Tuexenia 34: 305–328. Göttingen 2014.
doi: 10.14471/2014.34.014, available online at www.tuexenia.de

Do short-lived ruderal and arable weed communities reflect regional climate differences? A case study from SE Styria

Folgen kurzlebige Ruderal- und Segetalgesellschaften regionalen Klima-Mustern? Eine Fallstudie aus der südöstlichen Steiermark

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Abstract

The Feldbach district is situated near the town of Feldbach in the southeastern province of Styria, Austria. Since 2007, a climate observation network of 151 climate stations within an area of approximately 20 x 15 km (grid cell 1.4 × 1.4 km) has provided a unique collection of spatial and temporal meteorological data. Examining short-lived ruderal and arable weed communities, we search for correlations and spatial patterns between the community composition and climate data. Do such plant communities respond to temperature differences within an agricultural landscape and on a regional scale? Data of 277 relevés from short-lived weed communities were collected across the investigated area during the summer of 2011. Relevés were assigned to the corresponding climate stations and classified. Average Ellenberg indicator values for temperature were calculated for each relevé and community cluster. Measured temperature data were assigned and correlated with community data by applying linear regression and redundancy analyses (RDA). The classification resulted in six associations; the two most frequently observed associations were divided into subtypes resulting in 13 vegetation clusters that could be analyzed further. A significant relationship could be found only between the clusters of arable weed communities and the average winter temperatures. Site variables explain twice as much variance as measured climate variables; this ratio changes to 50 : 50 when we analyzed only arable field community data. No clear spatial patterns concerning mean annual temperature were visible. However, the *Setaria faberi* subtype of the *Echinochloo-Setarietum* and the *Sorghum halepense* subtype of the *Convolvulo-Agropyretum* show a tendency toward a temperature-induced spatial pattern, such that both were sensitive to winter temperature. On a regional scale, the occurrence and composition of short-lived ruderal plant communities correlated weakly with climate variables. However, the studied arable weed communities showed a certain tendency to follow small-scale temperature differences, especially those of average winter temperature. We conclude that short-lived weed communities have the potential to be indicators for global warming, but the spatial temperature gradients are not clear enough in our approach to allow the production of better regression models and elucidation of distinct spatial patterns.

Keywords: climate data, global warming, linear regression, plant communities, RDA, WegenerNet

Erweiterte deutsche Zusammenfassung am Ende des Manuskripts

Manuscript received 16 January 2014, accepted 15 May 2014
Co-ordinating Editor: Brigitta Erschbamer

1. Introduction

Global warming is a reality and uncontroversial among climatologists (WALTHER et al. 2002) and will threaten the world's phytodiversity in a serious manner (THOMAS et al. 2004, THUILLER et al. 2005, GOTTFRIED et al. 2012). Scenarios in which the CO_2 concentration in the atmosphere continues to rise in the future predict a global temperature increase of 1.4 K to 5.8 K over the next hundred years (GITAY et al. 2002). According to IPCC (2007) the global temperature increased during the period of 1850–2001 by 0.76 (± 0.19) K. From 1890 to 1999, the mean annual temperature in the Austrian lowlands rose to 1.22 K (AUER et al. 2001). This means that the mean annual temperature increase in Austria was almost twice as high as the global one.

A particularly sensitive climatic region in Austria is southeastern Styria. It is situated in the transition belt between the Mediterranean and Euro-Siberian regions, where the greatest changes in phytodiversity due to global warming are expected (WALTHER et al. 2002, THUILLER et al. 2005). Analysis of climate data in the Styrian lowlands by KABAS et al. (2011a) and KABAS (2012) show a temperature increase of 1.19 (± 0.40) K throughout the year and a maximum increase of 1.49 (± 0.59) K in summer for the period of 1901 to 2000. From the 1970s onward, a warming trend of 1.62 (± 0.68) K was observed. An extreme increase in temperature of 2.56 (± 0.83) K has been recorded in the summer. The winter months have a higher variability and do not allow any significant trend statement to be made. Looking at precipitation, a negative trend can be observed.

Several studies on climate change highlight the effects of global warming on the vegetation (BAKKENES et al. 2002, PAULI et al. 2012). An increase in temperature leads to earlier germination and flowering in plants, species ranges move toward the poles or to higher mountain areas, and the composition of plant communities changes (WALTHER et al. 2002, THUILLER et al. 2005, POMPE et al. 2008). ESCHBAMER et al. (2011) introduced the term 'thermophilization' for the process of species movement from lower to higher altitudes, and DE FRENNE et al. (2013) generalized the term to refer to the increase of thermophilous species in ecosystems. Particularly striking is the increasing spread of invasive alien plants at the regional level (BRADLEY et al. 2010). Examples for Austria include the highly allergenic ragweed (*Ambrosia artemisiifolia*), which reacts even to the slightest change of temperature (ESSL et al. 2009) and the thermophilous weed *Sorghum halepense* (FOLLAK & ESSL 2013). One of the regions in Austria affected most greatly is the Styrian lowlands (SE-Austria). This modern agricultural landscape with a focus on crop production has the most Mediterranean climate in Austria. In Austria, the region is the preferred entry area for many thermophile neophytes, which have shown remarkable spreading tendencies in recent years. Most greatly affected is the short-lived arable and ruderal weed vegetation ecosystem, which is more and more frequently invaded by species such as *Abutilon theophrasti, Commelina communis, Cyperus esculentus, Eragrostios pilosa, Panicum dichotomiflorum* and *Setaria faberi* (MAURER 1996–2006). The term "short-lived" is used here to refer to communities dominated by annuals. These communities function as an 'entrance gate' for thermophilous neophytes and bring them into the focus of climate research (BRANDES 2007). It is out of question that arable and ruderal weed vegetation is strongly related to human activities and therefore hardly reflect the macroclimate. On the other hand, their dynamic response to temporal and spatial factors implies a quick reaction to environmental changes. In contrast to the thoroughly investigated understory layer of temperate forests (DE FRENNE et al. 2013), no microclimate buffering of macroclimate effects due to higher plant layers occurs in these communities. Starting from the fact that thermophilous weeds and their communities only penetrate into landscapes with warmer climates, we address the question of whether the preference for warmer sites also is detectable on a local scale.

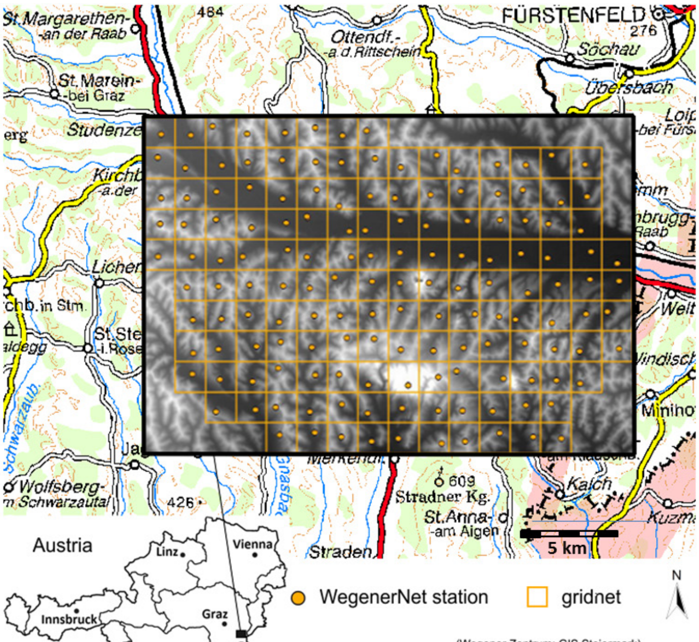
In the Feldbach district, in the center of the Styrian lowlands, a climate station network with a grid width of 1.4 x 1.4 km, the so-called WegenerNet, was established to conduct high resolution regional climate research in 2006 (KIRCHENGAST et al. 2008, KABAS et al 2011b, KIRCHENGAST et al. 2014). Using meteorological data collected in 2011 through the WegenerNet territory, the present study examined relationships existing between the distribution and composition of short-lived ruderal and arable weed communities. We hypothesize that short-lived ruderal and arable weed community composition and distribution respond to local temperature differences within this area. Determining these local distribution limits would enable us to use these communities as climate indicators, and to draw predictions about the further spread of the communities under different global warming scenarios.

