their proportion, and frequency of occurrence are considered. The species composition of phytocenosis depends on the flora of a given area, which is influenced by climatic and soil conditions, and its history. However, in the case of agrophytocenosis, an essential factor influencing the species composition of the flora is the crop production intensity [Stawicka et al. 2004]. Many ecological indicators have been developed to assess the biodiversity of phytocenoses. The most frequently used of these are the Shannon-Wiener diversity index (H) and the Simpson dominance index (C), which take into account the proportion of species and provide information about their role in the community [Shannon 1948, Simpson 1949].

The study aimed to assess changes in the species richness and diversity of weeds accompanying cereal crops in a selected habitat of southern Poland over 30 years (from 1993 to 2022).

MATERIAL AND METHODS

The study area is located in southern Poland (Małopolska voivodship, Kraków county, municipality of Kocmyrzów-Luborzyca) in the village of Goszcza (50°11'09"N, 20°03'27"E; Fig. 1, Phot. 1). According to the physical and geographical division of Poland [Kondracki 2009], the area is located within the Miechów Upland mesoregion.

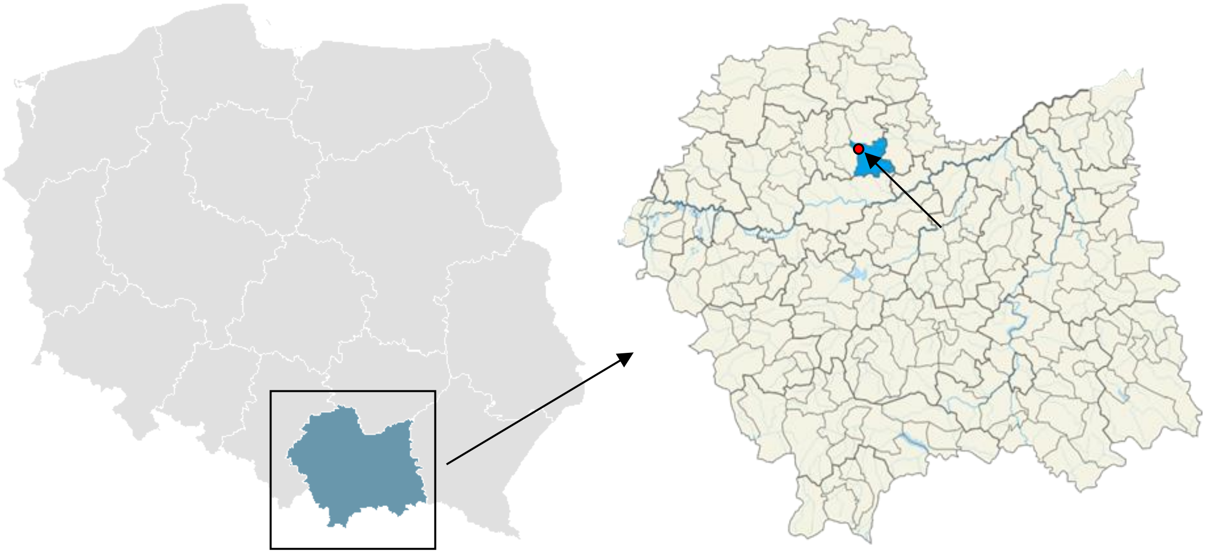


Fig. 1. The location of the village of Goszcza in the Małopolska voivodship and the municipality of Kocmyrzów-Luborzyca

Fig. 2. The cereal fields included in the study area
[photo: archive of the Department of Agroecology and Crop Production]

The research material consisted of 65 phytosociological relevés from selected years of the multiannual period, i.e., 1993, 1998, 2003, 2008, 2013, 2018, and 2022. The phytosociological relevés were made using the Braun-Blanquet method [Braun-Blanquet 1964].

In the research was applied, a 7-degree scale of the Braun-Blanquet, i.e., 5: 100–75.1% area coverage by species, 4: 75–50.1%, 3: 50–25.1%, 2: 25–5.1%, 1: 5–1%, +: <1%, r: single occurrence of plants of particular species.

Table 1. The weather conditions near the study area from 1993 to 2022

Temperature (°C)													
Year	Month												Mean for year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1993	–0.2	–1.7	2.0	7.5	13.7	16.2	16.9	17.5	17.9	10.5	–2.4	1.4	8.3
1998	0.0	2.9	3.6	9.4	10.0	13.5	15.5	14.9	14.1	5.2	–0.1	–1.2	7.3
2003	–3.6	–5.6	1.8	7.0	14.1	15.4	17.9	18.9	19.4	5.1	4.4	–0.2	7.9
2008	2.0	3.3	4.6	8.6	14.1	18.5	19.1	18.2	12.8	10.7	5.0	1.1	9.8
2013	–2.4	–0.6	–0.9	8.8	14.2	17.6	19.2	18.8	12.0	10.3	4.9	4.0	7.5
2018	1.0	–3.3	0.9	14.7	17.5	18.5	19.9	20.8	16.1	10.9	4.6	1.0	10.2
2022	0.4	3.4	4.0	7.1	15.2	19.7	19.6	20.6	12.9	11.8	4.2	0.4	9.9
Precipitation (mm)													
Year	Month												Sum for year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1993	22.1	17.5	24.4	19.8	45.1	58.0	47.1	63.5	27.5	30.0	35.4	20.1	410.5
1998	37.1	21.7	25.3	112.7	60.3	39.3	107.0	46.3	58.9	95.0	30.9	22.2	656.7
2003	32.9	17.9	26.7	40.9	33.8	92.3	40.0	44.8	16.0	38.7	14.9	19.7	418.6
2008	24.7	9.1	71.5	35.1	27.5	25.9	142.1	45.2	111.3	51.1	24.3	41.0	608.8
2013	62.0	22.1	32.3	20.1	98.8	213.1	27.2	25.7	86.1	13.7	70.8	47.5	719.4
2018	23.2	11.0	29.0	7.4	62.4	85.6	119.8	56.2	70.8	41.6	9.8	40.2	557.0
2022	21.6	24.4	14.6	41.0	20.6	35.2	85.8	65.2	51.8	17.4	39.6	63.4	480.6

The entire research material has been archived in the Department of Agroecology and Crop Production of the University of Agriculture in Kraków. Floristic research was conducted each year at the end of June or the beginning of July on the same set of spring and winter cereal fields. The area of the fields usually did not exceed 1 ha, and the area of each phytosociological relevé was approximately 100 m^2. The present research was carried out on heavy brown rendzina classified as agricultural soil complex 3 (defective wheat complex; 3Rb(c)) [Soil-agricultural map… 1992]. Based on laboratory analysis, the soil reaction was determined as neutral (pH in H_2O = 7.2; pH in KCl = 6.6). The top layer of soil was rich in carbonate rock debris.

Meteorological conditions near the study area in the years of the research were varied (Tab. 1). Comparing the first and last year of the study, an increase in the average air temperature and total precipitation was observed.

