AGRONOMY SCIENCE

Online first 2026

https://doi.org/10.24326/as.2026.5662

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Changes in segetal flora in a selected habitat of southern Poland from 1993 to 2022. Part 2. Anthropogenic transformations

Abstract. The study aimed to assess changes in the degree and direction of segetal flora transformation under anthropogenic impacts in cereal crops within a selected habitat (Małopolska voivodship; southern Poland) from 1993 to 2022. The research material comprised 65 phytosociological relevés collected over selected years of the analysed period. Changes in the proportion of species representing different geographical-historical groups were assessed using applicable anthropogenic transformation indices, namely: synanthropisation, anthropophytisation, archaeophytisation, kenophytisation, and modernisation. The flora of the study area was strongly transformed anthropogenically, as indicated by the high and steadily increasing value of the synanthropisation index, which reached 100.0% in 2022, compared with 89.3% in 1993. Alien species (anthropophytes) dominated the weed flora of the investigated crops over native species (spontaneophytes). The anthropophytisation index amounted to 53.6% in the first year of the study and increased to 60.0% in the last year. The number of archaeophytes remained relatively stable, with the archaeophytisation index decreasing slightly from 48.2% in 1993 to 47.3% in 2022. In the early years of the study, the proportion of kenophytes in the flora of the research area was low; however, their importance increased over time. This trend is reflected in the doubling of the kenophytisation index (from 5.4% in 1993 to 12.7% in 2022) as well as in the modernisation index (from 10.0% in 1993 to 21.2% in 2022).

Keywords: agroecosystems, field weeds, anthropophytes, spontaneophytes, synanthropisation index

INTRODUCTION

Contemporary agroecosystems are undergoing dynamic transformations driven by human activity, one of the most evident manifestations of which is a change in the composition of segetal flora. Anthropogenic factors such as the intensification of agriculture, increased use of agrochemicals,

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changes in land-use practices, as well as urbanisation and infrastructural development, lead to the gradual homogenisation of habitats and the decline of many species associated with traditional farming systems [Pinke et al. 2012, Storkey et al. 2012, Richner et al. 2015, Gala-Czekaj et al. 2024]. In segetal habitats, the spread of alien and ruderal species is increasingly evident, further destabilising the phytocoenotic structure of arable fields. Research findings indicate a marked increase in the proportion of kenophytes, reflecting an advancing process of synanthropisation and escalating anthropogenic pressure [Lososová et al. 2004, Tokarska-Guzik 2005, Balcerkiewicz and Pawlak 2010a]. Increasingly, segetal floras are dominated by widely distributed species with broad ecological tolerance, which effectively compete with native flora and lead to the simplification of the species structure of plant communities. This process is accompanied by a decline in the proportion of spontaneophytes – native plants that have been associated with cultivated fields for centuries and are unable to compete under conditions of high habitat pressure [Lososová et al. 2004, Balcerkiewicz and Pawlak 2010b, Skrajna 2021, Gala-Czekaj et al. 2024]. Such changes not only serve as indicators of anthropogenic impact but may also pose a threat to the conservation of the floristic heritage of agroecosystems [Sutcliffe et al. 2015].

Among non-native plants, invasive species are of particular significance, as their high ecological plasticity, rapid growth, and effective dispersal allow them to colonise ruderal habitats, field margins, and often even the interiors of agroecosystems. In addition to well-known annual species, such as *Ambrosia artemisiifolia* or *Erigeron annuus*, recent decades have seen a dynamic expansion of perennial and long-lived species with high invasive potential. The most problematic species include: goldenrods (*Solidago canadensis*, *S. gigantea*), knotweeds (*Reynoutria japonica*, *R. sachalinensis*, *R. ×bohemica*), and balsams (*Impatiens glandulifera*, *I. parviflora*) [Tokarska-Guzik 2005, Tokarska-Guzik et al. 2012]. Their presence in agricultural landscapes not only reduces species diversity but also alters habitat structure, negatively affects soil quality, and complicates land management and nature conservation [Hejda et al. 2009].

Less drastic than the invasion of alien species are changes in the proportion of plants of native and non-native origin. Within the non-native flora, shifts in the relative abundance of archaeophytes and kenophytes are also observed. Floristic transformations encompass two co-occurring processes: apophytisation, involving the movement of native species from natural habitats into anthropogenic ones and anthropophytisation, resulting from the direct and indirect influence of human activity on the vegetation of arable fields and other managed ecosystems [Chmiel 2006].

The intensifying floristic changes in agroecosystems caused by human activity make systematic research on their extent and nature essential. Assessing the degree of synanthropisation in segetal flora and the shifts in native and non-native species within weed communities is particularly important. Monitoring these processes can enhance our understanding of how anthropogenic factors affect crop biodiversity and support efforts to conserve the floristic heritage of agricultural landscapes. With the ongoing expansion of kenophytes and the decline of spontaneophytes, such studies are vital for maintaining phytocoenotic balance and guiding the sustainable management of agricultural land.

