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ORIGINAL RESEARCH PAPER

The study of the transformation of segetal flora richness and diversity in selected habitats of southern Poland over a 20-year interval

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Abstract

The aim of study was to evaluate diversity of segetal flora and its transformations over a more than 20-year period in 19 field habitats representative for cereal crops of southern Poland. The research hypothesis assumed that: (***i***) the diversity of habitat conditions determines the abundance of arable land flora, (***ii***) it also affects farming intensity which is the main cause of the decline in the biodiversity of agrocoenoses.

Based on 415 phytosociological relevés (sampled using the Braun-Blanquet method), weed species richness (S_r), phytosociological constancy of species (S), cover index (*D*), Shannon's diversity index (*H*) and Simpson's dominance index (*C*) were determined. Measurements were done for each habitat during two research periods. The results were subjected to ANOVA analysis. To assess the similarities of the studied habitats' weed flora in each period and their changes over time, Ward's hierarchical cluster analysis was used. The distance matrix was calculated from Jaccard's similarity indices. The results are presented in the form of hierarchical trees.

The study showed that species richness of the weed communities and their diversity were strongly determined by habitat conditions. Preservation of the value of the diversity index and even its increase (especially in a considerable part of mountain habitats) showed that extensive methods of reducing weed infestation had remained at a similar level of efficacy during the 20-year interval. Hierarchical cluster analysis showed differences between the first and second study period in the weed communities for habitats of lowland soil complexes. The exception were the habitats with the greatest potential for crop cultivation, located on chernozems and rendzinas. In the mountain habitats, there were no significant changes in the segetal flora during the study interval. An increase in weed flora abundance indicates a lack of threats to the diversity of agrophytocoenoses in this part of Poland.

Keywords

segetal weeds; diversity index; dominance index; weed community similarity; mountain habitats; lowland habitats; cereal crops; southern Poland

Introduction

Numerous publications, issued during the last decade, showed significant changes in flora and segetal communities in Europe [1–8]. The authors emphasized the decline in diversity, the uniformity of phytocoenoses, and even the possibility of losing some of the weed species. This phenomenon is usually caused by agricultural practice: changes in land use, reduced tillage and crop rotation, intensive mineral fertilization, purification of seed material, and especially the very common use of herbicides. Some researchers point to the presence of weeds as specific indicators of the intensity of management and use of agricultural land [1,3,6]. According to these reports, in extreme cases, e.g., in Germany, there has been a drastic loss of weed species encountered [7]. On the other hand, the increasing occurrence of some problematic species, including grass weeds, is indicated regardless of farming intensity and climate conditions [9–11]. Similar risks are also present in Poland, especially in relation to weeds that are most vulnerable to the progressive intensification of farming [12–14].

For many years, numerous researchers have also indicated the intrinsic value of weeds and their importance in the proper maintenance of agroecosystems [12,15,16]. For example, recently Fagúndez [17] summarized the role of arable weeds in terms of their ecosystem services. Weeds as the basis of agricultural food webs, and especially their importance for domestic and wild pollinators, were also presented recently by Bretagnolle and Gaba [18]. It is also worth to note that for many years in different countries of Europe efforts have been undertaken to preserve endangered weed species [13,15,19–21].

The specificity of economic conditions: adverse habitat conditions, agrarian fragmentation, and extensive farming methods in southern Poland (especially in mountain habitats), has a positive impact on the floristic diversity and makes the anthropogenic transformations of segetal flora slower and less intensive [22–25]. On the other hand, local habitat conditions usually more strongly influence the level of weed infestation than human activity itself [22] and the diversity of weed communities, accompanying extensive conventional and organic crops, is usually not very significant [25–27]. This phenomenon also occurs in other regions of Poland due to the mosaic of habitats and varied farming intensity [28,29]. Therefore, there are suggestions for verification of pre-existing Polish lists of endangered weeds [30], since the knowledge of their actual status is a prerequisite for the optimal selection of weed infestation reduction methods and saving some of particularly endangered species, especially rare archaeophytes [14,21].

If comparative studies were conducted in the same field habitats, they might form a benchmark for further research on the dynamics of segetal communities [7,8]. However, one observes in the local literature the lack of studies related to transformations of segetal flora in different habitat conditions, carried out on large areas, in the same sites and over long-time intervals. The aim of our study was to evaluate the richness and diversity of weed flora accompanying cereal crops in selected habitats of southern Poland as well as its evolution over a period of more than 20 years. The research hypothesis was that habitat diversity, which affects farming intensity – the primary cause of contemporary changes in agrophytocoenoses, also determines the specificity and abundance of segetal flora and its diversity.

Material and methods

The study involved cereal crops within 19 arable habitats in the southern part of Poland (Tab. 1). Soil conditions were analyzed based on agricultural soil maps for the localities at 1:5000 scale [31,32]. The research area was characterized by large physiographic and soil diversity, which, as is well known, affects agricultural suitability of arable lands. The study was carried out on two types of soil complexes. The first one, classified as lowland habitats (rated to be advantageous for intensive agricultural production), was located in four physiographic mesoregions: Olkusz Highland, Tenczynek Ridge, Proszowice Plateau, and Bochnia Foothills. The second one – mountain land habitats, which are located in three mesoregions, Wieliczka Foothills, Beskid Wyspowy Mts, and Gorce Mts, has greater total areas of different semi-natural habitats and is generally less useful for agriculture, as remarked by Kondracki [33].

The selected habitats represent the mosaic of conditions for agricultural suitability typical for southern Poland and they cover soils prevailing in the studied mesoregions.

Lowland habitats, except for the Bochnia Foothills, are characterized by a large share of agricultural land [32], which covers more than 75% of the study area (in the most agriculturally valuable area – the Proszowicki Plateau – the share of arable land is even above 90%). In contrast, in mountainous locations the share of farmland

Tab. 1 Research conditions and material collected during research periods.

