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Incidence of thermophilic, grass and rare arable weeds in cereal fields in the Czech and Slovak Republic

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Abstract: Our objectives were to characterise arable weeds of the Czech and Slovak Republic in cereals, especially considering important groups of species: thermophilic, weedy grasses, and rare and endangered species. The three-year phytocoenological survey was conducted from 2006 to 2008 in five climatic regions and eight different soil types. 379 relevés were recorded, and 281 weed species were found. The effects of both the climatic region and soil type were found to be statistically significant. Species richness increased with altitude. Several species were distinctly associated with soil type, from fertile chernozems to less fertile cambisols, while fluvisols were strongly associated with e.g. *Calystegia sepium* (L.) R. Br. The incidence of species outside their expected regions generally fit two categories: the most pervasive weeds found almost in all climate regions, such as *Echinochloa crus-galli* (L.) P. Beauv., or rare weeds in higher altitudes than expected, such as *Lolium temulentum* L. Rare and endangered species were more likely to be found in a colder climate and poorer soils, and this is linked to less intensive management; however, not all endangered arable species can tolerate such conditions. Even though this data is not recently collected, this is still valuable information on the distribution of weedy species, especially concerning the current interest in maintaining biodiversity.

Keywords: agrobiodiversity; weed vegetation; soil type; climate regions; endangered species

The two currently independent countries – the Czech Republic and Slovak Republic – have a common historical development. During the period of shared national identity from 1918–1992, agriculture completely changed and the agricultural policy of one state largely unified conditions throughout the whole country (Krejčí and Machonin 1996). In the second half of the century, there was violent collectivisation, large-scale socialist management and further intensification of agriculture especially resulting in the existence of large farms with large areas of land, narrow crop rotations, high doses of mineral fertilisers and the broad application of herbicides (Grešlová-Kušková 2013, Pinke 2020). The introduction of a new political market economy regime after 1989 combined with private property restitution, privatisation of state property and transformation of agricultural cooperatives (Kanianska et al. 2014).

Of course, these changes also affected weed communities and diversity. Intensive farming in large

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areas has reduced weed species richness, with many species drastically declined or even vanished – especially habitat specialists (Kropáč 2006, Richner et al. 2015). The composition of predominant weed taxa has changed in favour of herbicide-tolerant species and species easily adaptable to the conditions of the applied farming regime (Lososová et al. 2008). Widespread and uniform use of some products has increased the incidence of herbicide resistance (Hamouzová et al. 2011), and the distribution of potentially resistant species has been found throughout the Czech arable landscape (Kolářová et al. 2023). Meanwhile, the expanding body of work on weed ecology has improved our understanding of the role of diversified and rare species. Since the regime change in 1989, there have been expanding market opportunities for organic farming and other low-input systems (Richner et al. 2015).

Cereals have long been one of the most important field crops in the Czech and Slovak Republics (Grešlová-Kušková 2013), with 54.3% and 58.4% share of arable land, respectively (CZSO 2021, SOSR 2021). Cereal production and management practices determine weed composition and density (Storkey et al. 2012). As winter cereals occupy a large part of the cereal area each year, this tends to favour annual, over-wintering and early spring weed species. Grass weeds are particularly difficult to control in cereal crops, and herbicide resistance is often detected (Hamouzová et al. 2011). Although they represent a relatively small group of species, weedy grasses can have a significant impact to yield. Some grass weeds may fair even better under future climate scenarios. In one example, a shift from snow to rain in late winter could simplify the range expansion of *Bromus tectorum* L. (Concilio et al. 2013). Other thermophilic, late-emerging and other opportunistic weeds have become more abundant in some cropping systems, expectedly due to climatic shifts (Peters et al. 2014). The results of Hyvönen et al. (2012) suggest that even under moderate climate scenarios, drastic changes in the weed establishment risk can be expected to take place, a species gain in northern parts of Europe and a species loss in southern parts in future.

Monitoring the diversity and structure of weediness is, therefore, an important task for recognising changes in weed vegetation. After the division of former Czechoslovakia into independent countries, such surveys and analyses only take place individually, e.g., Májeková et al. (2019) and Tyšer et al. (2021). Therefore, the combined dataset of weed diversity in cereal crops undertaken in the same years and under the same methodology is a unique opportunity to observe spatial trends of weeds in the largest group of crops across the landscape.

The main objectives of our article were (1) to evaluate the occurrence of thermophilic species in different climate regions; (2) to describe the distribution of weedy grasses that are difficult to manage in cereals; and (3) to report the incidence of rare and endangered species, all within the representative relevés across the Czech and Slovak Republic.

