Arable weed vegetation and germination traits of frequent weeds in Kosovo

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The thesis 'Arable weed vegetation and germination traits of frequent weeds in Kosovo' is based on the following three papers:

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II. Mehmeti, A., Demaj, A., Waldhardt, R., 2009. Plant species richness and composition in the arable land of Kosovo. - *Landscape Online* 11: 1-29.

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Author's contribution:

In paper **I** and **II**, I had the main responsibility for design, field work, data analysis and writing. The co-authors contributed valuable suggestions and comments. The first co-author, A. Demaj, performed support in the field survey. The second co-author, R. Waldhardt, helped to translate paper I into German.

In paper **III**, I had the main responsibility for design, field work, data analysis and writing. The first co-author, A. Demaj, performed support in the field experiment. The first and second co-authors contributed constructive suggestions and provided helpful ideas.

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1 General introduction and objectives

All over Europe, the **arable weed vegetation** has dramatically changed since the second half of the 20th century. On the larger part of the arable land, the formerly diverse weed vegetation reflecting site conditions such as soil base content and agricultural management such as summer or winter cropping (cf. e.g., Hüppe and Hofmeister 1990), is today species poor or dominated by few nitrophilic and often herbicide-resistant species adapted to 'conventional' arable farming (EEA 2007). Many arable weed species have become rare or extinct at local to regional scales and are thus included in Red Lists. The underlying driving forces of these changes are generally well understood: At the local scale, agricultural measures such as seed cleaning, herbicide use or frequent tillage and also land-use changes such as long-term arable abandonment or the conversion of former arable to developed land (e.g., houses, roads) are unsuitable for growth, survival and reproduction of most weed species (e.g., Korneck et al. 1998). At broader scales, the uniformisation of production systems, which in many regions concentrate on a few economically important crops such as wheat and maize, results in low habitat diversity and thus low species richness and diversity (cf. Waldhardt et al. 2004, Simmering et al. 2006).

Intensive research on changes in Europe's arable weed flora and vegetation has been conducted since about 1970 (e.g., Meisel 1972, Albrecht and Bachthaler 1988, Andreasen et al. 1996, Odette and Quentin 1999) and contributed to pave the way for nature conservation strategies, measures and programmes (reviews of the respective literature are given in Hilbig 1994, 2002). Some of these measures became part for the EU agri-environmental schemes to counteract the ongoing biodiversity loss in farmland. However, such research has concentrated on Central and Northern Europe and - despite the large acreage of the arable land in Southern Europe - only few data on changes in the arable weed flora and vegetation have been available from this part of the European continent (cf. Nezadal 1994). This holds also true for Kosovo, located in the centre of the Balkan Peninsula, Europe's major hotspot of biodiversity (Griffiths et al. 2004).

In general, Kosovo is known for its rich flora, comprising about 1.800 to 2.500 higher plant species, including 13 endemic to the country and about 150 to 200 species restricted to the Balkan Peninsula. However, the knowledge on Kosovo's flora and vegetation is still incomplete as stated in the report of the United States Agency for International Development (USAID) on the biodiversity of Kosovo (Ard-Bioflor Iqc. Consortium 2003). This is reflected in ongoing projects on floristic mapping. With respect to the region's arable weed flora and vegetation, the available data mainly result from comprehensive research by Kojić and

Pejčinović (1982), later also considered in Kojić (1986), Pejčinović (1987) and Pejčinović and Kojić (1988), and several smaller field and experimental studies (e.g., Banjska 1977, Lozanovski et al. 1980a, 1980b, Shala 1987). Moreover, Laban (1972, 1973, 1975) undertook extensive surveys in the agricultural landscape of Kosovo, considering the flora and vegetation of orchards. According to all these studies, the weed vegetation of the agricultural landscape was fairly diverse and species-rich in the past. However, arable weed vegetation is highly dynamic (Holzner 1978, Ellenberg 1996) and weed species may quickly adapt to new environmental conditions and land-use practices (cf. e.g., Otte 1996). Hence, and also indicated by some more recent studies conducted in a few arable fields with less diverse weed vegetation (Susuri et al. 2001, Mehmeti 2003, 2004, Mehmeti and Demaj 2006), it may be assumed that the data provided by those studies conducted about 40 to 20 years ago, do not reflect the recent situation. This may especially be expected against the background of the fundamental political and socio-economic changes in Kosovo since about 1990 (cf. Chapter 2). The research on the arable weed flora and vegetation in Kosovo is thus of interest from a vegetation ecological perspective and the perspective of biodiversity conservation.

Moreover, with respect to the arable land of Kosovo, substantial knowledge on the arable weed flora and vegetation is also valuable economically or from an agronomic perspective. Today, arable production is among the main economic activities contributing to the gross domestic product (Statistical Office of Kosovo 2009a). But for various reasons that are presented in more detail in Chapter 2, today's crop yields are comparatively low and do not meet the demands of the increasing population in Kosovo. In this regard, one of the shortcomings that urgently need to be solved is the often high weed infestation, mainly in maize fields. It becomes easily obvious in the agricultural landscape of Kosovo that current weed control measures are more or less unsuitable to prevent the germination, establishment and reproduction of some **frequent weed species**, namely *Amaranthus retroflexus* L., *Echinochloa crus-galli* L. and *Datura stramonium* L., that often reach high cover. To counteract this problem, changes in weed control are needed that focus on these problematic species but - given the outlined demands on biodiversity protection - also allow for the establishment of species-rich weed communities. In this context, information on species characteristics, including germination traits, may be helpful to determine optimal dates for effective weed control measures. In general, since all three species are among the most problematic weeds in large parts of the world, such information is available from many publications (e.g., Malan et al. 1982, Siriwardana and Zimdhal 1984, Reisman-Berman et al. 1989, Sellers et al. 2003, Martinkova et al. 2006). However, species characteristics may differ between the species' provenances (Keller and Kollmann 1999, Hamasha and Hensen 2009). Thus, region-specific information on species traits needs to be taken into consideration for the development of region-specific weed control strategies. Unfortunately, research on region-specific weed species traits in Kosovo has not been conducted at all since about 1990.

In this context - and also with respect to the diversity of weed communities, i.e. the frequencies and cover of the species contributing to species composition -, it may be questioned, if a region such as Kosovo represents *one* region or consists of several sub-regions characterised by indicator species (sensu Dufrêne and Legendre 1997) and specific species characteristics. This question, which is of interest from the landscape ecological perspective, but may also be relevant from the agronomic perspective, may especially arise due to the fact that Kosovo consists of two areas or sub-regions differing in climate and land use (cf. Kojić and Pejčinović 1982, Schmitt 2008, and see Chapter 2).

Against the backgrounds given above, **the objectives** of this thesis are as follows:

(i) to contribute to the ongoing floristic mapping of Kosovo,

(ii) to provide a reference database for future studies on land-use (change) and its effects on the regional arable weed flora and vegetation,

(iii) to provide quantitative information on the relationships between the vegetation of the arable land and both environmental features and agricultural management measures in this part of the world,

(iv) to elucidate within-region differentiations of weeds species frequencies, cover and germination characteristics, and

(v) to analyse region-specific germination traits of three frequent weed species, namely *A. retroflexus*, *E. crus-galli* and *D. stramonium*.

Focussing on the objectives (i) to (iii) and (v), today's arable weed vegetation of Kosovo and its relations to site conditions and agricultural management measures was studied in region-wide surveys in the vegetation periods 2006 and 2007 and the results were compared with some of the the above mentioned studies on the arable weed flora and vegetation that had been published between 1972 and 1986 (Chapter 4 and 5). Considering the findings of the surveys, two experiments carried out in autumn 2006 and in the vegetation period 2007 investigate the germination behaviour of *A. retroflexus*, *E. crus-galli* and *D. stramonium* in a climate chamber experiment and under field conditions and refer to the objectives (iv) and (v).

2. Study area

In 2008, Kosovo declared its independency as Republic of Kosovo that covers an area of 10.877 km² (Fig. 2.1) in the centre of the Balkan Peninsula. Kosovo is divided into 30 municipalities and includes about 1.500 villages and urban areas. The neighbouring countries of Kosovo are Macedonia (FYROM), Albania, Serbia and Montenegro.

In the nearer past, Kosovo belonged to the Socialist Federal Republic of Yugoslavia and, after this state formally dissolved in 1992, to the Federal Republic of Yugoslavia. Especially the period between 1989 and 1999 was characterised by armed conflicts that escalated to war. In 1999, Kosovo came under interim administration of the United Nations.

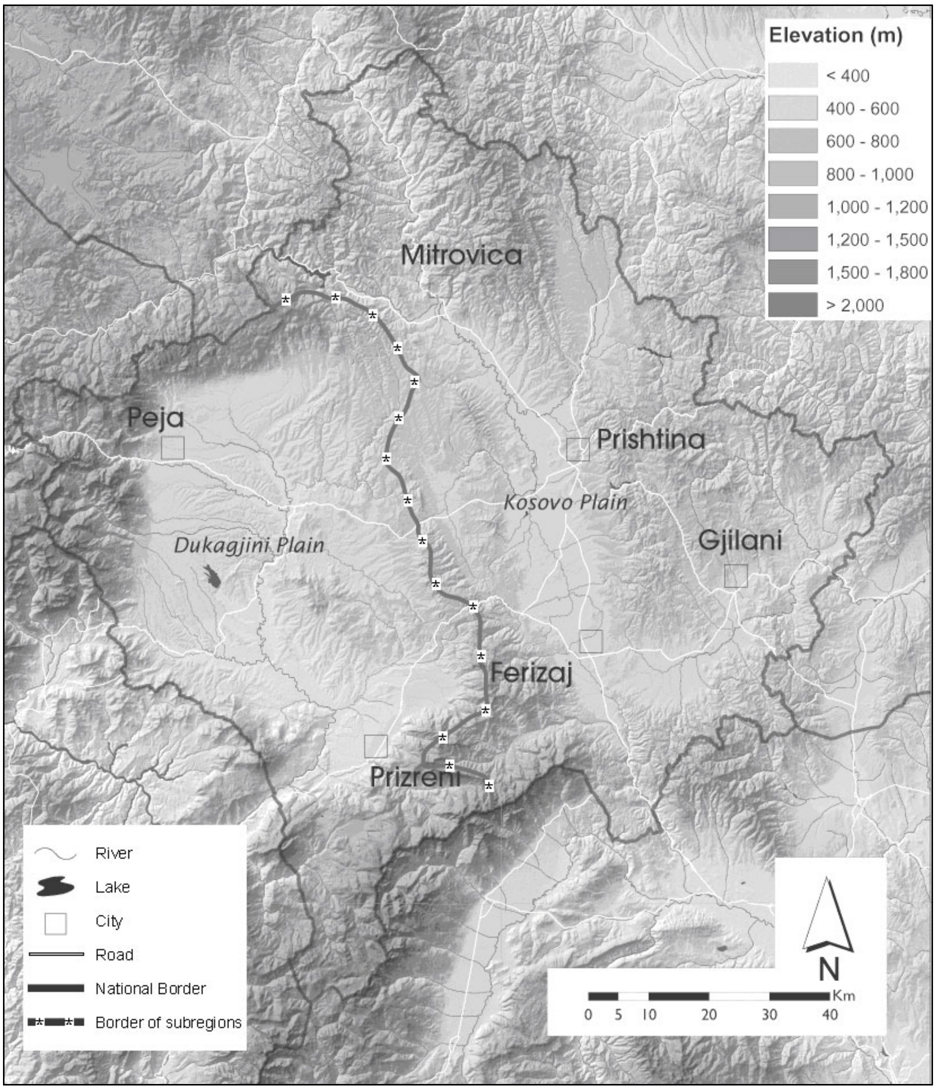

Fig. 2.1. Kosovo and its two sub-regions differentiated in this study.
Background information on the delineation of the two sub-regions is given in Chapter 2.

2.1 Topography, climate and soils

Kosovo is characterised by two large plains (the Dukagjin Plain in the western and the Kosovo Plain in the eastern part; lowest elevation: 265 m above sea level) and adjacent colline to montane areas and high mountains (Albanian Alps, Sharr Mountains, Kopaonik Mountains, Central Mountains; highest elevation: 2656 m above sea level), with about 80 % of the entire area below 1000 m above sea level.

Kosovo's climate is moderately continental. Air temperature may range from -20 °C to 35 °C. In the Kosovo Plain, about 170-200 days per year are frost-free and the mean annual rainfall is about 650 mm. In the Dukagjin Plain, the annual rainfall is higher (about 780 mm) and the frost-free period is longer (up to 225 days). This indicates a pronounced influence of Mediterranean climate in the western part of Kosovo.

According to Drezgić (1957), Babović (1960), Ivović and Mijović (1969), and a digital map of soil types (scale 1:50,000) provided by the Chair of Soil Science at Prishtina University (Elezi et al. 2004a), and also referring to the WRB-soil classification (IUSS Working Group WRB 2006), the most frequent soil types (Tab. 2.1) in the plains of Kosovo are fluvisols, whereas in the hilly areas, vertisols, cambisols and regosols are widespread. Due to comparatively high nutrient content and sufficient water availability, the agricultural land use concentrates on eutric cambisols, vertisols, fluvisols and dystric regosols. In general, many soils are significantly modified by agricultural use. Especially irrigation (mainly in the western part of Kosovo) and soil tillage are crucial factors that have impacted pedogenetic processes over centuries.

Tab. 2.1. Soil types in Kosovo and their agricultural use.
Data according to Elezi et al. 2004b. Total area: 10,877 km².

Soil type	Area	Agricultural used area
	----- % of the total area -----	
Dystric cambisols	26.0	8.6
Eutric cambisols	16.0	20.3
Umbric leptosols	11.2	0.3
Vertisols	10.0	19.1
Fluvisols	7.7	17.5
Dystric regosols	6.4	15.2
Stagnic podzolluvisols	3.7	8.0
Others	19.0	11.0

2.2 Population and economy

Today, the population of Kosovo is estimated to be around 2.2 million, i.e. about 200 inhabitants per km² (cf. Statistical Office of Kosovo 2008a). About half the population is younger than 25 years. Thus, Kosovo's population is by far the youngest in Europe.

In the period of armed conflicts between 1989 and 1999 - especially during the war in 1999, when more than 10,000 people were killed, large parts of the infrastructure, as well as of the rural and urban areas, were destroyed or abandoned. Moreover, approximately 20 % of the total population fled the region and settled (temporarily) in other parts of the world.

The region's economy has dramatically suffered from the armed conflicts, but also has been affected by the far reaching political changes of the post-socialist era in general. Albeit recent progress in economic growth and poverty reduction, the state of Kosovo's economy is still critical and the unemployment rate is around 44 % (Statistical Office of Kosovo 2007a). Further intensive efforts at the local to national and international level (e.g., UNDP 2009) will be essential to overcome the ongoing socio-economic crisis.

2.3 Agricultural land use

In the agricultural sector, many farms and their machinery were destroyed during the war in 1999 and the whole sector, which was organised around cooperatives and agro-kombinats (state farms) during socialism, was reorganised in a still ongoing process of privatisation. Nevertheless, given an employment share of 21.4 % (Statistical Office of Kosovo 2007a), agriculture is among the region's main economic activities.

According to the data provided by the Statistical Office of Kosovo (2008b), the agricultural sector may be characterised as follows: Private farmers own about 88 % of the agricultural land, whereas about 12 % have been managed by enterprises. Around 93 % of the agriculture land managed by private farmers (259,800 ha; Fig. 2.2) belongs to small farms, each comprising less than 5 ha. The mean farm size is only 1.5 ha. In the arable land (119,900 ha plus some abandoned fields; Fig. 2.3), cereals (mainly winter wheat and maize including mixed-cropping of maize and beans) predominate. Winter wheat is sown in October or November and harvested in June to August. Maize is usually sown in April and harvested in September to October. Moreover, vegetables such as paprika, tomato and onion are produced.

Given the proportions of the predominating crops, the most important crop rotation is wheat-maize (Banjska and Dushi 1989, Fetahu and Aliu 1997, Dushi et al. 1997). In vegetable production, which concentrates on the western part of Kosovo, the most common rotation is pepper-tomato (Zhitia 1996), but also monoculture of vegetable is practiced (Fetahu and Aliu 1997).

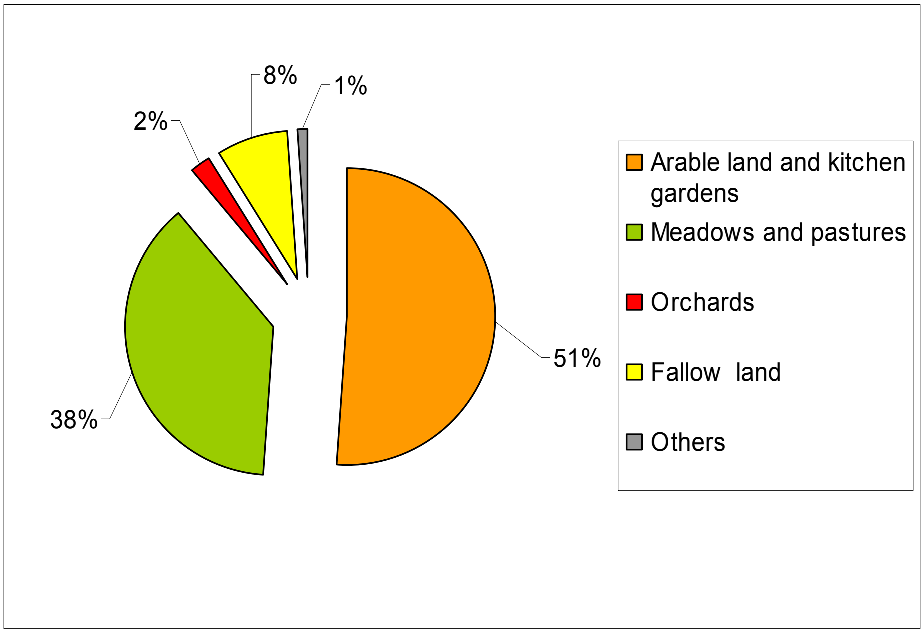

Fig. 2.2. Proportions of land-use classes contributing to the agricultural land of Kosovo.
According to data of the Statistical Office of Kosovo (2009b).
Total area of the agricultural land managed by private farmers: 260,000 ha.

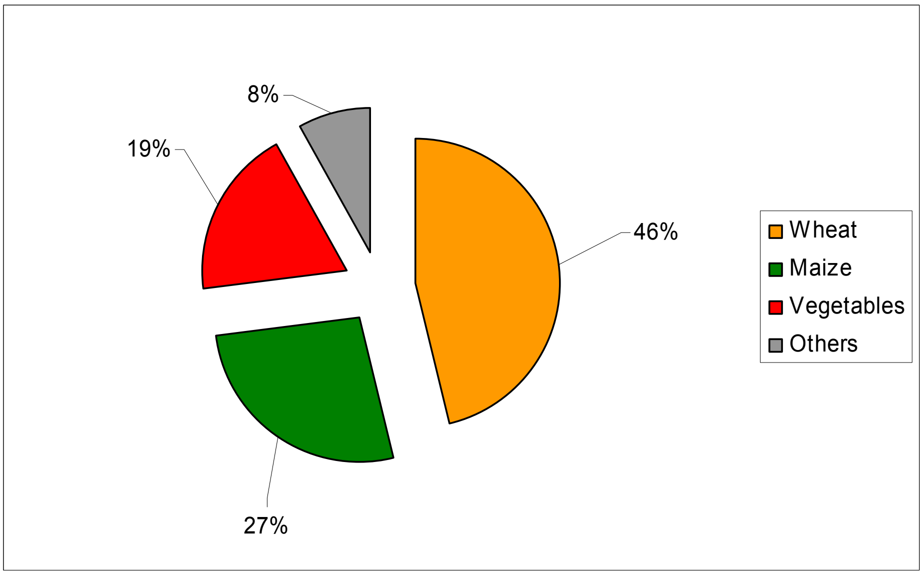

Fig. 2.3. Proportions of crop classes in the arable land of Kosovo.
According to data of the Statistical Office of Kosovo (2009b).
Total area of the arable land managed by private farmers (without abandoned fields): 134,000 ha.

Most arable fields are fertilised with mineral fertiliser or organic manure, often used as a base dressing at sowing or planting and additional top dressing applications during crop growth. However, around 11 % of the smallest farms and 8 % of larger farms do not use any kind of mineral fertiliser, and 56 % of small farms and 32 % of the large farms do not use organic manure. In comparison to EU member states, the level of mineral fertilisation is slightly lower, whereas the level of manure application and biological N-fixation (mainly by *Medicago sativa*) are slightly higher in Kosovo (Znaor 2008). About 37,000 ha of the arable land, mainly in the western part of the country, are irrigated. In 2001, almost 60 % of the farmers applied pesticides during the cultivation of potatoes and barley (MAFRD 2001). The corresponding rates are lower for wheat (37 %), pepper (33 %), and grapes (31 %). At present, pesticides (around 2,600 t in 2006) and mineral fertiliser (around 68,000 t in 2006) are not being produced in Kosovo, but need to be imported (Statistical Office of Kosovo 2007b). In average, today's yields are fairly low (3.5 t/ha for wheat and 2.2 t/ha for maize; Statistical Office of Kosovo 2009b). The larger part of the harvested crops (69 %) is used for household needs and livestock feeding (around 22 %). Due to the low yields, but also due to the destruction of factories that formerly processed agricultural products (e.g., oil, sugar, tobacco and chili), the trading of arable products (either processed or unprocessed) is of marginal importance (Tab. 2.2).

Tab. 2.2. The use of crops in different parts of Kosovo.
Taken from the Statistical Office of Kosovo (2006).

Region	Household needs	Animal feed	Sold	Processed and than sold	Lost
	------------------------ % of harvested crops --------------------------------				
Kosovo	69.0	21.6	5.6	0.4	3.5
Prishtine	74.6	18.9	4.8	0.2	1.5
Mitrovice	70.6	21.3	5.3	0.3	2.6
Peje	67.5	20.7	8.6	0.1	3.1
Gjakove	62.5	22.4	9.8	0.5	4.8
Prizren	62.7	27.5	5.9	0.0	3.9
Ferizaj	78.6	15.5	3.0	0.1	2.9
Gjilan	66.2	24.8	1.9	1.4	5.6

In comparison to the situation before 1990, the agricultural landscape of Kosovo is highly fragmented today. Moreover, the total area of the managed agricultural land decreased by about 10,000 ha within a few years (Zajmi 1996) and is even smaller today, mainly resulting from the construction of factories, houses and roads. Moreover, the diversity of arable products decreased around 1990 and some products such as sugar beet (1987: around 20,000 ha; 1992: 3,300 ha), rape seed (1980: 3,300 ha; 1992: 225 ha) and tobacco (1980: 3,800 ha; 1992: 1,900 ha) are nowadays less important (Zajmi 1996). However, sophisticated and spatially-explicit data on Kosovo's landscape structure and changes in landscape structure, i.e. on (changes in) the area ratio of crops and field sizes, that might allow to analyse relationships between (changes in) habitat pattern and (changes in) biodiversity (cf. e.g., Thiele et al. 2008), are not available to date.

3. Material and Methods

This chapter provides an overview of the material and methods used in the studies presented in the Chapters 4 to 6. More detailed information on material and methods is given in the respective sections of the chapters. In general, the methods applied reflect that the research conducted for this thesis is mainly related to three scientific disciplines, namely vegetation ecology (Chapter 4 and 5), landscape ecology (Chapter 5), and autecology (Chapter 6), and comprises both empirical and experimental approaches.