Habitat description							
habitat No.	mesoregion	locality; elevation (m a.s.l.); GPS coordinates	agri-land (%)*	soil unit**	soil symbols in figures	Year (study period)***	No. of phytosociological relevés (herbicides)
1	Olkusz Highland (WO)	Biały Kościół; 400; 50°10′03″ N, 19°49′37″ E	82	2 Bw l li	2Bw	1979 (a)	11 (1)
						2006 (b)	11 (8)
2		Gotkowice; 440; 50°13′30″ N, 19°44′09″ E	83	2 A l·li	2A l	1981 (a)	11 (0)
						2006 (b)	11 (11)
3		Milonki; 410; 50°16′28″ N, 19°47′28″ E	77	4 A li	4A li	1981 (a)	11 (0)
						2006 (b)	11 (11)
4		Sułoszowa; 420; 50°16′60″ N, 19°40′49″ E	89	4 A l·li	4A l	1981 (a)	12 (0)
						2006 (b)	11 (9)
5	Tenczynek Ridge (GT)	Liszki; 220; 50°02′20″ N, 19°46′09″ E	82	2 Als:li	2A ls	1981 (a)	11 (0)
						2006 (b)	11 (11)
6				1 B ls: li	1B	1985 (a)	12 (3)
						2006 (b)	11 (11)
7				8 F płz	8F	1985 (a)	11 (4)
						2006 (b)	11 (11)
8		Brodła; 270; 50°02′35″ N, 19°35′18″ E	84	8 A ls	8A	1979 (a)	12 (3)
						2006 (b)	11 (10)
9	Proszowice Plateau (PP)	Kaczowice; 260; 50°17′15″ N, 20°14′07″ E	94	1 C ls	1C	1981 (a)	11 (1)
						2006 (b)	11 (9)
10		Niegardów; 220; 50°13′01″ N, 20°11′10″ E	91	2 R cc	2R	1981 (a)	11 (0)
						2006 (b)	11 (11)

Tab. 1 Continued

Habitat description							
habitat No.	mesoregion	locality; elevation (m a.s.l.); GPS coordinates	agri-land (%)*	soil unit**	soil symbols in figures	Year (study period)***	No. of phytosociological relevés (herbicides)
11	Bochnia Foothills (PB)	Fałkowice; 225; 49°54′11″ N, 20°10′17″ E	52	2 F gsp	2F	1981 (a)	11 (0)
						2006 (b)	11 (7)
12	Wieliczka Foothills (PW)	Bęczarka; 330; 49°52′39″ N, 19°52′01″ E	53	10 A ls li	10A (Be)	1981 (a)	11 (6)
						2005 (b)	10 (10)
13		Biertowice; 260; 49°52′17″ N, 19°47′32″ E	51	10 A ls li	10A (Bi)	1981 (a)	11 (4)
						2005 (b)	10 (9)
14		Dziekanowice; 290; 49°54′08″ N, 20°05′51″ E	52	10 A ls li	10A (Dz)	1981 (a)	10 (0)
						2005 (b)	10 (10)
15	Beskid Wyspowy Mts. (BW)	Jadamwola; 420; 49°35′09″ N, 20°30′38″ E	65	10 Bwθ płz·ip:gc	10Bwθ	1983 (a)	11 (2)
						2006 (b)	10 (3)
16		Jurków; 520; 49°55′97″ N, 20°14′02″ E	46	11 Bw□ gcp·gc:sz	11Bw□	1983 (a)	11 (6)
						2006 (b)	11 (7)
17		Pisarzowa; 420; 49°41′33″ N, 20°29′36″ E	51	12 Bwθ gcp:gc	12Bwθ	1978 (a)	11 (0)
						2006 (b)	11 (8)
18	Gorce Mts. (G)	Ochotnica Dolna; 550; 49°31′33″ N, 20°20′33″ E	39	12 Bw□ gcp·gc:sz	12Bw□gcp	1979 (a)	12 (1)
						2006 (b)	11 (5)
19		Niedźwiedź; 500; 49°37′14″ N, 20°04′39″E	38	12 Bw□ gsp-gc:sz	12Bw□gsp	1980 (a)	12 (0)
						2006 (b)	8 (5)

* Percentage of agricultural land in the locality area, according to Grabowska-Orządała [32]. ** Soil unit and soil symbols according to 1:5000 scale agricultural soil maps: 1–12 – complexes of agricultural soil suitability (1 – very good wheat; 2 – good wheat; 4 – very good rye; 8 – strong cereal-fodder; 10 – mountain wheat; 11 – mountain cereal; 12 – mountain oat-potatoes); A – luvisol; B – brown soil (Phaeozem); Bw – brown leached soil (Endoeutric Cambisol); C – chernozem; F – alluvial soil; R – rendzina (Rendzic Leptosol); θ – sedimentary rock formation with non-carbonate cementing material; □ – sedimentary rock formation with carbonate cementing material; cc – heavy chernozem; gc – heavy loam; gcp – heavy silty loam; gsp – medium silty loam; ip – silty clay; li – loess and loess-like clay sediments; ls – loess and loess-like ordinary sediments; płz – ordinary silt; sz – heavily skeletal soil. *** Study period: a – first; b – second.

represents no more than 65%, and at the highest altitudes even below 40%. This part of the study area has a proportionately larger share of permanent grassland (permanent meadows and pastures) and other types of land not suitable for agriculture (set-aside land, including areas covered with trees and shrubs). Moreover, these are areas with a large degree of forestation.

The study area consists mainly of extensive farms (94.5% of the total) with an average size of about 3 ha [32]. The area of fields generally does not exceed 1 ha, while in mountain habitats it is often less than 0.5 ha. The traditional agricultural methods, characterized by low use of mineral fertilizers and pesticides, were dominant in both study periods in mountain habitats.

For every individual habitat, the study was conducted twice at the turn of June and July: in the years 1978–1985 (hereinafter referred to as the first period of the research) and in the years 2005–2006 (designated as the second period of the research). In the case of two habitats, it covers 21 years, but mostly even 23–25 years or more. The choice of the habitats in the second period of the research resulted from the availability of archived phytosociological relevés made in the first period. It was based on the authors' study on the occurrence of most important segetal weeds in Poland (coordinated by the Institute of Soil Science and Plant Cultivation in Puławy). The results of this study, for the area overlapping with that of the present paper, were published in the form of unique maps of the distribution of hazardous weed species across the selected crops, including cereals [31]. It relates to the predominant soils of each mesoregion and therefore archived material may provide a reference for comparative study on changes in weed flora diversity. Since none of these aspects has been previously investigated, all these results may be of interest for future studies. The entire research material has been archived in the Department of Agrotechnology and Agricultural Ecology of the University of Agriculture in Krakow.