MATERIAL AND METHODS

Study area. The three-year phytocoenological survey was conducted in the Czech Republic and Slovak Republic from 2006 to 2008, sampling cereal fields throughout both countries. The national agricultural characteristics of both countries during the survey years are shown in Table 1. Together, the land of both countries is 127 905 km^2 (78 871 and 49 034 km^2 Czech and Slovak Republics, respectively), with the proportion of both countries under crops each year near 70%. Of the arable land, over 50% is under cereals each year; therefore, weeds in cereals represent a significant portion of the arable weed flora in the landscape.

Data collection. Cereal fields, representative of the area, were sampled containing any of the following crops: winter wheat (*Triticum aestivum* L.), winter barley (*Hordeum vulgare* L.), rye (*Secale cereale* L.), spelt (*Triticum aestivum Spelta Group*), triticale (× *Triticosecale rimpaui* A. Camus), spring barley (*Hordeum vulgare*), oat (*Avena sativa* L.) and spring wheat (*Triticum aestivum*). At each site, one phytosociological relevé of a standard size 100 m^2 (10 × 10 m, or in small fields 50 m^2, i.e., 5 × 10) was recorded in the field's core to avoid the edge effects. The species cover was assessed using the nine-degree Braun-Blanquet cover-abundance scale. Nomenclature followed by Kaplan et al. (2019). Monitoring was performed in fully developed vegetation in June and July. Each relevé was assigned by GPS coordinates, corresponding altitude, climate region and soil type. The altitude ranged between 101–700 m a.s.l., representing the important agricultural regions in both countries. The distribution of fields in different altitude levels can be categorised as such: 122 relevés (63 and 59 in Czechia and Slovakia, respectively) represented planar level (up to 200 m a.s.l.), 123 (77 and 46 in Czechia and Slovakia, respectively) represented

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Table 1. Agricultural characteristics of the Czech Republic and Slovak Republic (CZSO 2009, SOSR 2009)

	Czech Republic			Slovak Republic		
	2006	2007	2008	2006	2007	2008
Agricultural land (thousand ha)	3 565.98	3 596.72	3 571.59	1 939.28	1 930.57	1 936.94
Arable land (thousand ha)	2 628.76	2 618.11	2 592.15	1 344.08	1 342.81	1 349.31
Arable/agricultural land (%)	73.72	72.79	72.58	69.31	69.55	69.66
Cereals (%)	58.09	59.63	59.90	55.05	58.66	59.10
Fodder crops (%)	17.47	16.37	15.67	18.27	17.84	17.97
Root crops (%)	3.50	3.34	3.13	3.57	2.87	1.95
Nitrogenous fertilisers (kg N/ha a. l.)	74.10	77.60	82.21	43.70	49.30	48.10
Phosphatic fertilisers (kg P/ha a. l.)	6.56	7.17	7.43	4.14	4.88	4.44
Potassic fertiliSers (kg K/ha)	8.22	8.88	9.45	7.55	8.05	8.05
Herbicides (kg, L/ha)	1.37	1.50	1.89	1.12	1.16	1.03
Yield of cereals (t/ha)	4.17	4.53	5.37	4.00	3.56	5.18

a. l. – agricultural land

colinne level (201–400 m a.s.l.) and 134 (55 and 79 in Czechia and Slovakia, respectively) represented submontane level (401–700 m a.s.l.). The surveyed area covered five climatic regions: very warm, warm, moderate-warm, moderate-cold and cold, with mean annual temperatures of 9–10, 8–9, 6–8, 5–6 and < 5, respectively. Obtained relevés were recorded on eight different soil types: cambisols, fluvisols, chernozems, leptosols, luvisols, phaeozems, regosols and stagnosols. Due to the uneven distribution of relevés in individual soil types, only four soil types which each had more than 40 relevés in the group, were included in analyses (cambisols, fluvisols, chernozems and luvisols). A special focus was paid to thermophilic weed species and grass weeds relative to climate regions. Ellenberg values indicated thermophilic species for temperature (a scale from 1 to 9, in which higher values indicate requirements for higher temperature). As thermophilic species, we regarded those having values over 7, which relate to heat indicators (Chytrý et al. 2018). In total, 42 species had an Ellenberg value of 7 and three had an Ellenberg value of 8. Altogether, 30 species from the Poaceae family were recorded, of which 19 can be treated as weedy grasses, while the others were volunteer crops.

Additionally, all identified species were compared with the Red List of vascular plants of the Czech Republic (Grulich and Chobot 2017) and the Red List of ferns and vascular plants of the flora of Slovakia (Eliáš et al. 2015).