3.1 Vegetation sampling in cultivated and recently abandoned arable fields

In 2006 and 2007, the vegetation was sampled on 5 m x 5 m plots (vegetation relevés) in a total number of 432 cultivated and 41 recently abandoned arable fields (one plot per field), randomly distributed in the arable land of the study region. The geographic location of each plot was documented with the help of a GPS. The respective data were imported in a GIS (ArcGis 9.1) to allow for spatially explicit data analyses. To avoid edge effects in vegetation sampling, the minimum distance of each plot to the field border was 10 m. The sampling distinguished between three crop classes (winter crop, summer crop, abandoned) and was conducted between May and August. For each species, the cover (abundance / dominance) was recorded according to Barkman et al. (1964). The nomenclature follows Wisskirchen and Haeupler (1998) and, for those species that are not listed there, Tutin and Heywood (1964-1993).

3.2 Documentation of site characteristics and land-use data

For each plot, altitude (meters above sea level), relative topographic position (four classes ranging from the plain floor to the hilltop), and soil type were documented. Information on soil types was derived from the digital map mentioned in Chapter 2.1 and validated in the field. Based on this information, each plot was assigned to one of three classes of soil base-richness and also to one of three classes of soil moisture in late spring. A subset of 40 plots on cultivated arable land was classified with respect to weed management (herbicide use vs. mechanical weed control). Finally, each plot was assigned to one of two sub-regions of Kosovo (Fig. 2.1) delineated under consideration of the literature mentioned in Chapter 1 and the author's expertise on within-regional differentiation of climate and production systems.

3.3 Germination experiment in climate chambers and under field conditions

To characterise the germination behaviour of the three frequent arable weeds *A. retroflexus*, *E. crus-galli* and *D. stramonium,* climate chamber experiments were conducted at Justus-Liebig-University Giessen in autumn 2006, using RUMED-climate chambers (Type 3401). The six-week experimental approach followed Otte (1996) and Hölzel and Otte (2004) and considered temperatures ranging from 3 to 35 °C. The germination behaviour was investigated using a subsets (50 seeds per temperature; 5 repetitions) of six pooled seed samples (3 species, 2 sub-regions) originating from the delineated two sub-regions of Kosovo. Each pooled seed sample comprised 20,000 seeds that were sampled in summer 2006 in two sampling areas within each sub-region.

To characterise the germination behaviour of the same species under field conditions, a 25-week field experiment was conducted on an experimental site (2.0 m x 1.5 m x 0.3 m) in Viti (in the eastern part of Kosovo) with heat-sterilised soil from March to August 2007. Again, subsets of the six pooled seed samples (200 seeds; 5 repetitions) were used and sown at a soil depth of 2 cm. To relate the data on seed germination to the season's soil temperature and precipitation regime, the soil temperature was recorded at the experimental site, using HOBO data loggers at a soil depth of 5 cm, and precipitation data from the meteorological station at Ferizaj (Kosovo), located about 20 km away from Viti, were considered.

3.4 Data analysis and statistics

The data analysis and statistics mainly aimed at (i) quantifying and comparing species richness and species frequencies with respect to the considered crop classes and classes of weed management, (ii) relating the data on vegetation to site characteristics, (iii) comparing the vegetation data between the two delineated sub-regions, and (iv) relating the germination behaviour of the studied species to temperature and precipitation. To this end, the data were subjected to statistical analyses that were processed with the help of the PC-software packages PC ORD 5.0 (McCune and Mefford 1999) and STATISTICA 6.0 (StatSoft Inc. 2001). The following analyses were conducted:

- Detrended Correspondence Analysis (DCA) was used to explore gradients in the composition of vegetation sampled on cultivated and recently abandoned arable land (Chapter 5).
- Pearsons-r (Krebs 1999) was applied in order to detect correlations between DCA-ordination axes and site conditions based on the sample scores of ordination axes and environmental variables (Chapter 5).

- Indicator Species Analysis (Dufrêne and Legendre 1997) was applied to test for indicators of crop classes and classes of topographic position, soil base-richness and soil moisture. Moreover, Indicator Species Analysis aimed at finding differences in species composition between the two sub-regions (Chapter 5).
- General regression models (GRM) were conducted to quantify determinants of the α-species richness of the arable vegetation (Chapter 5).
- Student's unpaired t-tests we performed to test for differences in α-species richness between the two classes of weed management (Chapter 5).
- General Linear models GLM we performed to test for effects of sub-region and temperature on germination rates of *A. retroflexus*, *E. crus-galli* and *D. stramonium* in the climate chamber experiment (Chapter 6).
- Repeated-measure ANOVAS were conducted on the germination rates of each of the three species with region and week as factors (Chapter 6).

4. Ackernutzung und aktuelle Ackervegetation im Kosovo

Arben Mehmeti, Adem Demaj, *Rainer Waldhardt*

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4.1 Einleitung

Der im Auftrag der United States Agency for International Development (USAID) vorgelegte Bericht zur Biodiversität des Kosovo (Ard-Bioflor Iqc. Consortium 2003) betont die floristische Vielfalt der mit einer Gesamtfläche von 10.887 km² recht kleinen Region. Der Artenreichtum wird mit 1.800 bis 2.500 beziffert. 13 endemische Arten des Kosovo und 150 bis 200 endemische Arten des Balkan mit Vorkommen im Kosovo sind bislang nachgewiesen. Zugleich weist der Bericht darauf hin, dass weitere umfangreiche Erhebungen erforderlich sind, um den Artenreichtum genauer quantifizieren zu können.

Für ihre reiche Flora bekannt sind insbesondere die überwiegend bewaldeten Bergregionen im Süden (Malet e Sharrit-Gebirge) und Westen (Alpet Shqiptare-Gebirge und das Gebiet des Berges Koritniku). Einen weiteren hot-spot des Pflanzenartenreichtums bildet das Habitatmosaik aus lückigen Wäldern und Heiden der Kalk-Karstlandschaft entlang des Flusses Drini i Bardhe unweit der Grenze zu Albanien. Vegetationskundliche Untersuchungen aus den 1970er und 1980er Jahren (Horvat et al. 1974, Kojić and Pejčinović 1982, Pejčinović 1987) belegen zudem einen damals großen Artenreichtum des Kulturgraslands und des Ackerlands. Zum aktuellen Artenreichtum der Landwirtschaftsfläche, welche 53 % der Gesamtfläche des Kosovo ausmacht, liegen keine Arbeiten vor. Mit negativen Auswirkungen der jüngeren landwirtschaftlichen Nutzung auf den Pflanzenartenreichtum ist – wie in Kapitel 2 näher dargelegt – besonders im Ackerland zu rechnen.

Vor diesem Hintergrund soll mit der hier vorgestellten Untersuchung ein kurzer Überblick über die Ackernutzung und aktuelle Ackervegetation im Kosovo gegeben werden. Die zugrunde liegenden vegetationskundlichen Erhebungen zielten nicht darauf, besonders artenreiche Bestände zu dokumentieren, die gelegentlich im Randbereich von Ackerflächen ausgebildet sind. Vielmehr wurde unter Berücksichtigung der standörtlichen und nutzungsbedingten Vielfalt die Vegetation im Bestandesinneren bewirtschafteter und kürzlich brachgefallener Ackerschläge erhoben, um den Artenreichtum „in der Fläche“ abzuschätzen.

4.2 Untersuchungsgebiet und ackerbauliche Nutzung

Der Kosovo umfasst Höhenlagen zwischen 265 und 2.656 m ü. NN. Das Klima ist im Osten kontinental. Die Temperaturen sinken im Winter bis auf -20 °C ab und erreichen im Sommer Werte um +35 °C. 170 bis 200 Tage sind frostfrei. Der Jahresniederschlag liegt bei 650 mm. Im Westen ist das Klima mediterran beeinflusst. Die Zahl der frostfreien Tage ist dort mit 196-225 größer als im Osten und auch der Jahresniederschlag ist mit 780 mm höher.

Die Ackernutzung konzentriert sich auf zwei Ebenen, das zentrale Amselfeld (Fusha e Kosovës) und die besonders fruchtbare Dukagjin-Ebene im Westen, sowie das umliegende Hügel- und Bergland bis ca. 1.000 m ü. NN. Unter Verwendung der WRB-Bodenklassifikation (IUSS Working Group WRB 2006) herrschen in ebener Lage basenreiche und kalkhaltige Fluvisole und Gleysole vor. In Hanglagen sind basenarme bis kalkhaltige Vertisole, Cambisole und Regosole häufig.

Nach der Agrarstatistik für das Jahr 2005 (Statistical Office of Kosovo 2006) werden etwa 150.000 ha der Fläche des Kosovo ackerbaulich genutzt. Die Gesamtfläche des Ackerlands hat sich seit Anfang der 1980er Jahre kaum verändert, jedoch liegen zur Zeit etwa 10 % der Ackerfläche brach. Der Großteil der bewirtschafteten Ackerfläche wird von Kleinbauern in Subsistenzwirtschaft genutzt. Etwa 80 % der landwirtschaftlichen Betriebe bewirtschaften eine Gesamtfläche von nur ≤ 5 ha; nur 5 % der Betriebe hat eine Größe von >10 ha. Die vor dem Zusammenbruch des Sozialismus im ehemaligen Jugoslawien deutlich größeren Ackerschläge wurden im Kosovo überwiegend in Parzellen mit einer Größe von ca. 0,5 bis 1 ha untergliedert.

Mit Ausnahme von Winterweizen, der im Oktober auf einer Gesamtfläche von etwa 70.000 ha gesät und im Juli/August des folgenden Jahres geerntet wird, werden im Kosovo Sommerungen angebaut: Mais (ca. 37.000 ha; häufig als Mais-Bohnen-Mischkultur), Kartoffel (ca. 4.000 ha). Sommergerste (ca. 3.500 ha) sowie im klimatisch begünstigten Westen auch Paprika (ca. 2.500 ha), Kürbis (ca. 1.500 ha), Zwiebel (ca. 1.000 ha) und weitere Gemüsearten. Die Sommerungen werden überwiegend im April gesät bzw. gesetzt und im Juli bis September/Oktober geerntet. Ackerbrachen finden sich über die Landwirtschaftsfläche verstreut; allein in den ackerbaulichen Gunstlagen im Westen ist der Anteil des Brachlands deutlich geringer. Junge Ackerbrachen weisen besonders in siedlungsnahen Bereichen auf zunehmende Überbauung wertvoller Ackerböden hin. Das Brachfallen dieser Flächen ist nicht durch für ackerbauliche Nutzung ungünstige Bodeneigenschaften zu erklären.

Verlässliche Daten zur Menge und Qualität der im Ackerbau aktuell eingesetzten Dünge- und Pflanzenschutzmittel sowie zum Ertragsniveau fehlen weitgehend. Zur jährlichen mineralischen Düngung der Ackerflächen stehen heute etwa 200 kg N/ha zur Verfügung. Herbizide werden besonders im Getreideanbau eingesetzt, seltener im Gemüse- und Maisanbau. In Mais-Bohnen-Mischkulturen finden Herbizide keine Anwendung. Hier wird der „Verunkrautung“ durch intensive mechanische Bekämpfung im Spätfrühling entgegengewirkt. Nach der bereits zitierten Agrarstatistik des Kosovo lagen im Jahr 2005 die Erträge im Weizen- und Maisanbau bei jeweils 39 dt/ha. Als potenzielle Erträge werden bei weiterer Steigerung der Nutzungsintensität 60 (Weizen) bzw. 80 dt/ha (Mais) angesehen.

4.3 Vegetationskundliche Methoden

Die Vegetation des Ackerlands wurde im Jahr 2006 auf 432 bewirtschafteten und im Jahr 2007 auf 41 einjährigen Ackerbrachen aufgenommen. Der Aufnahmezeitraum erstreckte sich in beiden Jahren von Anfang Mai bis Ende August. Die Flächen waren über das Ackerland des Kosovo zufällig verteilt. In jeder untersuchten Parzelle wurde eine 25 m² große Aufnahmefläche bearbeitet. Die Aufnahmeflächen lagen mindestens 10 m vom Ackerrand entfernt. Die Abundanzen der angebauten Kulturen wurden in Prozent der Bodenbedeckung, die der Ackerwildkräuter in Deckungsgradklassen geschätzt.

4.4 Ergebnisse und Diskussion

In den Aufnahmeflächen wurden insgesamt 235 Gefäßpflanzenarten erhoben. Die Artenzahlen unterscheiden sich zwischen den angebauten Kulturen kaum voneinander (Tab. 4.1). Der Artenreichtum der einjährigen Ackerbrachen ist deutlich größer.

Tab. 4.1. Pflanzenartenzahlen (AZ) in bewirtschaftetem und brachgefallenem Ackerland des Kosovo.

Kulturart	N	mittlere AZ	min. AZ	max. AZ
Winterweizen	116	9,6	4	21
Mais A[1]	151	9,4	4	18
Mais B[2]	92	9,0	2	18
Kartoffel	47	8,0	3	13
Gemüse[3]	17	7,7	6	13
Sonstige Kulturen[4]	9	10,6	7	14
Brache[5]	41	18,8	11	26

[1]Mais-Bohnen-Mischkultur, selten auch Mais-Kuerbis-Mischkultur
[2]Mais-Reinkultur
[3]überwiegend Paprika, selten auch Wassermelone, Kohl, Zwiebel, Tomate
[4]Luzerne, Sommergerste, Erbeeren
[5]Erstes Brachejahr

Mit *Amaranthus retroflexus, Chenopodium album*, *Cirsium arvense* und *Convolvulus arvensis* wurden nur wenige Arten in über 50 % der Aufnahmeflächen und mit oftmals hohen Abundanzen von bis über 25 % Bodenbedeckung dokumentiert. Dabei kommt das typische „Maisunkraut“ *Amaranthus retroflexus* fast ausschließlich in den Sommerungen vor, und *Cirsium arvense* erreicht im Winterweizen die höchsten Abundanzen.

In 10 – 50 % aller Flächen und mit wiederum oft hohen Abundanzen bis über 25 % entwickelten sich mit deutlichem Schwerpunkt in den Sommerungen *Datura stramonium, Echinochloa crus-galli, Fallopia convolvulus, Hibiscus trionum* und *Sinapis arvensis* sowie mit Schwerpunkt im Winterweizen und in den Ackerbrachen *Centaurea cyanus, Consolida regalis, Elymus repens, Polygonum aviculare* und *Tripleurospermum perforatum. Anagallis arvensis, Matricaria recutita, Papaver rhoeas* und *Viola arvensis* kommen mit vergleichbarer Häufigkeit in den mit Winterweizen bestellten Äckern und in den jungen Ackerbrachen vor, ihre Abundanzen sind jedoch meist niedriger.

In maximal 5 % der Flächen und überwiegend in den untersuchten Ackerbrachen wurden die nach Ellenberg kalkzeigenden Arten (R-Zahl 8 oder 9) *Adonis aestivalis*, *Anagallis foemina*, *Bifora radians*, *Bupleurum rotundifolium*, *Conringia orientalis*, *Galeopsis ladanum*, *Legousia speculum-veneris*, *Nigella arvensis*, *Sherardia arvensis* und *Silene noctiflora* sowie *Adonis vernalis*, *Agrostemma githago*, *Althaea hirsuta, Consolida orientalis*, *Kickxia elatine* und *Ranunculus arvensis* erhoben. Wiederum handelt es sich überwiegend um winterannuelle Arten.

Die beschriebenen Gemeinsamkeiten der mit Winterweizen bestellten Äcker und der jungen Ackerbrachen sowie die Funde seltener winterannueller Arten in den Brachen belegen deutlich, dass auf den hier untersuchten Brachen nach Ernte der Kulturen im Vorjahr keine Bodenbearbeitung im Frühjahr erfolgte. Der im Vergleich zu den bewirtschafteten Flächen deutlich größere Artenreichtum der Brachen ist im Übrigen nicht allein durch bessere Entwicklungsbedingungen für annuelle Arten, sondern auch durch den Aufwuchs einiger mehrjähriger Arten wie *Hypericum perforatum, Lactuca serriola* und *Leontodon hispidus* zu erklären, die aus der umgebenden Vegetation rasch auf die Brachen übergreifen.

Der Schwerpunkt seltener Ackerwildkrautarten in den untersuchten jungen Ackerbrachen deutet darauf hin, dass der Boden-Samenvorrat der Äcker des Kosovo weniger verarmt sein könnte, als die sich auf den bewirtschafteten Flächen entwickelnde Vegetation. Es werden daher Untersuchungen der Boden-Samenbanken des Ackerlands empfohlen, um die potenzielle Häufigkeit und die Raummuster der Ackerwildkrautarten im Kosovo genauer zu quantifizieren. Außerdem wären ergänzende floristische und vegetationskundliche

Untersuchungen unter Einbeziehung der Ackerränder wichtig, um insbesondere den Gefährdungsgrad der hier als selten (Häufigkeit ≤ 5 %) aufgeführten Ackerwildkrautarten besser abschätzen zu können.

Die aktuelle Vegetation des bewirtschafteten Ackerlands des Kosovo ist nach den vorliegenden Daten „in der Fläche“ deutlich verarmt. Die mechanische „Unkrautbekämpfung“ im Spätfrühling, die auf den überwiegend kleinen Parzellen mit Mais-Bohnen-Mischkultur intensiv praktiziert wird, aber auch der Einsatz von Herbiziden im Getreideanbau und in Mais-Reinkulturen, wirken der Ausbildung einer artenreichen Ackerwildkrautvegetation entgegen.

4.5 Zusammenfassung

Die noch vor wenigen Jahrzehnten artenreiche Ackervegetation des Kosovo ist heute bei meist intensiver Nutzung mit vorherrschendem Anbau von Mais und Weizen im Bestandesinneren der Nutzflächen deutlich verarmt. Eine artenreichere Vegetation und Funde seltener Ackerwildkrautarten auf jungen Ackerbrachen deuten jedoch auf einen bis heute größeren Artenreichtum der Boden-Samenbanken des Ackerlands. Wir empfehlen daher umfangreiche Analysen der Boden-Samenbanken, um die potenzielle Häufigkeit und die Raummuster der Ackerwildkrautarten im Kosovo genauer zu quantifizieren. Wir empfehlen außerdem ergänzende vegetationskundliche Untersuchungen unter Einbeziehung der Ackerränder, um den Gefährdungsgrad der nach der vorliegenden Untersuchung seltenen Ackerwildkrautarten besser abzuschätzen.

4.6 Summary

Several decades ago, the arable weed vegetation of the Kosovo was species rich. Today, species diversity is low in the field centres, due to intensive cultivation of mainly maize and wheat. However, higher species diversity and the occurrence of rare species on recently abandoned fields reveal that species richness may still be high in soil seed banks. Thus, we recommend extensive soil seed bank analyses to gain more detailed information on the potential frequency and the spatial distribution of arable weeds in the Kosovo. Additional vegetation surveys along field edges would be helpful to estimate the degree of endangerment for species that were rarely found in this first study.

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5. Plant species richness and composition in the arable land of Kosovo

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Abstract

This study investigates today's plant species richness and composition in cultivated and recently abandoned arable land of Kosovo. Relationships between these aspects of vegetation and both environmental features and agricultural management measures are studied at the regional and plot scale. In 2006, 432 vegetation relevés with a standard plot size of 25 m² were recorded in cultivated fields. In 2007, data collection focussed on 41 plots in arable fields that had been abandoned the year before. With respect to the environment, data analysis accounts for topography, soil base-richness and moisture, and geographic location. As to the management, crops and weed control are considered. A total number of 235 species was documented. In comparison to literature dating back to about 1980, the regional weed flora considerably changed. At the plot scale, today's weed flora of Kosovo is fairly species-poor and species composition is rather uniform between plots. According to General Regression Model analyses, Indicator Species Analyses and Detrended Correspondence Analyses, species richness and composition mainly differ between crops and weed management, with highest mean species richness in recently abandoned and lowest in herbicide-treated maize fields.

Key words

weed flora, weed vegetation, agriculture, weed management, land-use change

5.1 Introduction

Kosovo is situated in the submediterranean floristic region that is known for its rich flora, especially in near natural habitats (cf. e.g., Fritsch 1909, 1918, Rexhepi 1976, Millaku 1999, Stevanović et al. 2003). According to the report of the United States Agency for International Development (USAID) on the biodiversity of Kosovo (Ard-Bioflor Iqc. Consortium 2003), about 1.800 to 2.500 higher plant species occur in the area, including 13 endemic to Kosovo and about 150 to 200 species restricted to the Balkan Peninsula, Europe's major hotspot of biodiversity (Griffiths et al. 2004). However, as stated in the USAID report, the knowledge on the regional flora (e.g., Kojić et al. 1975, Banjska 1977, Lozanovski et al. 1980a, Kojić 1986) is still incomplete or might be outdated. Due to land-use changes in the recent past, the latter may be especially true for the flora of the arable land. Thus, as also stated in the report, further efforts in floristic mapping need to be undertaken.

About 20 to 30 years ago, the vegetation of Kosovo's arable land was documented by Kojić and Pejčinović (1982). Results of this documentation were also published by Pejčinović (1987) and Pejčinović and Kojić (1988). According to these publications, the vegetation of the arable land was species-rich and differentiated in relation to environmental features and agricultural management. A contemporary documentation of today's arable weed vegetation of Kosovo has not been available to date.

Thus, essential data to evaluate Kosovo's weed flora and vegetation and potential changes since about 1980 have been widely unavailable. However, such an evaluation is urgently needed for at least two reasons: to sustain the development and implementation of both nature conservation strategies and concepts on multifunctional and sustainable agriculture (cf. Otte et al. 2007). This is especially important against the background that the Republic of Kosovo aims to meet the attitudes and regulations of the European Community for its further development.

Since centuries, the arable weed flora and vegetation of Kosovo has been affected by multiple environmental features and management measures at various spatial scales. With respect to the regional scale, differences in climate may be highly important for species pools of sub-regions. Besides direct climate effects related to ecological processes at the level of populations, differences in production systems depending on climate may significantly act as filters for species pools (c.f. Gurevitch et al. 2006). For Kosovo, climate effects were shown as being important for the spatial distribution of plant species in forests (e.g., Krasniqi 1968), but to date this aspect was not considered in research with respect to the regional arable weed flora. At the plot scale, agricultural management measures such as ploughing in spring or autumn, mechanical weed control and herbicide application, and environmental features such as soil quality may be expected to be the main factors affecting both richness and composition of arable weed vegetation (cf. Šarić 1991, Schneider et al. 1994 and, for Kosovo: Susuri 1998, Susuri et al. 2001, Mehmeti and Demaj 2006). Some recent comparative studies conducted in cultivated arable fields of selected municipalities in Kosovo (e.g., Susuri et al. 2001, Mehmeti 2003, 2004, Mehmeti and Demaj 2006) clearly exemplify a reduction in species richness resulting from herbicide application. Further, as shown by Kojić and Pejčinović (1982), species composition and richness in arable fields depend on the cultivated crop, with low diversity especially in maize fields. However, analogous to the situation described above, a region-wide and comprehensive study on relationships between arable weed vegetation and both environment and agricultural management has not been conducted in Kosovo to date.

Given this background, our study aims at the following: (i) to contribute to the ongoing floristic mapping of Kosovo, (ii) to serve as a reference database for future studies on land-use (change) and its effects on the regional arable weed flora and vegetation, and (iii) to provide quantitative information on the relationships between the vegetation of the arable land and both environmental features and agricultural management measures in this part of the world. In this context, we focus on the following hypotheses, referring to the regional and plot scale:

1. At the regional scale, the arable weed flora has changed since about 1980.
2. At the regional scale, today's arable weed flora differs between two sub-regions characterised by differences in climatic conditions, agricultural production systems, and settlement history.
3. At the plot scale, today's arable weed vegetation is related to environmental features and agricultural management measures.