Since about the mid-1990s, cereals dominated the crop structure in the study area. At the same time, in the last decade, some areas were excluded from arable use as a result of permanent sod cover or fallowing, which resulted in a reduction in the number of fields with cereal crops. During the study, traces of herbicide usage were recorded every time. Simultaneously, the number of fields where chemical weed control was used constantly increased (Tab. 2).

Table 2. The number of phytosociological relevés and the number of fields using herbicides in the study area from 1993 to 2022

Specification	1993	1998	2003	2008	2013	2018	2022
The number of phytosociological relevés	8	10	10	11	11	8	7
The number of fields with herbicides use	2	9	8	10	9	8	7

The aim of the research was achieved through:

1. analysis of changes in the total species richness of field flora in the study area (total number of species in the assessed set of fields) and species richness of an average plant patch (arithmetic average number of species in the phytosociological relevé);

2. analysis of flora taking into account botanical class (monocotyledonous and dicotyledonous species), persistence (short-lived species – annual and biennial, permanent species – perennial) and Raunkiær plant life forms (therophyte, hemicryptophyte, geophyte, and chamaephyte) [Zarzycki et al. 2002, Rzymowska 2013, Skrajna 2021];

3. assessment of changes in the species diversity of phytocenoses in the study area using ecological indicators: the Shannon-Wiener diversity index (*H*) [Shannon 1948] and the Simpson dominance index (*C*) [Simpson 1949], which were calculated for each phytosociological relevé from the assessed multiannual period according to the following formulas:

$$H = -\sum \left(\frac{ni}{N}\right) \log \left(\frac{ni}{N}\right)$$

$$C = \sum \left(\frac{ni}{N}\right)^2$$

where: n_i – the proportion of *i*-th species in the total area in the phytosociological relevé covered by weeds, *N* – the total coverage of the area by all species present in the phytosociological relevé.

The value of the diversity index (*H*) increases with an increase in the number of species and their equalized proportion in the phytosociological relevé, while the decrease in the value of the dominance index (*C*) indicates an increase in the diversity of the phytocenosis [Falińska 2004];

4. assessment of the role of individual species in weed infestation of cereal crops, expressed by cover index (*D*) and phytosociological constancy (S) [Pawłowski 1972], which were calculated for every species, in each year of study.

The cover index (*D*) shows the proportion of individual species in the flora of a given ecosystem:

$$D = \frac{s}{n} \cdot 100\ (\%)$$

where: *s* – the sum of the values of the average cover by a species in the individual phytosociological relevé, *n* – total number of phytosociological relevés.

Phytosociological constancy (S) determines the probability that at least one individual of a given species will occur within the soil unit covered by the research:

$$\mathrm{S} = \frac{N}{n} \cdot 100\ (\%)$$

where: *N* – the number of phytosociological relevés in which a given species occurred,
n – total number of phytosociological relevés.

The phytosociological constancy (S) is expressed on a 5-point scale, in which degree I means rare and sporadic species (occurring in 0.1–20.0% of phytosociological relevés within a soil unit), degree II – uncommon species (20.1–40.0% of relevés), degree III – moderately frequent species (40.1–60.0% of relevés), degree IV – frequent species (60.1–80.0% of relevés), degree V – permanent species (80.1–100.0% of relevés).

The nomenclature of the species and botanical families were given after Mirek et al. [2020].

Statistical analysis of selected results was performed a one-way analysis of variance (ANOVA) using the Statistica 13.3 software. The significance of differences between means was checked using Duncan's test with a significance level of $p \leq 0.05$.

RESULTS AND DISCUSSION

In the analyzed years of research, the presence of a total of 111 species of weeds accompanying cereal crops was recorded, which belong to 29 botanical families (Tab. 3). The most frequently represented plant species were from the *Asteraceae* (20 species), *Poaceae* (13 species) and *Fabaceae* (12 species) families. Whereas the least numerous in the segetal flora in the study area (1 representative) were species from the families: *Amaranthaceae, Campanulaceae*, *Convolvulaceae*, *Crassulaceae*, *Equisetaceae, Juncaceae, Papaveraceae*, *Primulaceae*, *Rosaceae*, *Oxalidaceae*, *Valerianaceae* and *Violaceae*.

Tab. 3. List of segetal flora species recorded in the study area from 1993 to 2022

No	Species	Family	Year of study														Persis-tence	Life form*	Occurrence year
			1993		1998		2003		2008		2013		2018		2022				
			S	D	S	D	S	D	S	D	S	D	S	D	S	D			
1	*Achillea millefolium* L. s.str.	*Asteraceae*	I	6.3	II	15.0							I	6.3			P	H	1993, 1998, 2018
2	*Adonis aestivalis* L.	*Ranunculaceae*	III	20.0	I	5.0					I	4.5					SL	T	1993, 1998, 2013
3	*Aethusa cynapium* L.	*Apiaceae*	III	31.3	III	25.0					I	4.5	I	6.3	III	4.3	SL	T	1993, 1998, 2013–2022
4	*Agrostis capillaris* L.	*Poaceae*									I	0.9					P	H	2013
5	*Amaranthus retroflexus* L.	*Amaranthaceae*											I	1.3			SL	T	2018
6	*Anagallis arvensis* L.	*Primulaceae*	III	25.0	IV	35.0			I	0.9	IV	29.1	III	10.0	I	14.3	SL	T	1993, 1998, 2008–2022
7	*Anthriscus sylvestris* (L.) Hoffm.	*Apiaceae*							I	1.8							P	H	2008
8	*Apera spica-venti* (L.) P. Beauv.	*Poaceae*	III	25.0	IV	45.0	II	20.0	III	496.5	II	178.2	II	220.0	V	307.1	SL	T	1993–2022
9	*Aphanes arvensis* L.	*Rosaceae*									I	4.5					SL	T	2013
10	*Arctium minus* (Hill) Bernh.	*Asteraceae*			I	1.0	I	1.0					I	1.3	I	1.4	SL	H	1998, 2003, 2018, 2022
11	*Arenaria serpyllifolia* L.	*Caryophyllaceae*							I	0.9							SL	T	2008
12	*Artemisia vulgaris* L.	*Asteraceae*			II	11.0	II	20.0	I	5.5	III	19.1	II	8.8	III	5.7	P	CH(H)	1998–2022
13	*Atriplex patula* L.	*Chenopodiaceae*	II	12.5													SL	T	1993