2. Study area and WegenerNet

2.1 Geographical situation

The study area includes the rectangular observation area of the WegenerNet around the town Feldbach (E15.89°; N46.95°, Fig. 1) with an area of approximately 300 km² (20 x 15 km) and an mean altitude of 317 m above the sea level. The four corners are defined by the cities Kirchberg an der Raab (northwest), Hatzendorf (northeast), Gnas (southwest) and Kapfenstein (southeast, KIRCHENGAST et al. 2008). The intensively farmed agricultural landscape has a human population density of 92 inhabitants per km² (STATISTIK AUSTRIA 2012) with a decentralized settlement structure. The largest settlement is the city of Feldbach with 4643 inhabitants (STATISTIK AUSTRIA 2012). On the 26,000 ha of arable land, primarily corn, barley, wheat, oilseed rape, Styrian oilseed pumpkin, broad bean and soybean are grown. Smaller areas are used for fruit (mainly apple) and vegetable production. Grasslands with approximately 9,000 ha are of little economic importance for the region. Technology and export-oriented industrial and service companies are almost completely absent (HULMAK et al. 2003).

The province of Styria is located at the transition of the European Alps in the west to the Pannonian Basin in the east. The study area is part of the Southeastern Alpine foreland. Bedrock types are volcanic as well as sedimentary (GASSER et al. 2009). The elevations range from 250 to 598 m. During the Pleistocene Epoch, the area remained unglaciated Bank erosion performed by rivers formed a terraced, hilly landscape (WINKLER-HERMADEN 1966). Soils from five soil groups according to the World Reference Base (FAO 2006) occur in the study area. Fluvisols (deep, nutrient-rich, alluvial soils) and gleyic fluvisols (weakly gleyed alluvial soils) can be found in areas that are periodically flooded by the river Raab and its confluents, which passes into Gleysols (lime-free gleys). On slightly inclined surfaces up to higher terraces, the Stagnosols (pseudogleys) are observed. Stagnosols are either impermeable or only slightly permeable to rainwater and are unfavorable for agriculture after high precipitation. On the hill ridges and slopes, a variety of different soil types occur, whereby the Cambisols (arable brown soils) and Regosols (eroded raw soils) are expected to predominate (KABAS 2012).



(Wegener Zentrum; GIS Steiermark)

Fig. 1. Topographic map of the Feldbach region (original scale 1 : 50000). The study area is marked by the WegenerNet grid net (with courtesy of Wegener Center, Digital Atlas of Styria).

Abb. 1. Topographische Karte der Feldbach-Region (Originalmaßstab 1 : 50000). Das Untersuchungsgebiet ist durch das WegenerNet-Rasternetz markiert (mit freundlicher Erlaubnis des Wegener Zentrums, Digitaler Atlas der Steiermark).

2.2 Climate

The climatic conditions in Austria are mainly influenced by the Alps. The Alpine crest represents a climatic border and shields the Southeastern Alpine foreland from the cold air masses originating to the northwest. The climate is more heavily influenced by winds coming from the Mediterranean and, less markedly, from the Pannonian region. This leads to mainly moderate submediterranean conditions with warm summer and mild winter temperatures (Illyric climate, WAKONIGG 1978). The amount of annual precipitation ranges from 790 to 840 mm (AMT DER STEIERMÄRKISCHEN LANDESREGIERUNG 2012) and exhibits a decline in rainfall from southwest to northeast (WAKONIGG 1978). The mesoclimatic conditions of the particular sampling points are influenced by the geomorphological situation (KABAS 2012). The valleys and enclosed basins are characterized by a weakly continental climate, with cold winters and warm summer temperatures. Here, windless periods are typical and cause an increase in fog and inversion probability. In contrast, the hill ridges exhibit mild winter and warm summer temperatures with more sunshine hours and fewer frost days than the valleys. Hence, there are particular differences in the temperature levels between the valleys and the hill ridges. Whereas the average winter temperatures in the valleys lie below 0 °C, the hill ridges may record year-round positive mean temperatures. Even the average temperature in July reflects the significantly lower temperature level in the basins with values around 20 °C, as compared to the hill ridges, with temperature values exceeding 20 °C (KABAS 2012).

2.3 WegenerNet climate station network – a pioneering weather and climate observation experiment

The climate station network of the Wegener Center for Climate and Global Change enables the observation of climate and weather with a unique level of spatial and temporal resolution. The current international research on regional climate modeling collects data with a spatial resolution of 10–50 km. Within the area of 20 x 15 km, the network comprises 151 meteorological stations arranged on an approximately 1.4 x 1.4 km grid net. Since the beginning of 2007, each climate station has provided continuous measurements of temperature, precipitation and humidity. The temporal sampling of each climate station is at five minute intervals and the climate data are available in near real time. All data of the WegenerNet are publically available via the WegenerNet data portal (www.wegenernet.org, KIRCHENGAST et al. 2008, KABAS et al 2011b).

3. Methods

3.1 Nomenclature

The nomenclature of taxa followed FISCHER et al. (2005) and the nomenclature of syntaxa MUCINA et al. (1993).

3.2 Data collection

The following vegetation types within the short lived ruderal and segetal weed communities according to the classification of MUCINA et al. (1993) were predetermined as targets:

- annual trampling communities of the class *Polygono-Poetea annuae*
- arable weed and short lived ruderal vegetation of the class *Stellarietea mediae*
- ruderal grassland communities of the order *Agropyretalia intermedio-repentis* within the class *Artemisietea vulgaris*

Stands with dominant and homogeneous dispersal of annual or creeping weeds were located across the complete area and within each of the 151 grid cells of the WegenerNet. At least one relevé has been made at any available stand of sufficient size (over 6 m²) and within each grid cell. Vegetation relevés were made by estimating all species, including lichens and bryophytes, within a 6 m² relevé area using the following abundance-dominance scale: r = 1 'individual' and ≤ 5% cover; + = 2–5 'individuals' and ≤ 5%; 1 = 6–50 'individuals' and ≤ 5%; 2m = > 50 'individuals' and ≤ 5%; 2a = 5–15% cover; 2b = 15–25%; 3 = 25–50%; 4 = 50–75%; 5 = >75% (REICHELT & WILMANNS 1973). The plot size was chosen according to the recommendations of DENGLER (2003). Field data are summarized in Table 1. Altitude, longitude and latitude were measured by GPS Garmin eTrex®. We call these 'site variables' as opposed to the measured 'climate variables'. Vegetation data were collected over a period extending from the 25th of June to the 23rd of August, 2011, to capture the summer aspects of the communities.

3.3 Data processing

To process and manage data, we entered the field data in the vegetation data management system TURBOVEG for Windows (HENNEKENS & SCHAMINÉE 2001). The complete dataset is available via the Austrian Vegetation Database (GIVD-Nr. EU-AT-001, see WILLNER et al. 2012). For further data processing, we transferred the data into the program JUICE 7.0 (TICHÝ 2002). For classification, we used the diagnostic species and syntaxon classification provided by MUCINA et al. (1993), crosschecked against SCHUBERT et al. (2001), BERG et al. (2004), and CHYTRÝ (2009). In order to reduce the heterogeneity and noise of the full dataset and improve the fit of linear regression models, we worked in part with community average data rather than single relevé data. For some analyses, we restricted the community data to subsets with the same management regime. Only the arable weed vegetation (*Mercuriali-Chenopodietum*, all subtypes of the *Echinochloo-Setarietum* and the *Convolvulo-Agropyretum*) provided a sufficient number of relevés.

Finally, we used the following datasets:

- single relevé data (*n* = 277)
- clustered data of the associations (*n* = 6) or subtypes (*n* = 13, see Table 4)
- clustered data of the associations and subtypes of the arable weed vegetation only (*n* = 10)

Table 1. Overview of site variables taken in the field, their abbreviations and statistical characteristics.

Tabelle 1. Überblick über die im Gelände erhobenen Standortvariablen, ihre Abkürzungen und statistischen Charakteristika.

Factor	Abbreviation	Range	Mean	Data type
Altitude (m)	ALT	257–424	317	continuous
Aspect (north -1; south +1)	ASP	-1 – +1	–	ordinal
Soil class (clay, loam, sand)	CLAY, LOAM, SAND	–	–	categorical
Soil moisture (dry, moderate dry, moderate moist, moist).	MOIST	-2 – +2	–	ordinal
Land use (trampling site, ruderal, arable field)	TRAMPL, RUD, ARAB	–	–	categorical

3.4 Indicator values and climate data

To characterize the relevés and associations with regard to their climatic preferences, we used the temperature indicator values of Ellenberg (ELLENBERG et al. 1991). Despite the fact that limitations on indicator values are recognized (ZELENÝ & SCHAFFERS 2012), they still provide diverse possibilities in vegetation science (DIECKMANN 2003, REGER et al. 2011) and are recommended as one selection criterion to find indicators for climate change monitoring (DE GROOT et al. 1995, RENETZEDER et al. 2010). Indicator values transform the multivariate species data into a normal distributed continuous sample dataset and, thus, provide the opportunity to use linear regression models. It should be mentioned that Ellenberg's temperature indicator values are of a different kind than the real 'ecological' indicator values for nutrients, moisture and soil reaction. The temperature values are not derived from the ecological behavior of the species in the habitat, but from their zonal range and altitudinal belt preferences. The same idea, but with the help of computer models, is used by PETERSON (2001) and DE FRENNE (2013) to evaluate the temperature preferences of species and plant communities.

