Tuexenia 36: 249–270. Göttingen 2016.
doi: 10.14471/2016.36.012, available online at www.tuexenia.de

Arable weed communities in the south of Western Siberia – impoverished species pools constrain diversity despite low land-use intensity

Ackerwildpflanzengemeinschaften in Südwestsibirien – geringe Diversität trotz niedriger Landnutzungsintensität durch kleinen Artenpool

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Abstract

Despite the high significance of the Western Siberian grain belt for crop production in Russia, its weed communities are largely unknown. In this region spring wheat is grown on fertile Chernozem soils with large field sizes but land-use intensity per area is low compared to Central Europe. By using a randomized sampling design we studied arable weed assemblages in the northern forest-steppe zone of Tyumen region on 99 within-field sampling plots of 100 m² size. Surprisingly, with average of 9.8 ± 3.8 species 100 m^{-2} species richness was low when compared with low-input farming in Central Europe and did not differ between areas of different land-use intensity. Against expectations species composition was not predominantly controlled by soil characteristics and climate, most likely due to short natural gradients. Instead, management factors such as fertilization and tillage intensity seemed to be important factors. Except for two species the Tyumen weed flora consisted mainly of species that are widespread throughout the temperate zone. We found only 10 species with an origin or core area in North Asia or Eastern Europe. The species pool was generally small and with 26% the proportion of non-native species (archaeophytes) was low, when compared to Central European weed communities. Given that weed communities with higher species richness are described from neighboring Bashkiria, we conclude that arable land-use intensity in Tyumen region is high enough to reduce community species richness within arable fields estimated by a randomized sampling design. Since measured soil nutrient values did not affect species richness, herbicide use is most likely the crucial management factor. Furthermore, species-richness was vitally restricted by the small species pool. The low proportion of thermophilous arable weed species that originate from the Mediterranean or Middle-Eastern area and contribute significantly to the Central European weed diversity indicate that climatic dispersal limitations may be responsible for the small number of weed species in the Tyumen flora. An additional constraint was the short history of arable farming in Western Siberia, where considerable arable land use was started only by the end of the 17th century.

Keywords: agroecosystem, arable land, cropland, grain belt, plant diversity, plant community, segetal vegetation, species richness, wheat

Erweiterte deutsche Zusammenfassung am Ende des Artikels

Manuscript received 20 February 2016, accepted 09 May 2016
Co-ordinating Editor: Florian Jansen

1. Introduction

In Europe, arable weed vegetation contributes significantly to the phytodiversity of cultural landscapes of the temperate zone (STOATE et al. 2009, EUROPEAN ENVIRONMENT AGENCY 2010). Species richness of arable weed vegetation at plot scale can be similar to grassland vegetation (KLEIJN et al. 2009) and species composition is very specific. Due to the unique habitat characteristics of arable land – which on large scales cannot be found in any natural ecosystem – arable weed species are highly specialized; they largely depend on the regular anthropogenic disturbance of their habitat (HOLZNER & NUMATA 1982, ELLENBERG 2009). Beyond that, species composition of arable weed communities is driven predominantly by differences in regional and local environmental factors such as climate and soil properties (LOSOSOVÁ 2004, SHAIKHISLAMOVA et al. 2004, PINKE et al. 2012, KOLÁŘOVÁ et al. 2014, SEIFERT et al. 2015). Consequently, temperature, soil moisture and soil pH or the availability of base cations are regularly the main factors reflected in classifications of arable weed vegetation in the temperate zone of Europe (e.g. HÜPPE & HOFMEISTER 1990, KROPÁČ 2006, ŠILC & ČARNI 2007, PINKE & PÁL 2008). The second important complex factor that is regularly found to drive species composition is the kind of agricultural management such as crop type and crop rotation – and inter-related with that – fertilization and tillage practice, as well as the timing of tillage operations and herbicide application (ALBRECHT & BACHTHALER 1990, FRIED et al. 2008). All these factors filter the species composition of arable weed communities with respect to plant functional traits such as, life form, phenology, seed dormancy, germination requirements, relative growth rate etc. (SMITH 2006, ELLENBERG 2009, GUNTON et al. 2011).

In the course of increasing agricultural improvement and industrialization land amelioration techniques such as liming, fertilization and drainage, have led to the simplification of environmental gradients and consequently to a decline in the diversity of arable weed communities (MEYER et al. 2013, MEYER et al. 2015). Several studies have shown that the species richness of arable weed communities is negatively affected by modern agricultural management (PYŠEK et al. 2005, SEIFERT et al. 2015). During the 20th century agricultural intensification has caused a dramatic decline in species diversity of arable weed vegetation in Europe, where 582 weed species are now rare or threatened (STORKEY et al. 2012) and species richness per plot has declined by 20–65% depending on the temporal and spatial scale of the study (ALBRECHT & BACHTHALER 1990, MEYER et al. 2013, RICHNER et al. 2015). Increased fertilizer and herbicide application are the most important management changes, but efficient seed cleaning, the shift from spring to autumn sowing in cereals, high crop densities and decreased crop diversity are other important factors responsible for the dramatic impoverishment of the European weed vegetation (STORKEY et al. 2012). Increased application rates of fertilizers enhance crop growth, which results in the competitive exclusion of weed species. KLEIJN et al. (2009) used nitrogen fertilization as a land-use intensity indicator and found that species richness of arable weeds on plot scale decreased exponentially with nitrogen input. Moreover, crop yield seems to be a good indicator for diversity decline of weed vegetation in Europe, where national proportions of threatened species are positively related to wheat yields (STORKEY et al. 2012). In post-Soviet Russia, species richness of arable weed vegetation increased in some areas as a consequence of reduced tillage intensity and reductions in the use of agrochemicals (MIRKIN et al. 2007).

Western Siberia is one of the important agricultural regions of the Russian Federation, holding more than 20% of the national arable land (ROSSTAT 2015). The so-called grain belt stretches over the entire forest-steppe zone in the southern part of the Western Siberian lowlands from the Ural to the Altai Mountains. Fertile Chernozems and Phaeozems are preferably cultivated with large field sizes up to several hundred ha. However, due to the flat topography with poor drainage and widespread soil wetness only well drained areas, mostly along river valleys, are used for arable cultivation. Consequently, the proportion of the landscape used as arable land is comparatively low with on average of only 27% of total land cover (KÜHLING et al. 2016). Across the Western Siberian grain belt land-use intensity is much lower than in Central Europe with spring wheat yields between 1 and 2 t ha^{-1} and annual nitrogen fertilization rates between 5 and 50 kg ha^{-1} (ROSSTAT 2015, KÜHLING et al. 2016), compared to yields between 5 and 9 t ha^{-1} and N-fertilization of 100 to 200 kg ha^{-1} yr^{-1} in EU countries with intensive land use, respectively (STORKEY et al. 2012).

Knowledge about the arable weed vegetation of the Western Siberian grain belt has been extremely sparse until recently (TRET'YAKOVA 2006). In adjacent Bashkiria, which is separated from the Western Siberian grain belt only by the rather low Ural Mountains, weed vegetation has been studied from a phytosociological point of view (MIRKIN et al. 1985, YAMALOV et al. 2007, KHASANOVA & YAMALOV 2013), whereas studies on arable weed ecology and diversity are missing. In a previous study we compared the Tyumen weed vegetation with the weed communities from Bashkiria using phytosociological methods (KÄMPF et al. 2016a). Another phytosociological study on arable weed communities in Northern Asia is available from the East Siberian Yakutia (MIRKIN et al. 1988). In the latter region, however, farming takes place only at very small scale due to the extreme continental climate.

The aim of our study was to analyze species composition and species richness of arable weed vegetation in relation to environmental and management factors in Tyumen region, which is located in the center of the Western Siberian grain belt. We focused on the weed vegetation of grain fields (mainly spring wheat), which cover roughly two thirds of the arable land (TYUMSTAT 2014). Because of the region's low land-use intensity we expected that arable weed vegetation would be diverse and species-rich. Since this has been shown for Europe (e.g. SEIFERT et al. 2015) we furthermore expected the community composition to be controlled predominantly by environmental factors and only to a lesser extent by management effects. In this study, we specifically aim at (1) analyzing the species composition of arable weed communities of the forest-steppe zone in Tyumen region, (2) examining the effect of soil characteristics and agricultural management on species richness and species composition, (3) assessing the conservation value of arable weed communities in relation to land-use intensity and in comparison with the situation in Europe.