The aim of this study was to assess the degree and direction of segetal flora transformations in cereal crops in a selected habitat of southern Poland between 1993 and 2022 under anthropogenic pressure.

MATERIAL AND METHODS

The research 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). The study was conducted on heavy brown rendzina soil, classified as agricultural soil complex 3 (defective wheat complex; 3Rb(c)) according to the soil-agricultural map at a scale of 1 : 5000 [Mapa glebowo-rolnicza… 1992].

The research material comprised 65 phytosociological relevés made in selected years of the long-term study period: 1993 (8 relevés), 1998 (10), 2003 (10), 2008 (11), 2013 (11), 2018 (8), and 2022 (7). The relevés were carried out using the Braun-Blanquet method [Braun-Blanquet 1964]. A seven-point Braun-Blanquet cover-abundance scale was applied, with the following classes: 5: 75.1–100% cover, 4: 50.1–75%, 3: 25.1–50%, 2: 5.1–25%, 1: 1–5%, +: <1%, and r: individual occurrences of a given species.

Floristic surveys were conducted annually in late June or early July on the same set of cereal fields. The size of each field generally did not exceed 1 ha, while each phytosociological relevé covered an area of approximately 100 m². During the study period, herbicide use was recorded for each field, while the proportion of fields subjected to chemical weed control steadily increased. In the first year of the study, herbicide protection was applied in only 25% of the fields, increasing to 80–90% during 1998–2022.

A detailed description of the study area, including its climatic and soil conditions, is provided in Part 1 of the study [Gala-Czekaj et al. 2024].

The aim of the study was achieved by assessing changes in:

1) the proportion of species belonging to geographical-historical groups [Kornaś 1968];

2) selected indices of anthropogenic transformation of the flora [Chmiel 2006], i.e.:

– the synanthropisation index,
– the anthropophytisation index,
– the archaeophytisation index,
– the kenophytisation index,
– the modernisation index.

The above-mentioned indicators illustrate the relationships between species groups differing in origin and degree of naturalisation. Each index, except the modernisation index, expresses the percentage of a particular group of species relative to the total number of species in the community, i.e. S + A (S; spontaneophytes, A; anthropophytes). The synanthropisation index (SI) quantifies the proportion of apophytes (Ap; native species occurring exclusively or almost exclusively in anthropogenic habitats) and anthropophytes (A) in the total species pool. It is calculated using the formula below:

$$\mathrm{SI} = \frac{\mathrm{Ap} + \mathrm{A}}{\mathrm{S} + \mathrm{A}} \times 100\%$$

Furthermore, the paper presents the following indices:

– The anthropophytisation index (AnI), showing the percentage of anthropophytes (A) in the total number of species found (S + A);

– The archaeophytisation index (ArI), expressed as the percentage of archaeophytes (Ar; species introduced or naturalised by humans before 1492) in the total number of species found (S + A);

– The kenophytisation index (KnI), which defines the percentage of kenophytes (Kn; species introduced or naturalised by humans after 1492) in the total number of species found (S + A);

– The modernisation index (MI), expressing the percentage of kenophytes (Kn) in the flora of permanently naturalised anthropophytes (Ar + Kn).

The nomenclature of plant species follows Mirek et al. [2020].

RESULTS AND DISCUSSION

Over the research period 1993–2022, a total of 111 weed species accompanying cereal crops were recorded (Table 1). The most numerous geographical-historical group was apophytes, represented by 47 species (42.7% of all species), followed by archaeophytes with 46 species (41.4%). Less numerous groups included kenophytes (11 species; 9.9%) and semi-synanthropic spontaneophytes (native species occurring in natural and anthropogenic habitats; 7 species; 6.3%). The similar proportions of archaeophytes and apophytes throughout the study period indicate strong synanthropisation and a relatively stable flora, with favourable conditions for both alien and native species. This pattern is typically associated with long-term cultivation and continuous agricultural use [Lososová et al. 2004, Balcerkiewicz and Pawlak 2010a, Storkey et al. 2012, Richner et al. 2015].

Table 1. List of plant species recorded in the study area and classified into geographical-historical groups