Statistical analysis. The species occurrence in different soil types and climate regions was analysed using multivariate analysis in CANOCO 5 software (ter Braak and Šmilauer 2018). The cover values based on the Braun-Blanquet scale were subsequently transformed to an ordinal scale (van der Maarel 1979). First, detrended correspondence analysis (DCA) was performed with detrending by segments. Due to long gradients on the first canonical axis (3.7 SD units) in the compositional turnover, a unimodal method, the canonical correspondence analysis (CCA), was used. The net effects of two explanatory variables, soil type and climate region on weed species occurrence were determined in the CCA. The net effect was tested using partial CCA (pCCA) and was obtained after the exclusion of the effect shared with another tested variable (which was used as a covariable). A certain canonical eigenvalue ratio to the sum of all eigenvalues (total inertia) was used to estimate the proportion of the explained variation (Borcard et al. 1992). The effects were evaluated using Monte Carlo permutation tests for the first canonical axis (999 permutations were used).

RESULTS

In total, 379 relevés were recorded in cereals (195 in Czechia and 184 in Slovakia), and 281 weed species were found (Figure 1).

Species richness increased with altitude (Figure 2). The mean number of species per relevé in the planar, colinne and submontane levels was 14.43, 19.12 and 26.98, respectively.

The net effects of both studied variables, climate region and soil type, were found to be statistically

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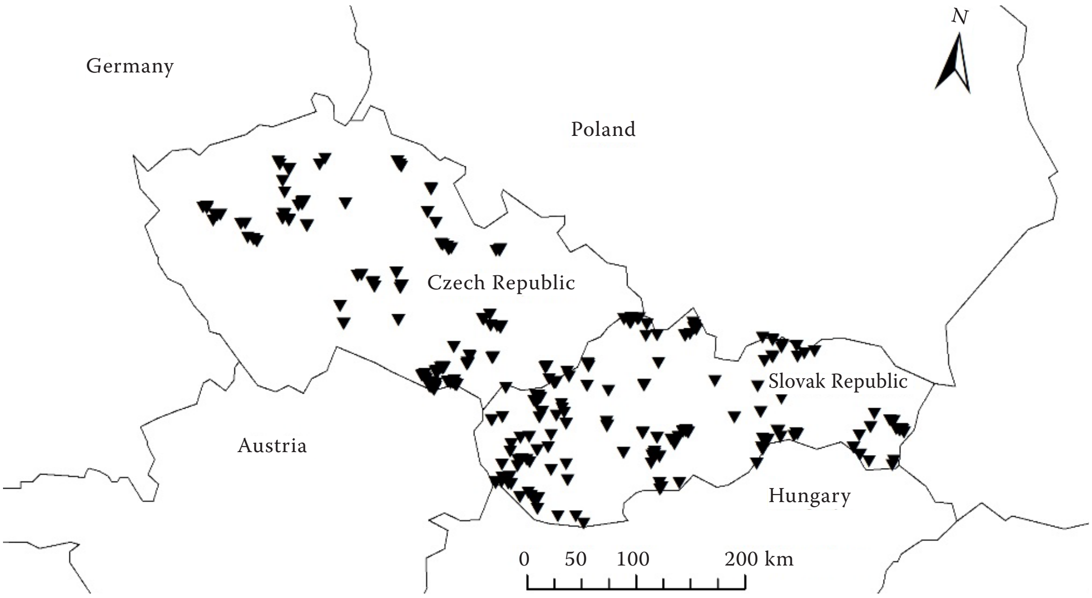

Figure 1. Map of the Czech Republic and Slovak Republic with recorded relevés

significant. Soil type counted for 3.01% of species data variability (P = 0.001, F = 2.8), while climate region explained 3.42% of the total variation (P = 0.001, F = 1.8).

The occurrence of weed species on different soil types is displayed in the CCA diagram (Figure 3), which singled out individual characteristic weed species. There was a distinct line from fertile chernozems to less fertile cambisols. Species such as *Hyoscyamus niger* L., *Mercurialis annua* L., *Datura stramonium* L., *Stachys annua* (L.) L., or *Consolida hispanica* (Costa) Greuter et Burdet were connected with the chernozem soil type. Species occurring on cambisols were *Scleranthus annuus* L., *Anthemis arvensis* L., *Gnaphalium uliginosum* L. Only a few species seemed typical of luvisols: *Chenopodium polyspermum* L., *Galium aparine* L. and *Vicia hirsuta* (L.) Gray. Species *Calystegia sepium* (L.) R. Br., *Rumex stenophyllus* Ledeb. or *Mentha longifolia* (L.) Huds. were found to be characteristic of fluvisols.