No	Species	Family	Year of study														Persis-tence	Life form*	Occurrence year
			1993		1998		2003		2008		2013		2018		2022				
			S	D	S	D	S	D	S	D	S	D	S	D	S	D			
14	*Avena fatua* L.	*Poaceae*	II	7.5	III	392.0	V	2870.0	III	854.5	V	1100.0	IV	1037.5	V	364.3	SL	T	1993–2022
15	*Bromus secalinus* L.	*Poaceae*									I	5.5	I	6.3	II	264.3	SL	T	2013–2022
16	*Campanula rapunculoides* L.	*Campanulaceae*	II	18.8	II	15.0											P	H(G)	1993, 1998
17	*Capsella bursa-pastoris* (L.) Medik.	*Brassicaceae*	II	12.5	I	5.0	I	5.0	I	9.1	II	6.4	II	7.5	III	37.1	SL	T	1993–2022
18	*Carduus crispus* L.	*Asteraceae*											I	1.3			SL	H	2018
19	*Centaurea cyanus* L.	*Asteraceae*	IV	31.3	II	20.0	III	25.0	V	190.0	IV	26.4	II	13.8	III	292.9	SL	T	1993–2022
20	*Chaenorhinum minus* (L.) Lange	*Scrophulariaceae*									I	0.9	I	1.3			SL	T	2013–2018
21	*Chamomilla recutita* (L.) Rauschert	*Asteraceae*	I	1.3	I	6.0	I	10.0	I	0.9	I	0.9			I	14.3	SL	T	1993–2013, 2022
22	*Chenopodium album* L.	*Chenopodiaceae*	V	68.8	III	35.0	IV	35.0	II	10.0	I	5.5	IV	26.3	V	307.1	SL	T	1993–2022
23	*Cichorium intybus* L.	*Asteraceae*					I	5.0									P	H(G)	2003
24	*Cirsium arvense* (L.) Scop.	*Asteraceae*	IV	37.5	IV	205.0	IV	45.0	III	20.0	IV	29.1	III	31.3	IV	44.3	P	G	1993–2022
25	*Consolida regalis* Gray	*Ranunculaceae*	V	732.5	V	56.0	III	41.0	IV	38.2	III	15.5	II	20.0	III	35.7	SL	T	1993–2022
26	*Convolvulus arvensis* L.	*Convolvulaceae*	V	1675.0	V	1490.0	V	85.0	V	245.5	V	222.7	V	56.3	V	335.7	P	G(H)	1993–2022
27	*Dactylis glomerata* L.	*Poaceae*	I	1.3					I	1.8	I	0.9	I	1.3	II	15.7	P	H	1993, 2008–2022
28	*Daucus carota* L.	*Apiaceae*			II	15.0					I	0.9	I	1.3	I	1.4	SL	H(T)	1998, 2013–2022

No	Species	Family	Year of study														Persis-tence	Life form*	Occurrence year
			1993		1998		2003		2008		2013		2018		2022				
			S	D	S	D	S	D	S	D	S	D	S	D	S	D			
29	*Echinochloa crus-galli* (L.) P.Beauv.	*Poaceae*							I	4.5	III	170.0	I	6.3	II	28.6	SL	T	2008–2022
30	*Elymus repens* (L.) Gould	*Poaceae*	IV	37.5	III	30.0			II	19.1	III	31.8	IV	31.3	IV	285.7	P	G	1993–1998, 2008–2022
31	*Equisetum arvense* L.	*Equisetaceae*							I	0.9					I	7.1	P	G	2008, 2022
32	*Erigeron annuus* (L.) Pers.	*Asteraceae*											I	1.3	I	1.4	SL	H(T)	2018, 2022
33	*Euphorbia exigua* L.	*Euphorbiaceae*	IV	43.8					I	4.5	I	5.5	IV	21.3			SL	T	1993, 2008–2018
34	*Euphorbia helioscopia* L.	*Euphorbiaceae*	III	31.3	V	50.0	III	21.0	III	15.5	III	24.5	IV	33.8	I	7.1	SL	T	1993–2022
35	*Falcaria vulgaris* Bernh.	*Apiaceae*	I	1.3					I	0.9			I	1.3	I	1.4	P	H	1993, 2008, 2018–2022
36	*Fallopia convolvulus* (L.) Á. Löve	*Polygonaceae*	V	68.8	V	45.0	IV	45.0	IV	32.7	IV	40.9	IV	50.0	V	357.1	SL	T	1993–2022
37	*Fumaria officinalis* L.	*Fumariaceae*					I	5.0					I	1.3			SL	T	2003, 2018
38	*Fumaria vaillantii* Loisel.	*Fumariaceae*	II	18.8													SL	T	1993
39	*Galeopsis ladanum* L.	*Lamiaceae*	I	1.3													SL	T	1993
40	*Galeopsis tetrahit* L.	*Lamiaceae*	III	25.0	III	30.0	II	20.0	II	10.0	II	14.5	I	6.3	II	8.6	SL	T	1993–2022
41	*Galinsoga ciliata* (Raf.) S. F. Blake	*Asteraceae*			II	20.0	I	10.0			I	4.5	I	1.3			SL	T	1998–2003, 2013–2018
42	*Galinsoga parviflora* Cav.	*Asteraceae*			I	5.0									I	1.4	SL	T	1998, 2022
43	*Galium aparine* L.	*Rubiaceae*	V	50.0	V	55.0	IV	45.0	V	50.0	IV	45.5	IV	31.3	V	78.6	SL	T	1993–2022

No	Species	Family	Year of study														Persis-tence	Life form*	Occurrence year
			1993		1998		2003		2008		2013		2018		2022				
			S	D	S	D	S	D	S	D	S	D	S	D	S	D			
44	*Galium mollugo* L. s.str.	*Rubiaceae*	I	6.3					I	0.9							P	H(G)	1993, 2008
45	*Geranium dissectum* L.	*Geraniaceae*	I	6.3							I	0.9					SL	T	1993, 2013
46	*Geranium pusillum* L.	*Geraniaceae*			II	10.0					I	1.8			III	18.6	SL	T	1998, 2013, 2022
47	*Heracleum sphondylium* L.s.str.	*Apiaceae*									I	0.9					P	H	2013
48	*Juncus bufonius* L.	*Juncaceae*									I	4.5					SL	T	2013
49	*Lactuca serriola* L.	*Asteraceae*			I	1.0					I	0.9	II	7.5	III	22.9	SL	H	1998, 2013–2022
50	*Lamium album* L.	*Lamiaceae*													I	14.3	P	H	2022
51	*Lamium amplexicaule* L.	*Lamiaceae*			I	5.0					I	0.9					SL	T	1998, 2013
52	*Lamium purpureum* L.	*Lamiaceae*	I	6.3	I	10.0	I	1.0			II	6.4			II	2.9	SL	T	1993–2003, 2013, 2022
53	*Lapsana communis* L. s.str.	*Asteraceae*	II	18.8	III	25.0	I	6.0			II	11.8	II	13.8			SL	T(H)	1993–2003, 2013–2018
54	*Lathyrus tuberosus* L.	*Fabaceae*	IV	26.3	III	30.0	I	10.0	I	9.1	I	9.1					P	H	1993–2013
55	*Lithospermum arvense* L.	*Boraginaceae*	II	12.5	III	25.0			I	5.5	I	4.5			I	1.4	SL	T	1993, 1998, 2008, 2013, 2022
56	*Lolium multiflorum* Lam.	*Poaceae*			II	15.0									III	22.9	P	H(T)	1998, 2022
57	*Lolium perenne* L.	*Poaceae*							I	0.9	I	10.0	I	1.3			P	H	2008–2018