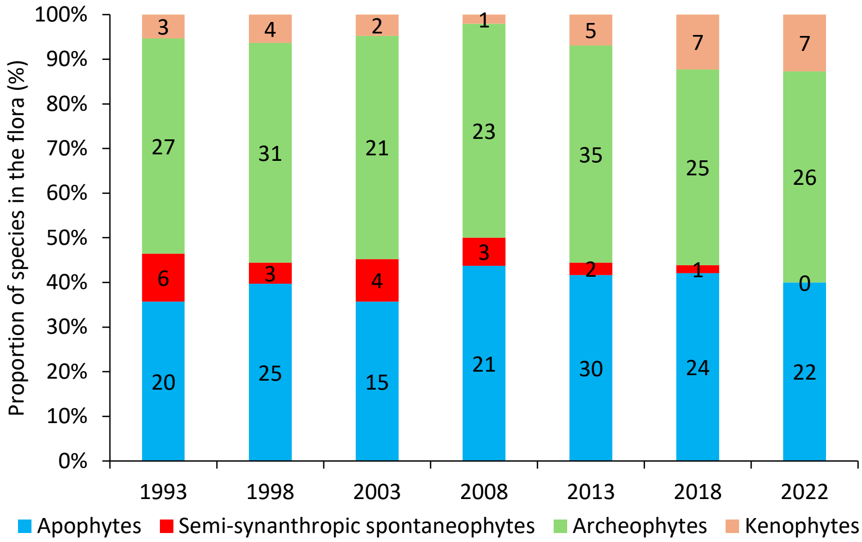
No	Species	Geographical-historical group*	Occurrence year
1	*Achillea millefolium* L. s.str.	Ap	1993, 1998, 2018
2	*Adonis aestivalis* L.	Ar	1993, 1998, 2013
3	*Aethusa cynapium* L.	Ar	1993, 1998, 2013–2022
4	*Agrostis capillaris* L.	Ap	2013
5	*Amaranthus retroflexus* L.	Kn	2018
6	*Anagallis arvensis* L.	Ar	1993, 1998, 2008–2022
7	*Anthriscus sylvestris* (L.) Hoffm.	Ap	2008
8	*Apera spica-venti* (L.) P. Beauv.	Ar	1993–2022
9	*Aphanes arvensis* L.	Ar	2013
10	*Arctium minus* (Hill) Bernh.	Ap	1998, 2003, 2018, 2022
11	*Arenaria serpyllifolia* L.	Ap	2008
12	*Artemisia vulgaris* L.	Ap	1998–2022
13	*Atriplex patula* L.	Ap	1993
14	*Avena fatua* L.	Ar	1993–2022
15	*Bromus secalinus* L.	Ar	2013–2022
16	*Campanula rapunculoides* L.	Ar	1993, 1998
17	*Capsella bursa-pastoris* (L.) Medik.	Ar	1993–2022
18	*Carduus crispus* L.	Ap	2018
19	*Centaurea cyanus* L.	Ar	1993–2022
20	*Chaenorhinum minus* (L.) Lange	Ap	2013–2018
21	*Chamomilla recutita* (L.) Rauschert	Ar	1993–2013, 2022
22	*Chenopodium album* L.	Ap	1993–2022
23	*Cichorium intybus* L.	Ar	2003
24	*Cirsium arvense* (L.) Scop.	Ap	1993–2022
25	*Consolida regalis* Gray	Ar	1993–2022
26	*Convolvulus arvensis* L.	Ap	1993–2022
27	*Dactylis glomerata* L.	Ap	1993, 2008–2022
28	*Daucus carota* L.	Ap	1998, 2013–2022
29	*Echinochloa crus-galli* (L.) P.Beauv.	Ar	2008–2022
30	*Elymus repens* (L.) Gould	Ap	1993–1998, 2008–2022
31	*Equisetum arvense* L.	Ap	2008, 2022
32	*Erigeron annuus* (L.) Pers.	Kn	2018, 2022
33	*Euphorbia exigua* L.	Ar	1993, 2008–2018

No	Species	Geographical-historical group*	Occurrence year
34	*Euphorbia helioscopia* L.	Ar	1993–2022
35	*Falcaria vulgaris* Bernh.	Ap	1993, 2008, 2018–2022
36	*Fallopia convolvulus* (L.) Á. Löve	Ar	1993–2022
37	*Fumaria officinalis* L.	Ar	2003, 2018
38	*Fumaria vaillantii* Loisel.	Ar	1993
39	*Galeopsis ladanum* L.	Ar	1993
40	*Galeopsis tetrahit* L.	Ap	1993–2022
41	*Galinsoga ciliata* (Raf.) S. F. Blake	Kn	1998–2003, 2013–2018
42	*Galinsoga parviflora* Cav.	Kn	1998, 2022
43	*Galium aparine* L.	Ap	1993–2022
44	*Galium mollugo* L. s.str.	Ap	1993, 2008
45	*Geranium dissectum* L.	Ar	1993, 2013
46	*Geranium pusillum* L.	Ar	1998, 2013, 2022
47	*Heracleum sphondylium* L. s.str.	Ap	2013
48	*Juncus bufonius* L.	Ap	2013
49	*Lactuca serriola* L.	Ar	1998, 2013–2022
50	*Lamium album* L.	Ar	2022
51	*Lamium amplexicaule* L.	Ar	1998, 2013
52	*Lamium purpureum* L.	Ar	1993–2003, 2013, 2022
53	*Lapsana communis* L. s.str.	Sp/Ap	1993–2003, 2013–2018
54	*Lathyrus tuberosus* L.	Ar	1993–2013
55	*Lithospermum arvense* L.	Ar	1993, 1998, 2008, 2013, 2022
56	*Lolium multiflorum* Lam.	Kn	1998, 2022
57	*Lolium perenne* L.	Ap	2008–2018
58	*Matricaria maritima* L. subsp. *inodora* (L.) Dostál	Ar	1993–2022
59	*Medicago lupulina* L.	Ap	1993–2013
60	*Melandrium album* (Mill.) Garcke	Ap	1993–2022
61	*Melandrium noctiflorum* (L.) Fr.	Ar	1993–1998
62	*Mentha arvensis* L.	Ap	1998, 2018, 2022
63	*Myosotis arvensis* (L.) Hill.	Ar	1993–2018
64	*Odontites serotine* (Lam.) Rchb. s.str.	Sp/Ap	1993–2013
65	*Oxalis fontana* Bunge	Kn	1993, 2003, 2013, 2018
66	*Papaver rhoeas* L.	Ar	1993–2013, 2022
67	*Phleum pratense* L.	Ap	1998–2022
68	*Pimpinella saxifraga* L.	Ap	2013, 2022
69	*Plantago intermedia* Gilib.	Ap	2013
70	*Plantago lanceolata* L.	Ap	2022
71	*Plantago major* L. s.str.	Ap	1998, 2013, 2018
72	*Poa annua* L.	Ap	2022
73	*Poa trivialis* L.	Sp/Ap	1993