The occurrence of thermophilic weed species indicated by Ellenberg indicator values 7 and 8 (Chytrý et al. 2018) for temperature in different climate regions is displayed in the CCA diagram (Figure 4). The warm and moderately warm regions overlap in the diagram, meaning that species occurrence in both regions can be regarded as the same. The ordination diagram shows that while many thermophilic species were mainly found in warm regions, as expected, several were also found in much cooler regions. *Lolium temulentum* L. was found explicitly in the cold region (four occurrences), and other species were found only in the moderate-cold region, like *Euphorbia virgata* Waldst. et Kit., *Anethum graveolens* L., *Falcaria vulgaris* Bernh. and *Muscari comosum* (L.) Mill. While not exclusive, *Fumaria schleicheri* Soy.-Will. occurred predominantly in the cold region.

Of all the species found, only three species had an Ellenberg value of 8. While *Diplotaxis muralis* (L.) DC. and *Portulaca oleracea* L. were found mostly in the moderate-warm and very-warm regions, respectively, and *Cerastium pumilum* Curtis was only found in the moderate-cold region.

Also interesting are the species which create the central cloud and were not as strongly connected to

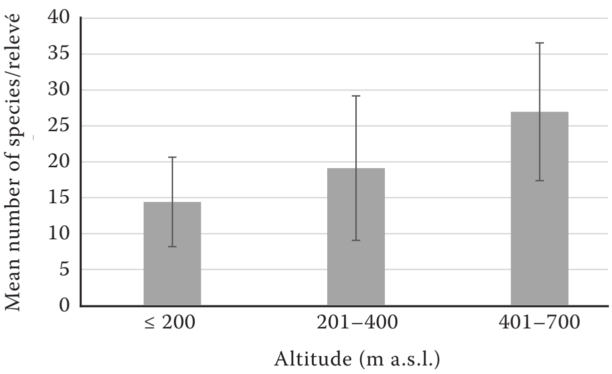

Figure 2. Number of species in different altitudes in the Czech Republic and Slovak Republic (error bars represent standard deviations of the means)

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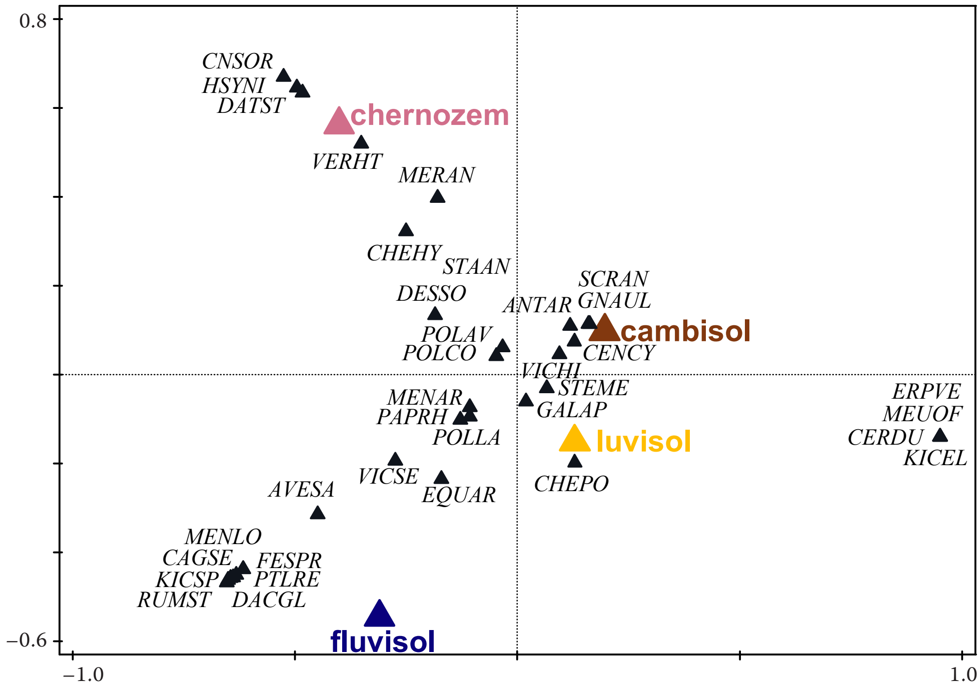

Figure 3. Ordination diagram partial canonical correspondence analysis (pCCA) showing distribution of weed species in different soil types. Minimum fit of displayed species is 3% (35 species of 281). Species are marked according to EPPO Codes (EPPO 2020)

a particular region. These thermophilic species are still prevalent in warm regions but are found in cooler regions as well. Of note are certainly *Amaranthus retroflexus* L. and *Datura stramonium*, as well as some grasses, which will be looked at more closely next.