5.2 Study region

The Republic of Kosovo covers an area of 10.877 km² in the centre of the Balkan Peninsula. The entire region is divided into three zones that developed in the Oligo-Miocene (cf. Gashi and Spaho 2002): (i) two plains, the Dukagjini plain in the western and the Kosova plain in the eastern part, and (ii) adjacent hilly areas divided by rivers mainly originating in the (iii) surrounding mountain areas. The elevation ranges from 265 m to 2656 m above sea level, with about 80 % of the entire area below 1.000 m. In the larger part of Kosovo's plains and adjacent hilly areas, climate and soils are suitable for agricultural land use.

The climate is moderate continental with warm summers and cold winters. In the plains and the adjacent hilly areas, air temperature may range from -20 °C to 35 °C. In the Kosovo plain, about 170-200 days per year are frost-free and the mean annual rainfall is about 650 mm. In the Dukagjini plain, the annual rainfall is higher (about 780 mm) and the frost-free period is longer (up to 225 days) than in the Kosova plain, indicating pronounced Mediterranean climate influence in the western part of Kosovo.

According to a digital map of soil types (scale 1 : 50000) provided by the Chair of Soil Sciences at Prishtina University (cf. Elezi et al. 2004a) and referring to the WRB-soil classification (IUSS Working Group WRB 2006), the most frequent soil types in the plains are fluvisols. In the hilly areas vertisols, cambisols and regosols are widespread. In general, the agricultural soils are significantly modified. Especially irrigation (mainly in the western part of Kosovo) and soil alteration are crucial factors that have impacted pedogenetic processes over centuries.

In 1991, about 300.000 ha were used as cultivated arable land. However, until 1996, the area of cultivated arable land decreased to 264.000 ha (Statistical Office of Kosovo 2002), and the area of abandoned arable land increased significantly. This land-use change reflects both political and socioeconomic changes and conflicts during the post-communist transformation process as part of the former Federal Republic of Yugoslavia, from which the Republic of Kosovo declared its independence of in 2008. Today, still about 10-15 % of the agricultural land is fallow land. However, in the recent past, the reasons for abandonment changed: The fallow land nowadays includes land that either left the agricultural sector as construction land, or was abandoned from cultivation due to poor soil quality (e.g., shallow calcerous soils) or high prices of variable cost (e.g. costs for fertiliser, seed, and fuel).

Today, the agricultural land of Kosovo is mainly used for subsistence production. About 88 % of the agricultural land is owned by private farmers, whereas only 12 % are managed by enterprises (Statistical Office of Kosovo 2006). The process of land privatisation is not yet completed. About 80 % of the agricultural land is managed in small farms, each comprising less than 5 ha. Thus, in comparison to the predominant cultivation of large fields during the socialist period, land fragmentation is pronounced (Zajmi 1996). Mean field size is below 1 ha. However, with respect to landscape structure and land fragmentation (Fig. 5.1), comprehensive data have not been available to date. In 2005, the most important crops (about 100.000 ha) were wheat and maize (mainly mixed-cropping of maize and beans), whereas other agricultural products such as pepper, onion and tomato were grown on much less acreage (about 4.000 ha; Statistical Office of Kosovo 2006) and concentrate on the western part influenced by Mediterranean climate (Fig. 5.2).

Mainly for economic reasons and due to a lack of supply, pesticide use has remained restricted to parts of the arable land since about 1990 - but was formerly common, including spraying from airplanes since 1980. The level of fertilisation also decreased significantly in the last two decades. However, reliable and differentiated information considering the entire region is not available.

Fig. 5.1. Land fragmentation in Kosovo is pronounced today.

The picture shows a mosaic landscape that in many parts of Kosovo has resulted from fragmentation of formerly large arable fields since about 1990. Weed species such as *Papaver rhoeas* and *Tripleurospermum perforatum*, to be seen in the foreground, occur along the field edges, but are often missing in the field center. The picture was taken in the eastern part of Kosovo (hilly area near Livoç) in May 2007. Photo by R. Waldhardt.

Fig. 5.2. Cultivation of pepper concentrates on the western part of Kosovo (Dukagjini Plain near Krusha e Madhe) in May 2007.

Many fields like this are kept mostly free of weeds by herbicide use or mechanical weed control. Photo by R. Waldhardt.

5.3 Material and methods

5.3.1 Vegetation sampling

In 2006, vegetation was documented on a total number of 432 cultivated arable fields, randomly distributed in the agricultural land of the study region (Fig. 5.3). On each field, one 5 m x 5 m plot was investigated. The location of each plot was recorded with the help of a GPS using the UTM system. To avoid edge effects, the minimum distance of each plot to the field border was 10 m. Vegetation was surveyed between May and August. The cover of crops and all other vascular plants was estimated as shown in Tab. 5.1.

It is well known from previous studies (cf. e.g., Waldhardt 1994) that abandoned arable fields in the earliest stage of vegetation succession often act as favourable habitats for arable weed species. We therefore, and due to the recently increasing proportion of abandoned arable land in Kosovo, additionally sampled the vegetation of 41 recently abandoned arable fields (first year of abandonment), again randomly distributed in the study region. Sampling was conducted in 2007, again between May and August. Information on the past land use of the abandoned fields, such as the date of the last tillage before abandonment, spring or autumn, was not gained. However, it may be assumed that abandonment was mainly after harvest in late summer to autumn 2006, as in most cases the vegetation of these fields was already well established in spring 2007.

Nomenclature follows Wisskirchen and Haeupler (1998) and, for those species that are not listed there, Tutin and Heywood (1964-1993). In the results and discussion chapter, we distinguish between ‘arable weeds s.str.’ and other species such as grassland or ruderal species. The term ‘arable weeds s. str.’ is applied to those species that according to the phytosociological classification of Hüppe and Hofmeister (1990) characterise different vegetation types of the subclass Violenea arvensis HÜPPE and HOFMEISTER 1990 of the arable land in Germany and that may also be addressed as ‘arable weeds s. str.’ in the study region (cf. appendix 1). Moreover, the term is applied to species that in Kosovo mainly occur in the arable land, but are not mentioned in this publication.

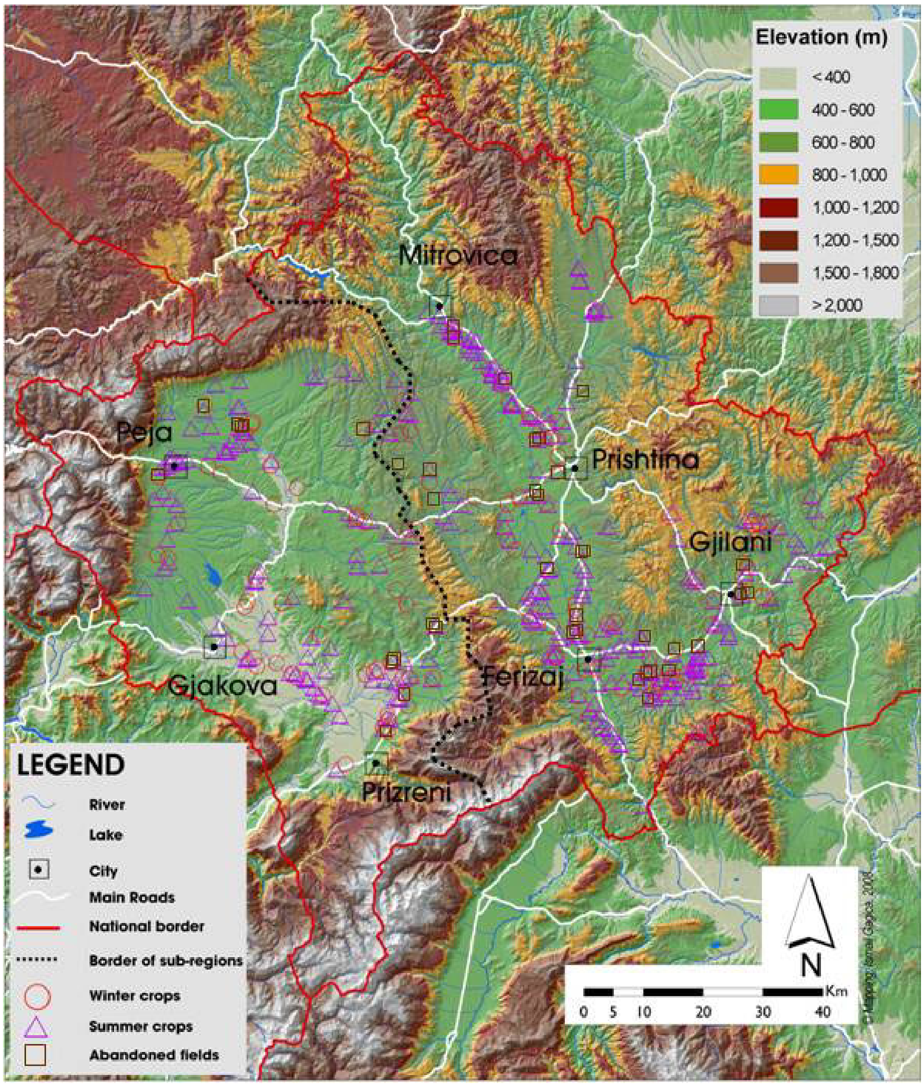

Fig. 5.3. Location of the investigated arable fields classified as winter crop, summer crop and recently abandoned fields in two sub-regions of Kosovo.
The two sub-regions differ in climate (a pronounced Mediterranean climate in the western part) and agricultural production systems (production of vegetables such as pepper, tomato and onion and, moreover, irrigation concentrate on the western part).

Tab. 5.1. Species cover (abundance/dominance) as recorded in the field and transformed to values of 'mean percentage species cover' as considered in the quantitative analyses of this study.

A	**r**	**+**	**1**	**2m**	**2a**	**2b**	**3**	**4**	**5**
A (%)	0.1	1	2.5	10	15	20	37.5	62.5	87.5

A: species cover (abundance/dominance) as recorded in the field (according to Barkman et al. 1964).
A (%): mean percentage species cover as considered in the analysis.

5.3.2 Documentation of environmental and land-use data

For each plot, altitude (meters above sea level), relative topographic position (four classes ranging from the plain floor to the hilltop), and soil type were documented. Information on soil types was derived from the digital map mentioned above and validated in the field. Based on this information, each plot was assigned to a certain class of soil base-richness (three classes representing a gradient from base-poor to calcareous) and also to a certain class of soil moisture in late spring (three classes representing a gradient from dry to moist). Soil classification with respect to base-richness and moisture (Tab. 5.2) considered information on the quality of soil types given by the IUSS Working Group WRB (2006) and the author's expertise on soil properties in Kosovo. Further, each plot was assigned to one of two sub-regions (Fig. 5.3) delineated under consideration of literature (e.g., Kojić and Pejčinović 1982, Schmitt 2008), maps and the author's expertise on within-regional differentiation of climate and production systems (cf. the previous chapter on the study region), topography and also settlement history in the study region.

Tab. 5.2. Classification of soil base-richness and soil moisture in late spring based on soil types. For classification, information on soil types (IUSS Working Group WRB 2006) and the author's expertise on soil properties in Kosovo were considered.

Soil type	B	M	Soil type	B	M
calcaric fluvisols	3	3	eutric fluvisols	2	3
calcaric regosols	3	1	eutric gleysols	2	3
calcaric vertisols	3	1	eutric regosols	2	1
chromic cambisols	2	2	eutric vertisols	2	1
dystric cambisols	1	2	mollic leptosols	2	1
dystric fluvisols	1	3	stagnic podzoluvisol	1	2
dystric regosols	1	1	umbric gleysols	1	3
dystric vertisols	1	1	umbric leptosols	1	1
eutric cambisols	2	2			

B = class of soil base-richness (1: base-poor; 2: base-rich; 3: calcareous).
M = class of soil moisture in late spring (1: dry; 2: mesic; 3: moist).

Additionally, information on the way of weed control, provided by farmers, was recorded for a subset of 40, i.e. about 10 %, of the investigated cultivated arable fields (10 maize fields with herbicide use and 10 maize fields without herbicide use, but with mechanical weed control; 10 wheat fields with herbicide use and 10 wheat fields without any weed control). The plots belonging to the four groups were randomly distributed in the study region.

5.3.3 Data analysis to test the first hypothesis

The first hypothesis was investigated under consideration of the above mentioned publications of Banjska (1977), Lozanovski et al. (1980a), Kojić and Pejčinović (1982), Kojić et al. (1975), Kojić (1986) and our data from 2006 and 2007. We compared the regional species pools (pooled species lists; cultivated crops were excluded from comparison) of the arable land recorded about 30 years ago with the species list derived from our data. For each species recorded in this study, we calcultated its relative frequencies of occurrence, separately for winter crop (n = 117), summer crop (n = 315), cultivated (n = 432), recently abandoned (n = 41), and all investigated fields (n = 473). The relative frequency *rf (%)* of a certain species *a* was calculated as

$$rf_a(\%) = (p_a / p) * 100\ \%$$

where p_a is the number of plots, in which species *a* was recorded, and *p* is the number of plots in the dataset.

Moreover, we calcultated the relative total cover of each species, separately for winter crop, summer crop, cultivated, and recently abandoned fields. The relative total cover *rc (%)* of a certain species s_x was calculated as

$$rc_{s_x}(\%) = \left(\sum_{p=1}^{n} c_{s_x} / \sum_{p=1}^{n}\left(\sum_{s=1}^{m} c_s\right)\right) * 100\ \%$$

where c is the species 'mean percentage cover' (cf. Tab. 5.1), *n* is the number of plots *p* in the dataset and *m* is the number of all species *s* in the dataset.

Additionally, information on species frequencies in the cultivated land was roughly derived from the former literature and compared with our dataset. However, data collection clearly differed between the considered former studies and our research. In contrast to our study, e.g., vegetation scientists in the past often deliberately selected species-rich fields and plots were not standardised with respect to size and localisation in the fields. Therefore, we do not compare past and today's species frequencies in detail. For the same reason, we do not compare past and today's species richness at the plot scale.

5.3.4 Data analysis and statistics to test the second hypothesis

To test hypothesis two, we randomly selected 135 plots per sub-region, estimated their total species richness and qualitatively compared the flora between the two sub-regions. Cultivated crops as well as species with less than three occurrences were excluded from comparison. Further, we conducted an Indicator Species Analysis (Dufrêne and Legendre 1997, McCune and Grace 2002) to determine indicator species for the two sub-regions. This analysis, considering both frequency and percentage cover of the tested species, was applied to the same dataset of 135 plots per sub-region. The Indicator Species Analysis was carried out with the help of the software package PC-ORD 5 (McCune and Mefford 1999). Percentage species cover was considered as given in Tab. 5.1. Significance of indicator values was tested by Monte-Carlo permutation tests with 5000 runs, only considering species with indicator values above 15.

5.3.5 Data analysis and statistics to test the third hypothesis

With respect to hypothesis three, we tested (A) the importance of determinants of species richness at the plot scale (α-species richness sensu Whittaker 1972), (B) differences in species composition between the considered classes (crop classes, classes of topographic position, soil base-richness and soil moisture) and (C) gradients in the sampled vegetation, reflecting β-diversity.

(A) To quantify determinants of α-species richness (cultivated crops were not considered), the following predictor variables were included in two General Regression Model (GRM) analyses with species richness as response variable: the UTM coordinates, the altitude above sea level, and the belonging to a certain class of topographic position, soil base-richness and moisture. Estimates of variance explained were calculated from the ratios of the sums of squares of a significant predictor variable to the total sum of squares in the respective model. In the first GRM analysis, only the data of cultivated arable fields ($n = 432$) were considered; the second GRM analysis was performed using the data of the abandoned fields ($n = 41$).

Focussing on the weed management and its potential effects on α-species richness, we additionally performed Student's unpaired t-tests, separately for the 20 selected maize resp. 20 wheat fields. Analysis was conducted using the software Statistica 6.0 (StatSoft Inc. 2001).
(B) Considering the entire dataset sampled in 2006 and 2007 ($n = 473$), Indicator Species Analyses (see above) were applied to test for indicators of the crop classes and the classes of topographic position, soil base-richness and soil moisture. Again cultivated crops were excluded from the analyses.

(C) Gradients in the sampled vegetation were detected in a Detrended Correspondence Analysis (DCA) (McCune and Grace 2002) comprising the entire dataset sampled in 2006 and 2007 ($n = 473$). In the 'main matrix' (vegetation data) the samples were distinguished under consideration of three crop classes (winter crops, summer crops, no crops = recently abandoned fields). Again, percentage species cover was considered as given in Tab. 5.1. Due to the fact that in 2006 data collection concentrated on cultivated arable fields, whereas in 2007 recently abandoned fields were investigated, we did not test for year effects in differences between the vegetation datasets of both years. In the 'second matrix' (environmental data) we distinguished between: (i) the four classes of relative topographic position, (ii) the three classes of soil base-richness, and (iii) the three classes of soil moisture. Further, we included (iv) the data on altitude and (v) the GPS coordinates of the plots. In an analogous way, we performed a DCA only considering the vegetation and environmental data of the abandoned fields (dataset sampled in 2007; $n = 41$). In both cases, data were arcsine squareroot transformed prior to analyses, and crop species as well as rare species with less than three (in the analysis of the entire dataset) or two occurrences (in the analysis of the abandoned fields) were excluded. Axes were rescaled and rare species were not down-weighted (due to their high proportion in the dataset). Method of detrending was by segments. To see how well the distances in the ordination spaces represent the distances in the original, unreduced spaces, we calculated the coefficient of determination (r^2) between distances in the ordination space and distances in the original space ('after-the-fact' evaluations under consideration of the relative Euclidean distances in the 'main matrices'). In order to detect correlations between ordination axes and site conditions Pearsons-r (Krebs 1999) was calculated based on the sample scores of ordination axes and environmental variables. We created joint plots; angles and lengths of environmental overlays tell the direction and strength of the relationships. DCA analysis was performed using software package PC-ORD 5.

In general, results may strongly depend on the structure of the considered datasets and the discussion of results needs to critically reflect on this. Against this background, Tab. 5.3 gives an overview on how the investigated plots are distributed among the considered environmental and management classes.

Tab. 5.3. Percentage belonging of the investigated plots to environmental and management classes.

Class	**CF** (n=432)	**AF** (n=41)	**Class**	**CF** (n=432)	**AF** (n=41)
Relative topographic position			**Sub-region**		
plain floor	72.7	75.6	western part	31.9	26.8
lower slope	19.9	19.5	eastern part	68.1	73.2
upper slope	5.1	4.9	**Crop class**	(n=473)	
Hilltop	2.3	-	summer crop fields	65.5	
Soil base-richness			winter crop fields	25.8	
base-poor	45.8	61.2	recently abandoned fields	8.7	
base-rich	25.3	14.4			
Calcareous	28.9	24.4			
Soil moisture					
Dry	32.4	19.5			
Mesic	22.0	29.3			
Moist	45.6	51.2			

CF: cultivated fields; AF: recently abandoned fields; *: as illustrated in Fig. 5.3; summer crop fields (n): maize/beans (151), maize (92), vegetables (64), others (8); winter crop fields (n): wheat (116), barley (1). Altitude of plots ranges from 305 to 1089 m, with n < 400 m: 50; 400-500 m: 91; 500-600 m: 264; >600 m: 68.

5.4 Results

5.4.1 Today's and past arable weed flora in Kosovo (Hypothesis 1)

The overall species number in the vegetation sampled in 2006 and 2007 is 235; among these, 94 species may be addressed as arable weed species s. str. (appendix 1). 140 species are recorded in winter crop fields (n = 117), 160 species in summer crop fields (n = 315) and 139 species in recently abandoned fields (n = 41). 108 species contribute to the overall species richness of both cultivated and abandoned fields.

In our study, the most frequent species (rf > 25 %; n = 473) are in decreasing order of frequency: *Convolvulus arvensis, Cirsium arvense*[+]*, Chenopodium album*[+]*, Amaranthus retroflexus*[+] (Fig. 5.4), *Echinochloa crus-galli, Polygonum aviculare*[+]*, Elymus repens* and *Consolida regalis*[+]. Among these species are also those with high relative overall cover (rc >10 %) in either winter crop, summer crop or recently abandoned fields. These species are marked with [+]. Only one more species, *Tripleurospermum perforatum*, reaches a high overall cover above ten (rc = 10.4 % in recently abandoned fields). In contrast, 187 species are recorded in less than 5 % of the investigated plots, in most cases with low relative overall cover (rc < 1%), and thus are found to be rare in today's arable land of Kosovo. 55 arable weed species s. str. contribute to this group of rare species.

Some of the rare arable weed species s. str. reach higher frequencies in the investigated recently abandoned fields (that were most probably abandoned in late summer or autumn 2006; Fig. 5.5) than in the cultivated fields (mainly summer crop fields). This is especially true for species that typically occur in winter crop fields (e.g., *Adonis aestivalis, Agrostemma githago, Anthemis austriaca, Caucalis platycarpos, Lithospermum arvense, Ranunculus arvensis, Vicia pannonica*). Moreover, some less rare arable weed species s. str. that also typically occur in winter crop fields (e.g., *Alopecurus myosuroides, Anagallis arvensis, Avena fatua, Centaurea cyanus, Consolida regalis, Matricaria recutita, Papaver rhoeas, Tripleurospermum perforatum*) reach higher frequencies in the investigated recently abandoned than in the cultivated fields. On the other hand, several arable weed species s. str. that typically concentrate on summer crop fields (e.g., *Amaranthus retroflexus, Chenopodium album, Galinsoga parviflora, Persicaria maculosa, Polygonum aviculare, Sinapis arvensis*) reach lower frequencies in the recently abandoned than in the cultivated fields.

Most of the species sampled in 2006 and 2007 were also found by Kojić et al. (1975), Banjska (1977), Lozanovski et al. (1980a), Kojić and Pejčinović (1982), and / or Kojić (1986) about 30 years ago. In these studies, 23 species documented in our study were not recorded, and 25 species were documented that are not found in our study. Most of the species that were found only either in our study or in the past are grassland and ruderal species, which only occasionally occur on arable land. However, in the latter group, eight species may be addressed as arable weed species s. str. (*Amaranthus albus, Lathyrus aphaca, Lathyrus nissolia, Orlaya grandiflora, Raphanus raphanistrum, Scleranthus annuus, Vaccaria pyramidata* and *Xanthium spinosum*). Moreover, *Agrostemma githago, Aristolochia clematitis, Bifora radians, Caucalis platycarpos, Cynodon dactylon* and *Portulaca oleracea*, were more frequent in the arable land of Kosovo in the past.

Fig. 5.4. Mixed cropping of maize and beans on a dystric vertisol in the eastern part of Kosovo with high cover of *Amaranthus retroflexus*.
The picture was taken in early July 2006. Photo by A. Mehmeti.