No	Species	Geographical-historical group*	Occurrence year
74	*Polygonum aviculare* L.	Ap	1993–2022
75	*Polygonum hydropiper* L.	Ap	2013
76	*Polygonum lapathifolium* L. subsp. *pallidum* (With.) Fr.	Ap	1998–2018
77	*Polygonum persicaria* L.	Ap	1993, 2013, 2022
78	*Ranunculus repens* L.	Ap	1998
79	*Raphanus raphanistrum* L.	Ar	1998
80	*Rhinanthus serotinus* (Schönh.) Oborný	Sp/Ap	1993, 1998
81	*Rumex crispus* L.	Ap	2008, 2013
82	*Sedum maximum* (L.) Hoffm.	Sp/Ap	1993, 2008
83	*Setaria viridis* (L.) P.Beauv.	Ar	2013–2022
84	*Sherardia arvensis* L.	Ar	2013–2022
85	*Silene vulgaris* (Moench) Garcke	Ap	1998, 2003, 2013
86	*Sinapis arvensis* L.	Ar	1993–2022
87	*Solidago canadensis* L.	Kn	2022
88	*Solidago gigantea* Aiton	Kn	2013
89	*Sonchus arvensis* L.	Ap	1993–2003, 2013–2022
90	*Sonchus asper* (L.) Hill	Ar	1998, 2018
91	*Stachys palustris* L.	Sp/Ap	1993, 2003
92	*Stellaria media* (L.) Vill.	Ap	1993, 1998, 2013, 2018
93	*Symphytum officinale* L.	Sp/Ap	2003
94	*Taraxacum officinale* F.H. Wigg.	Ap	1993–2022
95	*Thlaspi arvense* L.	Ar	1998–2013, 2022
96	*Trifolium arvense* L.	Ap	1993
97	*Trifolium aureum* Pollich	Ap	2013
98	*Trifolium pratense* L.	Ap	1998
99	*Trifolium repens* L.	Ap	1993, 1998, 2008
100	*Tussilago farfara* L.	Ap	1998
101	*Valerianella dentata* (L.) Pollich	Ar	1998, 2018
102	*Veronica agrestis* L.	Ar	1993, 2013, 2018
103	*Veronica arvensis* L.	Ar	2003–2013, 2022
104	*Veronica persica* Poir.	Kn	1993, 1998, 2008–2022
105	*Vicia angustifolia* L.	Ar	1993–2013
106	*Vicia dasycarpa* Ten.	Kn	1993, 2013–2018
107	*Vicia grandiflora* Scop.	Kn	2022
108	*Vicia hirsuta* (L.) Gray	Ar	1998–2022
109	*Vicia tetrasperma* (L.) Schreb.	Ar	1998–2022
110	*Vicia villosa* Roth	Ar	2018
111	*Viola arvensis* Murray	Ar	1993, 1998, 2008–2022

* Ap – apophytes, Ar – archaeophytes, Kn – kenophytes, Sp/Ap – semi-synanthropic spontaneophytes

Figure 1. Proportions of geographical-historical groups in the segetal flora of the study area in selected years between 1993 and 2022