No	Species	Family	Year of study														Persis-tence	Life form*	Occurrence year
			1993		1998		2003		2008		2013		2018		2022				
			S	D	S	D	S	D	S	D	S	D	S	D	S	D			
58	*Matricaria maritima* L. subsp. *inodora* (L.) Dostál	*Asteraceae*	II	7.5	II	15.0	II	20.0	IV	29.1	III	20.0	IV	21.3	III	31.4	SL	H(T)	1993–2022
59	*Medicago lupulina* L.	*Fabaceae*	I	6.3	I	5.0	II	20.0	I	5.5	II	7.3					SL	H(T)	1993–2013
60	*Melandrium album* (Mill.) Garcke	*Caryophyllaceae*	II	18.8	I	5.0	II	15.0	II	6.4	I	0.9	III	5.0	I	14.3	SL	T(H)	1993-2022
61	*Melandrium noctiflorum* (L.) Fr.	*Caryophyllaceae*	I	12.5	I	5.0											SL	T	1993–1998
62	*Mentha arvensis* L.	*Lamiaceae*			I	10.0							I	6.3	IV	20.0	P	G	1998, 2018, 2022
63	*Myosotis arvensis* (L.) Hill.	*Boraginaceae*	IV	43.8	IV	40.0	I	5.0	I	9.1	III	27.3	I	12.5			SL	T(H)	1993-2018
64	*Odontites serotine* (Lam.) Rchb. s.str.	*Scrophulariaceae*	IV	37.5	II	20.0	II	21.0	I	164	I	0.9					SL	T	1993–2013
65	*Oxalis fontana* Bunge	*Oxalidaceae*	II	20.0			I	5.0			II	18.2	I	6.3			P	G	1993, 2003, 2013, 2018
66	*Papaver rhoeas* L.	*Papaveraceae*	IV	37.5	III	25.0	I	6.0	III	16.4	III	11.8			I	14.3	SL	T	1993–2013, 2022
67	*Phleum pratense* L.	*Poaceae*			I	5.0	I	6.0	III	8.2	II	22.7	II	13.8	IV	38.6	P	H	1998–2022
68	*Pimpinella saxifraga* L.	*Apiaceae*									I	0.9			I	14.3	P	H	2013, 2022
69	*Plantago intermedia* Gilib.	*Plantaginaceae*									II	13.6					P	H(T)	2013
70	*Plantago lanceolata* L.	*Plantaginaceae*													I	14.3	P	H	2022
71	*Plantago major* L. s.str.	*Plantaginaceae*			I	6.0					I	4.5	I	1.3			P	H	1998, 2013, 2018

No	Species	Family	Year of study														Persis-tence	Life form*	Occurrence year
			1993		1998		2003		2008		2013		2018		2022				
			S	D	S	D	S	D	S	D	S	D	S	D	S	D			
72	*Poa annua* L.	*Poaceae*													I	14.3	SL	H(T)	2022
73	*Poa trivialis* L.	*Poaceae*	I	6.3													P	H	1993
74	*Polygonum aviculare* L.	*Polygonaceae*	IV	50.0	IV	35.0	I	10.0	I	5.5	II	6.4	I	1.3	IV	42.9	SL	T	1993–2022
75	*Polygonum hydropiper* L.	*Polygonaceae*									I	9.1					SL	T	2013
76	*Polygonum lapathifolium* L. subsp. *pallidum* (With.) Fr.	*Polygonaceae*			III	26.0	I	10.0	I	0.9	II	7.3	II	20.0			SL	T	1998-2018
77	*Polygonum persicaria* L.	*Polygonaceae*	I	6.3							I	1.8			I	14.3	SL	T	1993, 2013, 2022
78	*Ranunculus repens* L.	*Ranunculaceae*			I	10.0											P	H	1998
79	*Raphanus raphanistrum* L.	*Brassicaceae*			I	6.0											SL	T	1998
80	*Rhinanthus serotinus* (Schönh.) Oborný	*Scrophulariaceae*	V	681.3	I	5.0											SL	T	1993, 1998
81	*Rumex crispus* L.	*Polygonaceae*							I	0.9	I	0.9					P	H	2008, 2013
82	*Sedum maximum* (L.) Hoffm.	*Crassulaceae*	I	6.3					I	0.9							P	G(H)	1993, 2008
83	*Setaria viridis* (L.) P.Beauv.	*Poaceae*									II	19.1	III	37.5	I	1.4	SL	T	2013–2022
84	*Sherardia arvensis* L.	*Rubiaceae*									I	5.5	II	7.5	I	1.4	SL	T	2013–2022
85	*Silene vulgaris* (Moench) Garcke	*Caryophyllaceae*			II	15.0	II	20.0			II	2.7					P	C(H)	1998, 2003, 2013
86	*Sinapis arvensis* L.	*Brassicaceae*	III	31.3	IV	40.0	I	10.0	I	4.5	I	2.7	I	6.3	I	1.4	SL	T	1993–2022
87	*Solidago canadensis* L.	*Asteraceae*													I	1.4	P	H(G)	2022