The research material consists of 415 phytosociological relevés sampled using the Braun-Blanquet method [34]. The area of each relevé is approximately 100 m^2. During the survey, traces of herbicide usage were recorded every time (Tab. 1). In the first period of research, their use was sporadic in all habitats, while in the second period widespread application of herbicides was noted in lowland habitats. In the mountain complexes, this practice occurred only in the area of the Wieliczka Foothills. At the same time, overall low efficiency of weed control methods in cereal crops was noted.

The number of species in the phytosociological relevé was adopted as a measure of average species richness (S_r). For every species, in both research periods, phytosociological constancy (S) as well as cover index (*D*) were determined after Pawłowski [34].

Species constant or frequent in the area of research (i.e., occurring in phytosociological constancy degree V or IV) as well as those that reached the cover index (*D*) at a level of ≥100 were treated as dominant.

As a measure of weed threat to the cereal crop, the sum of the coverage coefficients *D* was taken. Geographical and historical affiliation of the identified vascular plants was determined, using the work of Chmiel [35]. Native species (native taxa) were distinguished, including: apophytes (Ap) – plants which occur exclusively or almost exclusively in semi-natural and anthropogenic habitats; semi-synanthropic spontaneophytes (Sp/Ap) – taxa that are commonly found in semi-natural and anthropogenic communities; and non-synanthropic spontaneophytes (Sp), i.e., species occurring almost exclusively in natural and semi-natural habitats. The species identified in the studied flora as anthropophytes (A), i.e., taxa present in the weed communities due to human activity, were represented by archaeophytes (Ar) and kenophytes (Kn).

Moreover, for each vegetation patch two ecological indices were calculated [36]: the Shannon's diversity index (*H*) and Simpson's dominance index (*C*):

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

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

where: n_i – the share 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 participation in the phytosociological relevé, while the decrease in the value of the dominance index (*C*) indicates an increase in the diversity of the phytocoenosis. Both these indices are commonly used as measures of diversity of a phytocoenosis.

In order to assess the influence of the type of habitat, type of soil, and time on the above-mentioned values, ANOVA analysis was applied. It was done separately for mountain and lowland habitats. As far as the assumptions of ANOVA analysis are concerned, they were checked each time. In case of one-way ANOVA, the assumptions are met clearly, whereas in case of two-way ANOVA analysis, it sometimes happens that the check is quasi-negative due to the small subsample size.

First, we present one-way ANOVA with period as the dependent variable. This is shown in the form of a customized ANOVA table (Tab. 2). To enable deeper insight into interactions between soil type, study period, and habitat type, two-way ANOVA was performed and it is presented in the form of an ANOVA table (Tab. 3). As it is a more sophisticated case, additional illustration in the form of graphs (Fig. 1–Fig. 3) is added.

In order to separate homogeneous groups of weeds, Ward's method of hierarchical cluster analysis was applied. Distance measures of the examined objects were based on similarity indices. The results were presented in the form of hierarchical trees. For this purpose, Jaccard's similarity coefficients (S_J) were calculated and distance matrices of phytosociological relevés for each research period were determined according to the formula suggested by Dzwonko [37]:

$$S_J = \frac{a}{a + b + c}$$

where: *a* – the number of the species present in both compared sets of phytosociological relevés; *b* – the number of species present in set 1 and absent in set 2; *c* – the number of species present in set 2 and absent in set 1.

Statistical analyses were done using the package STATISTICA 10.0 (StatSoft Inc., USA). Vascular plant terminology follows the study of Mirek et al. [38].

Tab. 2 One-way ANOVA table for period.

Dependent variable	Habitats	Source of variation	Mean	*SE*	*SS*	*df*	*MS*	*F*	*p*
Number of species per phytosociological relevé (S_r)	Lowland	Period I	**20.78**	**0.589**	**448.21**	**1**	**448.21**	**10.42**	**0.0014**
		Period II	**23.49**	**0.596**					
	Mountain	Period I	25.24	0.770	104.06	1	104.06	1.97	0.1621
		Period II	26.80	0.807					
Shannon's diversity index (*H*)	Lowland	Period I	**0.97**	**0.028**	**0.46**	**1**	**0.46**	**4.85**	**0.0286**
		Period II	**1.06**	**0.028**					
	Mountain	Period I	0.99	0.031	0.34	1	0.34	3.87	0.0507
		Period II	1.08	0.033					
Simpson's dominance index (*C*)	Lowland	Period I	**0.22**	**0.016**	**0.13**	**1**	**0.13**	**4.16**	**0.0425**
		Period II	**0.17**	**0.016**					
	Mountain	Period I	0.21	0.018	0.01	1	0.01	0.28	0.5942
		Period II	0.20	0.019					

SE – standard error; *SS* – sum of squares; *df* – degrees of freedom; *MS* – mean square; *F* – *F*-statistic values; *p* – probability; values in bold are significant at the 0.05 level.

Tab. 3 Two-way ANOVA table for Period × Soil.

Dependent variable	Habitats	Source of variation	*SS*	*df*	*MS*	*F*	*p*
Number of species per phytosociological relevé (S_r)	Lowland	Period	**447.62**	**1**	**447.62**	**12.78**	**0.0004**
		Soil	**1726.80**	**10**	**172.68**	**4.93**	**0.0000**
		Period × Soil	**882.72**	**10**	**88.27**	**2.52**	**0.0068**
	Mountain	Period	91.40	1	91.40	2.16	0.1438
		Soil	**1386.89**	**7**	**198.13**	**4.68**	**0.0001**
		Period × Soil	**936.21**	**7**	**133.74**	**3.16**	**0.0038**
Shannon's diversity index (*H*)	Lowland	Period	**0.48**	**1**	**0.48**	**5.52**	**0.0197**
		Soil	**1.75**	**10**	**0.18**	**2.00**	**0.0342**
		Period × Soil	**1.77**	**10**	**0.18**	**2.02**	**0.0325**
	Mountain	Period	**0.31**	**1**	**0.31**	**4.38**	**0.0379**
		Soil	0.78	7	0.11	1.59	0.1429
		Period × Soil	3.00	7	0.43	6.11	**0.0000**
Simpson's dominance index (*C*)	Lowland	Period	0.13	1	0.13	4.55	**0.0339**
		Soil	0.41	10	0.04	1.41	0.1780
		Period × Soil	0.48	10	0.05	1.63	0.0986
	Mountain	Period	0.01	1	0.01	0.27	0.6053
		Soil	0.16	7	0.02	0.95	0.4707
		Period × Soil	**0.87**	**7**	**0.12**	**5.04**	**0.0000**

Explanations: see Tab. 2.