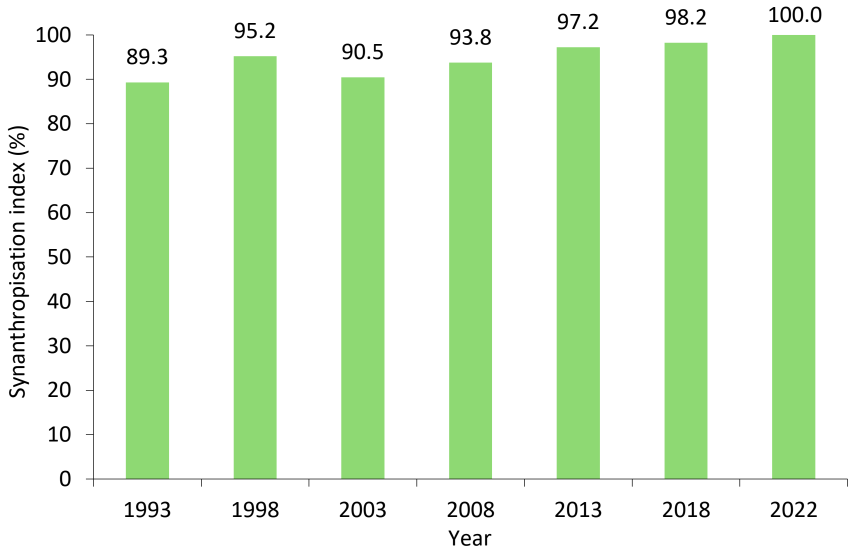


The proportion of apophytes during 1993–2022 showed only minor fluctuations and accounted for 35–45% of the recorded species (i.e. 15–30 species). However, in all years of the study, archaeophytes constituted the dominant group. These species are characteristic of agricultural landscapes but are also the most vulnerable to extinction as a result of the intensification of agricultural production. The proportion of archaeophytes in the flora of the research area ranged between 45–50%. The second group of alien species recorded in the study area comprised kenophytes. Both their total number and their proportional contribution to the investigated flora increased steadily over time. In the first year of the study, only three kenophyte species were recorded, representing 5.4% of all species. By the final year of the study, this number had increased to seven species, and their proportion in the flora reached 12.7%. Semi-synanthropic spontaneophytes constituted the least numerous geographical-historical group. In contrast to kenophytes, both the number of species and their proportional contribution to the flora declined steadily over time. In 1993, six species were recorded, whereas by 2018 only a single species remained, and in 2022 no representatives of this group were observed. The increasing proportion of kenophytes indicates a progressing synanthropisation of the flora, while the disappearance of semi-synanthropic spontaneophytes results primarily from their sporadic and incidental occurrence in segetal plant communities. The changes observed in the present study are consistent with trends reported for Europe, where agricultural homogenisation favours neophytes (including kenophytes) while limiting the occurrence of archaeophytes and native species. Large-scale analyses of arable fields across Central Europe have demonstrated a systematic increase in the proportion of neophytes, accompanied by a stable or declining proportion of archaeophytes and native taxa [Glaser et al. 2024, Colling et al. 2025]. Comparable shifts in the structure of segetal floras along gradients of agricultural land use were also documented by Lososová et al. [2004]. Under Polish conditions, studies have shown that spontaneophytes constitute a decreasing and often subordinate component of segetal communities [Balcerkiewicz and Pawlak 2010b], while archaeophytes are particularly vulnerable to extinction, mainly due to increased herbicide use, certified seed material and simplified crop rotations [Haliniarz and Kapeluszny 2014, Skrajna 2021]. In the study area, archaeophytes are predominantly calciphilous species with narrow ecological amplitudes. The disappearance of species recorded in the early years of the study, such as *Adonis aestivalis*, *Campanula rapunculoides* or *Fumaria vaillantii*, results in a substantial loss of overall biodiversity [cf. Gala-Czekaj et al. 2024]. The concurrent increase in the number of kenophytes observed in the present study is characteristic of the long-term accumulation of alien species, whose spread is closely linked to continuous propagule pressure and frequent disturbances in agroecosystems [Tokarska-Guzik 2005]. In the research area, this group also comprises invasive species, including *Solidago canadensis* and *Solidago gigantea* [cf. Gala-Czekaj et al. 2024].

The distinguished geographical-historical categories were used to assess the direction and intensity of changes in the arable flora during the study period (Figures 2–6). The flora synanthropisation index (SI), quantifying the proportion of apophytes and anthropophytes, ranged from 89.3% in the first year of the study to 100% in the last year (Figure 2). The obtained values of the synanthropisation index indicate a pronounced degree of anthropogenic transformation of the flora, confirming ongoing synanthropisation processes and an increasing proportion of species associated with anthropogenic environments.

Studies conducted previously in the Western Outer Carpathians demonstrated that the proportion of synanthropic species in segetal flora is highly variable and strongly dependent on habitat location, particularly altitude and slope exposure, which determine the agricultural suitability of sites. Dąbkowska and Grabowska-Orządała [2011] showed that synanthropic species often dominated weed communities even under unfavourable farming conditions, reflecting an advanced level of synanthropisation of cereal-crop habitats despite reduced management intensity. More detailed studies from the Beskid Wyspowy Mountains, conducted in ecological and extensive conventional cereal crops, revealed consistently high values of the synanthropisation index (85–88%), pointing to a pronounced anthropogenic transformation of the segetal flora and only limited differentiation between farming systems [Dąbkowska and Sygulska 2013].