Occurrences of grass weed species indicated in different climate regions are displayed in the CCA diagram (Figure 5). Overall, there is a clear distinction between the very warm and cold regions with associated species which is expected. The very warm climatic region was characterised by the occurrence of thermophilic grasses: *Panicum milliaceum* L., *Setaria viridis* (L.) P. Beauv. subsp. *viridis* and *Sclerochloa dura* (L.) P. Beauv. Meanwhile, the cold climate region was associated with species like *Holcus mollis* L., *Deschampsia cespitosa* (L.) P. Beauv., *Agrostis gigantea* Roth and *Lolium temulentum*. *Bromus secalinus* L. subsp. *secalinus* also occurred in the cold and moderate-cold regions.

Some grasses were found in all climatic regions: *Apera spica-venti* (L.) P. Beauv., *Avena fatua* L., *Elymus repens* (L.) Gould and *Poa annua* L. and the thermophilic grass, *Echinochloa crus-galli* (L.) P. Beauv., occurred in all climate regions except cold.

On the monitored fields, in total, 29 species were found in both countries from the Red List of vascular plants of the Czech Republic (26 species) and on the Red List of ferns and vascular plants of the flora of Slovakia (17 species) (Table 2). Two species occurred only in the Czech Republic (*Hyoscyamus niger*, *Odontites vernus* (Bellardi) Dumort.), while 11 species were found just in Slovakia (*Agrostemma githago* L., *Anagallis foemina* Mill., *Bromus secalinus* subsp. *secalinus*, *Cerastium dubium* (Bastard) Guépin, *Euphorbia virgata* Waldst. et Kit., *Kickxia elatine* (L.) Dumort., *Kickxia spuria* (L.) Dumort., *Lolium temulentum*, *Rumex stenophyllus*, *Veronica triloba* (Opiz) Opiz, *Veronica triphyllos* L.).

DISCUSSION

Richness related to elevation. While higher species richness in agriculture fields at increasing altitudes has been reported previously (Fried et al. 2008), the contributing factors can be put into two broad categories: natural environment and agricultural character. Initially, higher altitudes create some environmental limitations for plants, including cooler temperatures, less sunny days, shorter seasons, and poorer, more weathered soils. Therefore, more tolerant and specialised plants survive.

Additionally, the agricultural character related to altitude must be considered. Collectivisation merged

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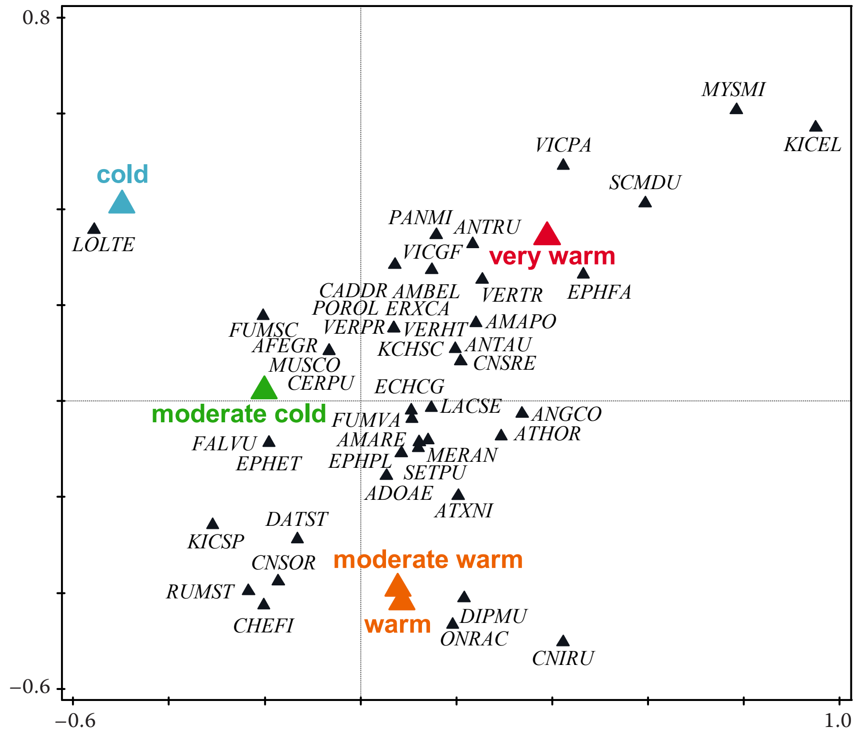