Results

Segetal flora richness and diversity indices

In the first part of this review of the results, we will focus on changes in average richness and diversity of phytocoenoses with respect to the passage of time. This can be seen in Tab. 2, which shows the mean values, standard errors, and the significance of respective differences in the indices S_r, *H*, and *C*. The main findings that are worthy of notice are following:

- The majority of effects (four of six) are significant.
- The indices S_r and *H* become higher in the second period, whereas index *C* diminishes, which is consistent with the meaning of these variables (it is worth to note that significant differences appear in the case of lowland habitats where more intensive use of herbicides was observed (see Tab. 1);
- The absolute values of S_r and *H* are higher in mountain habitats (as compared to lowland ones) in both periods. At the same time, index *C* is consistent with the above comments, but shows smaller sensitivity to time passage (changes are non-significant).

A complex picture of the specific circumstances of time and soil interactions is behind these bulk effects. These are summarized in Tab. 3 and illustrated with figures (Fig. 1–Fig. 3). In order to illustrate numerically the discussed results, we designed summary tables (Tab. S1–Tab. S5). They show the dominant species [i.e., constant (V) or frequent (V) and/or reaching the value of $D \geq 100$ in at least one of the studied habitats]. The lists are supplemented with combinations of sporadic taxa occurring in lowland (Appendix S1) and mountain habitats (Appendix S2).

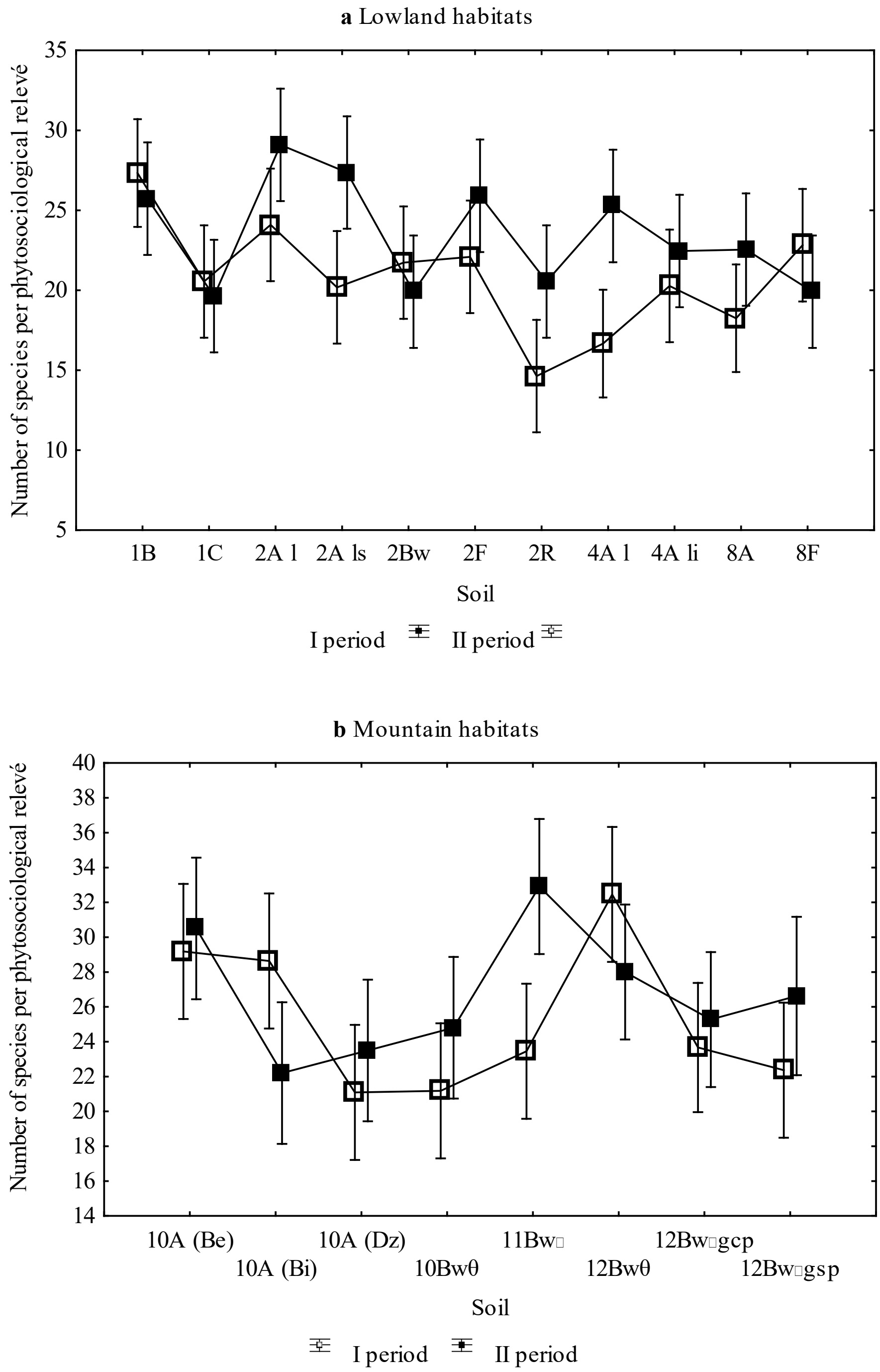

Fig. 1 Average species richness (S_r) and its changes over the research period, depending on habitat. Vertical bars reflect 95% of confidence intervals for mean; soil description – as in Tab. 1.