2. Study area

The study area is located in the southern part of Tyumen region, within the temperate pre-taiga and forest-steppe zone in the southwest of the Western Siberian lowland (Fig. 1). All sampling was carried out within the SASCHA project (SASCHA 2015) in three test areas of 20 km x 20 km in size, which are located in a distance of 150 km from each other along a latitudinal climatic gradient. The northern test area (*TA North*) is part of the hemiboreal forest eco-region or *pre-taiga* as referred to in Russian literature (e.g. VOROBEV & BELOV 1985, WALTER & BRECKLE 1999). About 100 km south of the city of Tyumen the light forest of the hemi-boreal zone is followed by the forest-steppe zone, a macro-mosaic of open birch forests and meadow steppe grasslands (SELEZNEVA 1973). Within this ecozone *TAs Center* and *South* are situated close to the district centers Omutinsk and Ishim, respectively.

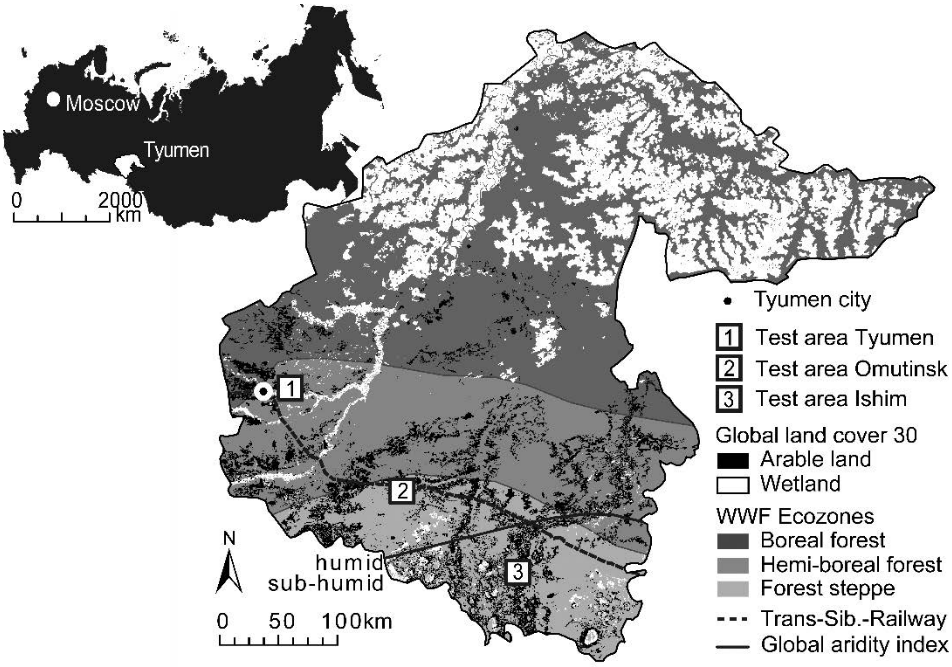

Fig 1. Map of Tyumen region (without autonomous provinces), displaying test areas for the research presented in this paper, ecozones (OLSON et al. 2001), extent of arable land and wetland (NGCC 2014) and climate (TRABUCCO & ZOMMER 2009).

Abb. 1. Karte der Region Tjumen (ohne autonome Gebiete). Dargestellt werden die Testgebiete dieser Studie, Ökozonen (OLSON et al. 2001), Ausdehnung der Äcker und Feuchtgebiete (NGCC 2014) und das Klima (TRABUCCO & ZOMMER 2009).

The climate of the region is continental with a short vegetation period of 160 days (SELEZNEVA 1973). The aridity increases from humid in *TA North* to sub-humid in *TA South* (TRABUCCO & ZOMMER 2009) with mean annual precipitation and temperature of 476 mm and 1.87 °C in Tyumen and 401 mm and 1.7 °C in Ishim, respectively (DEGEFIE et al. 2014). The parent material for soil development consists of calcareous loess-like sediments (FRANZ 1973). Main soil types used for arable farming are Chernozems and Phaeozems (SHAHGEDANOVA 2002). Gleyic horizons, however, are common in all soil types because of the poor drainage capacity of the Western Siberian plain and extreme seasonal groundwater-level changes (SELEZNEVA 1973). Due to its location in the fluvial terrace of the Tura river, *TA North* is less elevated (60 m a.s.l.) than *TA C*enter and *TA S*outh (120 m a. s. l.) and has a higher proportion of organic soils.

Arable land covers 17–34% of the test areas' surface and is mainly used for the production of summer grain (mainly wheat), which is used for animal fattening. Most arable land is cultivated by large agricultural enterprises and field sizes are large (dozens to several 100 ha) (KÜHLING et al. 2016). Due to the large field sizes in conjunction with the short growing season there is only a short time frame for management operations, which are often additionally constrained by limited farm machinery pools. Usually, herbicides and nitrogen fertilizers are applied only once per year (e.g. 2008: 49 kg N ha^{-1} yr^{-1} in Tyumen region, ROSSTAT 2015). All test areas are similarly well connected with traffic infrastructure as they are all located along the Trans-Siberian Railway and the E 22, which is the most important road connection from west to east. However, *TA North* is situated at the outskirts of Tyumen in close proximity to sales markets and the land-use intensity is higher with significant cultivation of potatoes and other vegetables as well as industrial animal husbandry, especially poultry. This study excluded fields that were used for potato and vegetable farming in the year of sampling. However, these crops might have been grown on the sampled grain fields in previous years. For more details on the study area please refer to (KÄMPF et al. 2016b), concerning the land-use intensity please refer to (KÜHLING et al. 2016).

3. Material and Methods

3.1 Study design and sampling

For the allocation of sampling sites within the three test areas we used a GIS-based randomized sampling design. The distribution of arable land was obtained from a supervised classification of remote sensing data from LANDSAT and RapidEye satellite images. The minimum distance between plots was 500 m. All sampling plots within arable fields were located at minimum in a distance of 100 m from the field margin. In June and July 2012 and 2013, a total of 99 plots of 100 m² were sampled. On each plot we recorded the percentage cover of all vascular plant species with an estimation accuracy of 1% as well as crop, weed and litter cover. For each plot the depth of the Ah layer was determined by a soil corer. For soil analyses five soil cores from a depth of 0–5 cm and 5–30 cm were taken separately and pooled together per depth.

3.2 Laboratory analyses

Air-dried soil samples were ground with a mortar and screened through a sieve with 2 mm mesh size. For the analysis of pH, potassium and phosphor the two soil samples from 0–5 cm and 5–30 cm depth were merged to one sample. The pH-value was determined with a glass electrode in a suspension of 10 g soil and 25 ml of 0.01 mol l^{-1} calcium chloride solution. Plant available P and K was measured photometrically in CAL extract (VDLUFA 2002). Total carbon (Ct) and total nitrogen (Nt) content were measured in aliquots of soil samples milled to fine powder with a CN Elemental Analyzer (Eurovector EA 3000, Milan, Italy).

3.3 Data analysis

Nomenclature of vascular plants follows the standard list for Russia and adjacent countries (CZEREPANOV 1995). Indicator values for soil humidity, variability of damping, acidity and nitrogen were derived from the Ukrainian flora (DIDUKH 2011) as best surrogate as other indicator values were not available. For each indicator value weighted means per relevé were calculated with square-root transformed abundance values of the species. The status of origin for all registered species was obtained by analyzing areal diagnostics (MEUSEL & JÄGER 1965, 1978, 1998), ecological species descriptions (KOMAROV et al. 2004) and distribution maps (HULTÉN & FRIES 1986). The “Flora of Tyumen”, an unpublished Flora by Igor Kuzmin (Tyumen) was used to determine if a species is part of the flora of Tyumen region. Twelve further vegetation relevés from ex-arable land with short time since abandonment of 1–2 years (KÄMPF et al. 2016b) were included in parts of the analysis as an additional habitat for arable weed vegetation.

For the cluster analysis we used a hierarchical procedure with Ward’s agglomeration method (WARD 1963). The dissimilarity matrix was calculated from square-root transformed percentage cover values by applying the Bray-Curtis dissimilarity index. The number of clusters was manually set to 4 to avoid small sample sizes within clusters. Species associations to clusters of samples were calculated by indicator species analysis (DUFRÊNE & LEGENDRE 1997). The indicator value combines the relative abundance and the relative frequency of a species within groups of samples. We used permutation tests of 999 permutations to estimate the statistical significance. Species with an indicator value of 0 have no indicator function while species with the maximum value of 100 are exclusively found in the designated group of samples (DUFRÊNE & LEGENDRE 1997).