Figure 4. Ordination diagram partial canonical correspondence analysis (pCCA) showing distribution of thermophilic species in different climate regions. Species are marked according to EPPO Codes (EPPO 2020)

small plots of land managed by individual farmers into large blocks managed by large cooperatives, reducing the former mosaic of arable land and grasslands (Kanianska et al. 2014), especially in fertile lowlands. Meanwhile, traditional methods and more diverse landscapes persisted on steep terrain, which was not accessible to heavy mechanisation, and, therefore, often survived collectivisation (Pinke 2020). Still today, commercial agriculture favours the cultivation of large areas in fertile lowlands, leaving smaller and diverse holdings in increasing altitudes. Thereby, increasing altitude and diverse landscapes also favour species diversity (Roschewitz et al. 2005). However, not all red-list species can retreat to higher altitudes, as a recent example of *S. annua* illustrates. Once a prominent species of the Carpathian Basin in alkaline stubble fields, Pinke (2021) has described the retreat of this species and the subsequent decline of dependent bee populations. In our study area, this species, as well as *Hyoscyamus niger* and *Veronica triloba* were associated with the fertile chernozem soils, which are vulnerable to further agriculture intensification.

Species association to soil types. Soil types are somewhat related to altitude but can be more revealing for species assembly due to specific properties, such as fertility and drainage. A distinct species transition is observed along fertility from chernozems to cambisols. Chernozems are slightly calcareous soils of loess cover in lowlands. In our results, species such as *Hyoscyamus niger*, *Mercurialis annua*, *Stachys annua*, *Consolida hispanica* are related to chernozems, confirming Kühn (1967). Cambisols are typical soils of hilly areas and lower to middle highlands. Kühn (1967) also confirms the cambisol affiliation to the species *Scleranthus annuus*, *Anthemis arvensis*, *Gnaphalium uliginosum*. Kropáč (2006) states that *Veronica triloba*, *Stachys annua* and *Consolida hispanica* are characteristic of chernozem communities, while *Scleranthus annuus* and *Anthemis arvensis* are frequent species of cambisol communities. Cimalová and Lososová (2009) also confirm the inclination of *Anthemis arvensis* to cambisols.

Cereal weed communities differ between warmer, drier lowland areas (often base-rich; *Caucalidion* alliance) and cooler, wetter, mid-elevation areas (often acidic; *Scleranthion annui* alliance) (Chytrý 2017). Soil pH, highly correlated to soil calcium, is an important variable affecting weed vegetation (Lososová et al. 2006). These dynamics can also be

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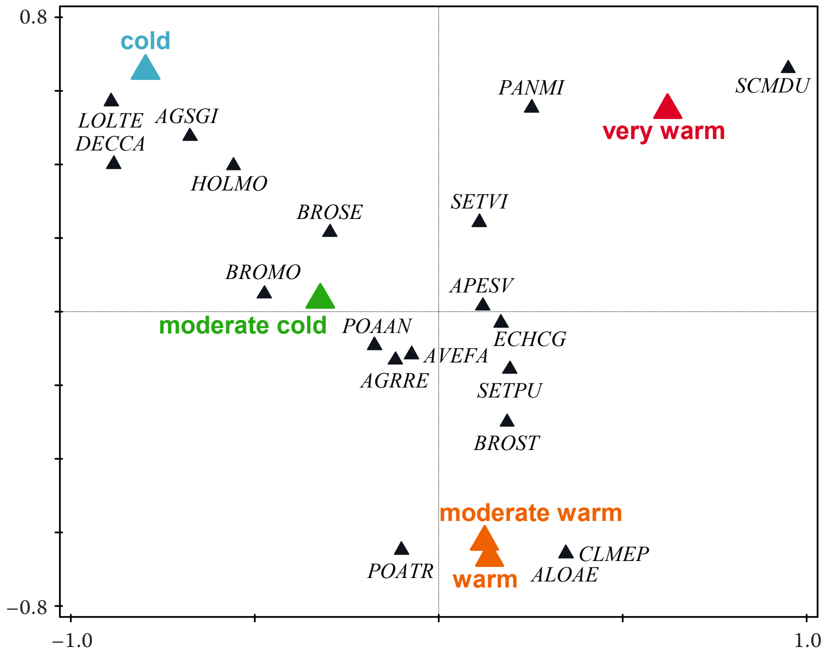

Figure 5. Ordination diagram partial canonical correspondence analysis (pCCA) showing distribution of grass weed species in different climate regions. Species are marked according to EPPO Codes (EPPO 2020)

clearly seen in our data (Figure 3). The species found in the chernozem sector were species with Ellenberg values for pH 7-8 (Chytrý et al. 2018), while the species found on cambisols usually had Ellenberg values of 4–6. The group of species in the central sector of the ordination diagram were not exclusively found in