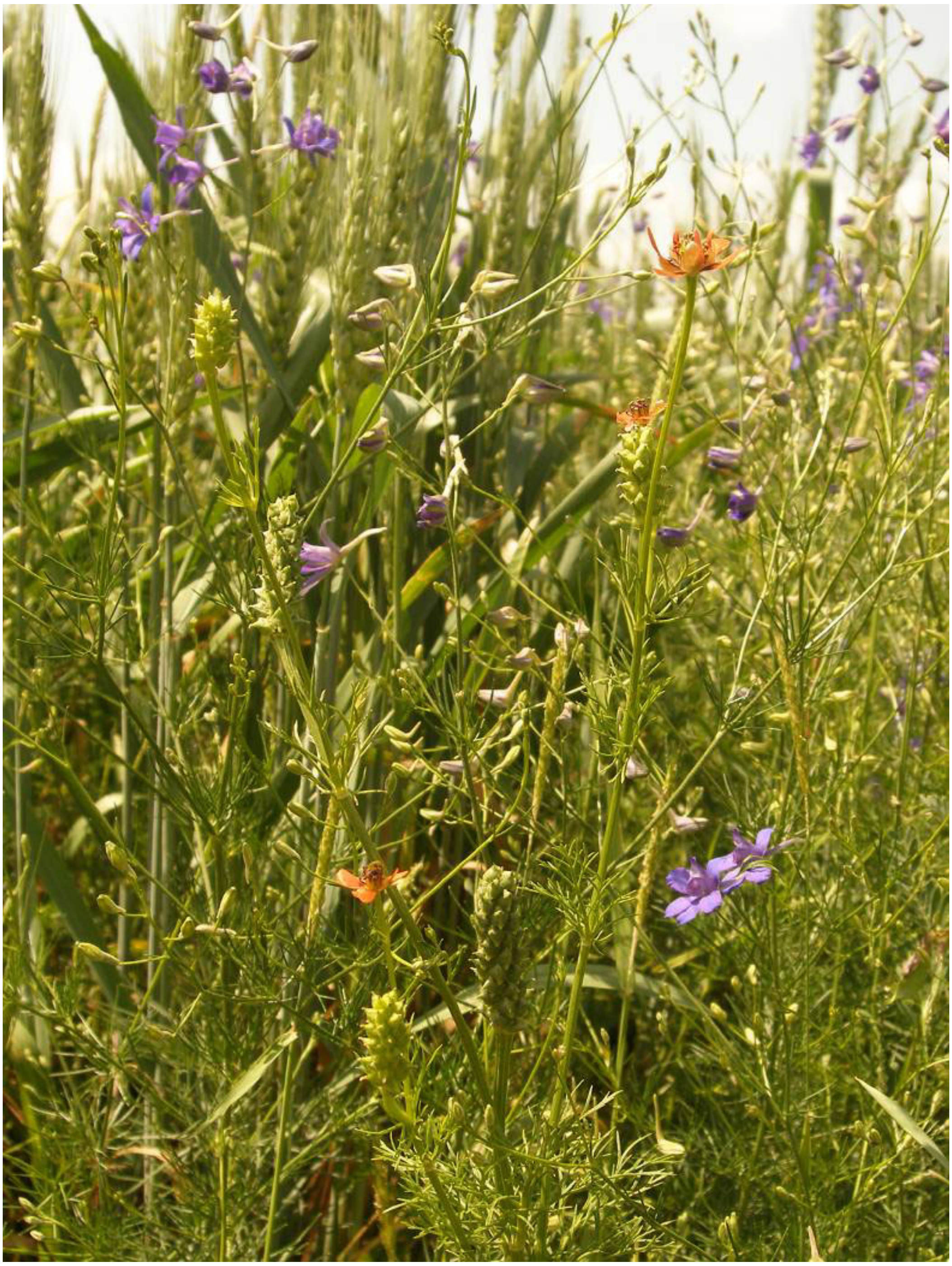

Fig. 5.5. Recently abandoned field on a eutric fluvisol west of Prishtina with *Adonis aestivalis* and *Consolida regalis.*
The picture was taken in May 2007. Photo by R. Waldhardt.

5.4.2 Today's flora and indicator species in the cultivated arable land of two sub-regions of Kosovo (Hypothesis 2)

The species richness of the two sub-regions is very similar. Given an overall number of 107 species occurring in more than three of the considered 270 arable fields, 98 species are recorded in the western part, while 102 species are found in the eastern part. The 14 species that are recorded in just one of the two sub-regions are mainly grassland species such as

Rumex obtusifolius, *Daucus carota* or *Salvia pratensis*, which only occasionally occur on arable land.

However, in the Indicator Species Analysis, two arable weed species that occur in both sub-regions are detected as indicator species ($p < 0.05$; indicator values in % in brackets): *Datura stramonium* (17.2), with high percentage species cover mainly in maize and vegetable, occurs more frequently and with higher abundance in the western part of the country. *Convolvulus arvensis* (46.6), with high cover mainly in maize and wheat, is more common in the eastern part.

5.4.3 Determinants of today's species richness and composition of Kosovo's weed vegetation (Hypothesis 3)

At the plot scale, species richness (α-species richness) is fairly low today, as already published in Mehmeti et al. (2008): Only between 2 and 26 species per plot are recorded. Mean species numbers in cultivated fields range from 8 (in vegetables) to 10 (in winter wheat), and species numbers are not significantly different between crops. In recently abandoned fields, mean species richness is significantly higher (18.8 species per plot). Based on the GRM analyses considering either the whole dataset (n = 473; no significant results) or only the abandoned fields (n = 41; no significant results), the UTM coordinates, the altitude above sea level, and the belonging to a certain class of topographic position, soil base-richness and moisture do not explain the given amplitude of α-species richness.

Comparison of species richness in fields with different ways of weed control (n = 40) reveals that, in both maize and wheat, the species richness of herbicide treated plots is significantly lower than of plots with mechanical weed control (maize) or without any weed control (wheat). In comparison of the investigated groups, the highest mean species number is found in wheat without any weed control, the lowest in herbicide treated maize fields (Fig. 5.6).

Differences in the species composition between the crop classes become apparent from the results of the Indicator Species Analysis for crop classes (n = 473). Seven summer annual species (plus one 'summer green' geo-/hemicryptophyte; terminology of leaf life span according to Ellenberg et al., 1992) are detected as indicator species of summer crop fields; three winter annual species indicate winter crop fields (Tab. 5.4). The plots of the recently abandoned fields are indicated by a large number of arable weed species, short-lived ruderals and grassland species (Tab. 5.5). No indicator species are found for the classes of topographic position, soil base-richness and soil moisture.

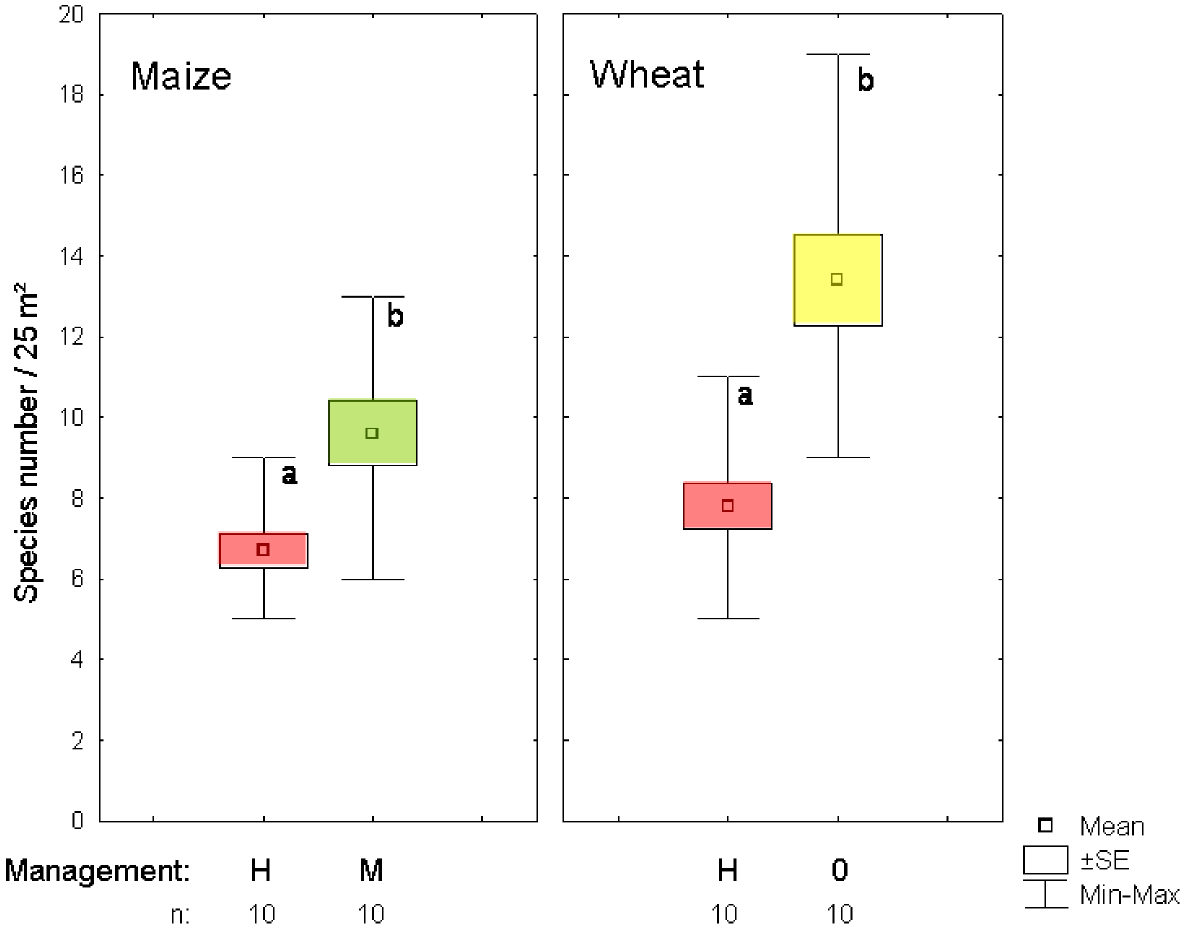

Fig. 5.6. Weed management and species richness at the plot scale.

Comparsion of the plant species in 40 selected arable fields of Kosovo with different weed control measurements. H: herbicide use; M: mechanical weed control in maize; 0: without any weed control in wheat; a, b: significant differences in mean species numbers (Student's t-test).

Tab. 5.4. Indicator species of summer and winter crop fields in Kosovo.

The analysis is based on a dataset comprising 473 standardised plots in arable land, classified as summer crop fields, winter crop fields and recently abandoned fields.

Summer crop fields (n=315)				**Winter crop fields (n=117)**			
	IV	**LF***	**LLS***		**IV**	**LF***	**LLS***
Amaranthus retroflexus	77.3	T	S	*Viola arvensis*	40.2	T	W
Echinochloa crus-galli	58.6	T	S	*Consolida regalis*	35.4	T	S
Chenopodium album	40.8	T	S	*Centaurea cyanus*	25.7	T	W
Sonchus arvensis	41.2	G, H	S				
Polygonum aviculare	40.5	T	S				
Persicaria maculosa	24.4	T	S				
Hibiscus trionum	19.4	T	S				
Datura stramonium	17.1	T	S				

Significance obtained by Monte-Carlo permutations test ($p < 0.001$); only species with indicator value > 15 are listed. IV: indicator value (%); LF: life form (T: therophyte, G: geophyte, H: hemicryptophyte); LLS = leaf life span (W: overwintering green; S: summer green);
* according to Ellenberg et al., (1992).

Tab. 5.5. Indicator species of recently abandoned arable fields in Kosovo.
The analysis is based on a dataset comprising 473 standardised plots in arable land, classified as summer crop fields, winter crop fields and recently abandoned fields.

Arable weed species				Ruderal and grassland species			
	IV	LF*	LLS*		IV	LF*	LLS*
Papaver rhoeas	56.7	T	S	*Lactuca serriola*	56.1	H, T	W
Tripleurospermum perforatum	39.2	T	W	*Taraxacum sect. Ruderalia*	45.7	H	W
Avena fatua	37.4	T	V	*Conyza canadensis*	34.7	T, H	S
Anthemis austriaca	31.6	T	W	*Trifolium repens*	22.7	C, H	W
Alopecurus myosuroides	26.5	T	W	*Rumex obtusifolius*	20.7	H	W
Matricaria recutita	23.1	T	W	*Vicia cracca*	19.8	Hli	S
Bifora radians	22.7	T	S	*Filago vulgaris agg.*	18.4	T	S
Galium aparine	21.7	Tli	V	*Melilotus officinalis*	15.3	H	S
Vicia pannonica	20.2	T	S				
Anthemis arvensis	18.8	T	W				
Consolida hispanica	17.1	T	S				
Plantago intermedia	15.1	H, T	S				

Significance obtained by Monte-Carlo permutation tests ($p < 0.001$); only species with indicator value > 15 are listed. IV: indicator value (%); LF: life form (T: therophyte, G: geophyte, H: hemicryptophyte); LLS = leaf life span (W: overwintering green; S: summer green; V: spring green);
* according to Ellenberg et al. (1992).

The DCA analysis of the entire vegetation dataset (n = 473) clearly illustrates differences in species composition between crop classes. In Fig. 5.7, three groups become obvious with respect to the crop classes along the first DCA axis. The vegetation in summer crop fields (in the left part of the diagram) is highly similar among itself (low β-diversity between the plots), the vegetation of winter crop fields (in the center of the diagram) is less similar among itself, and the vegetation of the recently abandoned fields (in the right part) is highly diverse (high β-diversity, i.e. species turnover, between the plots). With respect to the second DCA axis, it is noteworthy that 13 of the 20 herbicide-treated, but only 7 of the 20 unsprayed plots are in the upper half of the diagram. None of the environmental variables taken into account shows a significant correlation with the DCA axes in the joint plot.

Fig. 5.7. DCA diagram with scores of 432 cultivated and 41 recently abandoned arable plots. Given a high total inertia of 12.51 and a gradient length along the first axis of 3.98, most of the variance in the original dataset is accounted for by the first axis ($r^2 = 0.33$), while the second ($r^2 = 0.06$) and third axes ($r^2 = <0.1$) are of much lower importance. According to the DCA, vegetation of the arable land of Kosovo mainly differs between crop classes.

Focussing on the species distribution (Fig. 5.8) along the first DCA axis, summer green therophytes such as *Setaria viridis* and *Xanthium strumarium*, which mainly occur in summer crop fields, characterise the left part of the DCA diagram with scores of species. Winter green therophytes such as *Anagallis arvensis* and *Capsella bursa-pastoris*, which mainly occur in winter crop fields, are found in the center, and perennial plants concentrate on the right part of the DCA diagram. The distribution of the indicator species listed in Tab. 5.4 and 5.5, which are highlighted in colour in Fig. 5.8, is in accordance with the DCA results that clearly reflect the arrangement of summer crop, winter crop and recently abandoned fields along the first DCA axis.

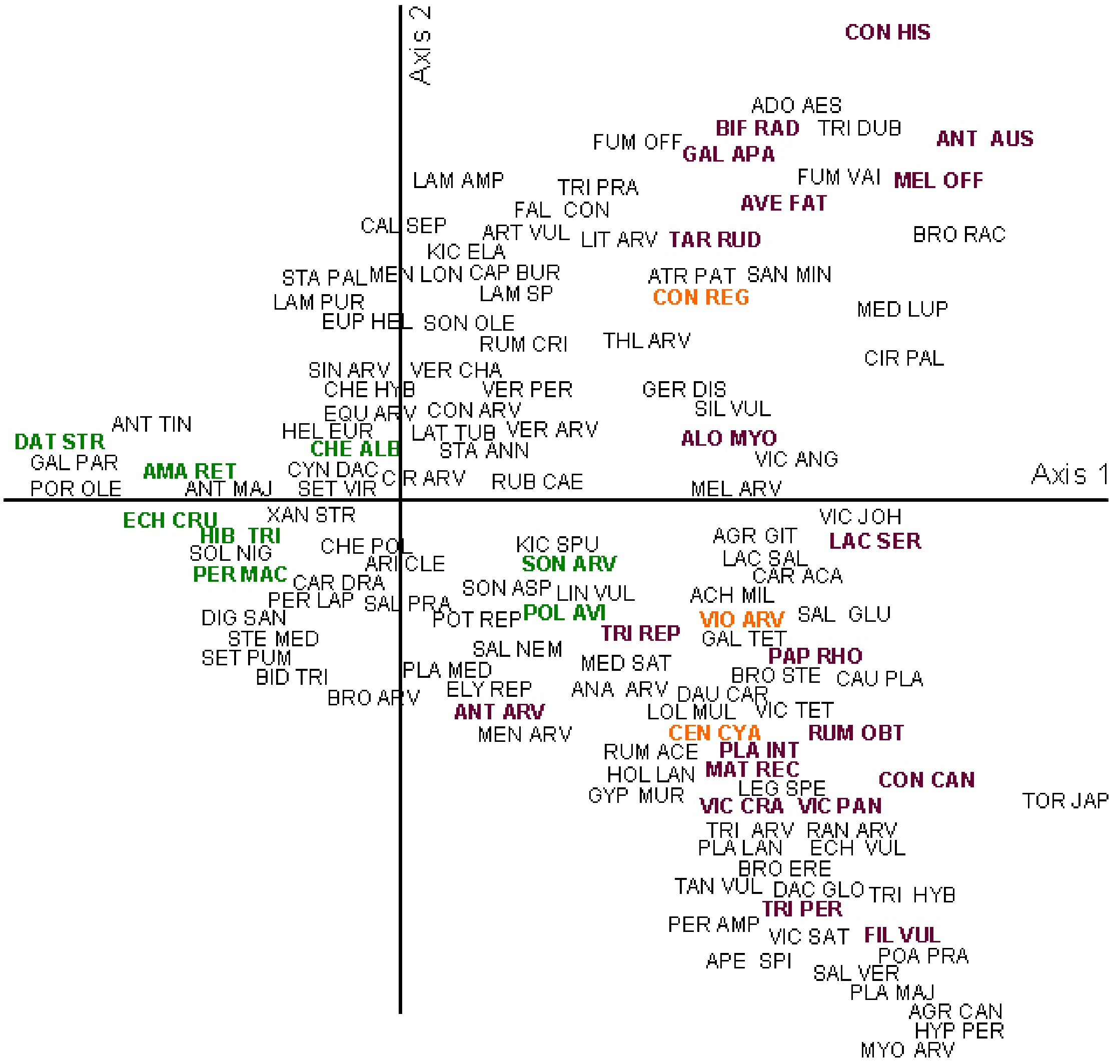

Fig. 5.8. DCA diagram with scores of species in 432 cultivated and 41 recently abandoned arable plots.
Only species occurring in more than three plots are shown. Abbreviation of species names as in appendix 1. Given a high total inertia of 12.51 and a gradient length along the first axis of 3.98, most of the variance in the original dataset is accounted for by the first axis ($r^2 = 0.33$), while the second ($r^2 = 0.06$) and third axes ($r^2 = <0.1$; not shown here) are of much lower importance. Indicator species of crop classes (cf. Table 4 and 5) are highlighted in colour (green: indicators of summer crop fields; orange: indicators of winter crop fields; brown: indicators of recently abandoned fields).

As shown in Fig. 5.9, relations between species composition and environmental variables become obvious in the DCA, if only the abandoned fields are taken into account. The environmental data are not related to the variance along the first axis. However, the second DCA axis displays correlations with topographic position (Pearson-r = 0.54), altitude (r = 0.44) and soil moisture (r = -0.44). Focussing on the species pattern of the DCA diagram, it becomes obvious that non-arable perennials such as *Plantago lanceolata, Hypericum perforatum, Daucus carota, Tanacetum vulgare* and *Bromus erectus* are more frequent in the left part of the diagram.

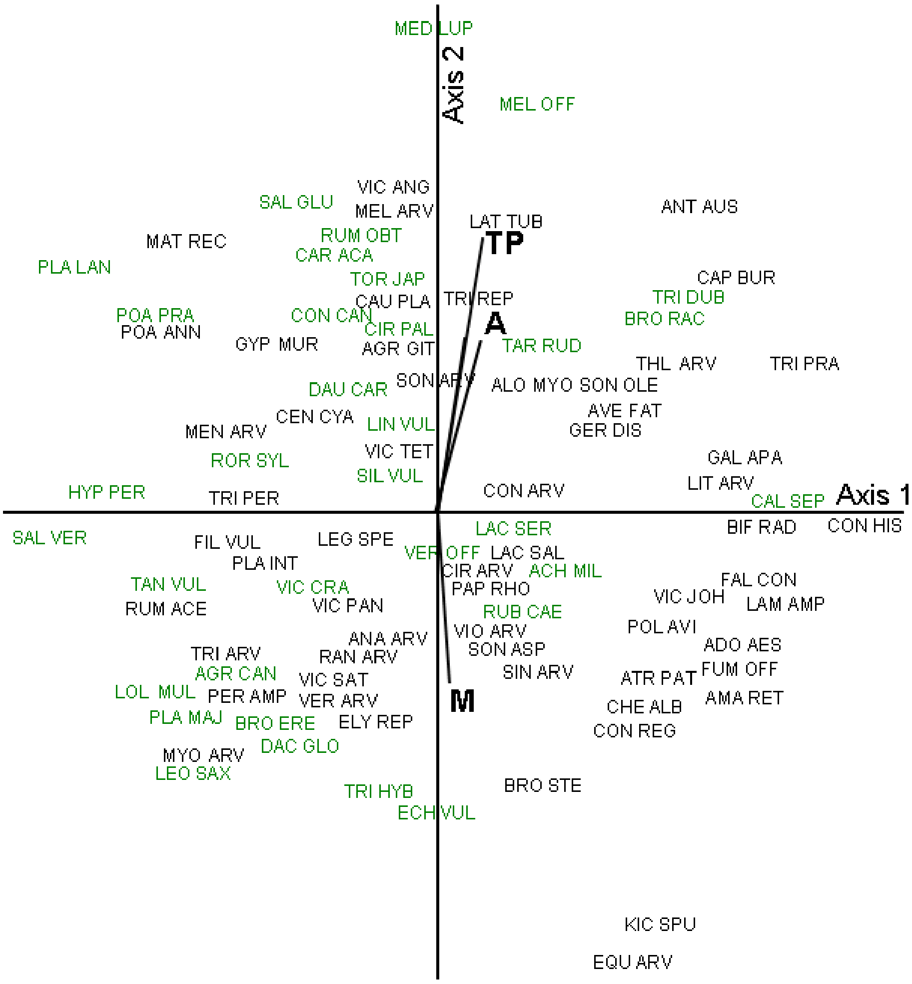

Fig. 5.9. DCA diagram of recently abandoned arable plots (n = 41).
Given a total inertia of 5.47 and a gradient length along the first axis of 3.65, most of the variance in the original dataset is accounted for by the first axis ($r^2 = 0.24$) and second axis ($r^2 = 0.15$), while the third axis ($r^2 = 0.08$; not shown here) is of much lower importance.
Joint plot with scores of all species occurring in more than two plots. TP: relative topographic position; A: altitude (above sea level); M: soil moisture. Overlay vectors (cutoff r^2 value: 0.2) were rescaled to 200 % for easier visual interpretation. Non-arable perennials in green colour. Abbreviation of species names as in appendix 1.

5.5 Discussion

5.5.1 Discussion of hypothesis 1 'At the regional scale, the arable weed flora has changed since about 1980.'

The arable weed flora of Kosovo, i.e. the regional species pool of the arable land, has considerably changed since about 1980: (i) Today, four highly competitive weeds, three summer annuals and one geophyte, are most frequent in the arable land of Kosovo. (ii) Several arable weed species s. str. are less frequent in comparison to the publication of Kojić and Pejčinović (1982). (iii) Eight arable weed species s. str. that contributed to the arable weed flora of Kosovo about 30 years ago are not surveyed in our study. In general, these results are in line with many publications on the arable weed flora and vegetation at the plot to the regional scale from different parts of the world (e.g., Volenik and Knezević 1984, Hilbig and Bachthaler 1992, Wilson and Aebischer 1995, Weiner et al. 2001, Lososová et al. 2004, Baessler and Klotz 2005, Gabriel et al. 2005, Pyšek et al. 2005, Waldhardt 2007, Fried et al. 2008), especially from 'productive regions', i.e. regions with highly fertile soils and suitable climate. From these studies and from monitoring and experimental studies (e.g., Lozanovski et al. 1980b, Arlt and Juttersonke 1992, Momirović et al. 1996, Susuri et al. 2001, Tuesca et al. 2001, Shrestha et al. 2002, Simić et al. 2003, Stešević and Jovović 2003, Bischoff 2004, Mehmeti 2003, 2004, Farkas 2006, Korolova et al. 2006, Mehmeti and Demaj 2006), the main reasons for both species endangerment and predominance are generally well known:

Species endangerment may be explained by e.g., herbicide sensitivity of weeds, modern seed cleaning techniques, lack of light in dense crops, short crop rotations, maize production, intensive soil tillage, decline in landscape complexity, and abandonment of cultivation. The predominance of species may be favoured by e.g., herbicide resistance, similar life cycles and habitat preferences of weeds and crops, high seed production, (moderately) persistent seed banks, rhizomes, and nitrophily. With respect to the major weeds in maize, a resistance to atrazine-related herbicides - which have been used in Kosovo and adjacent regions since decades - may be most important (e.g., Janjić et al. 2003; Pavlović et al. 2008).