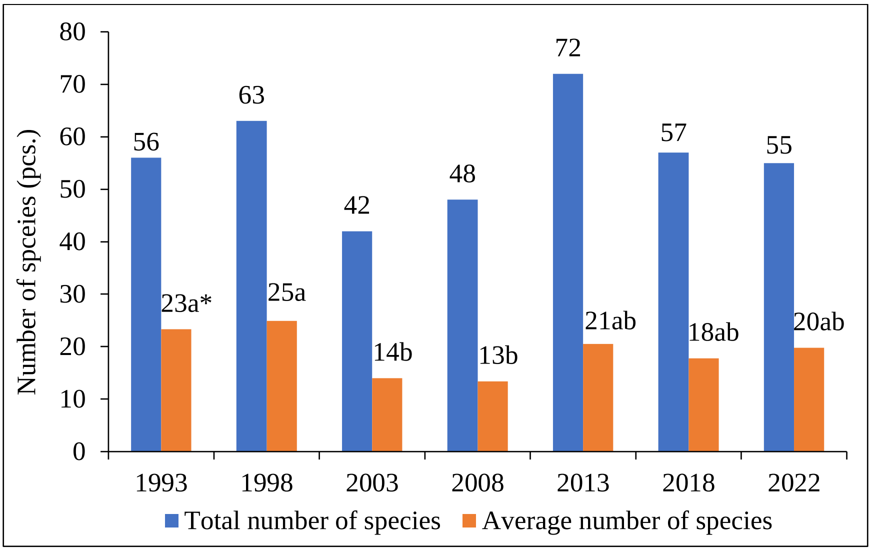
No	Species	Family	Year of study														Persis-tence	Life form*	Occurrence year
			1993		1998		2003		2008		2013		2018		2022				
			S	D	S	D	S	D	S	D	S	D	S	D	S	D			
88	*Solidago gigantea* Aiton	*Asteraceae*									I	0.9					P	H(G)	2013
89	*Sonchus arvensis* L.	*Asteraceae*	IV	68.8	IV	40.0	I	10.0			II	10.0	II	13.8	I	7.1	P	G(H)	1993–2003, 2013–2022
90	*Sonchus asper* (L.) Hill	*Asteraceae*			I	6.0							II	2.5			SL	T	1998, 2018
91	*Stachys palustris* L.	*Lamiaceae*	I	6.3			I	5.0									P	G	1993, 2003
92	*Stellaria media* (L.) Vill.	*Caryophyllaceae*	III	31.3	III	35.0					II	10.0	II	7.5			SL	T(H)	1993, 1998, 2013, 2018
93	*Symphytum officinale* L.	*Boraginaceae*					I	5.0									P	G(H)	2003
94	*Taraxacum officinale* F.H. Wigg.	*Asteraceae*	III	37.5	IV	45.0	II	15.0	I	0.9	II	14.5	III	26.3	I	7.1	P	H	1993–2022
95	*Thlaspi arvense* L.	*Brassicaceae*			I	5.0	II	16.0	I	5.5	I	0.9			III	17.1	SL	T(H)	1998–2013, 2022
96	*Trifolium arvense* L.	*Fabaceae*	I	1.3													SL	T	1993
97	*Trifolium aureum* Pollich	*Fabaceae*									I	0.9					P	H	2013
98	*Trifolium pratense* L.	*Fabaceae*			I	5.0											P	H	1998
99	*Trifolium repens* L.	*Fabaceae*	I	1.3	I	5.0			I	4.5							P	H(C)	1993, 1998, 2008
100	*Tussilago farfara* L.	*Asteraceae*			I	5.0											P	G	1998
101	*Valerianella dentata* (L.) Pollich	*Valerianaceae*			I	5.0							I	1.3			SL	T	1998, 2018
102	*Veronica agrestis* L.	*Scrophulariaceae*	I	6.3							II	10.0	I	1.3			SL	T	1993, 2013, 2018

No	Species	Family	Year of study														Persis-tence	Life form*	Occurrence year
			1993		1998		2003		2008		2013		2018		2022				
			S	D	S	D	S	D	S	D	S	D	S	D	S	D			
103	*Veronica arvensis* L.	*Scrophulariaceae*					I	1.0	I	4.5	III	19.1			II	15.7	SL	T	2003–2013, 2022
104	*Veronica persica* Poir.	*Scrophulariaceae*	II	18.8	II	20.0			II	6.4	II	23.6	IV	31.3			SL	T	1993, 1998, 2008–2022
105	*Vicia angustifolia* L.	*Fabaceae*	II	25.0	I	5.0	II	20.0	I	5.5	II	6.4					SL	T	1993–2013
106	*Vicia dasycarpa* Ten.	*Fabaceae*	I	6.3							I	13.6	II	2.5			SL	T	1993, 2013–2018
107	*Vicia grandiflora* Scop.	*Fabaceae*													I	14.3	SL	T	2022
108	*Vicia hirsuta* (L.) Gray	*Fabaceae*			III	25.0	II	25.0	I	9.1	II	10.0	I	1.3	I	7.1	SL	T	1998–2022
109	*Vicia tetrasperma* (L.) Schreb.	*Fabaceae*			II	11.0	II	20.0	I	0.9	II	10.0	II	7.5	I	7.1	SL	T	1998–2022
110	*Vicia villosa* Roth	*Fabaceae*											I	1.3			SL	T(H)	2018
111	*Viola arvensis* Murray	*Violaceae*	II	18.8	III	30.0			II	168	III	27.3	III	21.3	I	1.4	SL	T	1993, 1998, 2008–2022

S – degree of phytosociological constancy, D – cover index, P – perennial species, SL – short-lived species, C – chamaephyte, G – geophyte, H – hemicryptophyte, T – therophyte

* The first plant life form given in the table was used for calculations

The species of field flora found in each of the assessed years of the multiannual period, which usually maintained a high area cover index, were: *Apera spica-venti* (*D* = 25.0–496.5), *Avena fatua* (*D* = 7.5–2870.0), *Centaurea cyanus* (*D* = 13.8–292.9), *Chenopodium album* (*D* = 5.5–307.1), *Cirsium arvense* (*D* = 20.0–205.0), *Consolida regalis* (*D* = 15.5–732.5), *Convolvulus arvensis* (*D* = 56.3–1675.0), *Fallopia convolvulus* (*D* = 32.7–357.1), and *Galium aparine* (*D* = 31.3–78.6). In the study area, in addition to typical segetal weeds, accidental species were also recorded, entering from contact communities (usually ruderal ones). These included among others, *Erigeron annuus*, *Solidago canadensis*, *Solidago gigantea*, *Lactuca serriola*, *Plantago major*, and *Plantago lanceolata.* These species were not a permanent component of agrocenoses. However, remaining in the field edge zone, they increased the total number of species in the studied flora.The total number of species on the assessed set of fields in the multiannual period decreased slightly, comparing the first and last year of the study (Fig. 3).



* Means with various letters are significantly different, according to Duncan test ($p \leq 0.05$).

Fig. 3. The total and average number of segetal flora species in the study area in assessed years of the multiannual period from 1993 to 2022

In the first year of the study, a total of 56 species were recorded, compared to 55 in the last year of the study. The highest number of weeds – 72 species – was observed in 2013, a figure which is nearly double that observed in 2003 (the lowest total number of species). The highest average number of species in the phytosociological relevé was recorded in 1993 (23 species) and 1998 (25 species); this is significantly higher than the lowest average number of species recorded in 2008 (13 species) and in 2003 (14 species). The poverty of species in 2003 and 2008 is probably a result of the increase in the application of herbicides in the study area during this period (cf. Tab. 2). Comparing the average number of weeds in the phytosociological relevé over the multiannual period, it may be noted that a slight decrease in the number of species in 2022 concerning the first year of the study, but the difference between these years is not significant. However, the impoverishment of flora was visible in the decrease in the constancy of occurrence or even disappearance of species, especially calciphilous (including *Adonis aestivalis*, *Fumaria officinalis*, *Fumaria vaillantii*, *Lithospermum arvense*, *Campanula rapunculoides*, *Valerianella dentata* and *Lathyrus tuberosus*) and the decrease in coverage of the area by weeds (cf. Tab. 3).