Table 2. Species found which are included on the Red List of vascular plants of the Czech Republic (Grulich and Chobot 2017) and on the Red List of ferns and vascular plants of the flora of Slovakia (Eliáš et al. 2015)

Species	Czech	Slovak	Species	Czech	Slovak
Adonis aestivalis L.	NT	LC	*Odontites vernus* (Bellardi) Dumort.	EN	VU
Agrostemma githago L.	CR	CR	*Papaver argemone* L.	NT	EN
Anagallis foemina Mill.	NT	–	*Papaver dubium* L.	–	NT
Aphanes arvensis L.	NT	EN	*Ranunculus arvensis* L.	EN	NT
Bromus secalinus L. subsp. *secalinus*	CR	EN	*Rhinanthus alectorolophus* (Scop.) Pollich	VU	–
Cerastium dubium (Bastard) Guépin	VU	NT	*Rumex stenophyllus* Ledeb.	EN	NT
Euphorbia exigua L.	NT	–	*Sclerochloa dura* (L.) P. Beauv.	VU	–
Euphorbia falcata L.	VU	–	*Silene noctiflora* L.	NT	–
Euphorbia virgata Waldst. et Kit.	–	LC	*Stachys annua* (L.) L.	VU	–
Fumaria vaillantii Loisel.	DD	–	*Valerianella dentata* (L.) Pollich subsp. *dentata*	LC	–
Galium spurium L.	NT	–			
Hyoscyamus niger L.	VU	–	*Veronica agrestis* L.	EN	CR
Kickxia elatine (L.) Dumort.	EN	LC	*Veronica triloba* (Opiz) Opiz	VU	VU
Kickxia spuria (L.) Dumort.	EN	LC	*Veronica triphyllos* L.	–	NT
Lolium temulentum L.	RE	CR	*Viola tricolor* L.	DD	–

The following levels of endangerment according to International Union for Conservation of Nature (IUCN): RE – regionally extinct; CR – critically endangered taxa; EN – endangered taxa; VU – vulnerable taxa; NT – near threatened; LC – least concern; DD – data deficient

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one soil type (e.g., *Polygonum aviculare* L., *Fallopia convolvulus* (L.) Á. Löve, *Stellaria media* (L.) Vill.) and other literature supports that these species have a wide amplitude of occurrence on soil types (Kühn 1967). Lososová et al. (2008) state these species as one of the cereals' most abundant weeds and are often connected with slightly acid soils.

Few species in our data showed a strong connection to luvisols, which are lowland soils mainly on loess subsoils and a moderately strong ilimerisation process. According to Kühn (1967), *Galium aparine*, *Vicia hirsuta* and also *Centaurea cyanus* could be expected in a luvisol. Our data, however, found *Centaurea cyanus* L. more affiliated with cambisols.

Fluvisols are typically floodplains. One linked species was *Calystegia sepium*, which grows preferentially on moist soils, flooded river coasts, streams and stagnant waters (Gala-Czekaj et al. 2016). Similarly, *Rumex stenophyllus* or *Mentha longifolia* characteristically occur in habitats well supplied by water (Chytrý et al. 2018). With a more distant relationship to fluvisols, *Equisetum arvense* is also known to inhabit soils with a high water table (Holec and Jursík 2008).

Expansion of thermophilic species. Overall, most of the recorded species (including widespread, e.g., *Amaranthus retroflexus*, *Amaranthus powellii* S. Watson, *Datura stramonium*, *Mercurialis annua*, *Setaria pumila* (Poir.) Roem. et Schult.) were found concentrated in very-warm to moderately-warm climate regions; yet, some of the thermophilic species are oriented to moderately-cold to cold regions. We might have expected to find thermophilic species beyond their traditional range, but it is surprising to find thermophilic species exclusively in colder regions. A closer examination of the species illuminates the matter. First, these species were minimally represented in the dataset, with few and rare occurrences within the relevés, exclusively at higher altitudes. These areas tend to have lower management intensity, as discussed previously, and it follows that some of these species are included on the Red Lists (Table 2). The richer mosaic and landscape structure at higher altitudes compared to larger uniform production in lowlands allowed these species an opportunity to succeed in these agrophytocenoses.

Additionally, many of the species occurring in the moderate-cold to the cold region are also linked to calcium-rich soil conditions (*Fumaria schleicheri*, *Fumaria vaillantii* Loisel., *Euphorbia virgata*, *Falcaria vulgaris*, *Cerastium pumilum* – Ellenberg indicator value 8) (Lososová et al. 2006).