Species composition was analyzed by using non-metric multidimensional scaling (NMDS). We used the R-function "metaMDS" with 3 dimensions and Bray-Curtis dissimilarity. Only species with a minimum frequency of 2 occurrences in the dataset were included and cover values were transformed by Wisconsin double standardization. After 77 random starts a stable solution with a stress of 0.22 was found. Subsequently we fitted environmental variables onto the ordination by using "envfit"; significance of correlation was tested with 999 permutations.

To be able to compare γ-diversity between the test areas, which were sampled with different sample sizes (*TA North*: 29 plots, *TA Center*: 30 plots, *Ta South* 40 plots), we used rarefaction curves (COLWELL et al. 2004) to interpolate the number of species to the smallest sample size (*TA North*: 29 plots). For each 100 m² plot α-diversity was calculated. A Generalized Linear Model (GLM) with Gaussian error structure was used to evaluate the effects of environmental variables on α-diversity. The target variable was square root-transformed to improve the fit to the Gaussian error structure prior to the analysis. Stepwise backward selection based on Akaike's information criterion was used to remove non-informative variables from the initial model (step function in R). Finally, we calculated the Mc Fadden Pseudo r² by using the pR2-function of the R-package "pscl" (JACKMAN 2015).

We used the statistical software R (R CORE TEAM 2015) for all analyses including the packages "indicspecies" (DE CACERES & LEGENDRE 2009), "vegan" (OKSANEN et al. 2015) and "car" (FOX & WEISBERG 2011).

4. Results

A total of 87 vascular plant species was found in 99 sampling plots with an average of 9.8 ± 3.8 (mean ± 1 SD) vascular plant species per 100 m². Mean arable weed cover was highly variable with 12 ± 11% while average crop cover was 49 ± 22%. Neither α- nor γ-diversity differed significantly between the three test areas (data not shown).

The cluster analysis resulted in the delineation of 4 vegetation clusters (Fig. 2), which mainly corresponded with differences in soil type and agricultural management (Fig. 3). In the first two clusters the soil types Chernozems and Phaeozems dominated and most plots were located in *TA South* and *TA Center*. The significantly lower P-availability values of the plots in clusters 1 and 2 compared to plots of the other clusters reflected the low land-use intensity with low application rates of fertilizers. The generally high Potassium values and mighty Ah-horizons (Fig. 3), however, represented the natural conditions of the region's Chernozem and Phaezoem soils. Plots in cluster 1 differed from those in cluster 2 by a higher soil CN ratio, lower mean indicator value for nitrogen and variability of damping (soil humidity variability), lower species richness, a lower proportion of therophytes and a higher proportion of geophytes. Species richness was significantly highest in cluster 2 (Fig. 3). Sampling plots of clusters 3 and 4 were characterized by high amounts of plant available P, high nitrogen indicator values and narrow CN ratio and were mainly located in *TA North*. A lower cover of the litter layer and a significantly lower proportion of geophyte species indicate higher tillage intensity compared to clusters 1 and 2. Soil types differed between clusters 3 and 4 with gleyic soils and Histosols in cluster 3, Phaeozems, and Chernozems with shallow Ah-horizon or Stagnosols in cluster 4. The latter was differentiated from cluster 3 by the dominance of therophytes, few hemicryptophytes and a lower mean indicator value for the variability of damping. Soil pH-values were rather homogenous with average values of 6.2 ± 0.4 in cluster 1, 6.1 ± 0.4 in cluster 2, 6.9 ± 0.8 in cluster 3 and 6.4 ± 0.7 in cluster 4

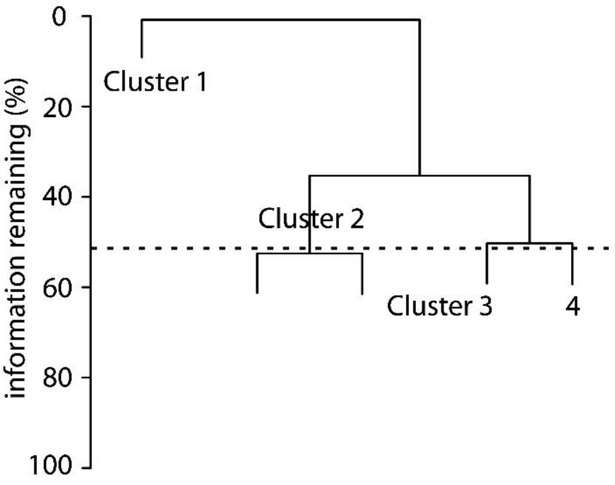

Fig. 2. Hierarchical cluster analysis dendrogram (Ward's agglomeration method) for the arable weed communities of Tyumen region, cut level marked with dashed line at 52% information remaining. Sample sizes in cluster 1: *n* = 29; 2: *n* = 37; 3: *n* = 18; 4: *n* = 15.

Abb. 2. Dendrogramm für die hierarchische Clusteranalyse (Ward Agglomerationsmethode) der Ackerwildpflanzengemeinschaften der Tjumener Region. Die gestrichelte Linie markiert den Schnittlevel bei 52 %. Stichprobenumfang in Cluster 1: *n* = 29; 2: *n* = 37; 3: *n* = 18; 4: *n* = 15.

(mean ± 1 SD). Only the pH-value of cluster 3 was significantly different from clusters 1 and 2 (unpaired Wilcoxon test with Holm correction). While crop types were more or less evenly distributed in clusters 1, 2 and 4 (dominantly wheat, but also oat and barley), cluster 3 was dominated by oat.

An Indicator Species Analysis revealed 31 indicator species for the four clusters (Table 1). The indicator species well reflected the higher fertilizer applications and higher tillage intensity in plots of clusters 3 and 4. Whilst clusters 1 and 2 contained many geophytes, such as *Euphorbia esula* (facultative geophyte), *Stachys palustris*, *Linaria vulgaris*, as well as hemicryptophytes such as *Sonchus arvensis* and *Lathyrus tuberosus*, clusters 3 and 4 were mainly characterized by annual species. Apart from the high frequency of *Lathyrus tuberosus* cluster 1 was only negatively characterized by very low frequencies of the therophytes *Chenopodium album*, *Avena fatua*, *Echinochloa crus-galli* and *Fallopia convolvulus,* which reached high abundance in all other clusters. The indicator species group of cluster 3 contained *Phragmites australis* as soil humidity indicator, *Chenopodium glaucum* and two crop species, which occurred as arable weeds in our relevés. Moreover, it was characterized by low frequencies of *Convolvulus arvensis*, *Setaria viridis* and *Galium aparine*. Cluster 4 was characterized by annuals, among them nitrophytic species such as *Cannabis ruderalis*, *Amaranthus retroflexus* and *Solanum nigrum*.

The NMDS illustrated the separation of the clusters, however, clusters 1 and 2 were less well separated than clusters 3 and 4 (Fig. 4a). The first NMDS axis reflected a nutrient gradient with positive correlation of the axis scores with soil phosphor and nitrogen indicator value (Table 2, Fig. 4a). Additionally, the proportion of geophytes was negatively and the proportion of therophytes was positively correlated with the first axis. Clusters 3 and 4 were