The high number of recently introduced species in our dataset made it necessary to generate temperature indicator values for plant species which were lacking in ELLENBERG et al. (1991). According to the rules of ELLENBERG et al. (1991), we used the world distribution data of the species given in JÄGER (2011) and present these in Table 2.

For each relevé, we calculated a mean temperature value in JUICE 7.0, weighted by the cover values of the species. In species-poor vegetation, a weighted calculation is recommended (ELLENBERG et al. 1991). These data were used to calculate a mean temperature value for each association and subtype. For statistical analyses, each relevé was associated with the climate data of the corresponding climate station within the WegenerNet. Finally, we used the climatic variables measured over the period from 2007 to 2011 to minimize seasonal weather fluctuations, which data is presented in Table 3.

We tried many other combinations of temperature values without achieving a satisfactory result. Most of them showed collinerarity to one of the factors provided in Table 3. In particular, the precipitation values were all highly correlated, so we finally used only the value for mean annual precipitation (MAP). For the spatial analysis, we used the mean annual temperatures of 2011.

Table 2. Zonal distribution according to JÄGER (2011) and newly generated temperature indicator values of neophytes found in the area. * see MELZER (2000); ** see MAURER (1996–2006); + from gardens; ++ from agriculture

Tabelle 2. Zonale Verbreitung nach JÄGER (2011) und neu generierte Temperaturzeigerwerte von Neophyten des Untersuchungsgebiets. * s. MELZER (2000); ** s. MAURER (1996–2006); + aus Gärten; ++ aus der Landwirtschaft

Plant species	Zonal distribution	First occurrence in Styria	Newly generated temperature indicator value
Abutilon theophrasti	Meridional – south temperate	1998*	8
Commelina communis	Subtropical – south temperate	1957**	8
Cyperus esculentus	Austral – meridional	1998*	8
Euphorbia lathyris	Meridional – south temperate	escaped+	8
Panicum capillare	Austral – subtropic – temperate	1970**	7
Panicum dichotomiflorum	Meridional – temperate	1980**	8
Panicum milleaceum	Submeridional	1970**	8
Phacelia tanacetifolia	Meridional – submeridional	escaped++	8
Setaria faberi	Submeridional – south temperate	1980**	8
Trifolium alexandrinum	Meridional	escaped++	8

Table 3. Overview of mean Ellenberg's temperature indicator value (calculated as weighted mean of the 277 relevés) and measured **c**limatic variables (derived from the WegenerNet stations in the period 2007 to 2011), their abbreviations and statistical characteristics.

Tabelle 3. Überblick über mittlere Ellenberg-Temperaturzeigerwerte (errechnet als gewichteter Mittelwert der 277 Vegetationsaufnahmen) und gemessene klimatische Variablen (abgeleitet aus WegenerNet-Stationen von 2007 bis 2011), ihre Abkürzungen und statistischen Charakteristika.

Variable	Abbreviation	Range	Mean	Data type
Mean Ellenberg's Indicator value temperature	EIV-t	5.38–7.91	6.62	continuous
Mean annual temperature	MAT	9.53–10.92	10.28	continuous
Mean temperature over the growing season (April-October)	GSMAT	15.03–16.96	15.76	continuous
Mean temperature over the winter season (December, January and February)	DJFMAT	-0.90–0.70	-0.06	continuous
Mean temperature over the summer season (June, July and August)	JJAMAT	18.89–20.13	19.55	continuous
Mean annual precipitation	MAP	598.0–803.5	721.6	continuous

3.5 Statistical analysis

To reveal correlations between the temperature indicator values and the measured climate data, we used linear regression models with the reduced major axis (RMA) algorithm. The significance of the regression was tested by a permutation test that included 10,000 replicates. For this test, the software packages R2.12.2 (R CORE TEAM 2012) and PAST (HAMMER et al. 2001) were used. To calculate the within-group Sørensen-Dissimilarity, we used the analysis-module implemented in JUICE 7.0 (TICHÝ 2002). The index for two relevés a and b was calculated as Ds = 1–2m / (2m+a+b), with m representing the number of common species and a and b, representing the number of species that only occurred in relevé a or b, respectively. The final within-group Sørensen-Dissimilarity was calculated as the average of all pair distanced.

To perform multivariate statistical analyses (redundancy analysis, RDA), we used the program CANOCO for Windows 4.5 (LEPŠ & ŠMILAUER 2003).

3.6 Distribution maps

In order to display climatic spatial patterns of plant communities, we created distribution maps using the program ArcGIS Desktop 10 (ESRI Inc.). We tried to identify a spatial pattern of the distribution of plant communities in terms of the spatial distribution of temperatures in 2011, as revealed by isotherm lines. Seasonal maps of the mean temperature distribution (e.g., summer or winter isotherm maps) gave no interpretable results. The mean annual temperature in 2011 provided the best fit and reflected the expected temperature distribution as specified by the topography of our study area.

4. Results

4.1 Classification

The classification process resulted in the following six associations:

Class: *Polygono-Poetea annuae* Rivas-Martínez et al. 1991
    Poetum annuae Felföldy 1942

Class: *Stellarietea mediae* R. Tx., Lohmeyer et Preising in R. Tx. 1950
    Echinochloo-Setarietum pumilae Felföldy 1942 corr. Mucina 1993
    Mercuriali-Chenopodietum polyspermi Holzner 1973
    Eragrostio-Polygonetum arenastri Oberd. 1954 corr. Mucina 1993
    Erigeronto-Lactucetum serriolae Lohmeyer in Oberd. 1957 em. Mucina 1978

Class: *Artemisietea vulgaris* Lohmeyer &. al. ex von Rochow 1951
    Convolvulo arvensis-Agropyretum repentis Felföldy 1943

The most frequent association observed was the *Echinochloo-Setarietum pumilae*, whereby 175 of 277 relevés (63 %) belonged to this association. To adjust the numbers of relevés within each cluster, the 175 relevés of the *Echinochloo-Setarietum pumilae* and the *Convolvulo arvensis-Agropyretum repentis* were split into appropriate, but informal, subtypes. Table 4 lists all associations and subtypes used for analyses with their abbreviations and selected diversity components. Generally, the communities are species-poor (average species number between 9.79 and 18.74), with the highest species number per plot occurring in the *Sisymbrion*-community *Erigeronto-Lactucetum serriolae*. The dataset is also quite heterogeneous with Sørensen-dissimilarity indices ranging between 0.5697 and 0.7162.

4.2 Indicator values and temperature data

For each community, the mean temperature indicator values and selected temperature data are shown using box-whisker plots (Fig. 2a–c). The groups were ordered according to the classification given in Table 2. A particularly high proportion of species with high EIV-t were observed in the *Eragrostio-Polygonetum arenastri* and the *Setaria faberi*- as well as the *Panicum dichotomiflorum*-subtype of the *Echinochloo-Setarietum pumilae* (Fig. 2a). The medians of the various temperature datasets (Fig. 2b, c) are very close together, and show no clear correlation according to temperature preferences of the particular community types.

Table 4. Name of communities and subtypes with abbreviations and some diversity components. **N** = number of relevés; **mean α** = mean species number within group; **Sp** = total number of species within group; **Ds** = within group Sørensen-Index (dissimilarity, pair compared).

Tabelle 4. Name der Gesellschaften und ihrer Untereinheiten mit Abkürzungen sowie einige Diversitätskomponenten. **N** = Zahl der Vegetationsaufnahmen; **mean α** = mittlere Artenzahl innerhalb einer Gruppe; **Sp** = absolute Artenzahl innerhalb einer Gruppe; **Ds** = Sørensen-Index innerhalb einer Gruppe (Unähnlichkeit, paarweiser Vergleich).