5.5.2 Discussion of hypothesis 2 'At the regional scale, today's arable weed flora differs between two sub-regions characterised by differences in climatic conditions, agricultural production systems, and settlement history.'

Our results do not reveal pronounced differences in the arable weed flora between the western and the eastern part of Kosovo. The species pool of both sub-regions is largely identical. In that, the second hypothesis is not verified, indicating that either the differences between the distinguished sub-regions are too small, or the weed flora is highly affected by (an) other factor(s) operating in the entire region. In this context, herbicide use may be crucial, as herbicide use highly affects the arable weed vegetation at the plot scale (cf. Fig. 5.6 and discussion of hypothesis 3). This assumption may be supported by the ecology of the two indicator species, *Datura stramonium* and *Convolvulus arvensis*, which significantly differ in their frequencies and / or cover between the two sub-regions and are difficult to control chemically.

Datura stramonium, an invasive weed species, which most probably originates from Mexico but has been found in Europe since about 1600, Wein (1954), is obviously more typical of the western part of Kosovo where it reaches high abundances in maize and vegetables. Since several decades, *Datura stramonium* has led to severe crop losses in Kosovo and adjacent areas of the Balkan Peninsula, especially in maize (Kojić and Ajder 1989, Oljaća et al. 2007). According to the European Weed Research Society (EWRS 2008), *Datura stramonium* has become frequent on arable land not just on the Balkan Peninsula but also in other parts of southern Europe and, due to its toxicity and as a highly competitive weed, causes increasing problems for agriculture (e.g., in Hungary in vegetable production). Some main reasons for its spread in summer crop fields and vegetables are obvious: Similar to the predominant summer annual species mentioned above, its seeds mainly germinate in late spring (high germination rates between 20-30 °C; cf. Lauer 1953), its seed bank is persistent (Benvenuti 1995), and herbicide resistances are known (e.g., Williams et al. 1995, Stanković et al. 1996). *Datura stramonium* may produce seeds until late autumn, if temperatures are above freezing and adequate water is present (Heeger 1956). This might explain the 'higher importance' of *Datura stramonium* in the western part of Kosovo, where the frost free period is longer and the annual rainfall is higher than in the eastern part.

Convolvulus arvensis, the indicator species for the eastern sub-region, is less frequent and reaches lower abundances in vegetable than in maize. All over Europe, *Convolvulus arvensis* is a problematic weed in maize and other crops, as this geophyte is generally difficult to control chemically (e.g., Pfirter et al. 1997, Rusu et al. 2007) and may reach high abundances especially in no-tillage and reduced tillage systems (Jurado-Expósito et al. 2005). Thus, the 'lower importance' of *Convolvulus arvensis* in the western sub-region might indicate a comparatively high tillage intensity and / or intensive mechanical weed control in vegetable production.

Apart from these two species, the second hypothesis is not verified, indicating that either (i) the differences between the distinguished sub-regions are too small, or (ii) the weed flora is highly affected by (an) other factor(s) operating in the entire region. In this context, herbicide use may be crucial, as herbicide use highly affects α-species richness at the plot scale (cf. Fig. 5.6 and discussion of hypothesis 3) and both indicator species are difficult to control chemically.

5.5.3 Discussion of hypothesis 3 'At the plot scale, today's arable weed vegetation is related to environmental features and agricultural management measures.'

At the plot scale, α-species richness does not differ between crop classes or classes of topographic position, soil base-richness and soil moisture. However, with respect to agricultural management practices, species richness differs between different ways of weed management (cf. Fig. 5.6). This indicates that weeds control, and especially herbicide application, might be the most important limiting factor of α-species richness in the arable land of Kosovo today.

With respect to species composition at the plot scale, both the Indicator Species Analyses (Tab. 5.4 and 5.5) and the DCA analyses (Fig. 5.7 and 5.8) highlight clear differences between the distinguished crop classes. This is in accordance with results of other studies from Central Europe and the Balkan Peninsula (e.g., Kojić and Pejčinović 1982, Šinžar et al. 1996, Pysek et al. 2005). Focussing on environmental features, the vegetation composition of recently abandoned arable land differs in relation to several physical site characteristics (relative topographic position, altitude above sea level, soil-moisture; cf. Fig. 5.9). All these results are in accordance with our third hypothesis.

Given the pattern of herbicide-treated and unsprayed plots along the second DCA axis of the cultivated fields (Fig. 5.7), vegetation differentiation might also reflect herbicide effects. Moreover, given the pattern of non-arable perennial species along the first axis in the DCA of the recently abandoned fields (Fig. 5.9), vegetation differentiation might also be related to the past land use cf. Waldhardt (1994) and / or the quality of the surrounding habitats (Gabriel et al. 2005): More non-arable perennials should be expected to occur in fields, if the period of abandonment was longer, past land use was less intensive with respect to e.g., herbicide use, plots were temporarily abandoned before this study and / or habitat diversity in the surrounding was high. However, the discussion of these potential determinants of vegetation differentiation has to remain speculative for three reasons. Information on herbicide use was not available for most of the studied cultivated fields. Detailed information on the date of abandonment of the studied abandoned fields was not available. The surroundings of the investigated fields were not surveyed.

In our study, vegetation differentiation along environmental gradients is low. This may be partly explained by the structure of our datasets (cf. Tab. 5.3): As large areas of the arable land of Kosovo are situated in two plains and we randomly selected the investigated plots, most of the plots are located on highly fertile soils in these plains. Thus, environmental gradients may be comparatively low in our study. Moreover, as in many other parts of the world (cf. publications listed in the discussion of hypothesis 1), agricultural management measures such as irrigation, fertilisation and herbicide use may have resulted in a vast homogenisation of site conditions and the predominance of only a few highly competitive arable weeds. As a consequence, in large parts of today's arable land in Kosovo and elsewhere the development and occurrence of weed species is so strongly hindered that formerly known relations between environmental site conditions and flora / vegetation patterns do not exist anymore or have become superimposed.

5.5.4 Summarising discussion

From our study, it is most obvious that today's flora and vegetation of the cultivated arable land in Kosovo is negatively affected by (i) weed control (especially herbicide use) that reduces α-species richness and most probably favours herbicide-resistant species and (ii) maize production that is highly unsuitable for those species, which concentrate on winter crop fields. Moreover, as in other parts of Europe, (iii) the abandonment of cultivation, especially on shallow calcareous soils, might endanger several weed species in Kosovo that belong to the phytosociological alliance Caucalidion platycarpi Tx. 1950 (e.g., *Adonis aestivalis, Caucalis platycarpos, Legousia speculum-veneris*). However, for several reasons, a detailed evaluation of the drivers of changes is difficult: (i) In our study, the comparison of the past and today's arable weed flora of Kosovo has to remain vague, mainly due to the differences in data sampling between the past and today. (ii) Detailed information on land management at the plot scale, and (iii) appropriate data on landscape structure and dynamics at the landscape scale are not easily available. (iv) Given the facts that not only current, but also the legacy of past land use are relevant for today's vegetation in agricultural landscapes, and that land-use practices have significantly changed in Kosovo in the recent past, the understanding of changes in the weed flora becomes even more difficult.

Although in Kosovo the agricultural management practices have significantly changed in the last 20 years, today's production systems are obviously unsuitable for the establishment of a rich arable weed flora and vegetation on most cultivated fields. At the same time, a high species richness at the regional scale and, moreover, a comparatively high α-species richness and a much more differentiated vegetation of recently abandoned fields indicate potentials for future development. These would probably become even more apparent if the vegetation at field margins was also taken into account (cf. Waldhardt 1994). In this context, we suggest comparative studies in field centres and margins, especially on frequencies and population sizes of the most rare weed species. Moreover, we suggest soil seed bank analyses, and population biological studies on selected rare species to quantify the development potential and the endangerment of the arable flora and vegetation that should be considered in future production systems and nature protection measures.

5.6 Conclusions

With this study, we contribute to the ongoing floristic mapping of Kosovo, which largely has neglected the arable land since about 30 years. Based on random sampling covering the entire agricultural land of Kosovo, we provide information on species occurrence, frequency and cover. At the same time, our data may serve as a reference for future studies on land-use (change) and its effects on the arable weed flora and vegetation in Kosovo. Moreover, we provide quantitative information on the relationships between the vegetation of the arable land and both environmental features and agricultural management measures.

Wheat and maize production predominate the arable land of Kosovo, resulting in a low α-species richness in large areas of the region. In that, today's arable land use may not be considered as ecologically sustainable. However, potentials for future development have become obvious from our study, especially with respect to the regional species richness and comparatively high α-species richness and β-species richness of recently abandoned fields. To facilitate the arable land flora and vegetation of Kosovo, measures such as the implementation of wider crop rotations and less intensive weed control would be most welcome. However, such measures need to be integrated in production systems that, at the same time, are sustainable with respect to landscape functions other than providing space for biodiversity. Against the background of the economic situation of Kosovo, this holds especially true for the production function. We thus conclude that, multi-, inter- and transdisciplinary research activities on sustainable arable land use in Kosovo need to be strengthened. At the same time, further political and socioeconomic stabilisation in Kosovo will be a prerequisite for sustainable land development and hopefully this will be achieved in the near future.

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Appendix 5.1. Species recorded in this study and in former studies on the flora and vegetation of the arable land in Kosovo.

C: cultivated fields; A: recently abandoned fields; K: species on arable land documented in vegetation relevés by Kojić and Pejčinović (1982); KBLK: species contributing to the regional flora according to Kojić et al. (1975), Banjska (1977), Lozanovski et al. (1980a) and Kojić (1986); W: winter crop fields; S: summer crop fields; rf: relative frequency; rc: relative overall cover; oc: species occurrence; AW: arable weed species s. str. in accordance with Hüppe and Hofmeister (1990) or, indicated by *, to own expertise on Kosovo's arable weed flora; ABBR: abbreviation of species names as in Fig. 5.8 and 5.9. Nomenclature in accordance with Wisskirchen and Haeupler (1998) or, indicated by **, Tutin et al. (1964-1993).

Species recorded …	**… in this study**									**… in former studies**		**AW**	**ABBR**
	C						**A**		**C + A**	**K**	**KBLK**		
Year of investigation (C; A) or publication (K; KBLK)	2006						2007		2006 + 2007	1982	1975 to 1986		
	W		**S**		**W + S**								
number of investigated plots	*117*		*315*		*432*		*41*		*473*	*33*			
number of species	*140*		*160*		*204*		*139*		*235*	*106*	*236*		
	Rf (%)	rc (%)	rf (%)	rc (%)	rf (%)	Rc (%)	rf (%)	rc (%)	rf (%)	oc	Oc		
Acer negundo	0.9	<0.1			0.2	<0.1			0.2				ACE NEG
Adonis vernalis	0.9	<0.1			0.2	<0.1			0.2		+		ADO VER
Aethusa cynapium			0.3	<0.1	0.2	<0.1			0.2		+	+	AET CYN
Agrostis capillaries	1.7	0.7			0.5	0.2			0.5		+		AGR CAP
Agrostis sp.			0.3	<0.1	0.2	<0.1			0.2				AGR SP.
Alchemilla vulgaris agg.			0.3	<0.1	0.2	<0.1			0.2		+		ALC VUL
Amaranthus blitoides			0.6	0.1	0.5	0.1			0.5		+	+*	AMA BLI
Anagallis foemina	0.9	<0.1			0.2	<0.1			0.2		+	+	ANA FOE
Anthemis arvensis	6.0	1.4	5.7	0.6	5.8	0.9			5.3	+	+	+	ANT ARV
Anthemis tinctoria			1.0	<0.1	0.7	<0.1			0.6		+		ANT TIN
Antirrhinum majus			1.6	<0.1	1.2	<0.1			1.1				ANT MAJ
Apera spica-venti	7.7	1.5	0.3	<0.1	2.3	0.5			2.1		+	+	APE SPI
Arrhenatherum elatius	0.9	1.0			0.2	0.3			0.2		+		ARR ELA
Artemisia vulgaris	3.4	0.1	0.3	<0.1	1.2	0.1			1.1		+		ART VUL

*Avena ludoviciana***			0.3	<0.1	0.2	<0.1		0.2		+	+*	AVE LUD
Ballota nigra			0.3	<0.1	0.2	<0.1		0.2		+		BAL NIG
Bidens tripartite			2.2	<0.1	1.6	<0.1		1.5		+		BID TRI
Bromus arvensis			1.0	<0.1	0.7	<0.1		0.6		+		BRO ARV
Bromus sp.	0.9	<0.1			0.2	<0.1		0.2	+			BRO SP.
Campanula persicifolia			0.3	<0.1	0.2	<0.1		0.2				CAM PER
Campanula sp.	0.9	<0.1	0.3	<0.1	0.5	<0.1		0.5				CAM SP.
Cardaria draba			1.3	<0.1	0.9	<0.1		0.8	+	+		CAR DRA
Centaurea calcitrapa			0.6	<0.1	0.5	<0.1		0.5		+		CEN CAL
Centaurea sp.	0.9	<0.1	0.3	<0.1	0.5	<0.1		0.5				CEN SP.
Chaenorhinum minus			0.3	<0.1	0.2	<0.1		0.2		+		CHA MIN
Chenopodium hybridum	2.6	0.2	5.4	0.2	4.6	0.2		4.2		+		CHE HYB
Chenopodium polyspermum	5.1	0.3	8.3	0.5	7.4	0.4		6.8		+	+	CHE POL
Cichorium intybus	0.9	0.2	0.3	<0.1	0.5	0.1		0.5	+	+		CIC INT
Datura stramonium			16.8	1.3	12.3	0.9		11.2	+	+	+*	DAT STR
Daucus sp.	0.9	<0.1			0.2	<0.1		0.2				DAU SP.
Digitaria sanguinalis	0.9	<0.1	7.9	0.3	6.0	0.3		5.5		+	+*	DIG SAN
Echinochloa crus-galli	1.7	<0.1	58.4	9.5	43.1	6.6		39.4	+	+	+*	ECH CRU
Epilobium parviflorum			0.3	<0.1	0.2	<0.1		0.2		+		EPI PAR
Epilobium tetragonum	0.9	<0.1			0.2	<0.1		0.2		+		EPI TET
Equisetum palustre			0.3	0.2	0.2	0.1		0.2		+		EQU PAL
Eragrostis pilosa			0.3	<0.1	0.2	<0.1		0.2		+		ERA PIL
Erigeron annuus	1.7	0.2			0.5	0.1		0.5		+		ERI ANN
Erucastrum gallicum			0.3	<0.1	0.2	<0.1		0.2				ERU GAL
Eryngium campestre	0.9	<0.1	0.3	<0.1	0.5	<0.1		0.5	+	+		ERY CAM
Euphorbia cyparissias	0.9	<0.1			0.2	<0.1		0.2	+	+		EUP CYP
Euphorbia esula	0.9	<0.1	0.3	<0.1	0.5	<0.1		0.5		+		EUP ESU
Euphorbia falcate	1.7	<0.1			0.5	<0.1		0.5		+	+	EUP FAL
Euphorbia helioscopia	3.4	0.1	4.8	0.1	4.4	0.1		4.0	+	+	+	EUP HEL

Falcaria vulgaris			0.6	<0.1	0.5	<0.1		0.5		+		FAL VUL
*Filago montana***	1.7	<0.1			0.5	<0.1		0.5		+		FIL MON
Galeopsis ladanum	0.9	<0.1			0.2	<0.1		0.2		+		GAL LAD
Glechoma hederacea			0.3	<0.1	0.2	<0.1		0.2		+		GLE HED
Gnaphalium uliginosum	0.9	<0.1			0.2	<0.1		0.2		+		GNA ULI
Gypsophila repens			0.3	<0.1	0.2	<0.1		0.2		+		GYP REP
Heliotropium europaeum	0.9	<0.1	3.8	0.4	3.0	0.3		2.7	+	+	+*	HEL EUR
*Hibiscus trionum***			19.0	1.9	13.9	1.3		12.7	+	+	+*	HIB TRI
Hieracium pilosella	0.9	<0.1			0.2	<0.1		0.2	+	+		HIE PIL
Hippocrepis emerus			0.3	<0.1	0.2	<0.1		0.2				HIP EME
Holcus lanatus	2.6	0.5	0.6	<0.1	1.2	0.2		1.1		+		HOL LAN
Kickxia elatine	1.7	0.1	1.0	<0.1	1.2	<0.1		1.1		+	+	KIC ELA
Lactuca quercina			0.6	<0.1	0.5	<0.1		0.5		+		LAC QUE
Lamium sp.	0.9	<0.1	0.6	<0.1	0.7	<0.1		0.6				LAM SP.
Lithospermum purpurocaeruleum	0.9	<0.1	0.3	<0.1	0.5	<0.1		0.5		+		LIT PUR
Lycopus europaeus			0.3	<0.1	0.2	<0.1		0.2		+		LYC EUR
Lythrum salicaria			0.6	<0.1	0.5	<0.1		0.5	+	+		LYT SAL
Malva sylvestris			0.3	<0.1	0.2	<0.1		0.2	+	+		MAL SYL
Medicago falcate			0.3	<0.1	0.2	<0.1		0.2		+		MED FAL
Medicago minima	0.9	<0.1			0.2	<0.1		0.2		+		MED MIN
*Medicago orbicularis***			0.3	<0.1	0.2	<0.1		0.2		+		MED ORB
Medicago x varia	1.7	<0.1			0.5	<0.1		0.5				MED VAR
Mentha longifolia	1.7	0.1	1.0	0.4	1.2	0.3		1.1		+		MEN LON
Nigella arvensis	1.7	<0.1			0.5	<0.1		0.5		+	+	NIG ARV
Papaver dubium			0.6	<0.1	0.5	<0.1		0.5		+	+	PAP DUB
Phragmites australis	0.9	<0.1			0.2	<0.1		0.2		+		PHR AUS
Picris hieracioides agg.	1.7	<0.1			0.5	<0.1		0.5		+		PIC HIE
Portulaca oleracea			7.0	0.3	5.1	0.2		4.7	+	+	+*	POR OLE
Potentilla reptans	0.9	<0.1	1.0	<0.1	0.9	<0.1		0.8	+	+		POT REP

Ranunculus repens			0.3	<0.1	0.2	<0.1			0.2	+	+		RAN REP
Rhinanthus minor	0.9	0.3			0.2	0.1			0.2		+		RHI MIN
Salvia nemorosa	0.9	<0.1	1.0	<0.1	0.9	<0.1			0.8		+		SAL NEM
Salvia pratensis	1.7	0.1	1.9	0.4	1.9	0.3			1.7		+		SAL PRA
Sanguisorba minor	2.6	0.1			0.7	<0.1			0.6		+		SAN MIN
Setaria pumila			2.5	0.9	1.9	0.7			1.7	+	+	+*	SET PUM
Setaria sp.			0.3	<0.1	0.2	<0.1			0.2				SET SP.
Setaria viridis	1.7	0.1	9.5	0.9	7.4	0.7			6.8	+	+	+*	SET VIR
Sherardia arvensis	0.9	<0.1			0.2	<0.1			0.2	+	+	+	SHE ARV
Silene noctiflora	0.9	<0.1			0.2	<0.1			0.2		+	+	SIL NOC
Solanum nigrum			14.0	0.7	10.2	0.5			9.3	+	+	+*	SOL NIG
Sonchus sp.			0.6	<0.1	0.5	<0.1			0.5				SON SP.
Sorghum halepense			0.6	<0.1	0.5	<0.1			0.5	+	+	+*	SOR HAL
Stachys palustris	5.1	0.6	4.8	0.2	4.9	0.3			4.5		+		STA PAL
Stellaria media agg.			2.9	0.1	2.1	0.1			1.9		+	+	STE MED
Symphytum officinale			0.3	<0.1	0.2	<0.1			0.2		+		SYM OFF
Symphytum sp.			0.3	<0.1	0.2	<0.1			0.2				SYM SP.
Tanacetum corymbosum			0.3	<0.1	0.2	<0.1			0.2		+		TAN COR
Tragopogon pratensis			0.3	<0.1	0.2	<0.1			0.2		+		TRA PRA
Trifolium montanum			0.3	<0.1	0.2	<0.1			0.2		+		TRI MON
Veronica chamaedrys	0.9	<0.1	1.0	<0.1	0.9	<0.1			0.8		+		VER CHA
Veronica hederifolia agg.			0.3	<0.1	0.2	<0.1			0.2	+	+	+	VER HED
Veronica officinalis			0.3	<0.1	0.2	<0.1			0.2		+		VER OFF
Xanthium strumarium	7.7	0.5	11.7	1.0	10.6	0.8			9.7	+	+	+*	XAN STR
Achillea millefolium agg.	3.4	0.1	0.6	<0.1	1.4	0.1	7.3	0.1	1.9	+	+		ACH MIL
Adonis aestivalis	0.9	<0.1			0.2	<0.1	12.2	0.1	1.2		+	+	ADO AES
Agrostemma githago	7.7	0.4	0.3	<0.1	2.3	0.2	17.1	0.3	3.6	+	+	+	AGR GIT
Alopecurus myosuroides	8.5	4.8	4.8	0.3	5.8	1.7	39.0	2.8	8.7		+	+	ALO MYO
Amaranthus retroflexus			80.3	18.8	58.6	13.0	7.3	0.2	54.2	+	+	+*	AMA RET