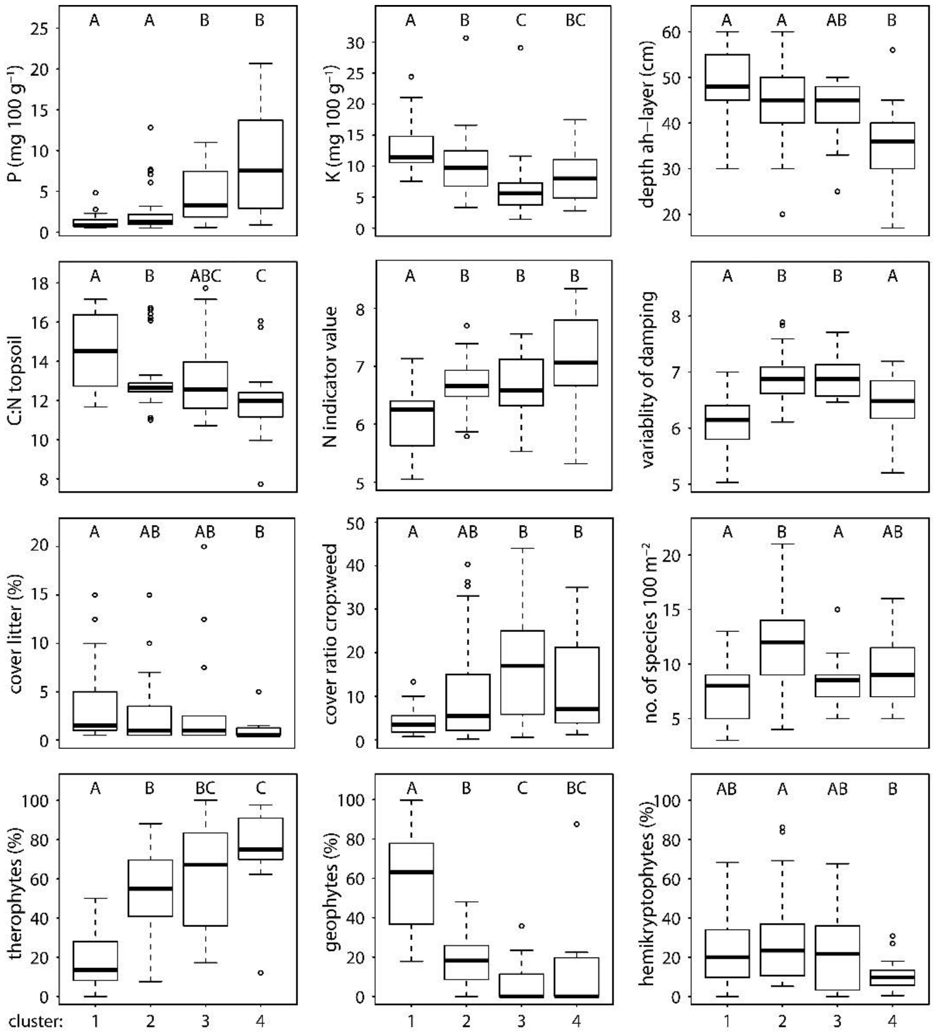

Fig. 3. Differences of soil characteristics and floristic composition between the four clusters of arable weed communities. For sample sizes see Figure 1. Significance tested with Kruskal-Wallis test and unpaired Wilcoxon test with Holm correction (post-hoc); equal letters indicate no significant difference. Note: for cover of litter the Kruskal-Wallis test was not significant (p = 0.051). For clarity of the figure, three outliers are not displayed: soil K content 67.7 (clu. 2), cover of litter 90 (clu. 3), cover crop:weed 93 (clu. 3).

Abb. 3. Bodeneigenschaften und floristische Zusammensetzung der vier Cluster der Ackerwildpflanzenvegetation. Stichprobenumfang s. Abbildung 2. Gleiche Buchstaben symbolisieren nicht-signifikante Unterschiede, die mit Kruskal-Wallis-Test und anschließendem, ungepaarten Wilcoxon-Test mit Holm-Korrektur getestet wurden. Beachte: für die Streuschicht-Deckung war der Kruskal-Wallis-Test nur knapp nicht signifikant (p = 0,051). Folgende drei Ausreißer wurden der Übersicht halber nicht dargestellt: Kalium: 67,7 (Clu. 2), Streuschichtdeckung: 90 (Clu. 3), Deckung Ackerfrucht:Beikraut: 93 (Clu. 3).

Table 1. Indicator species frequencies (%) for four clusters of arable weed communities in Tyumen region (Western Siberia). Indicator value after Dufrêne & Legendre (1997), significance calculated with 999 permutations (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Non-significant species (framed with dashed lines) were included when their frequency was at least 14% and two times higher compared with non-designated clusters.

Tabelle 1. Prozentuale Stetigkeit für die Indikatorarten der in vier Cluster aufgeteilten Ackerwildpflanzengemeinschaften der Region Tjumen (Westsibirien). Indikatorwert nach Dufrêne & Legendre (1997), Signifikanz mit 999 Permutationen berechnet (* $p < 0{,}05$; ** $p < 0{,}01$; *** $p < 0{,}001$). Nicht signifikante Arten wurden markiert (gestrichelte Umrandung), wenn ihre Stetigkeit mindestens 14 % betrug und doppelt so hoch war wie in nicht ausgewiesenen Clustern.

	Cluster				Total	Indicator value
	1	2	3	4		
Indicator species clusters 1 and 2						
Sonchus arvensis	59	57	28	13	45	72**
Euphorbia esula	48	27	6	7	26	56*
Stachys palustris	24	30	6	7	20	48 n.s.
Viola arvensis	17	22	6	0	14	42 n.s.
Thlaspi arvense	14	24	0	0	13	44 n.s.
Nonea pulla	17	14	0	0	10	39 n.s.
Indicator species cluster 1						
Lathyrus tuberosus	41	19	6	0	20	52*
Species with low frequency in cluster 1						
Chenopodium album	17	68	78	73	56	83***
Avena fatua	17	59	50	40	42	72**
Echinochloa crus-galli	17	41	33	93	40	69**
Fallopia convolvulus	10	68	33	40	40	71**
Indicator species cluster 2						
Linaria vulgaris	14	30	0	0	15	50**
Elytrigia repens	0	19	6	0	8	40*
Equisetum arvense	0	19	0	0	7	44**
Euphorbia helioscopia	0	16	0	0	6	40*
Camelina microcarpa	0	14	0	0	5	37*
Fumaria officinalis	3	22	6	7	11	38 n.s.
Vicia tetrasperma	3	16	0	0	7	33 n.s.
Indicator species clusters 3 and 4						
Persicaria lapathifolia	0	5	39	13	11	50**
Persicaria amphibia	7	5	22	40	14	41 n.s.
Indicator species cluster 3						
Chenopodium glaucum	0	3	39	13	10	58***
Hordeum vulgare	3	11	39	0	12	57***
Triticum aestivum	3	8	39	0	11	57***
Phragmites australis	0	5	33	0	8	57***
Chenopodium urbicum	0	0	11	0	2	33*
Species with low frequency in cluster 3						
Convolvulus arvensis	93	65	11	40	60	84***
Setaria viridis	66	65	11	40	52	76***
Galium aparine	28	54	6	20	32	62**

	Cluster				Total	Indicator value
	1	2	3	4		
Indicator species cluster 4						
Erodium cicutarium	28	38	11	93	38	74***
Cannabis ruderalis	7	27	11	60	23	66***
Amaranthus retroflexus	3	3	11	53	12	72***
Solanum nigrum	0	0	22	53	12	72***
Brassica napus	0	5	22	40	12	49*
Panicum miliaceum	0	11	0	27	8	50**
Polygonum aviculare	0	0	6	13	3	34*
Species with lower frequency in cluster 4						
Cirsium setosum	86	89	67	47	78	88***
Raphanus raphanistrum	41	46	28	0	34	64**
Taraxacum officinale	31	46	28	13	33	60 n.s.
Indicator species clusters 2 and 4						
Galeopsis bifida	14	43	0	20	23	54*

separated along the second axis, which correlated positively with the proportion of hemicryptophytes and the soil humidity indicator value. The above described affiliation of the indicator species to the four clusters was reflected well in the NMDS (Fig. 4b).

We were not able to find a relation between plant species richness and any of the tested environmental variables. In the GLM the stepwise backward selection function according to AIC-values excluded all predictors from the initial model: soil type, crop type, P, K, CN, pH, test area, cover of litter and the cover ratio crop:weed.

The species inventory showed that most of the detected arable weeds are common species in the temperate zone and not very specific for Tyumen region. Except for *Dracocephalum thymiflorum* and *Cirsium setosum* – the latter replaces *Cirsium arvense* which is not common in Asia – all recorded species have also been found in the Central European weed flora (though *Cannabis ruderalis* and *Draba nemorosa* are not permanently established alien species in Central Europe, WISSKIRCHEN & HAEUPLER 1998). The majority of the weed species originated from natural habitats and most of them were cosmopolites or distributed throughout the whole temperate zone of Eurasia. Only 26% of the 87 registered species were not native, known as archaeophytes or anecophytes in Central Europe (Supplement E1). Two of the detected species, *Amaranthus retroflexus* and *Conyza canadensis*, originate from America. Only 10 species had their origin or core area in North Asia or Eastern Europe, namely *Camelina microcarpa*, *Cannabis ruderalis*, *Dracocephalum thymiflorum*, *Fagopyrum tataricum*, *Lactuca tatarica*, *Lappula squarrosa*, *Lathyrus tuberosus*, *Malva pussila*, *Nonea pulla* and *Thlaspi arvense*.

We found only few additional arable weed species in young ex-arable land (data from KÄMPF et al. 2016b) and in the Tyumen flora in general (Table 3). Ex-arable land with an abandonment time of one or two years contained only a few more annual weed species than we found on arable land. This group contained species known from perennial weed communities such as *Crepis tectorum* and *Sisybrium loeselii*, which are only facultative annuals.