Association and subtypes	Abbreviation	N	mean α (area 6 m²)	Sp	Ds
Poetum annuae	PA	20	10.75	78	0.7021
Echinochloo-Setarietum pumilae	ES	175	11.95	189	0.6706
– *Bidens tripartitus* subtype	ESBT	13	11.38	53	0.6224
– *Galinsoga parviflora* subtype	ESGP	26	14.62	85	0.5757
– *Panicum dichotomiflorum* subtype	ESPD	42	9.79	77	0.5697
– *Persicaria lapathifolia* subtype	ESPL	41	11.39	88	0.5744
– *Setaria faberi* subtype	ESSF	17	12.76	77	0.6191
– *Solanum nigrum* subtype	ESSN	8	16.13	61	0.6114
– typical subtype	ESTA	28	12.14	107	0.6984
Mercuriali-Chenopodietum polyspermi	MC	28	17.29	134	0.7162
Eragrostio-Polygonetum arenastri	EP	13	12.92	65	0.6649
Erigeronto-Lactucetum serriolae	EL	19	18.74	140	0.7574
Convolvulo arvensis-Agropyretum repentis	CA	22	11.14	87	0.6801
– *Sorghum halepensis* subtype	CASH	9	10.77	62	0.5768
– typical subtype	CATA	13	11.67	47	0.6873

4.3 Linear regression

No correlation with temperature data could be found when testing the single relevé data of the entire dataset. e.g., the mean annual temperature (MAT, Fig. 3a). We tested the mean values based on our classification and, indeed, the coefficient of determination increased in the regression, but without achieving any level of significance. Examples with aggregated values from the communities including subtypes are given in Figure 3b, and from the associations, in Figure 3c. Our last attempt involved a further restriction to the arable field data. Here, we found our only significant linear regressions of the arable field datawith the winter temperatures: mean January-temperature, $r^2 = 0.44$, p-value = 0.04, and as the best regression, mean winter temperature, DJFMAT, $r^2 = 0.49$, p-value = 0.02 (Fig. 3d).

4.4 Multivariate analysis

A detrended correspondence analysis (DCA, species percentage cover log transformed, downweighting of rare species) provides the length of gradient, which is informative about linear or unimodal response of the dataset. For all 277 relevés, the length of gradient of the first axis is 4.119, whereby for a reduced dataset only with arable field data (225 relevés), it was 3.424. These values lie at the boundary between a linear and unimodal species response and allow using both redundancy analysis (RDA) and canonical correspondence analysis (CCA). For better comparability, we followed PINKE et al. (2012) and KLEYER et al. (2012), who recommended the use of RDA for the investigation of species relationships to climate and environmental data. As a management variable, we used presence of trampling

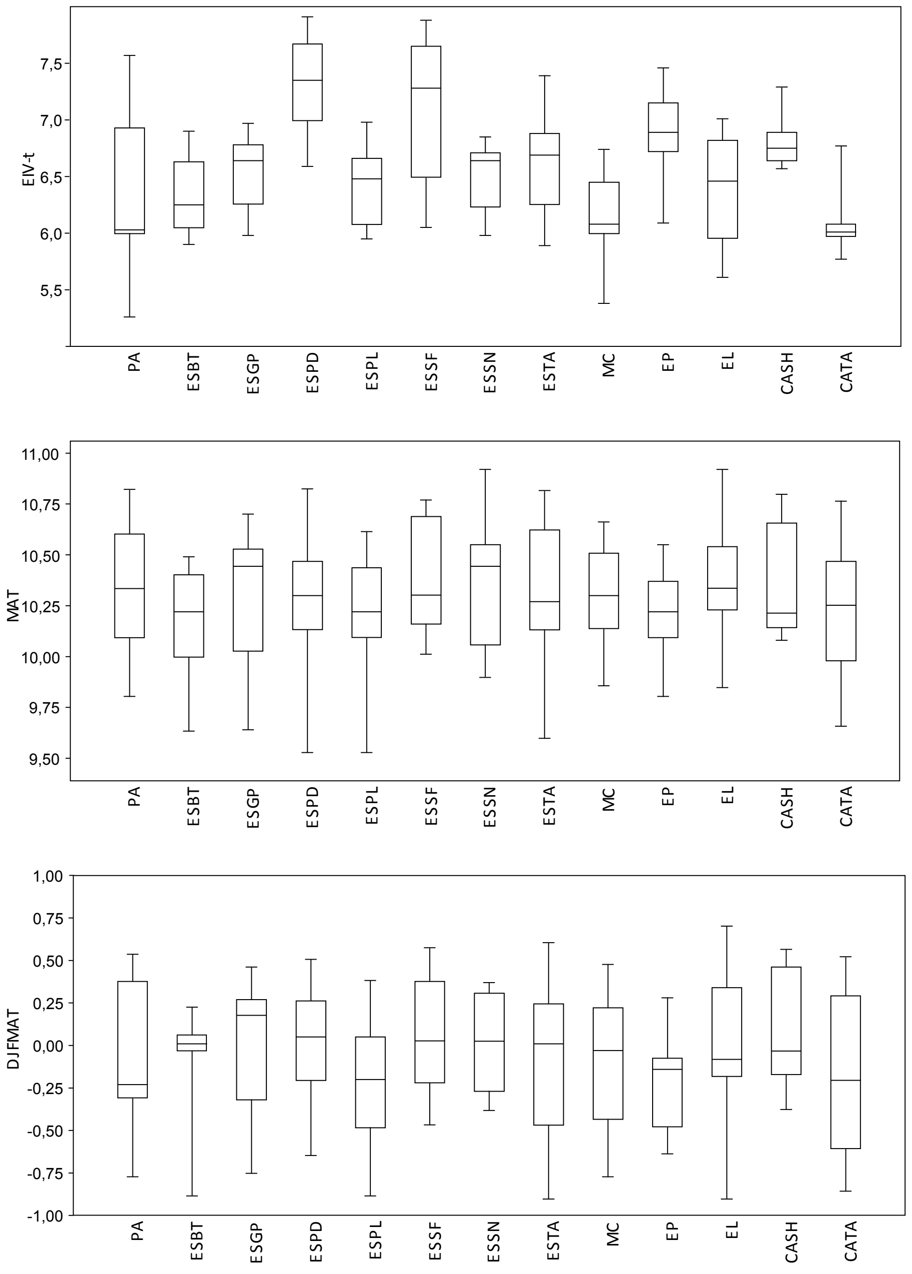


Fig. 2. Mean temperature indicator values and temperature data of the individual community plots. **(a)** Ellenberg's temperature indicator values (EIV-t); **(b)** mean annual temperature (MAT) in °C; **(c)** mean winter temperature (DJFMAT) in °C. For community abbreviations see Table 4.

Abb. 2. Mittlere Temperaturzeigerwerte und Temperaturdaten der einzelnen Gesellschaftsflächen. **(a)** Ellenberg-Temperaturzeigerwete (EIV-t); **(b)** mittlere Jahrestemperatur (MAT) in °C; (c) mittlere Wintertemperatur (DJFMAT) in °C. Für die Abkürzungen der Gesellschaften s. Tabelle 4.

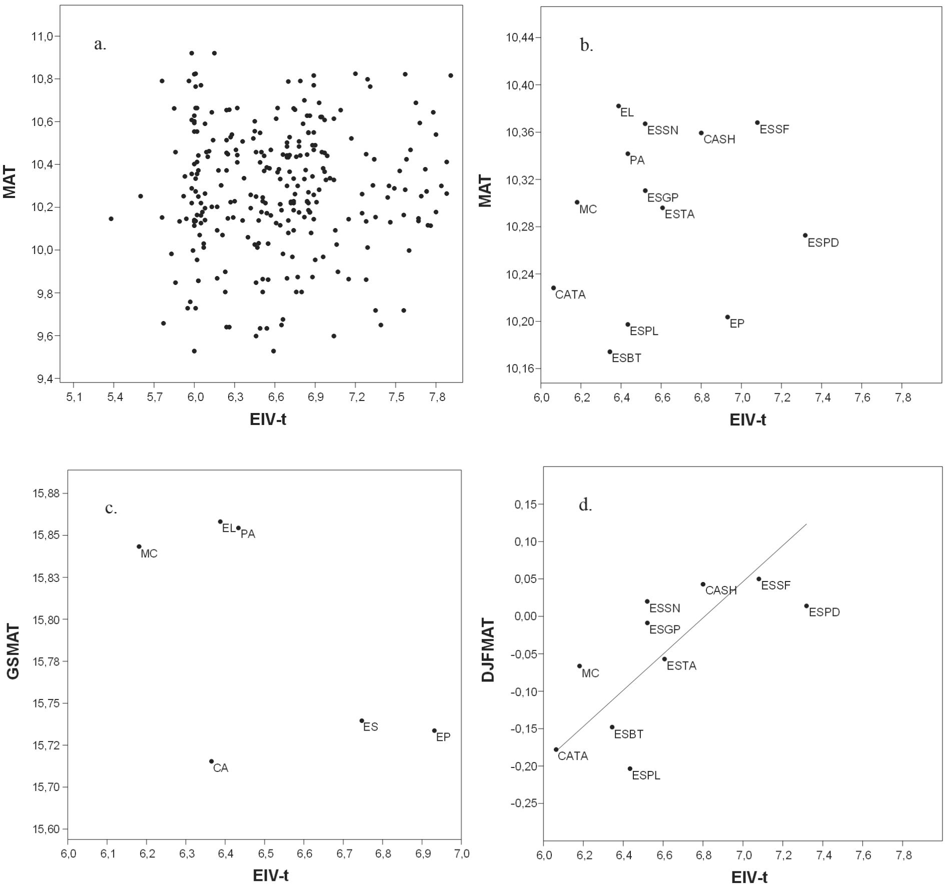


Fig. 3. Scatter plots with regression line; **(a)** EIV-t of the relevés are not correlated with MAT ($r^2 = 0.002$; $p = 0.43$); **(b)** Mean EIV-t of the communities, including subtypes do not correlate significantly with MAT ($r^2 = 0.024$; $p = 0.61$); **(c)** Mean EIV-t of the associations do not correlate with the mean temperature during the growing season (GSMAT) ($r^2 = 0.352$; $p = 0.21$); **(d)** Mean EIV-t of the arable weed communities, including subtypes show a correlation with the temperature during the winter months (DJFMAT) ($r^2 = 0.49$; $p = 0.02$). For community abbreviations see Table 4.