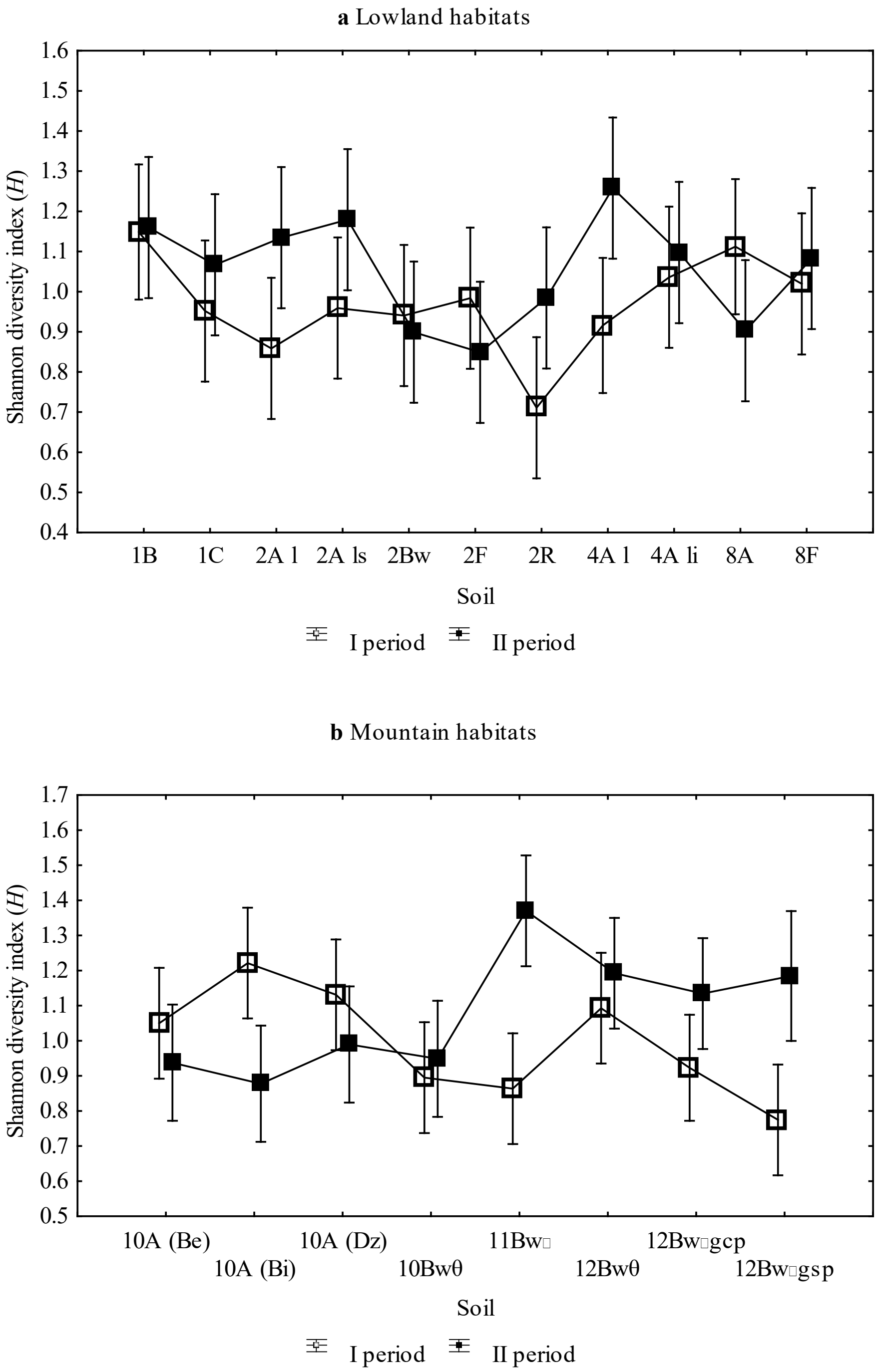

Fig. 2 Mean values and value ranges for the Shannon's diversity index (*H*) in the research periods, depending on habitat. Vertical bars reflect 95% of confidence intervals for mean; soil description – as in Tab. 1.