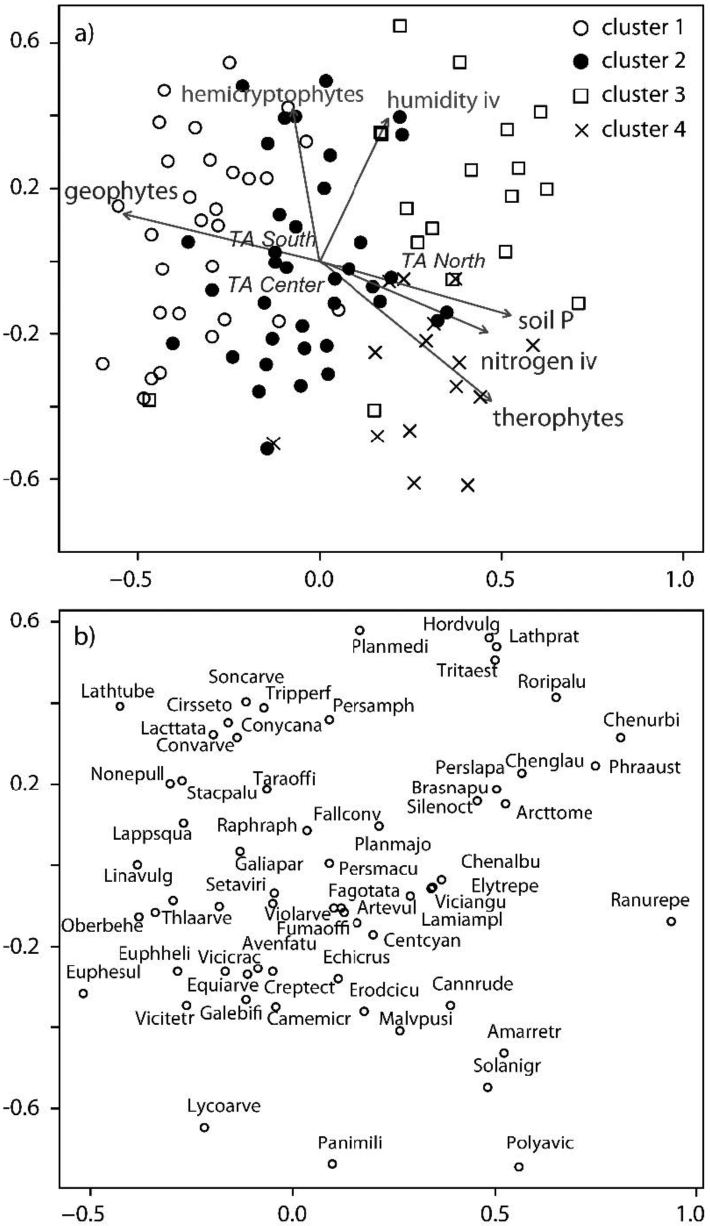

Fig. 4. NMDS ordination of 99 weed relevés from Tyumen region (species with less than 2 occurrences were excluded from the analysis). Different symbols represent the clusters identified by Ward's cluster analysis (Fig. 2). Environmental variables were fitted onto the ordination subsequently to the ordination, for statistical details see Table 2.

Abb. 4. NMDS Ordination der 99 Ackerwildkrautaufnahmen aus Tjumen. Die vier Cluster (siehe Abb. 2) werden durch unterschiedliche Symbole dargestellt. Die Vektoren der Umweltvariablen wurden nach Durchführung der Ordination berechnet, die Statistik dazu findet sich in Tabelle 2.

Table 2. Vector fitting results for the correlation of environmental factors onto the NMDS ordination shown in Figure 4, goodness of fit displayed as squared correlation coefficient, iv = indicator value (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

Tabelle 2. Quadrierte Korrelationswerte und p-Werte für die Korrelation von Umweltvariablen mit der NMDS Ordination, die in Abbildung 4 dargestellt wird, iv = Zeigerwert (* $p < 0{,}05$; ** $p < 0{,}01$; *** $p < 0{,}001$).

	r^2	p
Therophytes	0.48	***
P (plant available)	0.36	***
Geophytes	0.34	***
Test area	0.33	***
N indicator value	0.28	***
Soil humidity iv	0.22	***
Hemicryptophytes	0.22	***

The species pool of the Tyumen weed communities was very similar to the species pool of weed communities from Bashkir region. Apart from occasionally occurring accompanying species with low frequencies all Bashkir weed species from the *Caucalidion lappulae* Tx. ex von Rochow 1951 and *Galeopsion bifidae* Abramova in Mirkin et al. 1985 were present in the Tyumen flora, most of them observed by the authors (Table 3).

5. Discussion

5.1 Species composition

Our results show that despite the large geographical distance almost all arable weed species found in the Tyumen region of Western Siberia are also occurring in Central Europe. Furthermore, also the species composition is to some extent similar to basiphilous segetal communities of Eastern Europe (KROPÁČ 2006). In our study, plant communities from *TA North* (many relevés from cluster 4) resemble the *Fumario-Euphorbion* Th. Müller ex Görs 1966, which is a typical segetal community in root crops (KROPÁČ 2006). Diagnostic species for this alliance present in our plots such as *Solanum nigrum*, *Amaranthus retroflexus* and *Persicaria lapathifolia* are nitrophytes, which may profit from the higher fertilization levels in *TA North*, where vegetables are often part of the crop rotation system (KÜHLING et al. 2016). Species of the *Caucalidion lappulae* such as *Lathyrus tuberosus*, *Camelina microcarpa* and *Nonea pulla* were present in some of the plots of clusters 1 or 2, but apart from *Lathyrus tuberosus* as indicator species for cluster 1 the frequencies of these species were rather low in our study. Moreover, no diagnostic species from order level, *Centaureetalia cyani* Tx., Lohmeyer et Preising in Tx. ex von Rochow 1951, was present apart from *Avena fatua*. This means that the segetal vegetation of Tyumen region is similar compared with weed communities of Central Europe, but seems to be impoverished in species.

According to the classification of weed communities of Bashkiria (MIRKIN et al. 1985), which is located 800 km west of Tyumen, also in the forest-steppe zone, c. 50% of our relevés (the majority of them from clusters 1 and 2) can be assigned to the *Galeopsion bifidae* and to the *Caucalidion lappulae* Tx. ex von Rochow 1951. Again, diagnostic species have rather low frequencies, especially in the *Caucalidion* (KÄMPF et al. 2016a). This is in

Table 3. Weed species of the Tyumen flora (Kuzmin, unpublished), which were not recorded or underrepresented in arable land plots of our randomized sampling design. Percentage frequency is given for all samples of arable land and for 12 ex-arable fields abandoned 1–2 years before sampling (data from KÄMPF et al. 2016b). Field observations result from random qualitative observations of different ruderal habitat types. *in weed communities of Bashkir region, **occurence in Tyumen region likely but nor proven (Kuzmin, unpublished).

Tabelle 3. Prozentuale Stetigkeit für die Ackerwildpflanzenarten der Flora von Tyumen (Kuzmin, unveröffentlicht), welche nicht mittels des randomisierten sampling designs erfasst wurden oder unterrepräsentiert waren. Zusätzlich werden hier Daten aus 12 jungen Ackerbrachen mit einem Brachealter von 1 bis 2 Jahren (aus KÄMPF et al. 2016b) und zufällige, qualitative Beobachtungen in verschiedenen Ruderalhabitaten angegeben (field observations). *in Ackerwildkraut-Gesellschaften von Baschkirien-Region, **Vorkommen in der Tyumen Region wahrscheinlich, aber nicht bestätigt (Kuzmin, unveröff.).

Species	Frequency (%)		Field observations
	Arable land (n = 99)	Young ex-arable land (n = 12)	
Weeds in young ex-arable land			
Capsella bursa-pastoris	0	17	+
Psammophiliella muralis	0	17	+
Descurainia sophia	0	17	+
Sonchus asper	0	8	+
Galeopsis ladanum	0	8	+
Chenopodium ficifolium	0	8	+
Atriplex tatarica	0	8	+
Weeds with higher frequency in young ex-arable land			
Polygonum aviculare	3	58	+
Crepis tectorum	2	33	+
Sisymbrium loeselii	1	33	+
Vicia sativa	1	25	+
Dracocephalum thymiflorum	1	25	+
Lepidium ruderale	1	17	+
Spergula arvensis	1	17	+
Weeds detected in additional field observations			
Arenaria serpyllifolia	0	0	+
Buglossoides arvensis	0	0	+
Potentilla norvegica	0	0	+
Sinapis arvensis	0	0	+
Stachys annua	0	0	+
Weeds with diagnostic value in MIRKIN et al. (1985)*			
Neslia paniculata	0	0	-
*Consolida regalis***	0	0	-
Brassica campestris	0	0	-
Apera spica-venti	0	0	-

line with MIRKIN et al. (1985), who stated that for climatic reasons the *Caucalidion* reaches its eastern distribution limit in the Ural Mountains of Bashkiria and is replaced by the *Galeopsion bifidae* in the forest-steppe zone and the *Lactucion tataricae* Rudakov in Mirkin et al. 1985 in the steppe zone. Some of our relevés contained not only typical arable weed species but also a high proportion of ruderal species typical for perennial weed communities such as *Taraxacum officinale*, *Linaria vulgaris* and *Nonea pulla* (Fig. 4b). A generally high proportion of perennial ruderal species is an indicator for low tillage intensities and was also observed in Bashkir (MIRKIN et al. 2007, YAMALOV et al. 2007) and Novosibirsk region (SINESHCHEKOV et al. 2008).