Abb. 3. Scatter Plots mit Regressionsgerade; **(a)** EIV-t der Vegetationsaufnahmen sind nicht mit MAT korreliert ($r^2 = 0{,}002$; $p = 0{,}43$); **(b)** Mittlere EIV-t der Gesellschaften einschließlich ihrer Untereinheiten korrelieren nicht signifikant mit MAT ($r^2 = 0{,}024$; $p = 0{,}61$); **(c)** Mittlere EIV-t der Assoziationen korrelieren nicht mit mittleren Temperaturen während der Vegetationsperiode (GSMAT) ($r^2 = 0{,}352$; $p = 0{,}21$); **(d)** Mittlere EIV-t der Ackerwildkrautgesellschaften einschließlich ihrer Untertypen zeigen eine Korrelation mit der Temperatur während der Wintermonate (DJFMAT) ($r^2 = 0{,}49$; $p = 0{,}02$). Für die Abkürzungen der Gesellschaften s. Tabelle 4.

(TRAMPL); as further site variables, we used altitude (ALT), soil moisture (MOIST), the soil class sand (SAND), and aspect (ASP). As measured climate variables, we used mean annual temperature (MAT), mean temperature over the winter season (DJFMAT), mean temperature over the growing season (GSMAT) and mean annual precipitation (MAP). Corresponding categorical variables were removed due to collinearity, indicated by high

(> 8) variance inflations factors. Because the explained variance depended on the number of variables (Pinke et al. 2012), we used an equal number of site and climate variables during the analysis.

The results show, in correspondence to the results of the linear regression, a high level of heterogeneity, weak species-environmental correlations and a low level of explained variance. The eigenvalues of the first and second axes in an RDA plot of all relevés are 0.054 and 0.014, respectively. The forward selection and Monte-Carlo permutation tests (499 permutations) indicated TRAMPL ($P = 0.002$), SAND $p = 0.002$), ALT ($P = 0.002$), DJFMAT ($P = 0.008$), GSMAT ($P = 0.002$), and MOIST ($p = 0.01$), in this order, as the most important variables. As Figure 4 shows, the variables TRAMPL and SAND as well as MOIST are related to the first axis, while the climate variable DJFMAT (and MAP, n.s.) is related to the second axis.

To reduce the variance and noise of the dataset and to eliminate the important management factor TRAMPL, we performed another RDA including only arable field data and excluding the management factor. In this case (Fig. 5), the forward selection and Monte-Carlo permutation tests revealed mean temperature over the winter season (DJFMAT, $p = 0.004$), altitude (ALT, $p = 0.004$), mean temperature over the growing season (GSMAT, $p = 0.006$), and soil class SAND ($p = 0.046$) as the most significant factors, whereby climate variables were now represented along the first axis, while altitude and soil moisture were represented along the second axis.

The data show the substantial impact of climate data on the weed communities, especially when the variability that is derived from management is kept small. More evidence is provided by a variance partitioning of a partial RDA (pRDA). We used the variables in Figure 5: ALT, MOIST, SAND, and ASP as site variables (or covariables), and MAT, DJFMAT, GSMAT and MAP as climate variables (or covariables). In a pRDA of the whole dataset, 54.6% of the explained variance can be explained by the site variables, while 23.7% of the variance can be explained by the climate variables (Table 5). In comparison, using the reduced arable field dataset, 49.1% of the variance is explained by the site variables, while 50.9% of the variance can be explained by the climate variables.

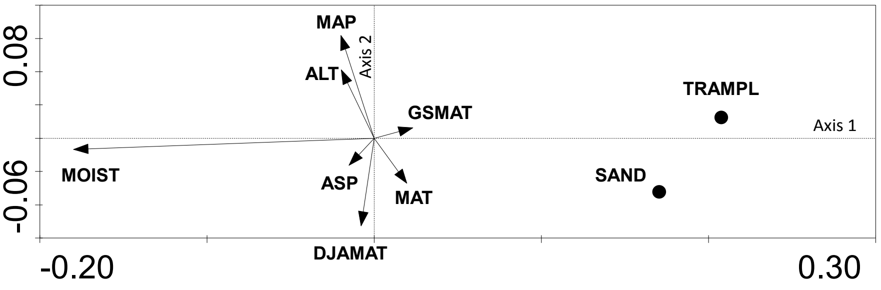


Fig. 4. Ordination RDA plot of the explanatory variables using all relevés. Data log transformed, the eigenvalues of the first and second axis are 0.054 and 0.014. For variable abbreviations see Table 1 and 3.

Abb. 4. RDA Ordinationsplot der erklärenden Variablen unter Verwendung aller Vegetationsaufnahmen. Daten log-transformiert, die Eigenvalues der ersten und zweiten Achse sind 0,054 und 0,014. Für die Abkürzungen der Variablen s. Tabellen 1 und 3.

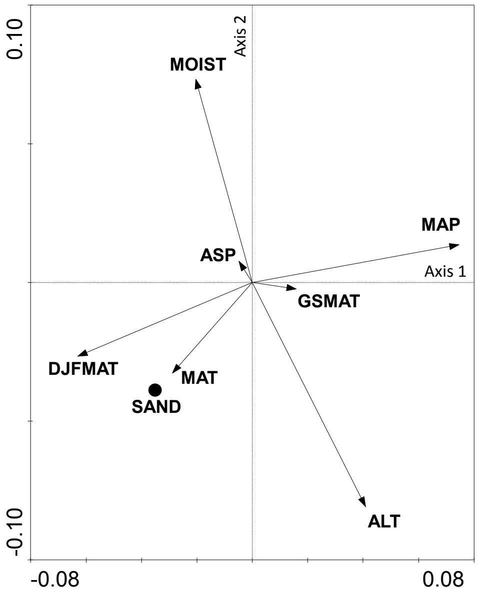


Fig. 5. Ordination RDA plot of the explanatory variables using only arable field relevés. Data log transformed, the eigenvalues of the first and second axis are 0.018 and 0.013. For variable abbreviations see Table 1 and 3.

Abb. 5. RDA-Ordinationsplot der erklärenden Variablen nur unter Verwendung der Acker-Vegetationsaufnahmen. Daten log-transformiert, die Eigenvalues der ersten und zweiten Achse sind 0,018 und 0,013. Für die Abkürzungen der Variablen s. Tabellen 1 und 3.

Table 5. Results of variance partitioning of a RDA of all 277 relevés and of the arable field data (225 relevés).

Tabelle 5. Ergebnisse der Varianz-Partitionierung einer RDA aller 277 Vegetationsaufnahmen und der Ackerdaten (225 Aufnahmen).

	All data			Only arable field data		
	Eigen-values	% total	% of explained variance	Eigen-values	% total	% of explained variance
Total variance (Sum of all eigenvalues)	1.000	100	–	0.972	100	–
Total explained variance	0.097	9.7	–	0.055	5.5	–
Explained variance environment	0.053	5.3	54.6	0.027	2.7	49.1
Explained variance climate	0.023	2.3	23.7	0.028	2.8	50.9
Explained variance environment + climate	0.021	2.1	21.6	0	0	0

In both RDA analyses, the species scores gave no clear correlation along one axis. Figure 6 illustrates the most important species, with an EIV-t of 7 or 8 of the species. Because the climate data explain only a small part of the variance, the species are ordered according to the site variables related to the first axis. The trampling and ruderal species are located on the right side of the plot, and arable weeds are located on the left side.The reduced arable field dataset also allows no clear conclusions to be drawn with relation to climate variables.