In many European regions [Tyšer et al. 2009, Meyer et al. 2013, Richner et al. 2015], including Poland [Bomanowska 2006, Dąbkowska et al. 2007, Kapeluszny and Haliniarz 2010, Dąbkowska and Sygulska 2013, Rzymowska 2013, Skrajna 2021], a decrease in the species richness of segetal flora was observed. Although consistent with this tendency, the changes recorded in our study area from 1993 to 2022 were not so radical. For example, Tyšer et al. [2009], based on research conducted in the middle and northern Bohemia during the period from 1975 to 2005, reported a reduction in species richness in phytosociological relevés, of about 46% (1975 – 33 taxa, 2005 – 18 taxa). Meyer et al. [2013] point to losses of segetal plant species in Central Germany between the 1950s/1960s and 2009. The research showed a reduction in the regional species pool of 23% (from 301 to 233 vascular species) and plot-level diversity (from medians of 24 to 7 species). Similarly as in our study, the authors noticed that disappearing species, such as *Adonis aestivalis* or *Lathyrus tuberosus*, included species associated with base-rich soils. In research conducted by Baessler and Klotz [2006], typical weed species with highly significant decrease were, e.g., *Consolida regalis* and *Lithospermum arvense*. Kapeluszny and Haliniarz [2010] indicated *Fumaria officinalis*, *Fumaria vaillantii*, *Adonis aestivalis*, *Lathyrus tuberosus*, *Campanula rapunculoides*, *Valerianella dentata* as the endangered species of segetal flora in the central-eastern Poland. Additionally, our results confirm the observations made by Dąbkowska et al. [2007], conducted in the same area (in the 1993–2005 years). The authors noted a systematic reduction in area coverage and phytosociological constancy of the above-mentioned calcareous species.

In the studied flora, a constant increase in the number and proportion of monocotyledonous species of the *Poaceae* family was observed in the weed infestation of crops (Fig. 4).

Comparing the first and last years of the study, the number of monocotyledonous species doubled (5 in 1993, 10 in 2022), and their proportion more than doubled (10% in 1993, 23% in 2022). In 1993, the occurrence of the following species was recorded in the study area: *Avena fatua* (AVEFA), *Apera spica-venti* (APESV), *Dactylis glomerata*, *Elymus repens* and *Poa trivialis.* All of these, excluding *Poa trivialis* were recorded in each analyzed year of the study. The remaining species of monocotyledonous recorded in the subsequent years of the study were *Phleum pratense* since 1998, *Echinochloa crus-galli* since 2008, *Bromus secalinus* since 2013, and *Setaria viridis* since 2018. Among the species found only once in the analyzed period were reported *Agrostis capillaris* (2013), *Poa annua* (2022) and *Lolium multiflorum* (2022). Moreover, the presence of *Lolium perenne* was also observed between 2008 and 2018.

Analyzing the threat to crops, expressed as the sum of the cover indexes, a decrease in the total coverage of the area by weeds, along with a substantial rise in the coverage of the area by monocotyledonous species, was recorded in the subsequent years of the study (Fig. 5).

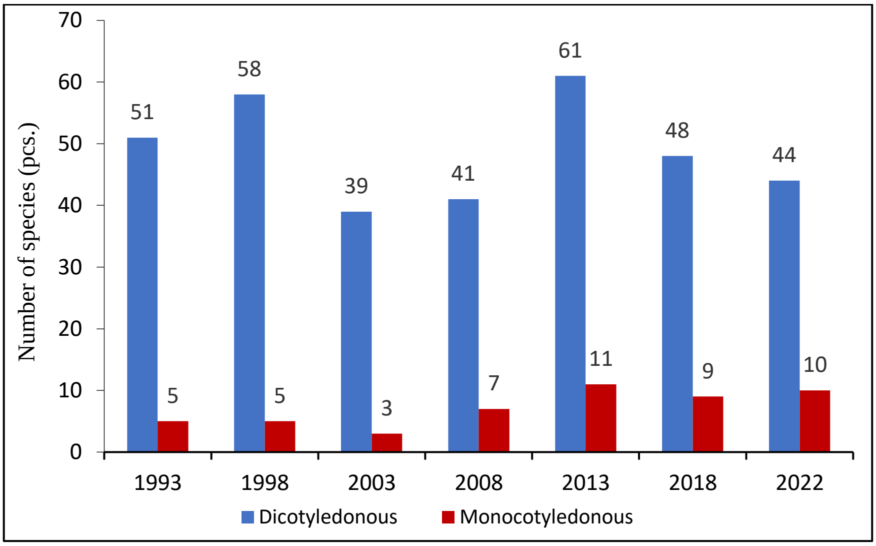


Fig. 4. The total number of monocotyledonous and dicotyledonous species of segetal flora in the study area in assessed years of the multiannual period from 1993 to 2022

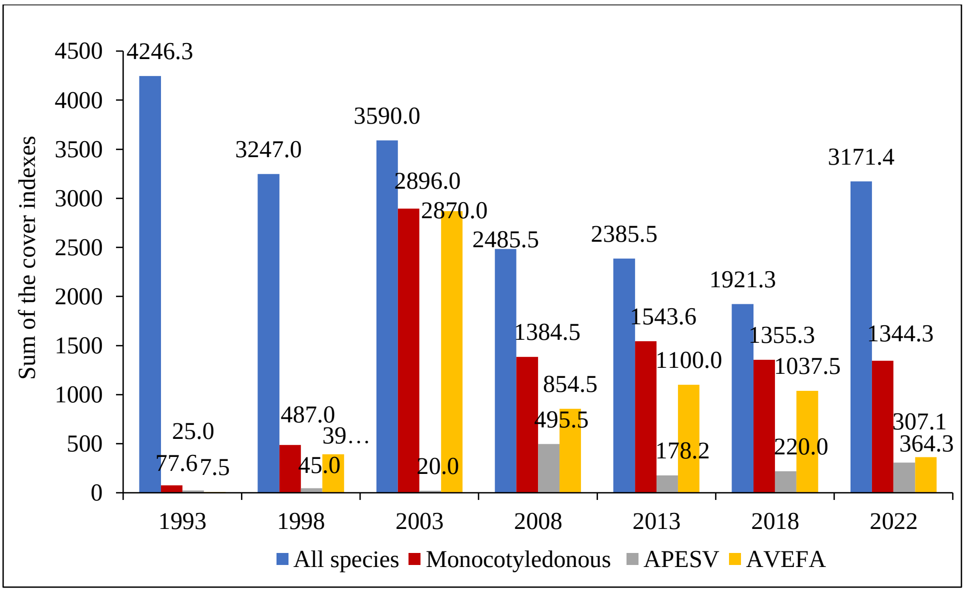


Fig. 5. Sums of the cover indexes of the cereal crop by segetal flora in the study area in assessed years of the multiannual period from 1993 to 2022