Unexpectedly, in our study species composition was not predominantly controlled by differences in soil conditions and climate, which is in contrast to most findings from Central Europe (e.g. LOSOSOVÁ et al. 2004, KROPÁČ 2006, ELLENBERG 2009, KOLÁŘOVÁ et al. 2014). The weak effects of environmental factors on species composition may be explained by a generally low variability of site characteristics in arable land of the Western Siberean lowland. Due to the short growing season and the poor drainage capacity in the Western Siberian grain belt, arable land use is restricted to elevated sites that dry off early enough in spring for cultivation, mainly Chernozems. Because the geological parent material consists over large areas uniformly of calcareous loess-like sediments soil characteristics are homogenous (SELEZNEVA 1973). Therefore, an effect of soil type on the weed community composition was only present in *TA North*, where fens have been drained for cultivation. As a consequence cluster 3 was mainly differentiated from cluster 4 by indicators for high soil humidity. The cluster 3 indicator species *Phragmites australis* reflects the constantly high groundwater levels in this area (SELEZNEVA 1973).

Although we were not able to collect plot-specific management data, the fertilization gradient reflected in the CN ratios and P availability and the differences between the life-form types of the four clusters of the weed vegetation indicate a strong influence of the agricultural management on species composition. Low fertilization rates in the plots of cluster 1 resulted in low densities of nutrient-demanding weed species such as *Chenopodium album* and *Echinochloa crus-galli*. At the other end of the soil nutrient gradient in plots of cluster 4, species indicating high nutrient availability (DIDUKH 2011), e.g. *Amaranthus retroflexus*, *Solanum nigrum* and *Cannabis ruderalis* were abundant. Given that most plots of cluster 1 were found in *TA North*, where land-use intensity is highest (KÜHLING et al. 2016), we conclude that the detected nutrient gradient was mainly of anthropogenic origin. Naturally higher soil fertility could be expected in clusters 1 and 2, which include many plots of the southern test area with fertile Chernozem soils and not in clusters 3 and 4 where Phaeozems are frequent. However, the natural differences in soil fertility have strongly been altered by the higher land-use intensity in areas north of the city of Tyumen, indicated by high P-availability in soils, the high nitrogen indicator value and the narrow CN ratio (clusters 3 and 4, *TA North*). In this area, land use is characterized by high-input agriculture and a concentration of intensive poultry farming due to the proximity to sales markets (KÜHLING et al. 2016).

Alongside the nutrient gradient the increasing proportion of annuals and the decreasing litter cover from cluster 1 to cluster 4 hints on a tillage gradient. Conservation tillage is a reasonable strategy to cope with water limitations in cereal cropping in Siberia (MUELLER et al. 2016), typically occurring in the dryer south (clusters 1 and 2), while in the more humid *TA North* (clusters 3 and 4) vegetable farming with intensive soil disturbance is frequently part of the crop rotation systems (see above). Since reduced tillage results in the accumulation of surface residues (BAKER et al. 2007), the cover of litter can, at least to some extent, indicate the intensity of tillage. This goes along with a decline in annuals and an increase in geophytes along a gradient of decreasing tillage intensity. Such a filtering effect of tillage intensity on the life form spectrum of weed vegetation has also been described by

FRIED et al. (2012), whereas NICHOLS et al. (2015) found only inconsistent trends. As conservational tillage practices at least do not totally destroy the perennating organs of root and rhizome weeds they facilitate the growth of perennial species (CONN 2006, FRIED et al. 2012, ARMENGOT et al. 2015). On the other hand, annual species depend on regular disturbance induced by higher tillage intensities such as moldboard plowing (ZANIN et al. 1997). Our results are in line with SEIFERT et al. (2015), who also found a generally large influence of the tillage type on species composition of arable weed vegetation.

5.2 Species richness

Contrary to our expectations, α-diversity of weed communities in the interior of arable fields in Tyumen province was low with an average of only 10 species 100 m^{-2}. In Central Europe, much higher species richness is common in arable land managed at relatively low intensity. SEIFERT et al. (2014) found 21 species per 100 m^2 in the interior of fields managed according to agro-environmental schemes. Grain fields of Eastern Europe (*Caucalidion lappulae*) – where land-use intensification is lower compared to Central Europe – contained 29 species 100 m^{-2} (MÁJEKOVÁ & ZALIBEROVÁ 2014). A synthesis of all segetal communities of the Czech Republic found on average of 33 species 100 m^{-2} (KROPÁČ 2006). On the other hand, in intensively managed fields of Central Europe much lower species richness can be observed, e.g. < 5 species 100 m^{-2} in the field interior of conventionally managed arable land in Central Germany (SEIFERT et al. 2014). In contrast to species richness, weed cover responded – as expected – to the low land-use intensity in our study area; with an average of 12% it was much higher than in intensively used arable land of Central Europe, where < 1% weed cover was found e. g. by SEIFERT et al. (2014). Even though some species, such as *Galeopsis ladanum*, *Sinapis arvensis*, *Stachys annua* and *Neslia paniculata* (Table 3), were underrepresented, the species pool that we found in Tyumen was very similar to Bashkir weed communities described from MIRKIN et al. in 1985 (see also KÄMPF et al. 2016a). Species richness in Bashkiria – most likely sampled in well-developed stands for the phytosociological study – was typically 10 to 20 species per 100 m^2 and almost all Bashkir species were present in our relevés but many of them with very low frequency. In *Galeopsion bifidae* relevés from the Ural forest-steppe region of Bashkiria even an average of 25 species per 100 m^2 was found (YAMALOV et al. 2007).

In summary our results indicate that arable land-use intensity in Tyumen region is high enough to reduce the density of certain weed species, which results in a low community species richness when plots are chosen by a randomized sampling design. Since the measured soil nutrient levels and crop densities were low (except for soil P contents in *TA North*), herbicide use, which was commonly observed in the field, might be the most important responsible factor for reduced species densities. The negative effect of herbicide application on species richness is described in the literature (STORKEY et al. 2012, MEYER et al. 2015) and was shown in a field trial for Tyumen weed communities (KÄMPF et al. 2016a). An additional management effect is the low variety of different cropping systems in Tyumen region, which is known to limit the diversity of weed vegetation (MEYER et al. 2013). Due to the harsh continental winter conditions, autumn sowing is rarely been practiced. Instead, the majority of fields are sown in late spring and around the same time because the short vegetation period critically limits the time frame for cropping operations.

Apart from the land-use effects the small species pool of arable weeds in Tyumen region seems to limit the species richness of the weed communities. The species pool is restricted because of the region's continental location, which results in unfavourable agroclimatic conditions with long and cold winters, a short growing season and frequent drought stress. Harsh climatic conditions are known to reduce the species richness of weed communities e.g. in the cold climate of the boreal zone of northern Finland (GLEMNITZ et al. 2006), the even more continental climate of Yakutia (MIRKIN et al. 1988), or due to drought stress in the steppe zone, as shown for the *Lactucion tataricae* (MIRKIN et al. 1985). Many thermophilous archaeophytic weed species, typical of European arable weed communities are absent from the Tyumen flora because they reach their eastern distribution limit already west of the Ural Mountains (MEUSEL & JÄGER 1965, 1978, 1998, HULTÉN & FRIES 1986). In Central Europe, archaeophytes add an important component to the diversity of weed communities (KROPÁČ 2006) and their proportion of the total species richness can be higher than 50% (LOSOSOVÁ & CIMALOVÁ 2009). In Tyumen the proportion of these non-native species was only 26% and the missing Central European weed species are not substituted by (East-) Asian counterparts. We found only two species not known from Central Europe in the Tyumen weed communities (*Dracocephalum thymiflorum* and *Cirsium setosum*), which is an extremely low proportion when considering that as much as one third of the species of the whole flora of the Tyumen region are not occurring in Central Europe (KUZMIN, unpublished).The fact that species pools of arable weeds decrease towards colder climate (towards North in Europe) was already described by HOLZNER (1978). Because of their origin in semi-deserts and steppe regions of the Mediterranean and the Middle East, the "Fertile Crescent", non-native (archaeophytic) arable weed species are adapted to warm climate and winter rain and many of these species are winter annuals (ELLENBERG 2009, POSCHLOD 2015). In Central Europe, the proportion of archaeophytic species in weed vegetation decreases with increasing altitude, although archaeophytes of adjacent lowlands have invaded already thousands of years earlier (LOSOSOVÁ et al. 2004).