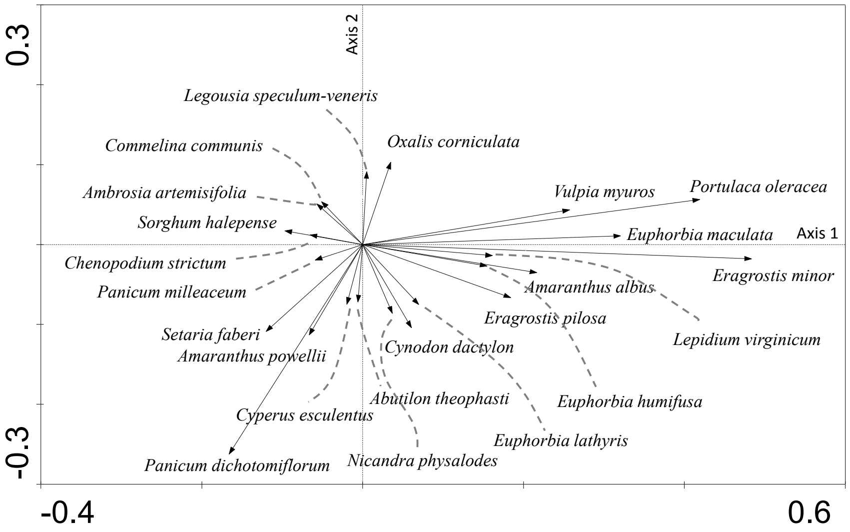


Fig. 6. RDA species plot. Only species with EIV-t of 7 or 8 are shown. The plot corresponds to the explanatory variables of Figure 4. The eigenvalues of the first and second axis are 0.054 and 0.014.

Abb. 6. RDA-Artenplot. Nur Arten mit EIV-t von 7 oder 8 sind gezeigt. Der Plot korrespondiert mit den erklärenden Variablen von Abbildung 4. Die Eigenvalues der ersten und zweiten Achse sind 0,054 und 0,014.

4.5 Spatial patterns of the communities

The mean annual temperature data within the study area varied around 1.4 °C. Our communities within this amplitude showed no significant climate-induced spatial pattern. The *Panicum dichotomiflorum* subtype of the *Echinochloo-Setarietum pumilae* (Fig. 7a) provided an example. Their occurrences were scattered over the entire area and fell within temperatures ranging from the climate-favored Gleichenberger basin to the cooler Raabtal, despite the fact that this community showed the highest median of a temperature indicator value of all weed communities in the area (Fig. 2a).

The *Setaria faberi* subtype of the *Echinochloo-Setarietum pumilae* (Fig. 7b) and the *Sorghum halepense* subtype of the *Convolvulo arvensis-Agropyretum repentis* (Fig. 7c) showed weak tendencies to form temperature-induced spatial patterns. Both communities were not found in 'cooler' areas in 2011, and both communities occurred in areas with the highest temperature minima in comparison with all other communities (Fig. 2b).

5. Discussion

The supposition that short-lived weed communities are omnipresent in the Central European landscape is not realized within the Feldbach region. Real 'waste places' are hardly to be found in an intensively farmed agricultural landscape with prevalent small-scale land use and ownership structure. The same observation was recently reported in areas around German villages (HUWER & WITTIG 2013). Even the arable weed vegetation – dominated by maize crops – is strongly controlled by herbicides. Thus, we performed one vegetation relevé whereever we found our target vegetation, and the total number of relevés depended on their limited occurrence and the small study area.

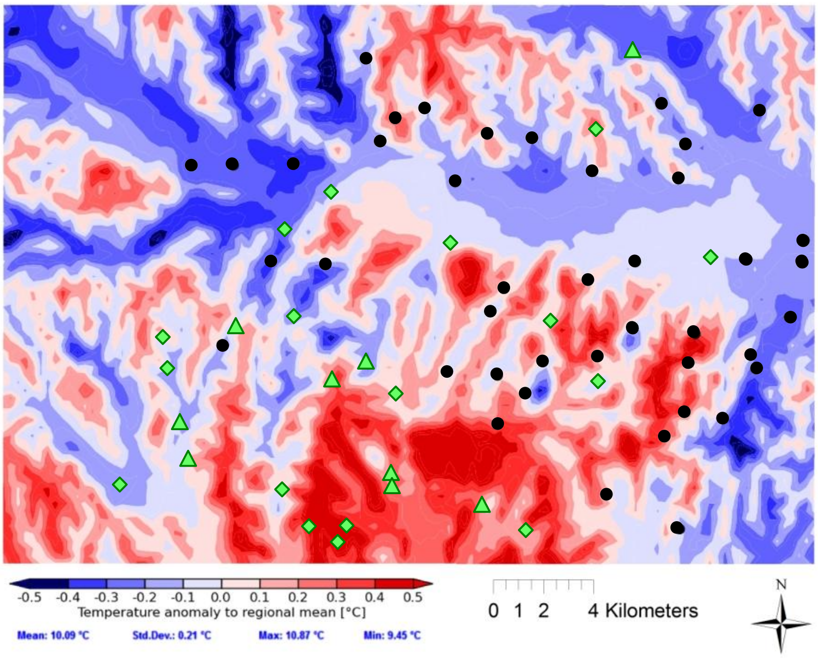


Fig. 7. Distribution map three plant community types in 2011: a) *Echinochloo-Setarietum pumilae*, *Panicum dichotomiflorum* subtype (ESPD, black dots); b) *Echinochloo-Setarietum pumilae*, *Setaria faberi* subtype (ESSF, green diamonds); c) *Convolvulo arvensis-Agropyretum repentis*, *Sorghum halepense* subtype (CASH, green triangles). Mean annual temperature 10.09 °C (± 0.21); Min: 9.45 °C, Max: 10.87 °C.

Abb. 7. Verbreitungskarte der drei Pflanzengesellschaften im Jahr 2011: a) *Echinochloo-Setarietum pumilae*, *Panicum dichotomiflorum*-Untertyp (ESPD, scharze Punkte); b) *Echinochloo-Setarietum pumilae*, *Setaria faberi*-Untertyp (ESSF, grüne Rauten); c) *Convolvulo arvensis-Agropyretum repentis*, *Sorghum halepense*-Untertyp (CASH, grüne Dreiecke). Mittlere Jahrestemperatur 10,09 °C (± 0,21); Min: 9,45 °C, Max: 10,87 °C.

Recently introduced species such as *Abutilon theophrasti, Amaranthus albus, Commelina communis, Cyperus esculentus, Nicandra physalodes* or *Sorghum halepense* have spread from the south and are not yet been well established regionally. This situation leads to an inhomogeneous dataset, despite the fact that weed vegetation data are generally “noisier” than data from more stable environments due to stochastic effects. The number of ‘zeros’ in our data is quite high; only 15 species reach a frequency of 20%, whereas 75 species occur only once and 39 twice, corresponding to 41% of all 267 species. Thus, classification is also difficult and the within-group heterogeneity is high (see Table 4, Sørensen-dissimilarity).

To transform multivariate abundance-dominance data of plant communities into a continuous, climate relevant data series, we used Ellenberg’s temperature indicator value (DE GROOT et al. 1995, RENETZEDER et al. 2010). As climate variables, we used the measured weather data from the WegenerNet, within a maximum distance of 700 m.

In our study area, no temperature optimum curves of the communities could be formed, and significant correlations between climate and short lived weed vegetation data were barely detectable. The reduction of the dataset to classified units led to better regression coefficients, but a significant regression with determination coefficients around 0.45 were stated only with winter temperatures and the groups of arable field vegetation. One explanation could be that the winter temperatures in the area cluster around the freezing point. Frost tolerance of seedlings is known as one crucial parameter for invasion success of plants (SKÁLOVÁ et al. 2011), especially in segetal communities with a high proportion of winter annuals (LEIBLEIN-WILD et al. 2014). KREYLING et al. (2011) emphasize the importance of winter in the climate change process with reference to species composition, and focus on the increasing frequency of soil freeze-thaw cycles. Dormancy, vernalization and germination time and conditions of plant individuals could play further roles. The process is certainly not fully understood, but it is a matter of fact that the 0 °C January isotherm separates frost-sensitive and frost-resistant species and vegetation types (JÄGER 1968). In Great Britain, DE ALBUQUERQUE et al. (2011) found that the species richness of exotic plants was primarily and positively associated with temperature, while RENETZEDER et al. (2010) in their comprehensive study among Austrian habitats found the strongest relationship with temperature. FOLLAK (2010) describes many species of neophytes in the arable weed communities of Austria as thermophilous and as having low frost resistance. This could mean that the winter 0°C isotherm is crucial for monitoring climate-induced range shifts.