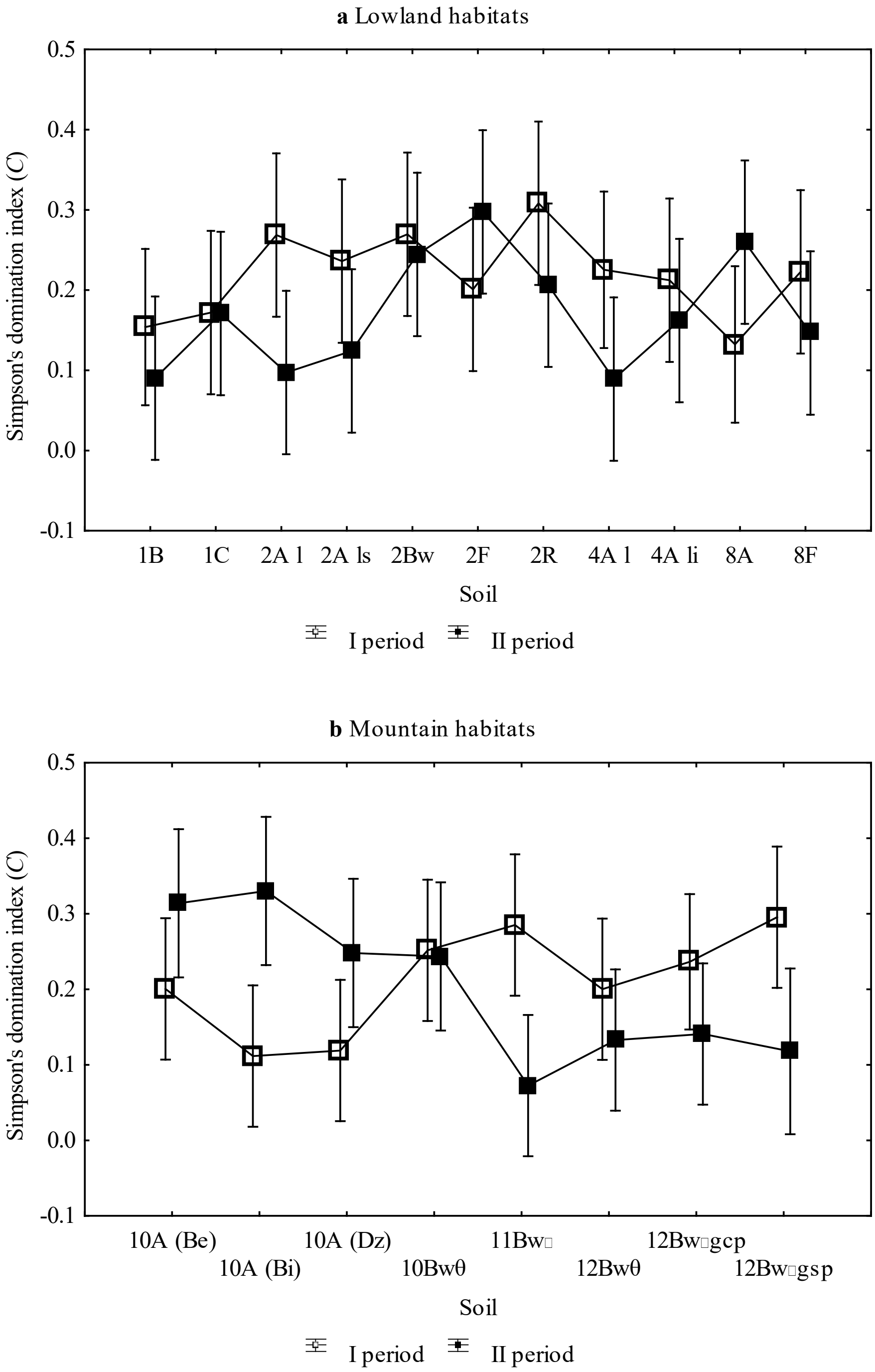

Fig. 3 Mean values and value ranges of Simpson's dominance index (*C*) during the research periods, depending on habitat. Vertical bars reflect 95% of confidence intervals for mean; soil description – as in Tab. 1.

It is noteworthy that in many of the studied habitats, an increase in the total number of species was observed during the multi-year study periods. In the lowland mesoregion of Olkusz Highland (Tab. S1), it affected especially soil 2A l (26%), 4A li (17%), and 4A l (37%). In the case of the Tenczynek Ridge (Tab. S2), an increase in the number of species affected soil 2A ls (16%) and 8A (25%). In the Proszowicki Plateau (Tab. S3), on the chernozem we saw an increase in species richness by about 10%, and on rendzinas up to 30%. The flora of alluvial soil (2F) in the Bochnia Foothills was significantly enriched (27%). Similar trends were found in mountain habitats, especially on soils 10A (Bi) and 10A (Dz) in the Wieliczka Foothills as well as in the mesoregion of the Beskid Wyspowy Mts where an increase by about 35% was noticed (11Bw□). The increase in the total number of species corresponds well with Fig. 1, where the number of species in the phytosociological relevé was presented as a measure of average species richness (S_r).

Also, values of diversity indices (*H*) well reflect the state of the examined species richness. In five of the analyzed lowland habitats (Fig. 2a), the *H*-index value increased over many years, but the most significant change took place in the case of luvisol complexes (2A l, 2A ls, 4A l) and rendzina (2R). At the same time, in these habitats (except the rendzina) the *H* index reached the highest values noted in the second period of the research (H = 1.13–1.79). Only in two of examined lowland habitats (2F, 8A) the flora diversity index appeared to decrease in the time between the studies. A particularly important change occurred in the 8A soil units, which confirms a simultaneous significant increase of the dominance index (*C*) in the second period of the research (Fig. 3a). Habitats that preserved similar total and mean species richness and diversity index in the period between the studies are the soils located in the most favorable conditions for agriculture in the research area (1B, 2Bw).

In the soils of mountain complexes (Fig. 2b), in the second period of the research a significant reduction in the *H*-index value was noted in the phytocoenoses of the Wieliczka Foothills [soil units: 10A (Be), 10A (Bi), and 10A (Dz)] where widespread use of herbicides was recorded at the time (Tab. 1). In the remaining locations within this group of habitats, covered with flysch soils, a visible increase in the floral diversity of the agrocoenosis was noted (except 10Bwθ), wherein the largest differences were recorded for two soil units: 11Bw□ and 12Bw□gsp. It is distressing as it relates to the fields that in the second period of the research underwent chemical weeding to a wider extent than in the initial period. This was also accompanied by an increase in the total number of species and the mean number of weeds recorded in the phytosociological relevé, compared to the initial period, which may show insufficient effectiveness of applied weeding methods.

The reduction of the studied phytocoenoses' *H* index manifested itself in the increase (undesirable from the agricultural viewpoint) of Simpson's dominance index (*C*), particularly strong in the lower situated mountain habitats of the Wieliczka Foothills. This pattern also manifested itself in other mountain habitats of the study area, with the exception of soil unit 10Bwθ in the Beskidy Mts (Fig. 3). Throughout the whole study area, the increase of the *C* index was generally associated with the dominance of a few species (see Tab. S1–Tab. S5), including the silky bent grass [*Apera spica-venti* (L.) P. Beauv.].

This applies to most of the lowland habitats (Tab. S1–Tab. S3) where *Apera spica-venti* was continuously (S = V) or frequently (S = IV) present in cereal crops, in multiple locations and in both periods, making a significant contribution to the total value of the coverage coefficients. Noteworthy is the occurrence of *Avena fatua* L. (Tab. S1, Tab. S2) only in the second period of research [or an increase in its importance compared to the first study period (Tab. S3)]. An especially important problem, however, seems to be the persistence of *Apera spica-venti* in the multi-year period and its presence or an increase in its share in the areas situated high above sea level (Tab. S4, Tab. S5). In the Wieliczka Foothills (Tab. S4), *Apera spica-venti* reached in the second period of research significantly high values of the total cover index *D* (21.7– 62.3%).

Regardless of the location and date of research, the species richness of phytocoenoses was predominantly determined by native taxa. Among them, apophytes (Ap) were the dominant part, whereas alien species were mainly represented by archaeophytes (Ar).

Numerous species found in the analyzed crops with constancy I–III and having a cover index *D* < 100 are listed in Appendix S1 (lowland habitats) and Appendix S2 (mountain habitats). Also, in both types of habitats native species predominate in number. Among alien species, archaeophytes dominate. We found some of them, e.g., *Adonis aestivalis* L., *Agrostemma githago* L., *Bromus secalinus* L., *Camelina sativa* (L.) Crantz, *Euphorbia helioscopia* L., *Euphorbia exigua* L., *Geranium dissectum* L., *Fumaria officinalis* L., *Neslia paniculata* (L.) Desv., *Nigella arvensis* L., *Valerianella dentata* (L.) Pollich, *Sherardia arvensis* L., only in a limited number of habitats. Moreover, if they were recorded in both study periods, then in the second one generally they had lower constancy degree (S) and a minimal cover index (*D*).