Another possible explanation for the small weed species pool in Tyumen is dispersal limitation as, the land-use history of arable farming in Tyumen is very short. Although a concentration of Neolithic settlements was found in the southern part of the Tobol-Ishim area (south of Tyumen region) and climate as well as soils were preferable for farming (ZAKH et al. 2010), the Neolithic transformation to arable agriculture did not spread to Western-Siberia. This is in contrast to the forest-steppe regions of European Russia, where first evidence for arable farming is dated to 5500 years BP (RYABOGINA & IVANOV 2011). There is sporadic palaeoecological evidence for the cultivation of grain in the southwest of Western Siberia (Trans-Ural region) for the turn of the 4th to the 3rd millennium BP (RYABOGINA & IVANOV 2011) but palaeobotanical as well as archaeological studies agree that arable farming was never dominant in the people's way of life before the Modern Age (PARZINGER 2011, SCHNEEWEIß & RYABOGINA 2014). Instead, people's lifestyle was dominated by sedentary and semi-sedentary animal-breeding, which was further fostered by the Mongolian rule in Siberia from the 13th century onwards. Only by the end of the seventeenth century arable farming was gradually brought to southwest Siberia in the course of the Russian colonization (NAUMOV 2006). Arable expansion was especially boosted by the construction of the Trans-Siberian railway at the beginning of the last century and finally by the virgin land campaign during the Krushchevera in the 1950s, which was the most extensive of three Soviet large-scale cultivation campaigns and led to the cultivation of almost half of the total Tyumen cropland area (DURGIN 1962). Thus, large-scale arable land use in the region is hardly older than 100 years.

Erweiterte deutsche Zusammenfassung

Einleitung – Der westsibirische Getreidegürtel erstreckt sich im Süden des Tieflandes vom Ural bis zum Altaigebirge und umfasst gut ein Fünftel des russischen Ackerlandes (KÜHLING et al. 2016). Während die floristische Zusammensetzung von Ackerwildpflanzengemeinschaften im angrenzenden Baschkirien westlich des Urals bereits beschrieben wurde (MIRKIN et al. 1985), ist über die Segetalflora des westsibirischen Getreidegürtels bisher fast nichts bekannt. Der Getreideanbau, hauptsächlich Sommerweizen, findet dort auf produktiven Böden statt (Schwarzerden und degradierte Schwarzerden), ist aber begrenzt durch das stark kontinentale Klima mit kurzen Vegetationsperioden und zeitweiliger Trockenheit. Obwohl die Schlagflächen sehr groß sind, ist die Landnutzungsintensität im Vergleich zu Europa gering mit Ernten von 1 bis 2 t ha^{-1} und Düngemengen von bis zu 50 Tonnen Stickstoff pro Hektar. Demzufolge erwarteten wir auf den westsibirischen Äckern artenreiche Segetalgesellschaften, die in ihrer Zusammensetzung hauptsächlich durch natürliche Standorteigenschaften und nicht durch die Bewirtschaftungsweise geprägt sind. Ziel der vorliegenden Arbeit ist die Beschreibung der Ackerwildpflanzenvegetation der Region Tjumen, die im westlichen Teil des Getreidegürtels liegt. Dabei sollen die Einflüsse verschiedener Umweltfaktoren (Bodeneigenschaften, Klima, Bewirtschaftung) auf die Artenzusammensetzung und Phytodiversität analysiert und eine naturschutzfachliche Bewertung vorgenommen werden.

Material und Methoden – Das Untersuchungsgebiet liegt im südlichen Teil der Oblast Tjumen (Westsibirien) im Übergangsbereich von der hemiborealen Zone zur Waldsteppenzone (Abb. 1). Die durchschnittlichen Jahresniederschläge liegen zwischen 401 und 476 mm bei mittleren Jahrestemperaturen von 2° C. Die Probeflächen wurden in drei Testgebieten (*TA North, TA Center, TA South*), die entlang einen klimatischen Gradienten lagen, mittels eines GIS-basierten, randomisierten Samplingdesigns ausgewählt (Mindestabstand zum Feldrand: 100 m). Im Sommer 2012 und 2013 wurden 99 Vegetationsaufnahmen auf 100 m² großen Flächen durchgeführt, Bodenproben genommen und Strukturparameter geschätzt. Für Zeigerwerte nach DIDUKH (2011) wurden gewichtete Mittelwerte berechnet. Der Herkunftsstatus der vorgefundenen Pflanzenarten wurde mittels Arealdiagnosen, Verbreitungskarten und ökologischer Beschreibungen analysiert (MEUSEL & JÄGER 1965, 1978, 1998, HULTÉN & FRIES 1986, KOMAROV et al. 2004). Die Analyse der Artenzusammensetzung der Pflanzengemeinschaften erfolgte mittels hierarchischer Clusteranalyse (Ward Methode), Indikatorarten-Analyse (DUFRÊNE & LEGENDRE 1997) und einer NMDS-Ordination (Mindeststetigkeit von 2 Arten, Stresswert von 0.22 nach 77 Durchgängen).

Ergebnisse – Insgesamt wurden 87 Gefäßpflanzenarten und mittlere Artenzahlen von 9.8 ± 3.8 pro 100 m² erfasst (Mittelwert ± Standardabweichung). Die Deckung der Ackerwildpflanzen war hoch und sehr variabel (12 % ± 11 %). Die Clusteranalyse ergab die Abgrenzung von vier Vegetationsclustern (Abb. 2, Abb. 4), die sich hauptsächlich durch Unterschiede der Lebensformtypen und einiger Bodenparameter unterschieden (Abb. 3). Die Indikatorarten von Cluster 1 und 2 waren zu einem größeren Teil mehrjährig (Tabelle 1), Indikatorarten von Cluster 3 und 4 hingegen waren überwiegend einjährig. Typisch für Cluster 3 waren Nassstandorte (z. B. mit *Phragmites australis*). Unter den Indikatorarten von Cluster 4 waren vor allem Nitrophyten dominant. Insgesamt gesehen war die erfasste Ackerwildpflanzenflora nicht sehr spezifisch für die Region. Außer *Dracocephalum thymiflorum* und *Cirsium setosum* sind alle Arten auch in Europa verbreitet, obwohl bezogen auf die gesamte Flora von Tjumen 30 % der Arten nicht in Mitteleuropa vorkommen. Lediglich 10 Arten mit einem Verbreitungsursprung oder -schwerpunkt in Osteuropa oder Nordasien wurden ermittelt. Der Anteil eingewanderter Arten an der Ackerbegleitfora – neben zwei Neophyten alles Arten, die in Mitteleuropa Archäophyten sind – war mit 26 % im Vergleich zu Mitteleuropa niedrig.

Diskussion – Die Artenzusammensetzung der vorgefundenen Pflanzengemeinschaften weist einige Ähnlichkeiten mit basiphilen Ackerwildpflanzengesellschaften Osteuropas auf, hauptsächlich mit dem *Caucalidion lappulae* und *Fumario-Euphorbion* (KROPÁČ 2006). Viele charakteristische Arten fehlen aber, insbesondere wärmeliebende Archäophyten mit mediterraner Herkunft. Auch im Vergleich zu den