In 1993, the sum of weed cover indexes was 4246.3, including only 77.6 for monocotyledonous species. In subsequent years, a systematic decrease in the sum of cover indexes of the area caused by undesirable species was observed, indicating a reduction in the threat posed to crops by weeds. In the last year of our study, an increase in the sum of weed cover indexes was observed. This could have resulted from, among other things, errors in the selection and use of herbicides, as well as intensification of the phenomenon of weed resistance to chemical plant protection products. One year, 2003, was worthy of particular note. Then there was a slight increase in coverage of the area by weeds (compared to the previous year) and a significant increase in the proportion of monocotyledonous species which accounted for 80% of the total coverage of the area. Since 1998, the most expansive monocotyledonous species was *Avena fatua* (Fig. 6a). During the period from 1998 to 2022, the sum of cover indexes (*D*) for this species ranged from 364.3 (2022) to 2870.0 (2003), attaining degrees III to V of phytosociological constancy (cf. Tab. 3). The next most expansive monocotyledonous species in the study area was *Apera spica-venti* (Fig. 6b), for which the sum of cover indexes ranged from 20.0 (2003) to 495.5 (2008). The high sums of cover indexes in the last year of the study for *Avena fatua* (given above) and *Apera spica-venti* (D = 307.1) and degree V of phytosociological constancy, showed that, despite chemical control, they were still competitors that pose a threat to cereal crops.

Representatives of the *Poaceae* family, along with species of the *Asteraceae* and *Fabaceae* families, constituted the most numerous group in the segetal flora of the studied set of fields (cf. Tab. 3). The importance of species belonging to those families in the weed infestation of cereal crops was observed in various regions of Poland [Bomanowska 2006, Dąbkowska and Łabza 2010, Rzymowska 2013, Skrajna 2021] and Europe [Glemnitz et al. 2000, Fanfarillo et al. 2020]. Moreover, numerous authors considered attention to the increasing importance of monocotyledonous species from *Poaceae* family, in the segetal flora of agrophytocenoses in Poland in recent decades. Dąbkowska et al. [2007], Dąbkowska and Łabza [2010], Kapeluszny and Haliniarz [2010], based on the results of multiannual analyses of flora in habitats of southern and central-eastern Poland, pointed to *Avena fatua* and *Apera spica-venti* as the most expansive grass weeds, posing the greatest threat to cereal crops in recent decades. As in our research, in the studies of Dąbkowska et al. [2007], Dąbkowska and Łabza [2010] as well as Kapeluszny and Haliniarz [2010], there was an apparent increase in the intensification of the proportion of *Avena fatua* in the weed infestation of cereal crops in the 1990s, especially on rendzina soils in lowland habitats. Dąbkowska et al. [2007], conducting research from 1993 to 2005 on the same land where our study was performed, noted a considerable increase in area coverage by monocotyledonous species. In 1993, the sum of cover indexes was 77.6, while in 1999 – it was nearly 10 times and in 2005 – over 20 times higher. However, Meyer et al. [2013] found a decline in the frequency and cover of most species of *Poaceae* in Central Germany, including some expansive species, such as *Avena fatua* or *Apera spica-venti*.

Fig. 6. The weed infestation of cereal crops in the study area by (a) *Avena fatua* and (b) *Apera spica-venti* (photos: archive of the Department of Agroecology and Crop Production)

In the segetal flora of cereal crops in the studied habitat short-lived species (especially therophytes) were predominant over perennial species (Fig.7 and Fig. 8). The smallest number of short-lived species was recorded in 2003, amounting to 30, while the most significant number was in 2013 – 53.

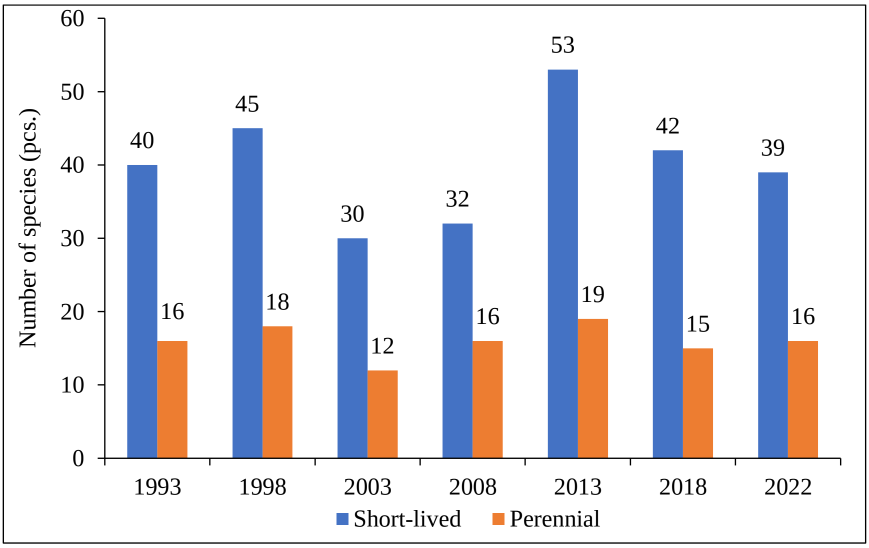


Fig. 7. The total number of short-lived and perennial species of segetal flora in the study area in assessed years of the multiannual period from 1993 to 2022

The proportion of short-lived species in the weed infestation of crops, in relation to the total number of species, oscillated in the range between 66.7% (2008) and 73.7% (2018). Moreover, an obvious predominance of therophytes over species representing other plant life forms was observed, which related to the agricultural nature of the land. The highest richness of therophytes was recorded in 2013 – 47 species (when it was the highest total species richness), and their proportion of the total number of species was 65.4%. In 2003, the lowest number of therophytes of 27 species was found, with a proportion of 64.3%. The number of hemicryptophytes fluctuated between 7 and 17 species (proportion of 16.7 to 29.8%). The number of geophytes during the multiannual period remained constant within the range of 5 to 7 species, and the number of chamaephytes stayed within the range of 0 to 2.