During the study period, the smallest changes in the values of the analyzed indices occurred for lowland soil units, ranked among the most useful for agricultural production (1B, 2Bw, and 1C). In the mountain habitats, it happened only in case of the 10Bwθ soil unit, i.e., in the location which is more favorable for agriculture than the other ones because of soil properties and altitude.

Analysis of weed community similarity

The results of similarity assessment of the analyzed weed communities were presented in the form of hierarchical trees (Fig. 4). Among weed communities occurring in the fields located on the soils of lowland complexes (Fig. 4a), three groups of clusters were found. The first one contains the communities accompanying crops in both periods of the study, growing in the most fertile soils (1C and 2R). A small linkage distance between particular soil units shows their great mutual similarity (0.65). The reason for this may be related to both terrain and altitude (about 220–260 m a.s.l.) as well as to the comparable level of farming intensity. These habitats are situated in the Proszowice Plateau, the mesoregion with one of the best agricultural conditions in Poland [33]. Two other groups are composed of nine items each. One of them brings together the communities examined in the second period of the study, while the second one – only those from the initial period. A greater linkage distance between them suggests that the changes in flora that took place in the studied period are significant. At the same time, a greater mutual similarity is characteristic for the communities observed in the subsequent period, which confirms the trend towards unification of agrophytocoenoses.

The hierarchical tree presenting the clusters of weed communities located on the soils of the mountain complexes (Fig. 4b) shows that they are much more similar to each other than the aforementioned ones. The maximum distance of their linkages is only 0.82, while in the case of lowland habitats this value is 1.28. In the mountain habitats, there are four conglomerations that stand out and their linkages are at a similar level (0.53–0.57). The presence of weed communities representing both research periods in each of them shows a great similarity of flora and its small changes over time, regardless of habitat conditions.

Discussion

Species richness strongly depends on soil conditions and is usually greater on fertile soil [12]. In such circumstances, however, usually more intensive agricultural production causes a drastic impoverishment of species composition [26,28].

In our study, the richness of segetal flora, surveyed over a 20-year period, was generally in line with results of Kolářová et al. [39]. They also found it to be higher in the less productive agricultural areas at higher altitudes of the Czech Republic. The mean values of the diversity index (*H*), higher in mountain habitats than in lowlands, support the opinion that weed communities in areas with a more developed farming culture are poorer in species than those in the areas less suitable for agriculture [32].

Similar values of diversity indices were obtained for luvisols of the Lublin region by Feledyn-Szewczyk et al. [28]. They, however, noted the impoverishment of segetal flora along with the intensification of farming methods. On the other hand, Dostatny [13] proved much higher floral diversity (*H* = 2.2–2.8) for rendzinas of the Niecka

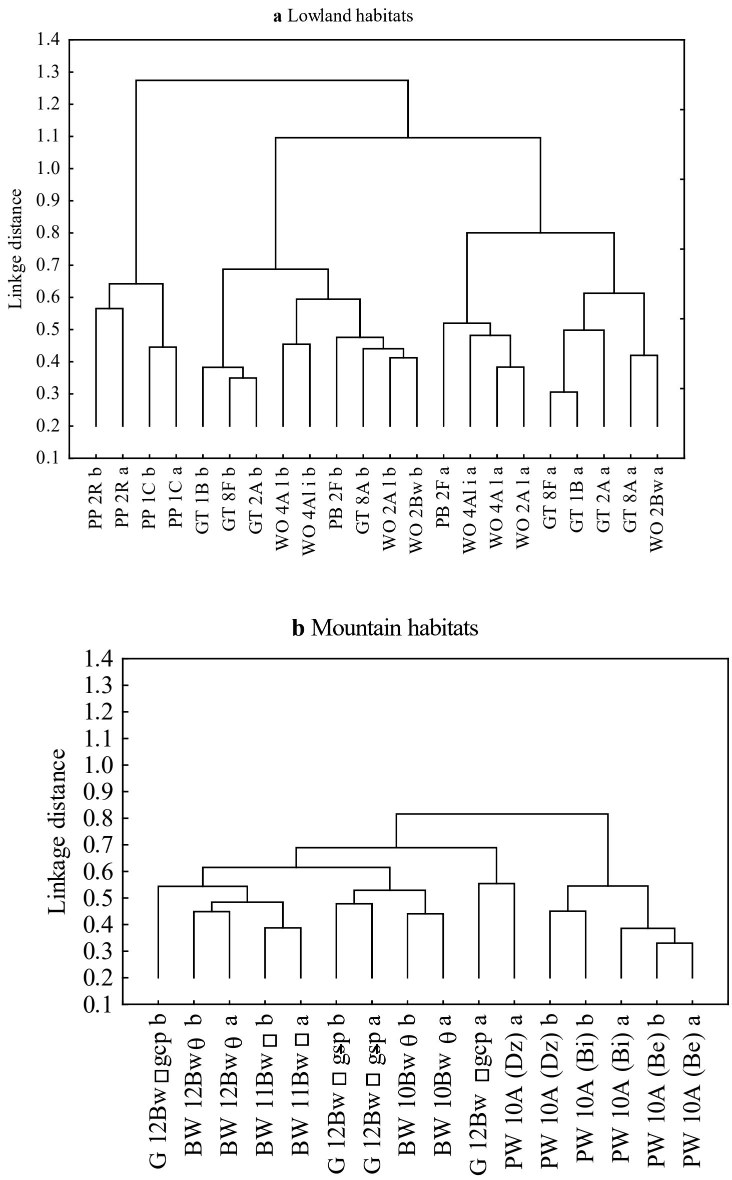

Fig. 4 Hierarchical tree of weed community similarity of the studied habitats in two research periods, designated using Ward's method (soil description – as in Tab. 1).

Nidziańska region in the corresponding period. This author also noticed a systematic decrease in the number of taxa in a single phytosociological relevé compared with the earlier periods of her study. It was previously observed also in southern Poland, especially in relation to the altitude and hillside slope as well as farming system [25,27]. Due to the steadily decreasing number of archeophytes [28,29], the loss or reduction of this group of segetal weeds is particularly unfavorable. In southern Poland, the risk of extinction of these rare species was recorded in the Miechowska Upland [40].