Segetalgesellschaften Baschkiriens (MIRKIN et al. 1985), welche westlich des Urals, aber auf gleichem Breitengrad liegen, fällt auf, dass viele dort häufige Arten in Tjumen nur geringe Stetigkeiten erreichen. Unterschiede in der Artenzusammensetzung lassen sich – entgegen der Erwartungen – nicht hauptsächlich durch natürliche Umweltgradienten erklären. Der geringe Einfluss der Bodeneigenschaften lässt sich durch geringe natürliche Standortunterschiede zwischen den Probeflächen begründen. Hohe Nährstoffgehalte und der daraus folgende hohe Nitrophytenanteil in Beständen von Cluster 3 und 4 (*TA North*) ergeben sich aus der erhöhten Landnutzungsintensität ihrer Standorte östlich der Stadt Tjumen. Das Überwiegen einjähriger Arten in Cluster 3 und 4 deutet auf höhere Pflugintensitäten hin, während in Cluster 1 und 2 ausdauernde Unkräuter von einer reduzierten Bodenbearbeitung profitieren, die sich auch in erhöhten Streudeckungen widerspiegelt (FRIED et al. 2012). Die vorgefundenen Artenzahlen sind im Vergleich zu extensiv genutzten Äckern Europas niedrig, im Vergleich zu konventionell bewirtschafteten Flächen hoch. So lassen sich in Osteuropa, wo die Intensivierung der Landwirtschaft langsamer vorangeschritten ist, Mittelwerte von 29 Arten pro 100 m² belegen (MÁJEKOVÁ & ZALIBEROVÁ 2014), im Inneren von Intensiväckern in Deutschland aber nur weniger als 5 Arten 100 m^{-2} (SEIFERT et al. 2014). Der insgesamt kleine Artenpool der Segetalflora in Tjumen (KUZMIN, nicht veröffentlicht), scheint der wichtigste limitierende Faktor für die Diversität der Ackerwildkrautvegetation zu sein. Der auffällig niedrige Anteil eingewanderter Ackerwildpflanzenarten, vor allem in Mitteleuropa als Archäophyten eingestufte Pflanzen, deutet auf klimatische Ausbreitungsgrenzen dieser oft wärmeliebenden Arten hin. Auch in Mitteleuropa sind viele Ackerwildpflanzenarten in ihrer Ausbreitung wärmelimitiert und fehlen z. B. in Mittelgebirgsregionen (LOSOSOVÁ et al. 2004). Die Ausbreitung nicht heimischer Arten ist in Westsibirien außerdem durch die kurze ackerbauliche Landnutzungsgeschichte eingeschränkt. Trotz klimatisch für den Ackerbau günstiger Phasen haben sich die Menschen Südwestsibiriens bis zur russischen Kolonisierung am Ende des 17. Jahrhunderts hauptsächlich durch Jagen, Sammeln und Tierhaltung in (halb)nomadischer oder sesshafter Lebensweise ernährt (NAUMOV 2006, ZAKH et al. 2010).

Acknowledgements

This work was conducted as part of the project SASCHA (‘Sustainable land management and adaptation strategies to climate change for the Western Siberian grain belt’). We are grateful for funding by the German Government, Federal Ministry of Education and Research within their Sustainable Land Management funding framework (funding reference 01LL0906D). We want to thank Johannes Kamp, Andrey Tolstikov and Roman Latyntsev for their support by organizing the entire infrastructure that was needed for our fieldwork. Many thanks to Sergey Tupitcyn, Sergey Sherstobitov, Gerlinde Gromes, Martin Freitag and Cornelia Mesmer for help with the laboratory work, to Rose Keller for improving our English.

Supplements

Additional supporting information may be found in the online version of this article.

Zusätzliche unterstützende Information ist in der Online-Version dieses Artikels zu finden.

Supplement E1. Frequency table of all registered species in arable weed plots (*n* = 99) of the Tyumen forest-steppe zone and their status of origin.

Anhang E1. Stetigkeitstabelle der in den Ackerwildpflanzengemeinschaften (*n* = 99) der Tjumener Waldsteppenzone nachgewiesenen Arten und ihr Herkunftsstatus.

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Supplement E1. Frequency table of all registered species in arable weed plots (n=99) of the Tyumen forest-steppe zone and their status of origin (obtained by analyzing areal diagnostics, see method section).

Anhang E1. Stetigkeitstabelle der in den Ackerwildpflanzengemeinschaften (n=99) der Tjumener Waldsteppenzone nachgewiesenen Arten und ihr Herkunftsstatus (ermittelt durch Analyse der Areale, siehe Methodenkapitel).

Species	Status of origin	Total frequency
Cirsium setosum	native	77
Chenopodium album	native	55
Sonchus arvensis	native	45
Echinochloa crus-galli	native	40
Taraxacum officinale	native	33
Galium aparine	native	32
Euphorbia esula	native	26
Cannabis ruderalis*	native	23
Galeopsis bifida	native	23
Lathyrus tuberosus*	native	20
Stachys palustris	native	20
Linaria vulgaris	native	15
Persicaria amphibia	native	14
Thlaspi arvense*	native	13
Persicaria lapathifolia	native	11
Chenopodium glaucum	native	10
Nonea pulla*	native	10
Elytrigia repens	native	8
Phragmites australis	native	8
Equisetum arvense	native	7
Plantago major	native	6
Camelina microcarpa*	native	5
Fagopyrum tataricum*	native	5
Lappula squarrosa*	native	4
Persicaria maculata	native	4
Arctium tomentosum	native	3
Malva pusilla*	native	3
Polygonum aviculare	native	3
Vicia cracca	native	3
Artemisia vulgaris	native	2
Chenopodium urbicum	native	2
Crepis tectorum	native	2
Lactuca tatarica*	native	2
Lathyrus pratensis	native	2
Oberna behen	native	2
Plantago media	native	2
Ranunculus repens	native	2
Rorippa palustris	native	2
Atriplex prostrata	native	1
Berteroa incana	native	1
Calamagrostis canescens	native	1
Chamaenerion angustifolium	native	1
Draba nemorosa	native	1
Dracocephalum thymiflorum*	native	1
Erysimum cheiranthoides	native	1
Galium palustre	native	1
Lathyrus palustris	native	1
Lepidium ruderale	native	1
Lythrum salicaria	native	1
Phalaroides arundinacea	native	1
Rumex maritimus	native	1
Silene nutans	native	1
Sisymbrium loeselii	native	1
Stellaria media	native	1
Thalictrum minus	native	1
Convolvulus arvensis	not native (archeophyte)	59
Setaria viridis	not native (anecophyte or archaeophyte**)	51
Avena fatua	not native (archeophyte)	42
Fallopia convolvulus	not native (anecophyte or archaeophyte**)	40
Erodium cicutarium	not native (archeophyte)	38
Raphanus raphanistrum	not native (anecophyte or archaeophyte**)	34
Viola arvensis	not native (anecophyte or archaeophyte**)	14
Amaranthus retroflexus	not native (neophyte, origin: America)	12
Solanum nigrum	not native (anecophyte or archaeophyte**)	12
Fumaria officinalis	not native (archeophyte)	11
Panicum miliaceum	not native (anecophyte or archaeophyte**)	8
Tripleurospermum perforatum	not native (anecophyte or archaeophyte**)	8
Vicia tetrasperma	not native (archeophyte)	7
Conyza canadensis	not native (neophyte, origin: America)	6
Euphorbia helioscopia	not native (archeophyte)	6
Silene noctiflora	not native (archeophyte)	4
Centaurea cyanus	not native (archeophyte)	3
Lamium amplexicaule	not native (archeophyte)	2
Lycopsis arvensis	not native (archeophyte)	2
Vicia angustifolia	not native (archeophyte)	2
Pastinaca sativa	not native (archeophyte)	1
Sonchus oleraceus	not native (archeophyte)	1
Spergula arvensis	not native (archeophyte)	1
Vicia hirsuta	not native (archeophyte)	1
Vicia sativa	not native (archeophyte)	1
Brassica napus	cultivated crop	12
Hordeum vulgare	cultivated crop	12
Triticum aestivum	cultivated crop	11
Medicago sativa	cultivated crop	1
Melilotus officinalis	cultivated crop	1
Pisum sativum	cultivated crop	1
Secale cereale	cultivated crop	1

*Main areal or distribution origin in Asia or Eastern Europe

**Anecophyte according to (Sukopp & Scholz 1997) but not consistent throughout the literature.

Note: We do not exactly know when agriculture and associated migrant weeds came to the Western Siberian grain belt and therefore cannot distinctively distinguish between archaeophytes and neophytes. *'there are indices of human activities occasionally evidenced by the diagnostic''anthropogenic'' pollen taxa in occupation layers otherwise absent of other cultural remains (Ryabogina and Ivanov, 2008) and suggesting presence of early agriculture in the interval of 2900–2500 BP'* (Zakh et al. 2010, p. 100). Sporadic founds of pollen from cereals and even from weed species such as *Chenopodium album*, *Centaurea cyanus* and *Sonchus* spec. in palaeoecological studies prove early occuring forms of arable farming (Ryabogina & Ivanov 2011). However, only by the end of the seventeenth century arable farming was brought to large parts of southwest Siberia (s. discussion, end of section 4.2). Except for *Centaurea cyanus* it is unknown to us if non native species were introduced before or after 1492, but due to their neophytic status in Central Europe, it is very likely that *A. retroflexus* and *C. canadensis* were introduced later than the other non native species.

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