It is striking that precipitation was shown to have only limited importance in our study, as well as in previous investigations in Austria (RENETZEDER et al. 2010). That might be because (1) precipitation is just one component of soil moisture, which depends mainly on several soil parameters including the groundwater level, (2) the spatial variability of precipitation is even higher than those of temperature ranges, and (3) the gradient in precipitation data is too short in our study area.

The multivariate ordinations provide results apart from the Ellenberg indicator values. Calculating the whole dataset, the dominance of site variables is significant and visible in the ordination biplot with all environmental variables (Fig. 4), as well as in the proportion of site variables (more than twice of climate data), at the explained variance (Table 5). When only the arable field data were used, the results change: the importance of climate variables increased in comparison with site variables, which were related to the second axis (Fig. 5), and the climate variables explained about an equal proportion of the variance (Table 4).

DE GROOT et al. (1995) suggested that plants with EIV-t > 6 were indicator species for global warming, but these species present no consistent picture in our RDA species plot (Fig. 6). Single species respond to different climate and habitat gradients in diverse ways (e.g. HAR-EDOM & STERNBERG 2009 for *Conyza canadensis,* BAKKENES et al. 2002), so we recommend using community data, instead of single species data.

The distribution patterns of the short-lived ruderal and segetal communities are mainly affected by anthropogenic influences, and only secondarily by the fluctuation of the climate variables, as CIMALOVÁ & LOSOSOVÁ (2009) demonstrated. Weak spatial correlations can be seen with the most thermophilous communities, such as the *Setaria faberi* subtype of the *Echinochloo-Setarietum* and the *Sorghum halepense* subtype of the *Convolvulo-Agropyretum*. The species *Sorghum halepense* that is currently invading our region generally prefers warmer landscapes during its spread northward (ESSL 2005, FOLLAK, & ESSL 2013).

Effects of global warming on the vegetation have been studied mainly in natural landscapes, far from human influence (BERRY et al. 2003, JEDRZEJEK et al. 2012, PAULI et al. 2012). It is obvious that the anthropogenic vegetation is less sensitive to climate change than natural vegetation (RENETZEDER et al. 2010). However, climate change will significantly affect crop production (ALEXANDROV & EITZINGER 2002) and arable weed community composition in the future (FOLLAK 2010). Once the effects of climate variables are filtered out, a high degree of unexplained variance remains, in our case with a limited number of independent environmental data points of more than 90%.

Ruderal communities rich in neophytes are generally considered as flexible and euryoecious with (mainly anthropogenic) habitat fluctuation and disturbance representing the most important factors for occurrence (JÄGER 1988, DAVIS et al. 2000, CATFORD et al. 2012), and will face fewer changes in species composition due to global warming as compared with natural habitats (RENETZEDER et al. 2010). However, even the anthropogenic vegetation follows climate patterns, and vegetation changes in ruderal and segetal plant communities could be attributed to climate variables in large-scale analyses (JÄGER 1988, BEERLING et al. 1995, ESSL et al. 2009, BRADLEY et al. 2010, DE ALBUQUERQUE et al. 2011). PINKE et al. (2012) found out that climate factors are among the most important environmental parameters for the composition and distribution of arable weed communities in Hungary. LOSOSOVÁ et al. (2004) present similar conclusions for the Czech Republic and Slovakia.

The advantages of using weed vegetation as a climate indicator include the high amount of temporal species turnover, its role as a first habitat for newly introduced neophytes, and particularlly the close integration with the human environment. At least some of our weeds meet the six demands for climate indicators postulated by DE GROOT et al. (1995: 939): climate sensitivity, habitat constraints, position at the border of distribution range, high dispersal capacity, functional position in the ecosystem and suitability for monitoring. There are also benefits within the setting of public debate. We can illustrate and communicate the impact of changes on our doorstep much more easily than those in the Arctic or on high mountain peaks. Disadvantages are the inhomogeneous data, the high influence of management and habitat, and the fact that these communities themselves will be endangered in the future (CHYTRÝ et al. 2012).

The influence of climate change on the vegetation has been studied and predicted mainly on a continental scale (BEERLING et al. 1995, BAKKENES et al. 2002, BRADLEY et al. 2010, PAULI et al. 2012). Data density of climate data was achieved by interpolation of coarser data (HIJMANS et al. 2005). The WegenerNet provides a unique density of measured data that can be directly used to check the response of the vegetation to climate fluctuations over a longer period. Here, the measurement points extend over an area of approximately 20 km x 15 km. If the environmental gradients are long enough, this size may be appropriate, as LE ROUX & MCGEOCH (2008) have shown for the comparably extensive Marion Islands. In our study area, however, the five year period of mean annual temperature showed a spatial difference of only 1.4 degrees (Table 3). The altitude of open habitats varied only around 170 m (Table 3). These differences are apparently too small to generate clear response patterns for plant communities.

CIMALOVÁ & LOSOVÁ (2009) found that the impact of climate variables decreases with decreasing length of the environmental gradients. SIEFERT et al. (2012) checked the vegetation–environment relationship in 63 published studies with regard to study area size and sampling plot density. They concluded that the relative effects of climatic variables on plant community composition increased with area size, and decreased with sampling plot density. All this suggests that, on a larger scale with longer climate gradients, climate-induced patterns would be more clearly evident.

6. Conclusions

Within the WegenerNet area, the gradients are too short to discern substantial climate-induced patterns for ruderal and segetal weed communities. Comparing different datasets, the dependence of short-lived weed communities on climate variables is more clearly visible in vegetation types that do not differ greatly in their management and habitat preferences. We found a significant relationship only by reducing the dataset to the arable weed communities. One may conclude that short-lived weed communities on a local scale only weakly reflect climatic differences. Our results indicate, on the other hand, that the arable field vegetation has potential to represent a climate indicator when considering larger study areas or longer temperature gradients. This would also allow monitoring the impact of global warming on plant community composition even in anthropogenically altered areas.

Erweiterte deutsche Zusammenfassung

Einleitung – Während die globale Durchschnittstemperatur in der Periode von 1850 bis 2001 um 0.76 °C anstieg (SOLOMON et al. 2007), konnte in der Südoststeiermark von 1901 bis 2000 ein Anstieg der mittleren Jahrestemperatur von 1.19 °C und der Sommertemperaturen von 1.49 °C nachgewiesen werden (KABAS et al. 2011a, KABAS 2012). Im Jahre 2006 wurde im Raum Feldbach ein hochauflösendes regionales Klimamessnetz mit Namen WegenerNet errichtet, welches 151 Messstationen mit einer Rasterdichte von 1,4 km umfasst (KIRCHENGAST et al. 2008, KIRCHENGAST et al. 2013).

Es steht außer Frage, dass selbst Ruderalpflanzen auf diese Erwärmung reagieren (BRANDES 2007, ESSL et al. 2009). Die Südoststeiermark ist Eintrittspforte für wärmeliebende Neophyten nach Mitteleuropa, wie beispielsweise derzeit die Ausbreitung von *Sorghum halepense* zeigt (FOLLAK & ESSL 2013). Doch kann man diese Entwicklung auch in sehr kleinräumigem Maßstab nachweisen? Zu diesem Zweck haben wir kurzlebige Ruderal- und Segetalgesellschaften im Bereich des WegenerNet untersucht. Wir gehen dabei von der These aus, dass diese Vegetationstypen zwar stark durch menschliche Aktivitäten bestimmt werden, andererseits aber durch ihre hohe räumliche und zeitliche Dynamik und eine flexible Artzusammensetzung sehr schnell auf veränderte Umweltbedingungen reagieren können. Ziel der Arbeit ist, Zusammenhänge zwischen kleinräumigen Klimaunterschieden im Gebiet des WegenerNet und der Verbreitung und Zusammensetzung der Ruderal- und Segetalvegetation im Jahre 2011 zu ermitteln.

Untersuchungsgebiet – Das Untersuchungsgebiet liegt im steirischen Bezirk Feldbach und erstreckt sich über eine Fläche von ca. 300 km² (20 km x 15 km). Es handelt sich um eine intensiv agrarisch genutze Hügellandschaft, Ackerland und Wald dominieren. Das Gebiet hat eine durchschnittliche Seehöhe von 317 m. Das Klima ist warm-temperat und wird vom Illyrischen Raum geprägt, mit warmen Sommern und milden Wintern.