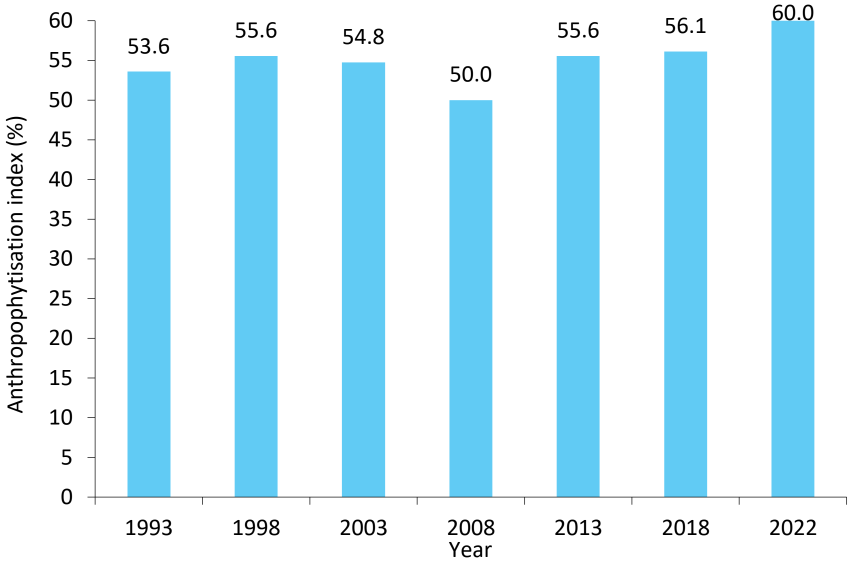
Figure 2. The synanthropisation index of flora in the study area in selected years between 1993 and 2022



In our research, carried out in conventional cereal crops, the synanthropisation index remained very high (90–100%), suggesting a further strengthening and persistence of anthropogenic pressure on weed communities. These findings are consistent with the synthesis by Jackowiak [2023], who showed that in strongly transformed habitats, including segetal vegetation, apophytic and anthropophytic species form a major part of the flora and effectively reflect human-driven changes.

The dynamics of the anthropophytisation index (AnI), reflecting the proportion of alien species (archaeophytes and kenophytes) in the studied flora, clearly illustrate the direction of changes occurring in the segetal communities of the research area (Figure 3).

Figure 3. The anthropophytisation index of flora in the study area in selected years between 1993 and 2022



Throughout the period 1993–2022, the values of this index remained high, ranging from 50.0 to 60.0%, indicating that more than half of the species recorded in the arable habitats of the study area were of alien origin, introduced or established through human activity. This confirms a very high level of anthropophytisation and a strong agricultural transformation of plant communities. Moreover, the proportion of anthropophytes showed a slight but consistent increase over time, pointing to a gradual decline of native species and an increasing dominance of alien, mainly segetal taxa. The consistently high values of the anthropophytisation index demonstrate that alien species constitute a structurally important and persistent component of the segetal flora in the studied area. Similar values were reported for segetal communities across Poland (19 associations; various regions), where anthropophytes constituted 32–66% of the total species pool [Balcerkiewicz and Pawlak 2010a]. In contrast, Bomanowska [2006] analysing the flora of arable fields in Kampinos National Park (central Poland), reported the predominance of native species (67.2%) over aliens (32.8%). However, the segetal flora of the study area may be influenced by the immediate proximity of semi-natural and natural phytocoenoses adjacent to the fields. In areas with unfavourable farming conditions, native apophytes also dominated over anthropophytes, indicating a lower degree of anthropophytisation [Dąbkowska and Grabowska-Orządała 2011]. A comparable pattern was reported from the Beskid Wyspowy Mountains, where the anthropophytisation index ranged from 27 to 39% [Dąbkowska and Sygulska 2013]. This is confirmed by Skrajna [2021], who compared the flora of cereal crop agrocenoses of the Kałuszyn Upland (eastern Poland) during a study period similar to that of the present study (1996–2021) and showed that apophytes (61.4%) prevailed over anthropophytes (38.6%). At the European scale, intensively managed agroecosystems are characterised by high proportions of alien weeds (>40–50%), whereas mountainous or extensively farmed landscapes exhibit markedly lower levels of anthropophytisation, highlighting the key role of land-use intensity [Lososová et al. 2006, Fried et al. 2008].

To assess the further trends in the flora of the study area under human influence, the contributions of anthropophyte groups, namely archaeophytes (Figure 4) and kenophytes (Figure 5), were analysed. Throughout the study period, the archaeophytisation index (ArI) of the flora remained consistently high, ranging from 43.9% to 50.0%, indicating a substantial and stable contribution of archaeophytes to the composition of the investigated communities.