Furthermore, *Lolium temulentum* was significantly affected by intensive agricultural management – especially seed cleaning and herbicide use (Korneck et al. 1998). While a significant weed across Europe in the mid-20th century, its distribution range has largely decreased to areas of reduced intensification. It is categorised as regionally extinct in the Czech Republic and critically endangered in the Slovak Republic (Table 1). It was marked as extinct in Slovakia at the end of the century (Holub 1999), but new occurrences have been documented since 2005 (Eliáš et al. 2010), including this survey, where it was found in Slovakia.

Grass weed distribution. The group of so-called millet grasses (*Panicum miliaceum*, *Setaria viridis*, *Setaria pumila*, *Echinochloa crus-galli*) showed a strong connection to very warm regions. These are non-native annual weed species often originating from the Mediterranean (Pyšek et al. 2012). Millet grasses use C4 metabolism, imparting a better transpiration efficiency and growth advantage at high temperatures (Jursík et al. 2018). However, they typically need higher soil temperatures for germination and are classified as late-spring weeds (Chytrý 2017).

Grass species occurring in the cold and moderate-cold regions had the lower temperature and higher moisture requirements (Lososová et al. 2006). *Deschampsia cespitosa*, characteristic of wet meadows and along watercourses, also has been recorded up to altitudes of 2 500 m a.s.l. (Chiapella 2000). Once again, the grass species in the colder regions are connected to soil type and acidity. *Holcus mollis* is an indicator of acidity (Tyler 1994). Like *Lolium temulentum*, *Bromus secalinus* subsp. *secalinus* survival is also susceptible to intensive management (Spahillari et al. 1999) and occurs on the red lists of threatened species (Eliáš et al. 2015, Grulich and Chobot 2017).

The species *Avena fatua*, *Apera spica-venti*, *Elymus repens* and *Poa annua* occurred without a distinct relationship to climate and were represented in all evaluated regions. This supports their success in large fields and intensive production, earning recognition as the most widespread grass weeds in central Europe (Krähmer 2016). *Echinochloa crus-galli*, although clearly having optimum growth in warm regions, was also found in the moderate-cold area. Pyšek et al. (2012) classify it as an invasive archaeophyte; it spreads to higher altitudes and latitudes, mainly in connection with the cultivation of maise and rising temperatures (Andreasen and Streibig 2011, Jursík et al. 2018).

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Presence of rare and endangered weeds. As the nature of agriculture has changed in the past century, many species which were once commonly found in arable crops have declined due to intensification. These species are an important part of landscape biodiversity which does not necessarily have another refuge space due to closely adapting to now obsolete procedures, such as improved seed cleaning, while some management changes could improve their prospects, such as reduced liming and fertilisation (Meyer 2020). In the 1990s, due to changes in land ownership and associated changes in land management, some of these species (e.g., *Adonis aestivalis* L.) reappeared in fields in the Czech Republic (Lososová 2003). Kolářová et al. (2013) observed the highest effects on the distribution of rare and endangered weed species for altitude with associated climatic (temperature, precipitation) and soil conditions, although we have already discussed at length how these factors are closely related to management options. Storkey et al. (2012) presented 84 and 63 threatened and rare species out of 166 and 167 arable plants occurring in the Czech and Slovak Republic, respectively. This disparity in the incidence of threatened species may be partially explained by the greater intensity of farming in the Czech Republic with higher total use of nitrogen fertilisers and herbicides; therefore, a higher expected yield and selection for competitive and potentially herbicide-resistant species (Table 1, Kolářová et al. 2023).

Caveats. Vegetation surveys such as these are difficult to carry out, requiring many people, coordination, and communication with various farmers and landholders. In trying to determine landscape character and species associations, there is always a balance of representing the landscape and having even sampling for different factors. Therefore, we often face a trade-off between having high-quality data for a limited area, having an extensive area surveyed in less than ideal conditions, or even trying to consolidate sets that were carried out with different objectives and methodologies. In this case, we have an extensive survey conducted in two countries with the same methods. Even though this data is not recently collected, this is still valuable information on the distribution of weedy species in cereals in the area of former Czechoslovakia. Furthermore, this represents an insightful time capsule of the weed diversity character 15 years after privatisation and separate national agricultural policies. Since the time of the survey collection, farming practices have remained fairly stable. We hope that in the future, this work may be carried out again to see the comparison and shifts from our own time, such as new policies that suggest incentivising farmers to value ecosystem services, reduce management intensity and value weed diversity.

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