The impact of altitude on diversity index was also considered by Kolářová et al. [39]. The greater abundance of segetal flora occurring in fields located higher above sea level and its lower susceptibility to changes are probably affected by the heterogeneity of habitat conditions and possible migration of some native species from crop edges and the mosaic of neighboring ecosystems, as indicated in studies of other authors [1,22,29,41–44]. According to Kovács-Hostyánszki et al. [42], the beneficial effect of semi-natural habitats on arable flora diversity may occur only in crop edges, but in case of high land fragmentation of our study area and low efficiency of weed control methods, the weed response (and consequently – species pool) may be stronger.

The results of the present studies are consistent with earlier reports from southern Poland, including the Beskidy Mts [22,45], where an increase was observed in the threat to cereal crops caused by weeds from the family of Poaceae, mainly compared to the state in the 1980's. In Poland, the issue of threats caused by *Apera spica-venti* is usually reported as associated with an increase in the intensity of farming, generally accompanied by an increase in the share of cereal crops in the total cropped area or their cultivation in monocultures [26,28,29]. The threat posed by silky bent grass and the necessity of effective ways of its reduction were also indicated by other European researchers in the past decade [10,11].

A noticeable trend towards unification of agrophytocoenoses was also mentioned by Baessler and Klotz [1]. Just like the previously discussed indices, the similarity analysis of the studied habitats' flora also indicates the influence of agri-environmental conditions on the transformations of agrophytocoenoses. This applies both to conditions recorded in each period of our study as well as to the direction and intensity of field flora changes over a period of several years. This is proved by a noticeable increase in the diversity of weed communities developed on the soils of mountain complexes compared to lowland ones as well as the lack of significant changes over time in field communities located in the mountain habitats. Likewise, similar results, i.e., higher diversity values, were found in extensive agricultural landscapes with traditional management, as presented by Pinke et al. [19].

Because of the restrictive influence of adverse habitat conditions in the Beskidy Mts, farmers more frequently decide to give up plough cultivation in favor of expanding the extensive grassland area [25,32]. They also willingly participate in the ecological farming system [27]. This can be one of effective measures for preservation of the diversity of agrocoenoses, which is consistent with the study conducted by Richner et al. [8]. The final result of that can also be supported by soil and landscape complexity [43].

Conclusions

- Ecological indices proved to be useful in assessing the floral diversity of agrocoenoses and their analysis showed the relationship of habitat conditions with the abundance of segetal flora as well as with the direction and extent of contemporary changes in this flora.
- Over nearly a quarter of a century, the abundance of weed communities of cereal crops did not undergo a visible reduction, whereas in some habitats, especially those located in mountain habitats, it increased.
- In habitats appropriate for more intensive agricultural production, there is a threat of reduced segetal flora diversity, combined with the dominance of *Apera spica-venti*.
- The potential effects of anthropogenic impact are considerably weaker for habitats located in the areas with habitat conditions unfavorable for agriculture. Habitat conditions combined with anthropogenic pressure will probably ensure abundance and diversity of weed communities associated with cereal crops.

Supplementary material

The following supplementary material for this article is available at http://pbsociety.org.pl/journals/index.php/aa/rt/suppFiles/aa.1712/0:

Appendix S1 List of sporadic weed species, i.e., present at lowland habitats with phytosociological constancy (S) I–III and cover index (*D*) <100.

Appendix S2 List of sporadic weed species, i.e., present at mountain habitats with phytosociological constancy (S) I–III and cover index (*D*) <100.

Tab. S1 List of dominant weed species occurring in the habitats of the Olkusz Highland.

Tab. S2 List of dominant weed species occurring in the habitats of the Tenczynek Ridge.

Tab. S3 List of dominant weed species occurring in the habitats of the Proszowice Plateau and Bochnia Foothills.

Tab. S4 List of dominant weed species occurring in the habitats of the Wieliczka Foothills.

Tab. S5 List of dominant weed species occurring in the habitats of the Beskid Wyspowy Mts and Gorce Mts.

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Badania nad przeobrażeniami bogactwa i różnorodności flory segetalnej w wybranych siedliskach Polski południowej w okresie ponad 20 lat

Streszczenie

Celem badań była ocena zróżnicowania flory segetalnej upraw zbóż i jej przeobrażeń w okresie ponad 20 lat, w 19 siedliskach reprezentatywnych dla południowej Polski. Hipoteza badawcza

zakładała, że: (***i***) zróżnicowanie siedliskowe określa bogactwo flory polnej, (***ii***) wpływa ponadto na intensywność gospodarowania, która jest główną przyczyną zmniejszania bioróżnorodności agrozenoz.
W oparciu o 415 zdjęć fitosocjologicznych wykonanych metodą Braun-Blanquet'a określono bogactwo gatunkowe chwastów (S_r), współczynniki pokrycia powierzchni przez chwasty (*D*) oraz wskaźniki: różnorodności Shannon'a (*H*) i dominacji Simpson'a (*C*). Ocenę przeprowadzono dla każdego z siedlisk w dwóch okresach badań. Wyniki poddano analizie statystycznej w programie ANOVA. W celu zbadania podobieństwa florystycznego badanych siedlisk przeprowadzono hierarchiczną analizę skupień metodą Ward'a, w której jako miarę odległości wykorzystano współczynniki podobieństwa Jaccard'a, a rezultaty zaprezentowano w postaci dendrogramów.
Badania wykazały, że bogactwo gatunkowe zbiorowisk chwastów i ich zróżnicowanie w czasie było silnie zdeterminowane warunkami siedliskowymi. Zachowanie wartości wskaźników różnorodności, a nawet ich zwiększenie (zwłaszcza w znaczącej części siedlisk górskich) potwierdziło, że ekstensywne metody ograniczania zachwaszczenia pozostały na podobnym poziomie efektywności w ciągu okresu ponad 20 lat. Hierarchiczna analiza skupień wykazała zróżnicowanie pomiędzy pierwszym i drugim okresem badań w przypadku zbiorowisk chwastów siedlisk nizinnych. Wyjątkiem były siedliska o największej przydatności dla uprawy roślin, zlokalizowane na czarnoziemach i rędzinach. Na siedliskach górskich nie stwierdzono znaczących zmian w obrębie flory polnej w ciągu okresu dzielącego badania. Wzrost bogactwa florystycznego świadczy o braku zagrożenia dla różnorodności agrofitocenoz w tej części kraju.