Figure 4. The archaeophytisation index of flora in the study area in selected years between 1993 and 2022

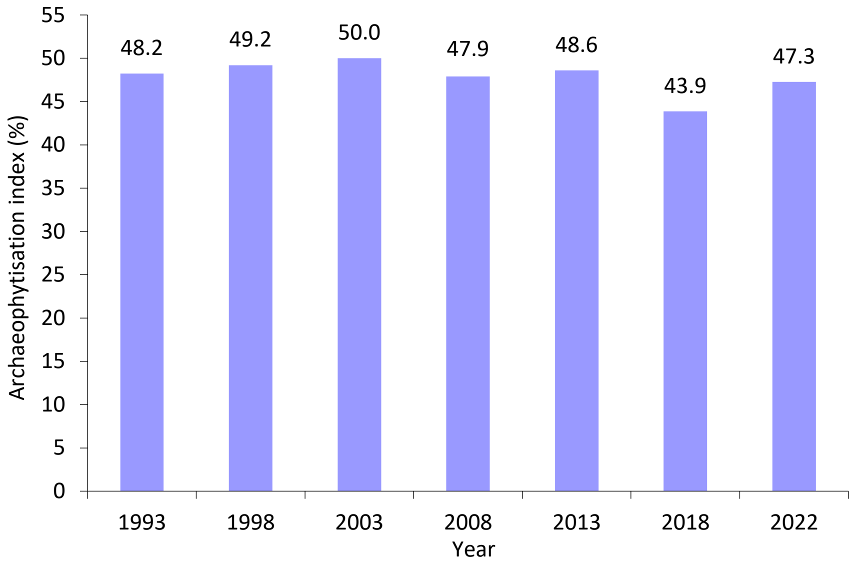
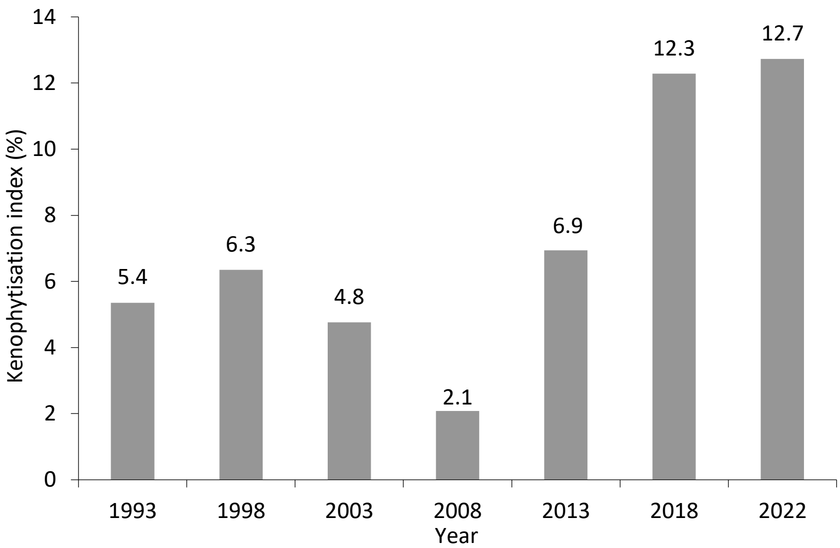


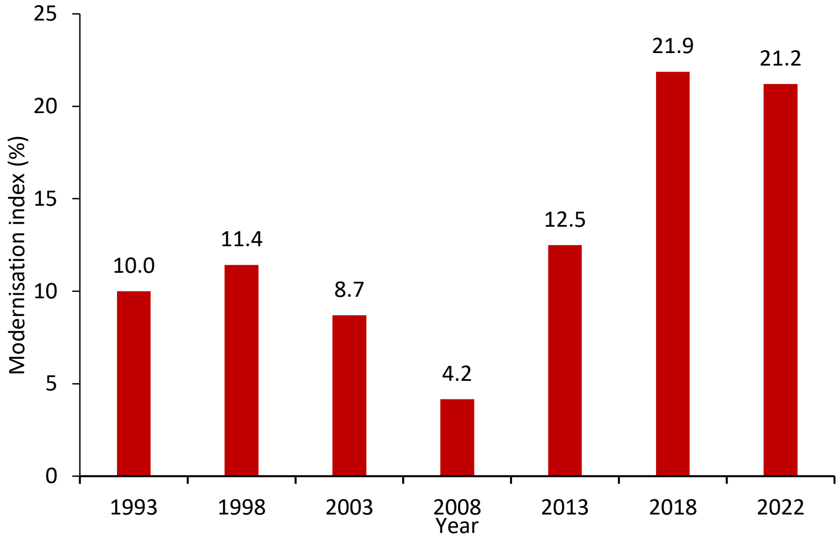
Figure 5. The kenophytisation index of flora in the study area in selected years between 1993 and 2022