Methoden – Im Sommer 2011 wurden folgende Vegetationstypen erfasst:

- Trittpflanzengesellschaften der Klasse *Polygono-Poetea annuae*
- Segetalgesellschaften und kurzlebige Ruderalgesellschaften der Klasse *Stellarietea mediae*
- Ruderales Grasland der Ordnung *Agropyretalia intermedio-repentis* (Klasse *Artemisietea vulgaris*)

Die Gesellschaften wurden gebietsweit erfasst und an jedem Fundpunkt und im Bereich jeder Messstation wenigstens eine Vegetationsaufnahme mit 6 m² Flächengröße angefertigt. Der Enddatensatz umfasst 277 Vegetationsaufnahmen. Um den Vegetationsaufnahmen einen klimarelevanten Wert zuzuordnen, wurden die mittleren gewichteten Temperaturzeigerwerte nach ELLENBERG et al. (1991) berechnet. Diese haben wir mit den entsprechenden gemessenen Temperaturwerten unterschiedlicher Intervalle (z. B. Jahresmittelwerte, Mittel über die Vegetationsperiode, Mittel über die Jahreszeiten usw.) sowie mit Isothermenkarten in Beziehung gesetzt.

Ergebnisse – Die 277 Aufnahmen wurden folgenden Assoziationen zugeordnet: *Poetum annuae, Echinochloo-Setarietum pumilae, Mercuriali-Chenopodietum polyspermi, Eragrostio-Polygonetum arenastri, Erigeronto-Lactucetum serriolae* und *Convolvulo arvensis-Agropyretum repentis*. Die häufigste Assoziation war das *Echinochloo-Setarietum pumilae* mit 175 von 277 Aufnahmen. Um die Aufnahmezahlen der einzelnen Cluster anzugleichen, haben wir die häufigen Gesellschaften in informelle Einheiten weiter untergliedert (Tab. 4). Die höchsten mittleren Temperaturzeigerwerte wiesen das *Eragrostio-Polygonetum arenastri* sowie die *Setaria faberi*- und *Panicum dichotomiflorum*-Untergesellschaft des *Echinochloo-Setarietum pumilae* auf (Abb. 2a). Die gemessenen Temperaturdaten differierten dagegen deutlich weniger (Abb. 2b, c). Im Zuge der linearen Regression konnte lediglich ein signifikanter Zusammenhang mit den Wintertemperaturen gefunden werden, und auch nur, nachdem wir die Variabilität des Datensatzes durch Beschränkung auf die Segetalvegetation und durch Verwendung des Mittelwertes der aller Aufnahmen der Gesellschaften herabgesetzt hatten. Im Rahmen einer Retundanzanalyse (RDA) stellten sich die Nutzung, der Bodentyp, die Seehöhe, die mittleren Wintertemperaturen, die mittleren Temperaturen über die Vegetationsperiode, und die Bodenfeuchte (in dieser Reihenfolge) als die wichtigsten Einflussgrößen der Vegetationszusammensetzung heraus (Abb. 4). Klimavariablen erklären nur einen kleinen Teil der Varianz. Eine RDA nur mit den Aufnahmen der Segetalvegetation ergab dann die mittleren Wintertemperaturen, die Seehöhe, die mittleren Temperaturen über die Vegetationsperiode und den Bodentyp als die wichtigsten Variablen. Hier zeigt sich ein deutlich höherer Beitrag der Klimavariablen zur Erklärung der Varianz (Abb. 5).

Die auf Artwerten basierende RDA liefert allerdings keinen einheitlichen Trend für die wichtigsten wärmeliebenden Arten (Abb. 6). Auch räumliche Muster der Bevorzugung wärmerer Bereiche durch Gesellschaften mit höheren mittleren Temperaturzeigerwerten deuten sich zwar an (Abb. 7–9), sind aber nicht signifikant.

Diskussion – Die Wintertemperaturen schwanken im Gebiet um den Gefrierpunkt, der eine ökologische Zäsur für Biozönosen darstellt (KREYLING et al. 2011), und die 0 °C Januar-Isotherme separiert Frost-sensitive und Frost-resistente Arten und Vegetationseinheiten (JÄGER 1968). Multivariate Verfahren wie die RDA liefern Resultate abseits der mittleren Zeigerwerte. Für unsren Datensatz war die Bedeutung von Standortparametern groß, während der Anteil von Klimavariablen zur Erklärung des Datensatzes deutlich zurückblieb. Versucht man die Variabilität der Standortdaten zu verringern, z. B. durch Beschränkung auf die Segetalvegetation, steigt der Anteil der Klimavariablen an der Erklärung der Datenvarianz deutlich an.

Obwohl DE GROOT et al. (1995) bereits früh auf die Möglichkeit hingewiesen haben, Arten mit Ellenberg'schen Temperaturzeigerwerten über 6 als Indikatoren für die globale Erwärmung zu nutzen, ergeben die wärmeliebenden Arten in der RDA kein klares Bild (Abb. 6). Die von uns verwendeten mittleren Zeigerwerte der Gesellschaften sind eher empfehlenswert.

Der Einfluss des Klimawandels auf die Vegetation wird weltweit überwiegend in Naturlandschaften weit ab von menschlichen Einfluss untersucht (BERRY et al. 2003, JEDRZEJEK et al. 2012, PAULI et al. 2012). Andererseits werden auch für Agrarflächen bedeutende Änderungen durch den Klimawandel erwartet (ALEXANDROV & EITZINGER 2002, FOLLAK 2010) und wir müssen uns der Aufgabe stellen, diese Effekte auch aus anthropogen beeinflussten Datensätzen herauszufiltern.

Ruderalgesellschaften sind in der Regel euryök. Ein hohes Maß an anthropogener Störung ist der wichtigste Faktor für ihr Auftreten. Doch auch diese Vegetation folgt Klimamustern (JÄGER 1988, ESSL et al. 2009, DE ALBUQUERQUE et al. 2011). PINKE et al. (2012) sowie LOSOSOVÁ et al. (2004) fanden heraus, dass klimatische Faktoren zu den wichtigsten Umweltparametern für die Zusammensetzung und Verteilung von Ackerunkrautgemeinschaften im östlichen Mitteleuropa gehören.

Die Vorteile der Ruderal- und Segetalvegetation als Klimaindikator sind der schnelle zeitliche Artenwechsel, ihre Rolle als Lebensraum für neu eingeführte Neophyten und die enge Integration mit der Umwelt des Menschen. Zumindest einige Arten erfüllen die Forderungen für Klimaindikatoren, welche DE GROOT et al. (1995) aufgestellt hat. Es gibt auch Vorteile für die öffentliche Debatte: Wir können Änderungen vor unserer Haustür viel besser kommunizieren als solche in der Arktis oder auf hohen Berggipfeln. Nachteilig sind der hohe anthropogene Standorteinfluss, die inhomogenen Daten und die Tatsache, dass diese Gemeinschaften selbst in der Zukunft gefährdet sein werden (CHYTRÝ et al. 2012).

Es ist offensichtlich, dass sich der Einfluss des Klimawandels auf die Vegetation besonders gut im kontinentalen oder globalen Maßstab untersuchen lässt (BEERLING et al. 1995, BAKKENES et al. 2002, BRADLEY et al. 2010, PAULI et al. 2012). Die Datendichte von Klimadaten dafür wird in der Regel durch Interpolation gröberer Daten erreicht (HIJMANS et al. 2005). Das WegenerNet bietet eine einzigartige Dichte von Messdaten, um die Reaktion der Vegetation auf Klimaschwankungen über einen längeren Zeitraum zu überprüfen. Allerdings zeigt die Jahresdurchschnittstemperatur nur eine räumliche Differenz von 1,4 Grad (Tab. 3). Die Seehöhe des Offenlandes des Gebietes variiert nur um rund 170 m (Tab. 3). Diese Unterschiede sind offenbar zu klein, um klare Reaktionsmuster von Pflanzengesellschaften zu generieren. Erst in einem größeren Maßstab mit mehr Klimagradienten wird die Ausprägung klimabedingter Muster offensichtlicher.

Schlussfolgerungen – Die Klimagradienten im Bereich des WegenerNet sind sehr kurz und ermöglichen derzeit noch keine deutliche Klima-Antwort ruderaler und segetaler Unkrautgesellschaften. Eine signifikante Beziehung konnte nur durch die Reduzierung der Datenmenge auf die Segetalgesellschaften gefunden werden. Unsere Ergebnisse zeigen, dass Segetalgesellschaften aber als Klimaindikatoren geeignet sein können, wenn die Temperaturgradienten größer sind. Dies würde ein Monitoring des Klimawandels auch in anthropogen stark veränderten Landschaften ermöglichen.

Acknowledgements

We thank Thomas Kabas and Jürgen Fuchsberger from the Wegener Center for Climate and Global Change, University of Graz, for their essential assistance with the WegenerNet data. We are grateful to Viktoria Wagner, Toby Spribille, Anton Drescher and Martin Magnes for valuable comments on the manuscript and Sara Crockett for language corrections.

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