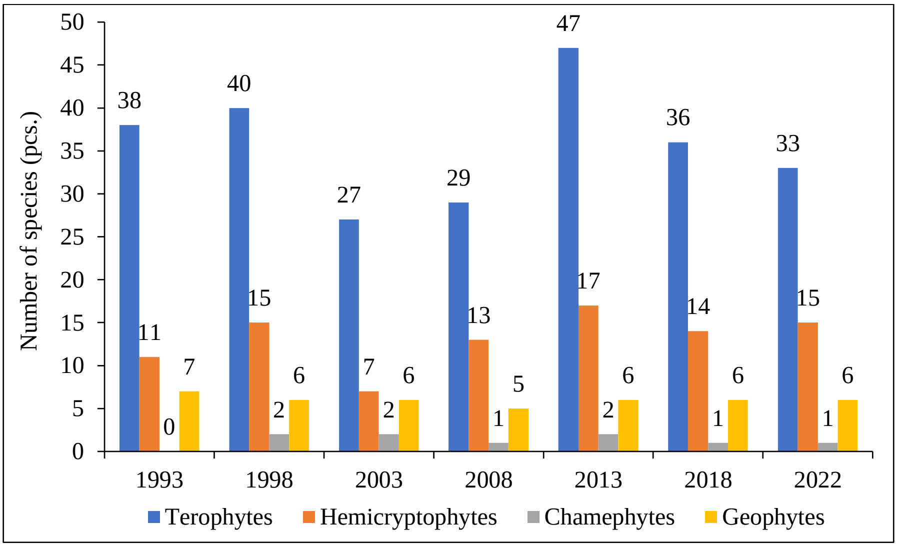
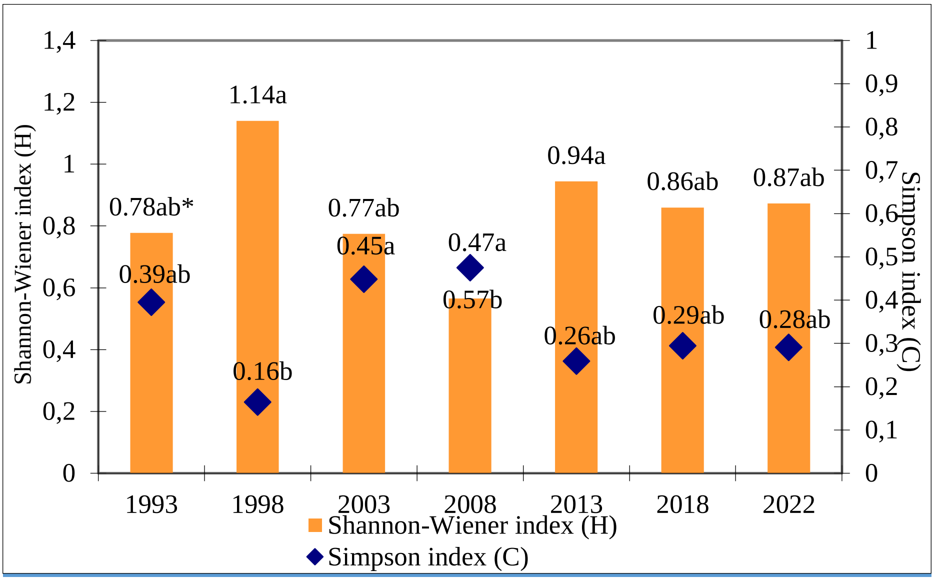


Fig. 8. The total number of plant life form of segetal flora in the study area in assessed years of the multiannual period from 1993 to 2022

Our findings are consistent with results obtained by other authors, who also underlined the predominance of short-lived species over perennial ones and therophytes over other plant life forms in the segetal flora of various regions of Poland. The results of research by Bomanowska [2006] showed the field flora of the Kampinos National Park was dominated by therophytes (46.9% of the flora), with a large proportion of hemicryptophytes (39.9%) and smaller for geophytes (9.2%) and chamaephytes (3.2%). Analysis of species persistence also revealed a slight predominance of short-lived species (51.5% of the flora) over perennial ones (48.5%). Skrajna [2021], comparing the flora of agrocenoses of the Kałuszyn Upland (eastern Poland) over a similar research period (1996 to 2021), presented that short-lived species (60%) prevailed over perennial ones (40%). Moreover, the proportion of individual plant life forms was similar to that obtained in our study, which is typical for annual crops.

The values of the Shannon-Wiener diversity index (*H*) and the Simpson dominance index (*C*) accurately reflect the state of the richness and species diversity of the studied agrophytocenoses (Fig. 9).



Means with various letters are significantly different, according to Duncan test ($p \leq 0.05$).

Fig. 9. The average Shannon-Wiener diversity index (*H*) and Simpson dominance index (*C*) of segetal flora in the study area in assessed years of the multiannual period from 1993 to 2022

For most years of the study, the average *H* index was at a similar level, ranging from 0.77 to 0.94, which proves that the proportion of individual segetal species in the weed infestation was relatively even. The highest value (1.14) was in 1998, and the lowest (0.57) was in 2008 (significant difference). A decrease in the Shannon-Wiener diversity index causes an increase (undesirable from the agricultural point of view) in the Simpson dominance index (*C*). The lowest dominance of individual species in the study area was found in 1998 when the *C* index was only 0.16 and was significantly lower than in 2008 (0.47; highest value). The low value of the *H* index and, also the high value of the *C* index recorded in 2008 were related, among others, to the dominance of monocotyledonous species in the infestation of the studied crops with weeds, namely *Avena fatua* and *Apera spica-venti* (cf. Fig. 5). However, comparing the first and last year of the study, a slight increase in the *H* index and a decrease in the *C* index can be found (for a similar total number of species in both years). This fact may indicate a fairly even proportion of individual species in the flora of the studied set of fields without a precise proportion of dominant species, and on relatively effective chemical control compared to the years in which dominant species were observed.

The value of the diversity and dominance indexes for the study area are similar to those obtained by Dąbkowska et al. [2017] in studies conducted in several locations within lowland habitats of southern Poland (assessed as favorable for intensive agricultural production) and located near the area of our research. In the research mentioned above, similar to the results of our study, the average *H* index was within the range of 0.7 to 1.3, while the average *C* index was from 0.1 to 0.3. In contrast, Dostatny [2006] found floral diversity to be much higher (*H* = 2.2–2.8) for rendzinas of the Niecka Nidziańska region in the same period. As Trzcińska-Tacik [2003] pointed out, the biodiversity of segetal communities depends on, among others, habitat conditions, including soil conditions, and it is greater on fertile soils. Skrajna [2021] confirmed this by comparing biodiversity indexes in cereal crops on compact and light soils of the Kałuszyn Upland (eastern Poland). In this study, the *H* index oscillated within the range of 1.32 to 1.61, and the *C* index was within the range of 0.29 to 0.40 for light and compact soils, respectively.

SUMMARY

The study conducted on the composition of segetal communities and changes in their diversity over the period from 1993 to 2022 allowed the following findings conclusions.

1. The total species richness of the segetal flora of the study area over the years in question did not undergo any apparent impoverishment. However, a decrease in the average number of species recorded on individual fields and the constancy of occurrence, as well as area coverage by determined species, especially calciphilous, was observed.

2. In the weed infestation of the studied crops, there was a noticeable increase in the number of monocotyledonous species, their proportion in the weed infestation and coverage of the area. Short-lived species were predominant over perennial species, and therophytes, along with hemicryptophytes, were the most numerous plant life forms.

4. The value of the Shannon-Wiener diversity index over the multiannual period remained at a fairly similar level, indicating that the diversity of the flora of the studied set of fields remained stable over time.

5. There was a decreasing trend in the Simpson dominance index over the years in question, which may be related to an increase in the intensity of the application of chemical plant protection products compared to the initial year of the study.

6. The results indicate that it is justified to continue research into the species richness and diversity of field flora of the study area to monitor the behavior of individual plant species and groups of weeds under the effect of the intensification of agriculture.

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