Ambrosia artemisiifolia			0.3	<0.1	0.2	<0.1	2.4	<0.1	0.4		+		AMB ART
Anagallis arvensis	19.7	1.2	6.7	0.2	10.2	0.5	29.3	2.2	11.9	+	+	+	ANA ARV
Anthemis austriaca			0.3	<0.1	0.2	<0.1	31.7	7.0	2.9		+	+*	ANT AUS
Aristolochia clematitis			3.8	0.4	3.0	0.3	2.4	<0.1	2.9	+	+	+*	ARI CLE
Atriplex patula	16.2	1.3	1.6	0.1	5.6	0.5	17.1	0.2	6.6		+	+	ATR PAT
Avena fatua	9.4	0.6	1.3	<0.1	3.5	0.3	46.3	0.7	7.2	+	+	+	AVE FAT
Bifora radians	8.5	1.1	1.0	<0.1	3.0	0.4	26.8	3.8	5.1	+	+	+	BIF RAD
Bromus erectus	0.9	<0.1			0.2	<0.1	4.9	0.3	0.6		+		BRO ERE
Bromus sterilis	0.9	<0.1			0.2	<0.1	4.9	0.2	0.6		+	+*	BRO STE
Bupleurum rotundifolium	0.9	<0.1			0.2	<0.1	2.4	<0.1	0.4		+	+	BUP ROT
Calystegia sepium	2.6	0.3	3.8	0.2	3.5	0.3	4.9	<0.1	3.6		+		CAL SEP
Capsella bursa-pastoris	0.9	<0.1	6.7	0.2	5.1	0.1	4.9	0.4	5.1	+	+	+	CAP BUR
Carduus acanthoides	2.6	0.1	0.3	<0.1	0.9	<0.1	9.8	0.1	1.7	+	+		CAR ACA
Caucalis platycarpos	3.4	0.1			0.9	<0.1	12.2	0.1	1.9	+	+	+	CAU PLA
Centaurea cyanus	22.2	5.0	9.8	0.3	13.2	1.8	43.9	2.8	15.9	+	+	+	CEN CYA
Centaurea scabiosa			0.3	<0.1	0.2	<0.1	2.4	0.1	0.4		+		CEN SCA
Chenopodium album	53.0	6.8	79.7	15.6	72.5	12.9	39.0	1.5	69.6	+	+	+	CHE ALB
Cirsium arvense	69.2	10.7	74.0	13.3	72.7	12.9	68.3	3.6	72.3	+	+	+*	CIR ARV
Cirsium palustre	0.9	<0.1	0.3	<0.1	0.5	<0.1	12.2	0.4	1.5		+		CIR PAL
Consolida regalis	76.1	11.5	3.5	0.2	23.1	4.1	51.2	8.3	25.5	+	+	+	CON REG
Convolvulus arvensis	68.4	6.5	74.9	6.0	73.1	6.5	85.4	2.0	74.2	+	+	+*	CON ARV
Conyza Canadensis	8.5	0.3	1.3	<0.1	3.2	0.2	39.0	2.4	6.3	+	+		CON CAN
Cynodon dactylon	2.6	0.3	4.8	0.9	4.2	0.7	2.4	0.1	4.0	+	+	+*	CYN DAC
Dactylis glomerata	0.9	0.2			0.2	0.1	4.9	0.3	0.6		+		DAC GLO
Daucus carota	9.4	0.4	1.0	<0.1	3.2	0.1	22.0	0.2	4.8	+	+		DAU CAR
Echium vulgare			0.3	<0.1	0.2	<0.1	4.9	0.3	0.6		+		ECH VUL
Elymus repens	9.4	1.9	33.3	4.7	26.9	3.9	31.7	5.6	27.3	+	+	+*	ELY REP
Equisetum arvense	5.1	0.5	14.6	1.6	12.0	1.3	7.3	1.1	11.6	+	+	+*	EQU ARV
Fallopia convolvulus	41.9	3.3	16.8	0.7	23.6	1.8	34.1	1.1	24.5	+	+	+	FAL CON

Filago vulgaris agg.	1.7	<0.1			0.5	<0.1	19.5	0.3	2.1				FIL VUL
Fumaria officinalis	0.9	<0.1	1.3	<0.1	1.2	<0.1	9.8	0.4	1.9		+	+	FUM OFF
Galeopsis pubescens	0.9	<0.1			0.2	<0.1	2.4	<0.1	0.4		+		GAL PUB
Galeopsis tetrahit	8.5	1.4	0.3	<0.1	2.5	0.5	2.4	<0.1	2.5		+		GAL TET
Galinsoga parviflora	1.7	0.1	13.7	1.6	10.4	1.1	2.4	<0.1	9.7	+	+	+*	GAL PAR
Galium aparine	18.8	2.0	2.2	0.1	6.7	0.8	34.1	1.7	9.1	+	+	+*	GAL APA
Galium sylvaticum			0.3	<0.1	0.2	<0.1	2.4	0.1	0.4		+		GAL SYL
Geranium dissectum			1.0	<0.1	0.7	<0.1	9.8	0.1	1.5	+	+	+	GER DIS
Geranium molle			0.3	<0.1	0.2	<0.1	2.4	<0.1	0.4		+		GER MOL
Gypsophila muralis	2.6	0.6	1.6	<0.1	1.9	0.2	4.9	0.1	2.2		+		GYP MUR
Kickxia spuria	17.1	0.7	5.4	<0.1	8.6	0.4	7.3	0.1	8.5	+	+	+	KIC SPU
Lactuca serriola			0.6	<0.1	0.5	<0.1	56.1	0.8	5.3	+	+		LAC SER
Lamium amplexicaule	1.7	0.1	5.7	0.2	4.6	0.1	9.8	0.2	5.1	+	+	+	LAM AMP
Lamium purpureum	0.9	<0.1	4.4	0.1	3.5	0.1	2.4	0.1	3.4	+	+	+	LAM PUR
*Lathyrus sativus***	0.9	<0.1			0.2	<0.1	2.4	0.1	0.4		+	+*	LAT SAT
Lathyrus tuberosus	6.8	0.4	11.7	0.6	10.4	0.5	7.3	0.1	10.1	+	+	+	LAT TUB
Legousia speculum-veneris	5.1	0.1			1.4	<0.1	4.9	<0.1	1.7		+	+	LEG SPE
Linaria vulgaris	12.0	0.4	5.4	0.2	7.2	0.3	17.1	0.3	8.1	+	+		LIN VUL
Lithospermum arvense	1.7	<0.1	1.6	<0.1	1.6	<0.1	4.9	0.1	1.9	+	+	+	LIT ARV
Lolium multiflorum	1.7	0.2	0.6	0.2	0.9	0.2	7.3	0.1	1.5	+	+	+*	LOL MUL
Lolium perenne			0.3	<0.1	0.2	<0.1	2.4	0.1	0.4		+		LOL PER
Lysimachia vulgaris	0.9	<0.1			0.2	<0.1	2.4	0.1	0.4		+		LYS VUL
Matricaria recutita	19.7	0.9	4.1	0.1	8.3	0.5	31.7	2.3	10.3		+	+	MAT REC
Medicago lupulina	0.9	<0.1	0.6	<0.1	0.7	<0.1	4.9	0.7	1.1	+	+		MED LUP
Medicago sativa	0.9	<0.1	0.6	<0.1	0.7	<0.1	2.4	0.1	0.8		+		MED SAT
Melampyrum arvense	6.0	0.2	1.3	<0.1	2.5	0.1	9.8	0.2	3.1	+	+	+	MEL ARV
Melilotus officinalis	2.6	0.2	0.3	<0.1	0.9	0.1	17.1	1.1	2.3		+		MEL OFF
Mentha arvensis	7.7	0.5	8.9	0.8	8.6	0.7	22.0	0.7	9.8	+	+	+*	MEN ARV
Myosotis arvensis	0.9	<0.1			0.2	<0.1	12.2	1.3	1.2		+	+	MYO ARV

Papaver rhoeas	17.9	0.5	0.6	<0.1	5.3	0.3	63.4	4.5	10.3	+	+	+	PAP RHO
Persicaria amphibium	0.9	<0.1	0.3	<0.1	0.5	<0.1	7.3	0.1	1.1		+		PER AMP
Persicaria lapathifolia	4.3	0.1	5.4	0.6	5.1	0.5	2.4	<0.1	4.9	+	+	+	PER LAP
Persicaria maculosa	6.0	0.5	30.8	1.9	24.1	1.5	2.4	<0.1	22.2		+	+	PER MAC
Phleum pratense			0.3	<0.1	0.2	<0.1	2.4	<0.1	0.4		+		PHL PRA
Plantago lanceolata	8.5	0.3	1.9	<0.1	3.7	0.2	12.2	0.5	4.4	+	+		PLA LAN
Plantago major intermedia	7.7	0.6	1.6	0.1	3.2	0.3	22.0	0.5	4.8				PLA INT
Plantago major major	0.9	<0.1			0.2	<0.1	9.8	0.3	1.0		+		PLA MAJ
Plantago media	8.5	0.2	9.5	0.2	9.3	0.2	2.4	<0.1	8.7	+	+		PLA MED
Poa annua			0.3	<0.1	0.2	<0.1	4.9	0.1	0.6		+		POA ANN
Poa pratensis	0.9	<0.1			0.2	<0.1	12.2	0.2	1.2	+	+		POA PRA
Polygonum aviculare agg.	65.8	13.7	30.2	1.9	39.8	5.9	24.4	1.8	38.5	+	+		POL AVI
Ranunuclus arvensis			0.3	<0.1	0.2	<0.1	12.2	0.1	1.2	+	+	+	RAN ARV
Rubus caesius	13.7	0.9	9.8	0.3	10.9	0.6	12.2	0.2	11.0	+	+		RUB CAE
Rumex acetosella	5.1	0.1	1.0	<0.1	2.1	0.1	4.9	0.1	2.3		+		RUM ACE
Rumex crispus	2.6	<0.1	0.6	<0.1	1.2	<0.1	2.4	<0.1	1.3	+	+		RUM CRI
Rumex obtusifolius	0.9	<0.1	1.0	<0.1	0.9	<0.1	22.0	0.2	2.7		+		RUM OBT
Salvia glutinosa	0.9	<0.1			0.2	<0.1	7.3	0.1	0.8				SAL GLU
Salvia verticillata	0.9	<0.1			0.2	<0.1	7.3	0.8	0.8		+		SAL VER
Securigera varia			0.3	<0.1	0.2	<0.1	2.4	0.1	0.4		+		SEC VAR
Silene vulgaris	2.6	0.1	0.3	<0.1	0.9	<0.1	4.9	0.1	1.2		+		SIL VUL
Sinapis arvensis	1.7	<0.1	15.9	2.0	12.0	1.4	9.8	1.0	11.8		+	+	SIN ARV
*Smyrnium perfoliatum***			0.3	<0.1	0.2	<0.1	2.4	<0.1	0.4			+*	SMY PER
Sonchus arvensis	6.0	0.5	12.1	1.2	10.4	1.0	56.1	1.2	14.4	+	+	+	SON ARV
Sonchus asper	10.3	0.2	8.9	1.0	9.3	0.8	14.6	0.2	9.8		+	+	SON ASP
Sonchus oleraceus	18.8	0.5	20.3	1.0	19.9	0.9	22.0	0.6	20.1	+	+	+	SON OLE
Stachys annua			1.9	<0.1	1.4	<0.1	2.4	<0.1	1.5		+	+	STA ANN
Tanacetum vulgare	1.7	0.1	0.3	<0.1	0.7	<0.1	4.9	0.1	1.1		+		TAN VUL
Taraxacum sect. Ruderalia	3.4	0.1	6.0	0.1	5.3	0.1	51.2	0.8	9.3	+	+		TAR RUD

Thlaspi arvense	5.1	0.5	0.6	<0.1	1.9	0.1	4.9	<0.1	2.2	+	+	+	THL ARV
Trifolium arvense	6.0	0.1	0.3	<0.1	1.9	<0.1	9.8	0.4	2.6	+	+		TRI ARV
Trifolium dubium	1.7	0.1	0.3	<0.1	0.7	<0.1	12.2	0.1	1.7		+		TRI DUB
*Trifolium incarnatum***	0.9	<0.1			0.2	<0.1	2.4	<0.1	0.4		+	+*	TRI INC
Trifolium pratense	10.3	0.3	2.9	0.1	4.9	0.2	7.3	0.1	5.1		+		TRI PRA
Trifolium repens	3.4	0.1	4.1	0.1	3.9	0.1	26.8	0.7	5.9	+	+		TRI REP
Tripleurospermum perforatum	12.0	3.0	4.8	0.3	6.7	1.0	46.3	10.4	10.1		+	+	TRI PER
Veronica arvensis	1.7	0.1	1.3	0.3	1.4	0.2	4.9	<0.1	1.7		+	+	VER ARV
Veronica persica	6.8	0.5	3.5	0.1	4.4	0.2	2.4	0.1	4.2	+	+	+	VER PER
Vicia angustifolia	1.7	0.1			0.5	<0.1	4.9	0.1	0.9		+	+	VIC ANG
Vicia cracca	3.4	0.1	2.9	0.1	3.0	0.1	22.0	1.9	4.6	+	+		VIC CRA
Vicia johannis	0.9	<0.1			0.2	<0.1	4.9	<0.1	0.6		+	+*	VIC JOH
Vicia pannonica	2.6	0.1			0.7	<0.1	22.0	1.2	2.5	+	+	+	VIC PAN
Vicia sativa agg.	2.6	0.2	0.3	<0.1	0.9	0.1	7.3	0.1	1.5	+	+	+	VIC SAT
Vicia tetrasperma			0.3	<0.1	0.2	<0.1	12.2	0.2	1.2		+	+	VIC TET
Viola arvensis	29.1	1.9	4.8	0.2	11.3	0.8	56.1	3.1	15.2		+	+	VIO ARV
Agrostis canina							14.6	0.6	1.3		+		AGR CAN
Althaea hirsute							2.4	<0.1	0.2		+		ALT HIR
Althaea officinalis							2.4	<0.1	0.2		+		ALT OFF
Bromus racemosus							9.8	1.8	0.8		+		BRO RAC
Campanula rotundifolia							2.4	0.1	0.2				CAM ROT
Chenopodium ficifolium							2.4	<0.1	0.2		+	+*	CHE FIC
Conium maculatum							2.4	<0.1	0.2		+		CON MAC
Conringia orientalis							2.4	0.4	0.2		+	+	CON ORI
Consolida hispanica							17.1	3.6	1.5		+	+*	CON HIS
Cruciata laevipes							2.4	<0.1	0.2		+		CRU LAE
Erodium cicutarium							2.4	<0.1	0.2		+	+	ERO CIC
Festuca pratensis							2.4	0.4	0.2		+		FES PRA
Festuca rubra agg.							2.4	<0.1	0.2				FES RUB

Fumaria vaillantii				2.4	0.1	0.2		+	+*	FUM VAI
Galium album				2.4	<0.1	0.2	+	+		GAL ALB
Geranium pusillum				2.4	<0.1	0.2		+		GER PUS
*Haynaldia villosa***				2.4	0.1	0.2			+*	HAY VIL
Hypericum perforatum				7.3	0.8	0.6		+		HYP PER
Hypochaeris radicata				2.4	0.3	0.2		+		HYP RAD
Lactuca saligna				7.3	0.1	0.6	+	+		LAC SAL
Leontodon saxatilis				4.9	<0.1	0.4				LEO SAX
Mentha × piperita agg.				2.4	0.1	0.2				MEN PIP
Rorippa sylvestris				4.9	0.1	0.4		+		ROR SYL
Scutellaria hastifolia				2.4	<0.1	0.2		+		SCU HAS
Senecio vernalis				2.4	<0.1	0.2		+		SEN VER
Torilis japonica				7.3	0.1	0.6		+		TOR JAP
Trifolium alpestre				2.4	<0.1	0.2		+		TRI ALP
Trifolium hybridum				7.3	0.1	0.6		+		TRI HYB
Verbascum phlomoides				2.4	0.1	0.2		+		VER PHL
Verbena officinalis				4.9	<0.1	0.4	+	+		VER OFF
Vicia villosa				2.4	0.1	0.2		+	+	VIC VIL
Amaranthus albus							+	+	+*	
Arctium lappa							+	+		
Centaurea jacea							+	+		
Centaurium erythraea							+	+		
Chondrilla juncea							+	+		
Holcus mollis							+	+		
Lathyrus aphaca							+	+	+	
Lathyrus nissolia							+	+	+	
Lotus corniculatus							+	+		
Minuartia verna							+	+		
Nasturtium officinale							+	+		

Onopordum acanthium						+	+		
Orlaya grandiflora						+	+	+	
Panicum capillare						+	+		
Poa trivialis						+	+		
Prunella vulgaris						+	+		
Pteridium aquilinum						+	+		
Raphanus raphanistrum						+	+	+	
Sambucus ebulus						+	+		
Scleranthus annuus						+	+	+	
Stachys recta						+	+		
Symphytum tuberosum						+	+		
Vaccaria pyramidata						+	+	+	
Vulpia myuros						+	+		
*Xanthium spinosum***						+	+	+*	

6. Germination traits of three problematic arable weed species in Kosovo

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Abstract

Amaranthus retroflexus, Echinochloa crus-galli and *Datura stramonium* are today's most problematic arable weeds of Kosovo. They may cause severe yield depression, contaminate fodder and negatively affect growth and reproduction of other weed species. To counteract these problems, region-specific plant protection strategies need to be developed. Such strategies should consider information on region-specific species germination traits. In this context, our study provides information on species' temperature requirements for germination. Seeds of *A. retroflexus*, *E. crus-galli* and *D. stramonium* were harvested in two sub-regions of Kosovo (western and eastern part) differing in climate and land use. They were used for seed germination experiments in climate chambers at temperatures ranging from 3 to 35 °C and under field conditions. In both experiments, the germination behaviour differed between the species and the provenances. In the climate chamber experiment, the germination rates of *E. crus-galli* were generally much lower than of *D. stramonium* and *A. retroflexus*. All three species did not germinate below 15 °C and reached highest germination rates between 24 to 31 °C. Seeds of *A. retroflexus* and *D. stramonium* originating from the western part of Kosovo reached higher germination rates and required a lower temperature for germination than seeds originating from the eastern part. In the field experiment, the time-dependent germination behaviour of *Datura stramonium* differed between provenances. In general, germination started when soil temperature was above 18 °C and continued as long as the soil was moist. Thus, our results on germination traits differ between the two experiments. The results are discussed in the context of the need for biodiversity-friendly weed management in Kosovo.

Key words

Agriculture, species traits, ecological adaptation, *Amaranthus retroflexus*, *Echinochloa crus-galli*, *Datura stramonium*

6.1 Introduction

Today's crop yields (3.5 t/ha for wheat and 2.2 t/ha for maize) of Kosovo (Southeast Europe) do not meet the demands of the increasing population for food and other agricultural products (Statistical Office of Kosovo 2008a, 2009b). Among the multiple reasons for the insufficient productivity of agriculture (e.g., land fragmentation, lack of machinery), is the predominance of three problematic weeds, namely *A. retroflexus L.*, *E. crus-galli L.* and *D. stramonium L.*, in the arable weed vegetation. These three weeds are predominant with respect to both their relative frequency at the regional scale and abundance at the plot scale (Mehmeti et al. 2009) and their competition often leads to significant yield losses. Moreover, due to its high concentrations of alkaloids, *D. stramonium* may contaminate the fodder, which is produced on large parts of Kosovo's maize fields.

At the same time, the strong competitors *A. retroflexus*, *E. crus-galli* and *D. stramonium* may have negative impacts on the populations of other, less competitive weed species. Further, chemical or mechanical weed control, which, from the agronomic perspective, needs to be carried out for the problematic weeds, may result in the endangerment of other weed species occurring in arable fields, including today's rare weeds of Kosovo (cf. Mehmeti et al. 2009).

To counteract the agronomic and ecological problems mainly caused by the three problematic weed species, plant protection strategies should be implemented that aim to reduce their level of infestation and, at the same time, allow for the establishment of species rich weed communities. In this context, information on species characteristics, including germination traits, may be helpful to determine periods in the life cycle, where weed control measures against the predominant weeds will be most effective (e.g., Guo and Al-Khatib 2003, Sellers et al. 2003, Ghorbani et al. 1999). In general, such information is available from many publications from different parts of the world on the occurrence, morphology, and ecology of *A. retroflexus*, *E. crus-galli*, and *D. stramonium* (see next Chapter). However, germination traits and other species characteristics may considerably differ between the species' provenances (Keller and Kollmann 1999, Hamasha and Hensen 2009). Thus, region-specific information on species traits needs to be taken into consideration for the development of region-specific weed control strategies. Unfortunately, research on region-specific weed species traits in Kosovo has not at all been conducted since about 1990.

Against this background, the main aim of our study is to provide such data based on climate chamber and field experiments. The focus of our study is on temperature requirements for the germination of *A. retroflexus*, *E. crus-galli*, and *D. stramonium*. To this end, we qualitatively compare the germination behaviour of the species. The following hypothesis is tested in more detail: The species specific seed germination behaviour of *A. retroflexus*, *E. crus-galli*, and *D. stramonium* differs between seeds from two different provenances within Kosovo (western part vs. eastern part of Kosovo).

6.2 Occurrence, morphology and ecology of *A. retroflexus, E. crus-galli, and D. stramonium*

For various reasons *A. retroflexus*, *E. crus-galli* and *D. stramonium* are common arable weeds on the Balkan Peninsula, all over Europe and beyond, especially on highly fertile soils (cf. Tab. 6.1): All three species produce a high biomass and a high seed number per individual. Herbicide-resistant genotypes are widespread and the long-lived seeds may accumulate in the arable soil.

The seed germination behaviour (cf. Tab. 6.1) of *A. retroflexus*, *E. crus-galli* and *D. stramonium* strongly depends on species' specific characteristics (e.g., dormancy) and environmental factors (e.g., soil temperature, soil moisture, and light irradiation). In general, the seeds of all three species investigated in this study mainly germinate in late spring, provided a soil temperature of above 15 C°. Thus, these species are potentially highly competitive to maize and other summer crops and may cause dramatic yield decreases.