The proportion of archaeophytes in the present study was higher than that reported from many regions of Poland, indicating their particularly strong and long-term integration into the segetal flora of the study area, while remaining consistent with general patterns described for Poland and Central Europe [Lososová et al. 2004, Balcerkiewicz and Pawlak 2010a]. For instance, in Central Poland archaeophytes constituted 19.6% of the segetal flora according to Bomanowska [2006], and 24.4% according to Warcholińska [2004]. Similarly, in the agrocenoses of the Mińsk Protected Landscape Area (central-eastern Poland), the archaeophytisation index reached 25.9% [Skrajna and Bogusz 2019]. In less intensive habitats, such as the Beskid Wyspowy Mountains, they accounted for 23–33% of the cereal-crop flora and remained relatively stable under extensive management [Dąbkowska and Sygulska 2013]. In the Kałuszyn Upland, archaeophytes accounted for 32.5% of the cereal-field flora, showing long-term integration into local weed communities despite less favourable agricultural conditions than in the present study sites [Skrajna 2021]. Their decline in cover over recent decades, despite a stable floristic proportion, mirrors long-term European trends of arable weed loss driven by intensification and habitat homogenisation [Storkey et al. 2012, Richner et al. 2015, Glaser et al. 2024, Colling et al. 2025]. This pattern highlights archaeophytes as a sensitive and diagnostic component of segetal flora, reflecting changes in land-use practices [Sutcliffe et al. 2015, Jackowiak 2023].

The proportion of kenophytes in the flora of the study area increased steadily, reflected in a more than twofold rise in the kenophytisation index (KnI) – from 5.4% in 1993 to 12.7% in 2022 (Figure 5). At the same time, a marked increase in the modernisation index (MI) was observed, rising from approximately 10% at the beginning of the study period to over 20% in 2022 (Figure 6), indicating a "rejuvenation" of the alien component of the flora in the study area.

Figure 6. The modernisation index of flora in the study area in selected years between 1993 and 2022



The results of the present study align with Balcerkiewicz and Pawlak [2010a], who reported that kenophytes, though a relatively minor component of Poland's segetal flora compared to archaeophytes, show a clear increasing trend, especially in communities strongly altered by intensive agriculture. In habitats with lower agricultural suitability, for example in mountainous areas, the flora modernisation index reached 10–15%, indicating a relatively advanced level of floristic change despite natural limitations to crop production [Dąbkowska and Grabowska-Orządała 2011]. Additionally, even in extensive cereal-crop systems of the Beskid Wyspowy Mountains, the kenophytisation index ranged from 7 to 11% and the modernisation index reached 12–18% [Dąbkowska and Sygulska 2013]. Bomanowska [2006] recorded a proportion of 7.4% kenophytes in the segetal flora of Kampinos National Park, suggesting that human influence on the flora can remain substantial even in less productive areas. Overall, these findings highlight the persistence of human-driven pressure on weed communities, regardless of natural constraints on crop production, and are consistent with broader European trends, where the increasing proportion of kenophytes is regarded as a key indicator of arable-flora modernisation, particularly in landscapes subjected to long-term agricultural intensification [Lososová et al. 2006, Fried et al. 2008, Storkey et al. 2012, Richner et al. 2015].

SUMMARY

This study on the transformation of field flora under anthropogenic influences over the period 1993–2022 led to the following findings and conclusions:

1. The flora of the study area exhibits a considerable degree of anthropogenic transformation, as indicated by the high and steadily increasing value of the flora synanthropisation index during the research period.

2. Throughout 1993–2022, alien species predominated over native species in the weed communities of the investigated crops. The proportion of anthropophytes increased slightly over the study period, as reflected by the rising value of the anthropophytisation index.

3. The archaeophytisation index confirms the close association between the flora and agricultural activity, evidenced by the slightly decreasing proportion of weeds permanently associated with cultivated fields, i.e. archaeophytes.

4. The doubling of the kenophytisation and modernisation indices during the study period points to a marked intensification of synanthropisation processes.

5. The results highlight the importance of continuing research on anthropogenic transformations of the field flora in the study area to monitor the responses of individual species and weed groups to agricultural intensification.

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Source of funding: This work did not receive any external funding.

Authors' contributions: D.G.-C. – conceptualisation, methodology, conducting the research, writing and review of the manuscript; T.D. – conceptualisation, methodology, conducting the research, review of the manuscript; T.Ł. – conceptualisation, methodology, conducting the research.

Received: 30.01.2026
Accepted: 1.07.2026
Online first: 18.08.2026

Citation: Gala-Czekaj D., Dąbkowska T., Łabza T., 2026. Changes in segetal flora in a selected habitat of southern Poland from 1993 to 2022. Part 2. Anthropogenic transformations. Agron. Sci., online first, 1–13. https://doi.org/10.24326/as.2026.5662