Tab. 6.1. Selected literature on the occurrence (A), morphology (B) and ecology (C) of *A. retroflexus*, *E. crus-galli*, and *D. stramonium.*

Amaranthus retroflexus		*Echinochloa crus-galli*		*Datura stramonium*	
Author and year	**Findings**	**Author and year**	**Findings**	**Author and year**	**Findings**
A1 Climate-dependent occurrence					
Siriwardana and Zimdahl 1984, Bürki et al. 1997, Sellers et al. 2003, GBIF 2009	nearly cosmopolitan; hotspots in North America, Europe and East Australia; widespread in the temperate zone; among the most troublesome arable weeds; mainly in summer crops	Siriwardana and Zimdahl 1984, Bosnic and Swanton 1997, Martinkova et al. 2006, GBIF 2009	nearly cosmopolitan; hotspots in North America, Europe, East Asia and East Australia; widespread in the temperate and subtropical zone; among the most troublesome arable weeds; mainly in summer crops	Malan et al.1982, Reisman-Berman et al. 1989, Saavedra et al. 1989, GBIF 2009	hotspots in North America, Europe and East Australia; widespread in the Mediterranean and subtropical zone; mainly in summer crops
A2 Occurrence on the Balkan Peninsula					
Vrbničanin et al. 2004, 2006	common and aggressive arable weed; mainly in maize	Vrbničanin et al. 2004	common and aggressive arable weed; mainly in maize	Stanković et al. 1996, Vrbničanin et al. 2006	common and noxious arable weed; mainly in maize
B1 Biomass (dry weight per plant)					
Kovačević et al. 2004, Sellers et al. 2003, Simončič and Leskošek 2005, Vrbničanin et al. 2006	up to 16 g	Nussbaum et al. 1985, Simončič and Leskošek 2005	up to 55 g	Benvenuti et al. 1994, Kovačević et al. 2004, Oljača et al. 2007, Vrbničanin et al. 2006	up to 355 g
B2 Seed number per individual					
Sellers et al. 2003	up to about 300000	Korsmo 1930, Nussbaum et al. 1985, Bosnic and Swanton 1997, Norris et al. 2001	over 400000	Korsmo 1930, Benvenuti et al. 1994	up to about 12500

C1 Herbicide resistance					
Janjić et al. 2003, Solymosi and Kostyal 1985	triazine resistant	Glauninger 1984, Maun and Barrett 1986	triazine resistant	Williams et al. 1995, Stanković et al. 1996	triazine resistant
C2 Seed longevity					
Thompson et al. 1997, Uremis and Uygur 2005	up to 40 years	Maun and Barret 1986, Thompson et al. 1997	up to 13 years	Kozlowski 1972, Malan et al. 1982, Thompson et al. 1997	up to 40 years
C3 Seed dormancy					
Omami et al. 1999, Cristaudo et al. 2007	primary dormancy that is gradually released after seed ripening and seasonal temperature change	Rahn et al. 1968, Barrett and Wilson 1983, Martinkova and Honek 1995, Honek et al. 1999	primary dormancy; time of ripening and harvesting may affect dormancy; increasing germination rates of seeds stored for several months	Reisman-Berman et al. 1991	primary dormancy; for buried seeds, no cyclic seasonal changes in dormancy were found
C4 Germination requirements on temperature					
Ghorbani et al. 1999, Guo and Al-Khatib 2003, Steckel et al. 2004, Baskin and Baskin 1977	optimal temperature for germination: 20-35° C	Vengris et al. 1966, Brod 1968	germination within a large range of temperatures; germination markedly affected by temperature	Malan et al. 1982	erratic germination at different temperatures
C5 Interspecific competition					
Kovačević et al. 2004	competitive to cultivated species; water, nutrient and light competition	Maun and Barrett 1986	competitive to cultivated species; nutrient competition	Cavero et al. 1999, Kovačević et al. 2004	competitive to cultivated species; water, nutrient and light competition
C6 Species' effects on yields					
Knežević et al. 1995	yield loss: 20-35 %	Bosnic and Swanton 1997	yield loss: 6-35 %	Cavero et al. 1999, Oljača et al. 2007	yield loss: 14-74 %

6.3 Material and methods

6.3.1 Study region, seed collection and preparation

Kosovo (Fig. 6.1) covers an area of 10877 km² in the centre of the Balkan Peninsula (Southeast Europe). The elevation ranges from 265 m to 2656 m above sea level, with about 80 % of the entire area below 1000 m and predominated by agriculture on fertile and, to some extent, irrigated soils (mainly fluvisols, vertisols, cambisols, and regosols). In general, the climate of

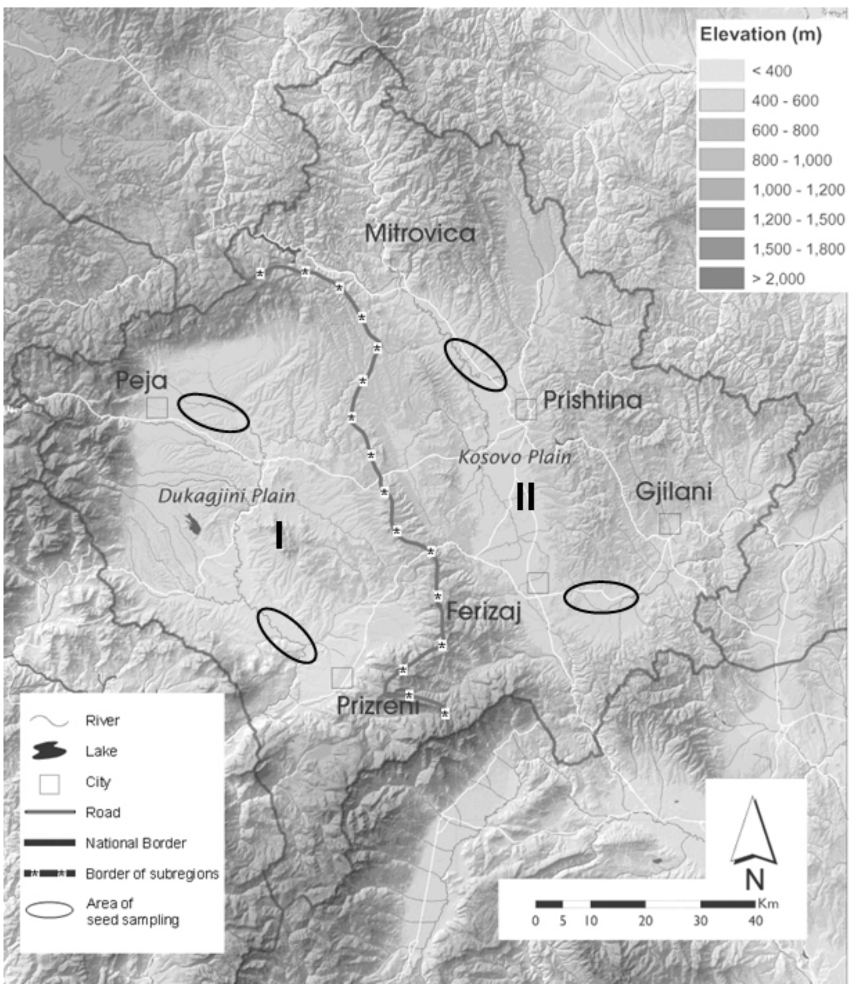

Fig. 6.1. Areas of seed collection in two sub-regions I and II of Kosovo.

Kosovo is characterised by warm summers and cold winters and air temperature may range from -20°C to 35 °C. However, in the western part of Kosovo, the average air temperature (11.0 C°) and the annual rainfall are higher (about 780 mm) and the frost-free period is longer (up to 225 days) than in the eastern part (9.8 C°; 635 mm; 170 to 200 days). About 14 % of the entire country is in arable production (Statistical Office of Kosovo 2008b). Wheat and maize are the most important crops. Pepper, onion and tomatoes are produced on less acreage (about 4.000 ha) and concentrate in the western part of the region. Pesticide use, including triazine herbicides, was common until about 1990. For economic reasons and due to a lack of supply, herbicide use has remained restricted to parts of the arable land in the last two decades (cf. Mehmeti et al. 2008, 2009).

In summer 2006, we harvested mature seeds of *A. retroflexus*, *E. crus-galli* and *D. stramonium* in two sub-regions of Kosovo differing in climate and land use as outlined above. In each sub-region, seed collection concentrated on 10 randomly selected arable fields in two smaller areas. We collected about 20000 seeds per species in each sub-region and stored the seeds as six pooled seed samples (3 species, 2 sub-regions) in a cool, dry and dark place.

To compare the quality of the seeds in the pooled samples, we measured the length and the width of 25 seeds per sample and calculated the means. Moreover, we estimated the thousand-kernel weight (TKW) of each pooled seed sample using a CONTADOR seed counter. Finally, we tested 25 seeds of each pooled sample for seed viability with tetrazolium prior to the experiments that are described next.

6.3.2 Experiment 1: Germination experiment in climate chambers

In autumn 2006, we conducted a seed germination experiment using climate chambers (RUMED Type 3401). We investigated the temperature-dependent germination behaviour of each of the six pooled seed samples for nine different treatments (constant temperatures of 3, 7, 10, 15, 20, 25, 30, and 35 °C, and diurnally fluctuating (8/16 hours) temperatures 5/15 °C) as described in Otte (1996) and Hölzel and Otte (2004). We put 50 seeds of each seed sample on a double layer of filter paper in sterile Petri dishes. For six weeks, we incubated the seeds of five dishes per seed sample and treatment. The light regime was equal for all seed samples and treatments, with permanent lightning during the whole period. We watered all dishes regularly with distilled water to optimize moisture conditions. Germinated seeds were counted weekly and removed. Germination was defined as the emergence of the radicule.

6.3.3 Experiment 2: Germination experiment under field conditions

From March to August 2007, i.e. during the whole season, we conducted a seed germination experiment under field conditions on an experimental site (2.0 m x 1.5 m x 0.3 m) with heat-sterilised soil in Viti (Kosovo). We divided the experimental site into 30 plots (30 cm x 30 cm x 30 cm). In each plot, we sowed 200 seeds of one species and sub-region at a soil depth of 2 cm. Five plots were used for each species. We did not irrigate the experimental site, except for the last two weeks in August due to drought at high temperatures. We weekly counted and removed the germinated seeds.

To relate the data on seed germination to the season's soil temperature and precipitation regime, we recorded the soil temperature at the experimental site, using HOBO data loggers at a soil depth of 5 cm and used precipitation data from the meteorological station at Ferizaj (Kosovo), located about 20 km away from Viti. The soil temperature was measured every six hours.

6.3.4 Data analysis and statistics

Experiment 1: For each Petri dish, we calculated the percentage germination rates of the seeds reached at the end of the six-week experiment. Mean values of germination rates were used for visual presentation. We performed separate general linear models (GLM) for all three species to test for the effects of region and temperature on the germination rates. Prior to the analysis, the percentage values were log-transformed to improve the normality of data distribution. Due to very low germination rates at low temperatures, the results gained at 3, 7, 10 and 5/15 °C were excluded from the analysis.

Moreover, we characterised the germination behaviour based on the following data as described in Olff et al. (1994) and Hölzel and Otte (2004):

LOPT, the optimal temperature for germination, was calculated as weighted average of germination rates over all constant temperatures and according to the equation

$(15\,P_{15} + 20\,P_{20} + 25\,P_{25} + 30\,P_{30} + 35\,P_{35})/(P_{15} + P_{20} + P_{25} + P_{30} + P_{35})$

where P_{15} or P_{20} was the percentage germination at 15°C or 20°C and so on;

LOW, the lowest constant temperature with a germination rate of at least 5%;

HIGH, the highest constant temperature with a germination rate of at least 5%;

AMP, the range in degrees Kelvin between HIGH and LOW.

Experiment 2: We calculated the percentage germination rates for all plots and performed a repeated-measure ANOVA on the germination rates of each of the three species with region and week as factors. Weeks without germination occurrences were excluded from the analysis. Mean values of weekly percentage germination rates were used for visual presentation.

All statistical analyses were carried out with STATISTICA 6.0 (Statsoft Inc. 2001).

6.4 Results

6.4.1 Seed size and weight and seed viability

The collected seeds of *A. retroflexus*, *E. crus-galli* and *D. stramonium* considerably differed between the species, with lowest mean seed lengths and widths and TKW for *A. retroflexus* and highest values for *D. stramonium* (Tab. 6.2). The mean seed lengths and widths of one species were nearly equal between the two sub-regions (Tab. 6.2). The TKW of *A. retroflexus* was slightly higher in sub-region II (eastern part), whereas the TKW of *E. crus-galli* and *D. stramonium* was slightly higher in sub-region I (western part).

According to the tetrazolium tests, more than 90 percent of the seeds from each pooled seed sample were viable prior to both experiments.

Tab. 6.2. Seed morphological characteristics of *A. retroflexus*, *E. crus-galli*, and *D. stramonium*, originating from two sub-regions of Kosovo.
I: western part of Kosovo; II: eastern part of Kosovo; TKW: thousand-kernel weight.

	Sub-region	Mean seed length (mm) and SD	Mean seed width (mm) and SD	TKW (mg)
n		*25*	*25*	
Amaranthus retroflexus	I	2.2±0.1	1.9±0.1	461
	II	2.3±0.1	1.9±0.1	495
Echinochloa crus-galli	I	5.3±0.1	3.2±0.1	2291
	II	5.4±0.1	3.2±0.1	2217
Datura stramonium	I	6.7±0.1	5.4±0.1	7461
	II	6.7±0.1	5.4±0.1	7319

6.4.2 Seed germination experiment in climate chambers

The seed germination rates reached at the end of the six-week experiment differed between the species (Fig. 6.2), with highest mean rates for *A. retroflexus* originating from the western part of

Kosovo (around 60 %), and lowest for *E. crus-galli* from the eastern part (around 10 %). In general, the germination rates of E. *crus-galli* were much lower than those of the other two species. Nearly the same results were gained after two weeks, since most seeds germinated within this period (the germination rates over time are not shown in detail here).

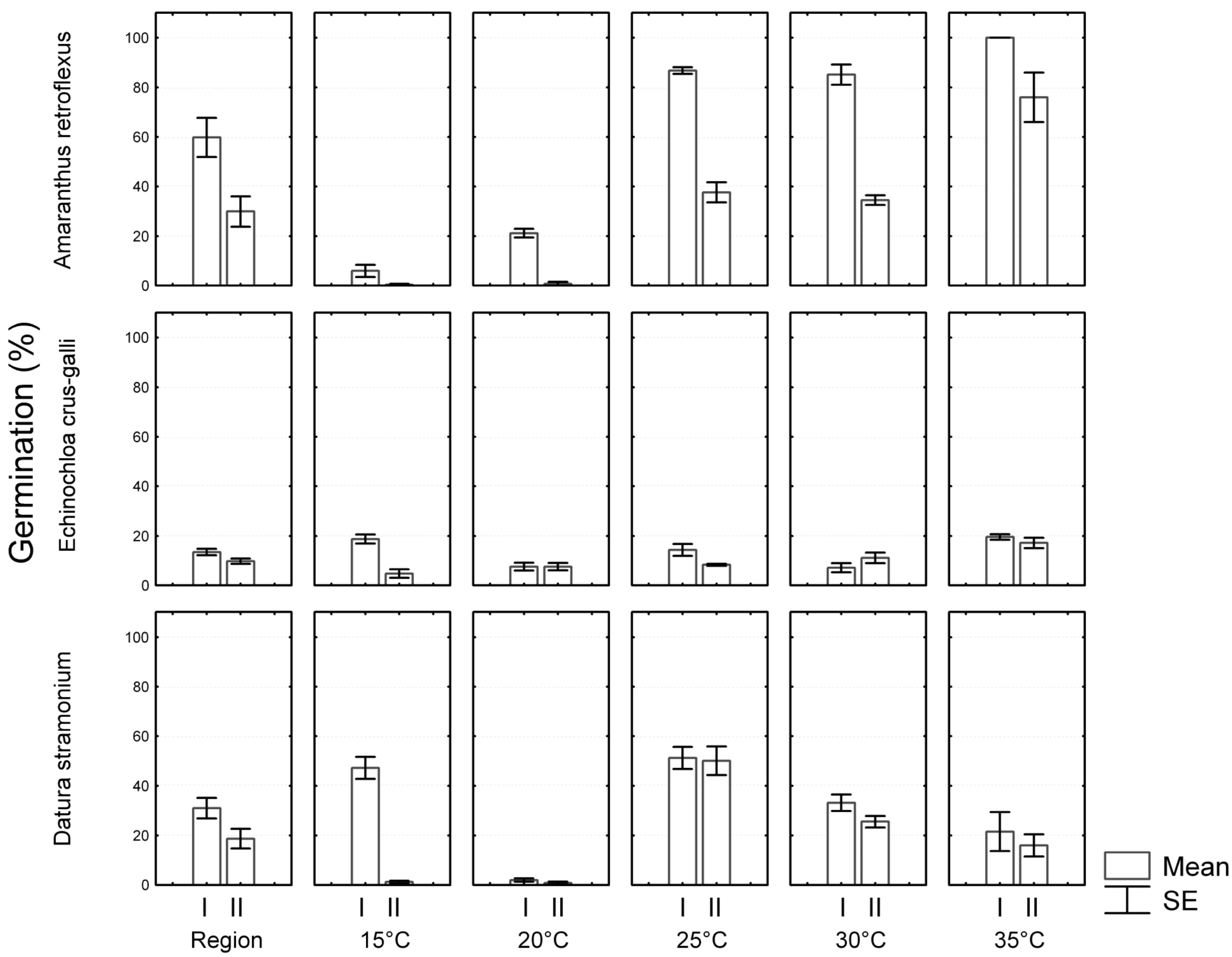

Fig. 6.2. Temperature-dependent mean seed germination rates of *A. retroflexus*, *E. crus-galli*, and *D. stramonium* reached at the end of a six-week period in a climate chamber experiment.
Seeds originated from two sub-regions (I: western part, II: eastern part) of Kosovo. Values show mean and standard error for five repetitions (50 seeds per repetition).

The germination rates were very low for temperatures below 15 °C and for 5/15 °C (not shown here). *A. retroflexus* and *D. stramonium* reached comparatively high germination rates at 25, 30 and 35 °C, with highest rates at 35 °C (*A. retroflexus*) or 25 °C (*D. stramonium*). However, 45 % of the seeds of *D. stramonium* originating from the western part of Kosovo also germinated at 15 °C.

Further, the germination rates of one species differed between the provenances, with often higher germination rates for seeds originating from the western part of Kosovo.

The differences in the temperature- and region-dependent germination rates were significant for all three species (Tab. 6.3). The significant interaction of temperature and sub-region indicates differences in temperature-dependency between the sub-regions.

Tab. 6.3. Results of GLMs on the effect of region and temperature on the seed germination rates of *A. retroflexus*, *E. crus-galli*, and *D. stramonium* (for details cf. Fig. 6.2).
SR: sub-region; T: temperature; df: degrees of freedom; MS: Mean squares; F: F-statistics; P: p-level.

		Amaranthus retroflexus			*Echinochloa crus-galli*			*Datura stramonium*		
	df	MS	F	P	MS	F	P	MS	F	P
Intercept	1	311.9	3096.8	<0.001	161.9	1182.1	<0.001	214.5	1106.0	<0.001
SR	1	13.9	138.5	<0.001	0.9	6.90	<0.05	6.3	32.3	<0.001
T	4	19.6	194.5	<0.001	1.0	6.9	<0.001	11.3	58.1	<0.001
SR*T	4	1.3	12.4	<0.001	0.9	6.8	<0.001	3.4	17.3	<0.001
Error	40	0.10			0.1			0.2		

For all three species, the optimal temperature for germination (LOPT) and the lowest constant temperature with a germination rate of at least 5% (LOW) were lower for seeds originating from the western part of Kosovo than for those from the eastern part (Tab. 6.4). Since the highest constant temperature with a germination rate of at least 5% (HIGH) was 35 °C for both, the range in degrees Kelvin between HIGH and LOW (AMP) was thus higher for seeds originating from the western part.

Tab. 6.4. Seed germination characteristics of *A. retroflexus*, *E. crus-galli*, and *D. stramonium* (for details cf. Fig. 6.2).

I: western part of Kosovo; II: eastern part of Kosovo. In accordance with Olff et al. (1994): LOPT: the optimal temperature for germination; LOW: the lowest constant temperature with a germination rate of at least 5%; HIGH: the highest constant temperature with a germination rate of at least 5%; AMP: the range in degrees Kelvin between HIGH and LOW.

	Sub-region	LOPT	LOW	HIGH	AMP
Amaranthus retroflexus	I	29.2	20	35	15
	II	31.2	25	35	10
Echinochloa crus-galli	I	25.1	15	35	20
	II	27.9	25	35	10
Datura stramonium	I	24.4	15	35	20
	II	27.9	25	35	10

6.4.3 Seed germination under field conditions

In the field experiment, seed germination started in the middle of May, when the soil temperature had reached 18 °C and the soil was wet due to some rainfall in early May (Fig. 6.3). Within only several days, in average of the five repetitions 13 % of the seeds of *A. retroflexus* originating from the western part of Kosovo and 20 % of the seeds from the eastern part germinated. A second peak of germination (germination rate about 5 %) was recorded in the beginning of June, several days after precipitation. At the same time, seeds of *E. crus-galli* and *D. stramonium* firstly germinated and reached germination rates of 6 % (*D. stramonium*, western part) to 15 % (*E. crus-galli*, eastern part). From early June to the middle of August, hardly any germination took place. This period was characterised by a lack of precipitation and high soil temperatures. Right after this typical summer drought and additionally stimulated by some irrigation of the experimental site, a third, but small peak of seed germination (germination rates up to 2 %) was recorded in the second half of August. At the end of the 25-week experiment, between 8.9 % (*D. stramonium*, western part) and 39.0 % (*E. crus-galli*, eastern part) of the seeds were germinated (Tab. 6.5). Under field conditions, the germination rates of *A. retroflexus* and *D. stramonium* were considerably lower than in the climate chamber experiment. In contrast, *E. crus-galli* reached much higher germination rates under field conditions.

According to the repeated-measure ANOVAs, the germination rates of all three species differed highly significant between time, but not between the sub-regions (Tab. 6.6). Only the germination rates over time of *D. stramonium* were different between the two sub-regions, as indicated by the significant interaction term in the respective ANOVA.

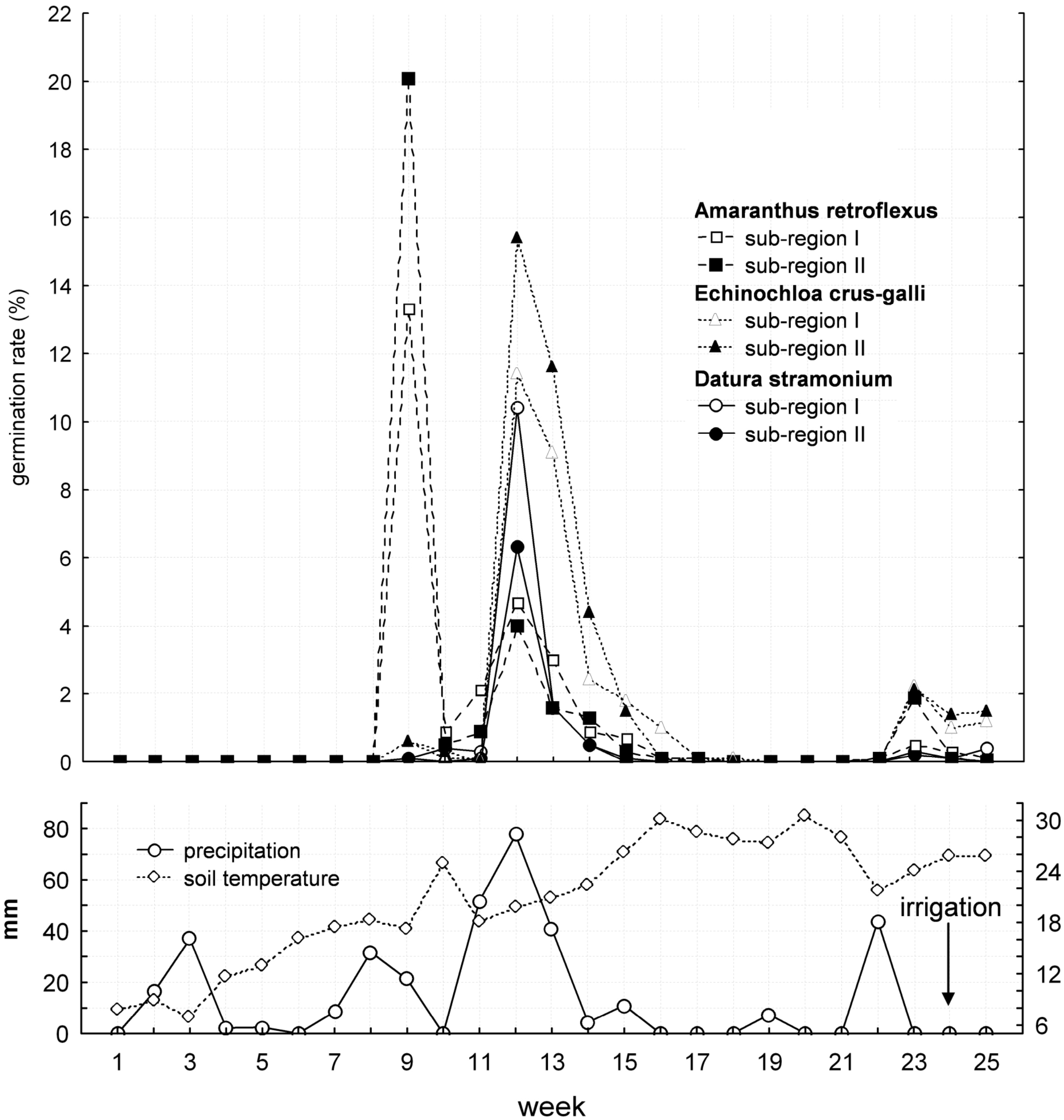

Fig. 6.3. Mean seed germination rates of *A. retroflexus*, *E. crus-galli*, and *D. stramonium*, originating from two sub-regions of Kosovo, in a germination experiment under field conditions.

The experiment with five repetitions (200 seeds per repetition) for each species was conducted in Viti (Kosovo) between March 9 and August 31, 2007. The experimental site was irrigated in the last two weeks. Precipitation: data from the meteorological station at Ferizaj (Kosovo); soil temperature: data gained at the experimental site. I: western part of Kosovo; II: eastern part of Kosovo.

Tab. 6.5. Seed germination rates of *A. retroflexus*, *E. crus-galli*, and *D. stramonium*, originating from two sub-regions of Kosovo, in two germination experiments (for details cf. Fig. 6.2 and 6.3).

Cumulative means (five repetitions) at the end of the experiments are presented. For the climate chamber experiment, calculation of means refers to the temperature with highest germination rates (cf. Fig. 6.2: *A. retroflexus* and *E. crus-galli*: 35 °C; *D. stramonium*: 25 °C).

Experiment		under field conditions	in climate chambers
	Sub-region	Mean germination rate (%) and SD	
Amaranthus retroflexus	I	26.7±9.6	100.0±0.0
	II	31.0±6.9	76.0±22.2
Echinochloa crus-galli	I	31.1±8.6	19.6±2.6
	II	39.0±3.9	17.2±4.6
Datura stramonium	I	14.2±6.1	51.2±9.9
	II	8.9±2.8	50.0±12.8

Tab. 6.6. Results of repeated-measure ANOVAs on the effect of region and week on the seed germination rates of *A. retroflexus*, *E. crus-galli*, and *D. stramonium*, originating from two sub-regions of Kosovo, in a field experiment (for details see Fig. 6.2).

SR: sub-region; W: week; df: degrees of freedom; MS: Mean squares; F: F-statistics; P: p-level.

	df	MS	F	P
		Amaranthus retroflexus		
Intercept	1	2561.0	118.3	<0.001
SR	1	14.2	0.7	0.44
Error	8	21.6		
W	12	815.9	31.5	<0.001
SR*W	12	42.7	1.6	0.09
Error	96	25.9		
		Echinochloa crus-galli		
Intercept	1	3780.008	275.5	<0.001
SR	1	48.008	3.5	0.09
Error	8	13.719		
W	12	716.891	56.4	<0.001
SR*W	12	18.891	1.5	0.14
Error	96	12.707		
		Datura stramonium		
Intercept	1	533.6100	59.62123	<0.001
SR	1	28.0900	3.13855	0.11
Error	8	8.9500		
W	9	263.9878	47.28139	<0.001
SR*W	9	15.9789	2.86189	<0.05
Error	72	5.5833		

6.5 Discussion

In our germination experiments, the temperature-dependent germination behaviour of *A. retroflexus*, *E. crus-galli* and *D. stramonium* clearly differed between the species. Moreover, the germination behaviour differed between the two experiments, with often higher germination rates in the climate chamber experiments for *A. retroflexus* and *D. stramonium*. This might be due to the fact that climate chamber experiments aim at providing optimal conditions for germination, especially with respect to light (most arable weed seeds are light-requiring) and water supply (cf. Otte 1996). In contrast, in the experiment under field conditions, the seeds were not exposed to the full light and the soil was nearly dry during summer drought. However, *E. crus-galli* reached much higher germination rates in the experiment under field conditions, indicating that other factors than optimal germination conditions may also affect seed germination. In this regard, we do not rule out the options that both the date (climate chamber experiment: autumn 2006; experiment under field conditions: spring to summer 2007) and the duration (climate chamber experiment: six weeks; experiment under field conditions: 25 weeks) of the experiments affected the degree of dormancy of the investigated seeds. This is especially obvious for *E. crus-galli*: According to Rahn et al. (1968) only about 1 % of fresh seeds may germinate and storage of seeds for four or eight months may increase germination rates to 19 or 44 %.

Nevertheless, both experiments revealed some differences in the germination behaviour of *A. retroflexus*, *E. crus-galli*, and *D. stramonium* from different provenances within Kosovo (western part vs. eastern part), and gave thus some indications for the validity of the hypothesis tested in this study: In the climate chamber experiment, the germination rates of all three species and, in the experiment under field conditions, the time-dependent germination behaviour of *D. stramonium* differed between the provenances. The within-region differentiation of the germination behaviour of the investigated species may reflect ecological adaptations to differences in climate and / or land use between the two sub-regions. However, in this study, we compared pooled seed samples and did not investigate discrete populations. In that, further research on the germination behaviour should be undertaken to quantify the degree of adaptation at the population level. Moreover, potential driving forces of adaptation processes (e.g., promotion of herbicide-resistant varieties that differ in temperature-dependant germination behaviour; cf. Otte 1996) need to be studied in detail.

Our results indicate that seeds of all three species originating from the western part of Kosovo may germinate over a broader range of temperatures than those originating from the eastern part. Given this result and the fact that the vegetation period is longer in the western part of Kosovo, weed infestation might be promoted there. With respect to *D. stramonium*, this is in accordance with Mehmeti et al. (2009). In this study, *D. stramonium* was found to be an indicator species (sensu Dufrêne and Legendre 1997), reaching higher abundances and frequencies in the western part of Kosovo.

To counteract the agronomic and ecological problems caused by *A. retroflexus*, *E. crus-galli* and *D. stramonium* in the arable land of Kosovo, strategies on biodiversity-friendly weed management are urgently needed. Against the background of the findings in this study and the literature mentioned in the second chapter, we suggest to concentrate on the following measures:

- Decrease of the proportion of summer crops (including maize) and vegetables in crop rotations;
- Mechanical weed control during May and repeated mechanical weed control between early June and late August about two weeks after rainfalls;
- Regular mechanical weed control (to be repeated every three weeks) on irrigated summer crop and vegetable fields;

As far as chemical weed control is indispensable, the use of herbicides that highly affect *A. retroflexus*, *E. crus-galli* and *D. stramonium* at early stages of their life cycles (e.g., glyphosates) is recommended under consideration of the principles of integrated weed management.

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7. General discussion

In this chapter, the main results of the studies presented in the Chapters 4 to 6 are summarised (indicated by **R1** to **R11**) and discussed against the background of the need to conserve biodiversity and the environment in the agricultural landscape of Kosovo and to also ensure and increase its productivity. In this respect, requirements for landscape functionality and sustainable land use are addressed. The discussion of the results thus refers to the notion of multifunctionality of agriculture drafted at the Rio Earth Summit in 1992 (UNCED 1992) and to the concept of sustainable land development first formulated in a scientific context in forestry about 300 years ago (von Carlowitz 1713) and intensively discussed as the core principle of land development since about 25 years (WCED 1987).

Further, the lack of available spatially-explicit databases are addressed. These have become obvious during the collection and analysis of the data on Kosovo's weed flora and vegetation. Finally, referring to questions that arose from the presented studies, suggestions for future research are outlined.

7.1 Multifunctionality of agriculture and sustainable land development

Given the main findings of the empirical study conducted in cultivated arable land of Kosovo, namely

(**R1**) the low α-species richness with mean species numbers between 8 (in vegetables) and 10 (in winter wheat) per 25 m²,

(**R2**) the predominance of few nitrophilic and often herbicide-resistant species such as *Amaranthus retroflexus*, *Echinochloa crus-galli* and *Datura stramonium* at the plot and regional scale,

(**R3**) the low cover (at the plot scale) and the low occurrence frequencies (at the regional scale) of the larger part of the weed species (187 of 235 species),

(**R4**) the decreased frequencies of some arable weeds s. str. (e. g., *Agrostemma githago*, *Bifora radians*) compared to the situation around 30 years ago,

(**R5**) the almost total lack of differences in species composition according to different site conditions (e.g. altitude above sea level, soil base-richness, soil moisture), and

(**R6**) the pronounced differences in species composition between fields that differ in crops and weed control,

today's cropping systems in Kosovo do not meet the demands of multifunctional agriculture from the vegetation and landscape ecological perspective. Similar to the situation in other European countries, today's arable weed flora and vegetation of Kosovo is much less diverse than expected given the region's diversity in site conditions. The main differences can be found between crop classes (cf. Fried et al. 2008).

At the same time, given

(**R7**) the often high weed infestation by three problematic species (*A. retroflexus, E. crus-galli, D. stramonium*) and

the low yields of the two predominant crops wheat (in average 3.5 t/ha) and maize (in average 2.2 t/ha; cf. Chapter 2.3), the arable production reveals severe shortcomings from the agronomic perspective. Moreover, it may be expected that today's arable cultivation in Kosovo negatively impacts the environment by e.g., pesticide or nitrate leaching, which may especially result from maize production and maize-wheat crop rotations (cf. e.g., Diez et al. 1997, Batista et al. 2002). However, despite these potential threats for the environment, which may also endanger human health (Ward et al. 2005), comprehensive research has not been conducted in the arable land of Kosovo since about 30 years.

Thus, considering ecological, economic and societal needs, concepts of sustainable future arable land use in Kosovo need to be improved or developed and implemented. To this end, apart from the general need to overcome the region's economic crisis and to integrate Kosovo into international markets, inter- and transdisciplinary research (cf. e.g., Fry 2001, Frede and Bach 2002, De Groot 2006), but also profound scientific education and training of agricultural students on e.g., integrated weed management and training of farmers, will be essential to overcome the obvious deficiencies. In general, such research, education and training should, among many other things, consider species traits such as the region-specific germination behaviour of weed species to allow for the development and implementation of region- and species-specific weed control measures. In this context, the results of the experimental studies, namely

(**R8**) the species-specific temperature-dependent germination behaviour of the problematic weeds *A. retroflexus, E. crus-galli, D. stramonium* and

(**R9**) the region-specific germination behaviour that differs between two sub-regions of Kosovo,

may provide some first data to be considered.

Even though today's arable weed flora and vegetation in cultivated arable fields reflect biodiversity-unfriendly management practices on the larger part of the arable land of Kosovo, the results of the empirical study conducted in recently abandoned arable land, namely

(**R10**) the higher α-species richness (in average 18.8 species per 25 m²) compared to cultivated arable fields and

(**R11**) the higher frequencies of arable weed species s. str. (e.g., *Adonis aestivalis*, *Caucalis platycarpos*) compared to cultivated arable fields,

indicate a potential for future development of species rich weed communities, provided by the soil seedbanks of the arable land. In that, the most important prerequisite for the (re-)establishment of species-rich and diverse weed communities, the occurrence of viable weed seeds in the arable soil, is fulfilled to date. However, this prerequisite is expected to successively decrease in today's species-poor communities. The soil seed banks of the recent arable fields will soon be depleted due to limitations in the species specific longevity of seeds (cf. Thompson et al. 1997). Especially for the more rare weed species, seeds persist often less than one decade (e.g., *Agrostemma githago, Papaver argemone*)

7.2 Unavailability of spatially-explicit databases

In this study, analyses on relationships between the arable weed flora and vegetation and site conditions remained limited to plot-related information such as altitude above sea level or soil characteristics and to the delineation of two sub-regions. However, biodiversity in the agricultural landscape may in many ways encompass determinants of e.g., biotic processes such as genetic exchange between populations and pattern of species occurrence at multiple spatial scales. Hence, research on landscape effects on biodiversity (e.g., Wagner et al. 2000, Le Coeur et al. 2002, Simmering et al. 2006, Dieкötter et al. 2008, Holzhauer et al. 2009, and cf. Otte et al. 2007) considering both landscape structure and dynamics, is highly important for the understanding of today's biodiversity and also in the context of action research on sustainable agriculture. In that, this study remains unsatisfying from the landscape ecological perspective.

In general, research on the effects of landscape structure and dynamics on biodiversity depends largely upon spatially-explicit databases such as high-resolution land-use maps for larger areas under study. Unfortunately, such databases are to date not available for Kosovo. This is especially true for region-wide updated maps on the geometry and spatial pattern of the agricultural land parcels and land use types. Given the pronounced land fragmentation and land-use changes in Kosovo since the last two decades (cf. Chapter 2.3), respective maps of former Yugoslavia are clearly outdated. The preparation of updated maps is still ongoing and will hopefully allow for more sophisticated landscape ecological analyses in the near future.

7.3 Suggestions for future research

Having in mind the results of both the empirical studies in the cultivated and recently abandoned arable land and the experimental studies on the germination behaviour of three problematic weed species of Kosovo, some questions and thoughts have arisen that, from the author's perspective, should be investigated in the future. Hence, this thesis ends with some suggestions on respective research:

● To better quantify the frequencies and to evaluate the degree of endangerment of arable weed species, additional research should be conducted along field margins.

It is known from several studies (e.g., van Elsen 1990, Waldhardt 1994, Walker et al. 2007) that weed species richness is higher along arable field margins than in field centres. Moreover, in some of these studies endangered weed species were found to reach higher frequencies and cover along field margins than in the field centres. Unfortunately, to date, no information is available if, or to what extent, this holds also true for the arable land in Kosovo. However such data would be especially helpful to evaluate the degree of endangerment of the region's arable weed species.

● To better quantify the frequencies and to evaluate the degree of endangerment of arable weed species, comprehensive soil seedbank analyses should be conducted.

Most arable weed species are annual species, which according to Grime (2001) may be addressed as r-strategists relying on plant functional strategies that allow for survival on frequently disturbed sites. One of such strategies is the ability to produce high amounts of seeds that ensure the reestablishment of weed populations after soil disturbances such as tillage. Due to the species-specific longevity of weed seeds (cf. Chapter 7.1), some of the seeds survive for several up to many years and, year by year, only those seeds germinate from the soil seedbanks that find species-specific appropriate conditions for germination. Thus, the established arable weed flora and vegetation recorded in field surveys only partially reflect the phytodiversity of a given plot. However, ‚to date there is no information available on the arable soil seedbanks of the Kosovo. In that, seedbank analyses should be conducted in the arable land (cf. e.g., Fuhr-Boßdorf 2003) and the composition of soil seedbanks should be considered in efforts to quantify the frequencies and the degree of endangerment of arable weed species.

● With respect to the most problematic weed species, additional research should be conducted to quantify their germination rates, productivity and reproduction success for different cropping systems.

In order to develop and implement strategies on arable land use that better fulfil demands of sustainability and multifunctionality, one research focus should be set on the question, of how the most problematic weeds could be better controlled by modifying today's cropping systems with respect to e.g., weed management and crop rotation. In this context, similar to e.g., Steinmann and Gerowitt (2000), long-term experimental studies under field conditions in different parts of Kosovo are suggested, which simultaneously should be used to quantify the effects of alternative land-use practices on measures of multiple landscape functions, including agronomic measures such as production costs and yields.

Summary

Research on changes in Europe's arable weed flora and vegetation, which resulted from changes in agricultural practices, has been conducted since about 1970, but has concentrated on Central and Northern Europe. Thus, only few data on changes in the arable weed flora and vegetation have been available from Southern Europe including the Republic of Kosovo, located in the centre of the Balkan Peninsula, Europe's major hotspot of biodiversity. In general, Kosovo is known for its rich flora and vegetation. However, the knowledge on Kosovo's flora and vegetation is still incomplete or might be outdated due to pronounced land-use changes in the last two decades. With respect to the arable weed flora and vegetation of Kosovo, no comprehensive research has been conducted since about 1980 and is thus of interest from a vegetation and landscape ecological perspective and the perspective of biodiversity conservation. Moreover, knowledge on Kosovo's arable weed flora and vegetation and on weed species traits is valuable from an agronomic perspective, since arable production is among the region's main economic activities contributing to the gross domestic product.

Against this background, empirical and experimental studies conducted in this thesis (i) contribute to the ongoing floristic mapping of Kosovo, (ii) provide a reference database for future studies on land-use change and its effects on the regional arable weed flora and vegetation, (iii) provide information on the relationships between the vegetation of the arable land and both environmental features and agricultural management measures, (iv) elucidate within-region differentiations of weed species' frequencies, cover and germination characteristics, and (iv) analyse region-specific germination traits of three frequent weed species, namely *A. retroflexus*, *E. crus-galli* and *D. stramonium*.

Based on the results of an empirical study in 432 cultivated arable fields in 2006, today's arable weed flora and vegetation of Kosovo is characterised by a low α-species richness with mean species numbers between 8 (in vegetables) and 10 (in winter wheat) per 25 m², the predominance of few nitrophilic and often herbicide-resistant species at the plot and regional scale, a low cover (at the plot scale) and low occurrence frequencies (at the regional scale) of the larger fraction of weed species (187 of 235 species), decreased frequencies of some arable weeds s. str. compared to the situation around 30 years ago, a nearly total lack of differences in species composition due to site conditions (e.g. altitude above sea level, soil base-richness, soil moisture), marginal differences in the weed flora between two sub-regions of Kosovo that differ in climate and land use, and pronounced differences in species composition between fields that differ in crops (summer vs. winter crops) and weed control (chemical vs. mechanical measures).

As it may be concluded from an empirical study conducted in 41 recently abandoned arable fields in 2007, the α-species richness (in average 18.8 species per 25 m^2) and the frequencies of arable weed species are higher in recently abandoned than in cultivated arable fields. This result indicates a potential for future development of species rich weed communities, provided by the soil seedbanks of the arable land.

Based on the results of a climate chamber experiment and a field experiment conducted in 2007, the germination behaviour of three problematic arable weeds of Kosovo, namely *Amaranthus retroflexus*, *Echinochloa crus-galli* and *Datura stramonium*, is found to be as follows: The temperature-dependent germination behaviour is species-specific and, for one species, the germination behaviour differs for seeds originating from different provenances within Kosovo, indicating ecological adaptation at the population level.

The results of the empirical and experimental studies are discussed against the need to develop and implement sustainable agricultural systems considering the multifunctionality of agriculture. Moreover, shortcomings in the availability of spatially-explicit databases on the geometry and pattern of Kosovo's agricultural land parcels and land use types are discussed in the context of relationships between biodiversity and landscape structure. Finally, suggestions for future research in the arable land of Kosovo and on traits of the region's problematic weed species are presented.

Zusammenfassung

In Europa seit etwa 1970 durchgeführte Untersuchungen belegen Änderungen in der Ackerflora und -vegetation als Folgen geänderter landwirtschaftlicher Praxis. Die meisten Arbeiten zu diesem Themenbereich erfolgten bislang in Mittel- und Nordeuropa, so dass entsprechende Kenntnisse aus Südeuropa nur vereinzelt vorliegen. Dies gilt auch für die als Hotspot der Biodiversität Europas bezeichnete Balkanhalbinsel, in deren Zentrum die Republik Kosovo liegt. Allgemein ist Kosovo für seine reichhaltige Flora und Vegetation bekannt, jedoch sind die Kenntnisse unvollständig oder könnten aufgrund ausgeprägter Landnutzungsänderungen, die seit zwei Jahrzehnten zu verzeichnen sind, veraltet sein. Zur Ackerflora und -vegetation des Kosovos liegen seit etwa 1980 keine umfassenden Arbeiten vor. Entsprechende Untersuchungen sind daher aus vegetations- und landschaftsökologischer Sicht und aus der Sicht des Biodiversitätschutzes von Bedeutung. Darüber hinaus sind das Wissen um die Ackerflora und -vegetation sowie Kenntnisse zu Arteigenschaften von Ackerunkräutern des Kosovos von agronomischem Interesse, da die landwirtschaftliche Produktion für das Bruttoinlandsprodukt der Republik Kosovo von größter Bedeutung ist.

Vor diesem Hintergrund wurden im Rahmen der vorliegenden Arbeit empirische und experimentelle Untersuchungen durchgeführt, die (i) zur laufenden floristischen Kartierung des Kosovos beitragen, (ii) eine Datengrundlage für künftige Untersuchungen zu Folgen geänderter Landnutzung auf die regionale Ackerflora und -vegetation bereitstellen, (iii) Informationen zu Beziehungen zwischen Vegetation, Standort und Ackernutzung geben, (iv) Erkenntnisse zu innerregionalen Unterschieden der Häufigkeiten, Abundanzen und Keimungseigenschaften von Unkräutern liefern und (v) das regionenspezifische Keimungsverhalten der drei häufigen Ackerunkräuter *Amaranthus retrofloexus*, *Echinochloa crus-galli* und *Datura stramonium* untersuchen.

Auf der Grundlage der Ergebnisse empirischer Erhebungen in 432 bestellten Ackerschlägen im Jahr 2006, ist die aktuelle Ackerflora und -vegetation des Kosovos durch einen niedrigen α-Artenreichtum mit im Mittel 8 (Gemüseanbau) bis 10 (Winterweizen) Arten pro 25 m², das Vorherrschen weniger nitrophytischer und oft herbizidresistenter Arten auf plot- und Landschafts-Ebene, niedrige Deckungsgrade (auf plot-Ebene) und geringe Häufigkeiten (auf Landschafts-Ebene) der meisten Ackerunkräuter (187 von 235 Arten), im Vergleich zur Situation vor etwa 30 Jahren heute geringere Häufigkeiten einiger Ackerunkräuter im engeren Sinne, fast

vollständiges Fehlen von Unterschieden in der Artenzusammensetzung in Abhängigkeit von Standorteigenschaften (z.B. geographische Höhe, Basenreichtum und Wasserversorgung der Böden), nur geringe Unterschiede in der Unkrautflora zweier Teilräume des Kosovos, die sich hinsichtlich Klima und Landnutzung unterscheiden, sowie ausgeprägte Unterschiede in der Artenzusammensetzung in Abhängigkeit von den angebauten Kulturen (Sommerungen vs. Winterungen) und der Form der Unkrautkontrolle (chemische vs. mechanische Kontrolle) gekennzeichnet.

Aus empirischen Erhebungen in 41 jungen Ackerbrachen im Jahr 2007 wird geschlossen, dass der α-Artenreichtum (durchschnittlich 18.8 Arten pro 25 m^2) und die Häufigkeiten von Ackerunkräutern in jungen Ackerbrachen höher als in bestellten Ackerflächen sind. Dies deutet auf ein durch die Bodensamenbank des Ackerlands gegebenes Potenzial zur künftigen Entwicklung artenreicher Ackerunkrautgemeinschaften hin.

Auf der Grundlage der Ergebnisse zweier im Jahr 2007 durchgeführter Experimente, eines Klimaschank-Experiments und eines Freilandexperiments, wird das Keimungsverhalten der drei im Kosovo problematischen Ackerunkräuter *Amaranthus retroflexus*, *Echinochloa crus-galli* and *Datura stramonium* wie folgt gekennzeichnet: Das temperaturabhängige Keimungsverhalten ist artspezifisch, und auf Artebene unterscheidet sich das Keimungsverhalten von Samen, die aus zwei unterschiedlichen Teilräumen des Kosovos stammen. Dies deutet auf eine ökologische Anpassung auf Populations-Ebene hin.

Die Ergebnisse der empirischen und experimentellen Untersuchungen werden vor dem Hintergrund der Notwendigkeit diskutiert, unter Berücksichtigung der Multifunktionalität der Landwirtschaft nachhaltige landwirtschaftliche Nutzungssysteme zu entwickeln und umzusetzen. Darüber hinaus werden im Kontext von Beziehungen zwischen Biodiversität und Landschaftsstruktur Defizite in der Verfügbarkeit räumlich expliziter Daten zur Geometrie und zu den Raummustern der landwirtschaftlichen Schläge des Kosovos und der dort implementierten Landnutzungen diskutiert. Schließlich werden Empfehlungen für künftige Forschungsarbeiten im Ackerland des Kosovos und zu den Eigenschaften der Problemunkräuter dieses Raumes gegeben.

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Erklärung

Ich erkläre: Ich habe die vorgelegte Dissertation selbständig und ohne unerlaubte fremde Hilfe und nur mit den Hilfen angefertigt, die ich in der Dissertation angeben habe. Alle Textstellen, die wörtlich oder sinngemäß aus veröffentlichten Schriften entnommen sind, und alle Angaben, die auf mündlichen Auskünften beruhen, sind als solche kenntlich gemacht. Bei den von mir durchgeführten und in der Dissertation erwähnten Untersuchungen habe ich die Grundsätze guter wissenschaftlicher Praxis, wie sie in der „Satzung der Justus-Liebig- Universität Gießen zur Sicherung guter wissenschaftlicher Praxis“ niedergelegt sind, eingehalten.