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„Impact of *Robinia pseudacacia* invading dry grassland in the UNESCO World Heritage Site Wachau, Austria"

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Curriculum Vitae

- **8.8.1989**

born as son of a US-American and an Austrian citizen, receiving dual citizenship

- **1996 – 2000**

educated bilingually in the Pestalozzi-elementary school in Wiener Neustadt

- **2000 – 2007**

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Abstract:

Invasive species have become a global issue for conservation making their study relevant on many levels, from policy to conservation practice. This study aims to better inform decisions regarding conservation measures and to aid practitioners with new tools to address invasive stands of *Robinia pseudacacia*, L. using the Austrian Wachau region as study area. Present for over two centuries, introduced to its new habitat for economical purpose, this species presents an ideal case to study. It has become naturalized and is still expanding throughout different habitats in the region, its encroachment into dry grassland - the focus of this study - requiring decades-long, expensive management efforts for eradication. By comparing uninvaded, invaded sites as well as sites completely overrun by *Robinia pseudacacia* I hoped to identify environmental factors influencing the invasion and the tipping points after which an invaded area becomes a degraded area. The factors found to influence invasion were present and historical land use, soil depth with the amount of uncovered topsoil influencing germination. *Robinia pseudacacia* seems to invade the region mainly vegetatively, after rare germination events making mitigating its damage and even partial eradication possible. With additional effort towards monitoring early establishment a situation safer in terms of reinvasion could be established.

key words: invasives, dry grassland, Black Locust, Wachau, conservation management

Invasive Arten sind wirtschaftlich wie ökologisch ein wachsendes globales Problem. Anhand der Invasion von Trockenrasen durch *Robinia pseudacacia* in der Region Wachau wird versucht Schlüsselfaktoren der Invasion zu identifizieen. Die Art wurde vor über zwei Jahrhunderten in die Region gebracht, hat sich etabliert und ihre Population wächst bis heute. Da sie auf Trockenrasen jahrzehntelange, teure Maßnahmen zur Eradikation benötigt stellt sie ein gutes Modellbeispiel dar. Im Vergleich von invasierten, uninvasierten und durch die Invasion völlig degradierten Standorten hoffte ich Schlüsselfaktoren finden zu können und die "tipping points" ab dem ein Ökosystem unter Invasion völlig degradiert zu finden. Die Faktoren mit dem größten Einfluss auf die Invasion waren Bodentiefe, vergangene und gegenwärtige Landnutzung, wobei der Offenbodenanteil die Keimung zu beeinflussen scheint. *Robinia pseudacacia* breitet sich im Gebiet hauptsächlich vegetativ aus, Keimereignisse sind selten. Dies erhöht Chancen zur Schadensbegrenzung und partiellen Ausrottung der Art. Mit zusätzlichen Ressourcen für lokale Bekämpfung und Monitoring von Keimereignissen könnte die Gefahr einer Reinvasion weiter reduziert werden.

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Introduction

About three percent of all vascular plant species have become naturalized outside of their previous range due to human activity, in terms of continents, Europe and North America are largely species donors (Van Kleunen *et al.* 2015). Species that can survive outside of their native range can become invasive in their introduced range and exert detrimental pressure on biodiversity, environmental and societal processes (Cronk & Fuller 2001; Nentwig 2007). This is why research regarding the mitigation of effects and early recognition of potentially invasive species is necessary (Mack *et al.* 2005). Many studies (e.g. Jeschke *et al.* 2014; Essl *et al.* 2015; Van Kleunen *et al.* 2015) focus on the biogeographical level of invasions, tracking species range and pathways of invasion which is important for legal decision-making, recognition and mitigation of ongoing and future invasions. However their scale is normally too high to directly aid regional management in terms of monitoring and improving practices, making studying invasions on a regional scale important. Studies spanning multiple scales (e.g. Asunción *et al.* 2016) are rarely found in the current literature.

The invasive of interest in this study is *Robinia pseudacacia*, a common invasive of dry grassland (Paar, Tiefenbach & Winkler 1994), which can rapidly establish and then requires annual manual removal for several years to a decade (Cierjacks *et al.* 2013) creating high costs for regional management (Seehofer 2016: pers. comm). Thus studying factors contributing to *Robinia pseudacacia* invasions is necessary and may even help prevent future invasions.

Study Area

The Wachau region in Lower Austria extends along the Danube river valley for approximately 30 km from Melk to Krems and thus lies on the western border of the Pannonian region to the Central European region (Fischer, Oswald & Adler 2008). Here, the Danube cuts a water gap through the Bohemian Massif of the Hercynian mountain system, a region with a somewhat cooler climate due to its higher elevation. These contrasting influences on climate characterize both the regions natural and in turn cultural history (Denk & Kraus 2008, Friedl 2014). Archaeological records (e.g. "The Venus of Willendorf") show 25,000 years of human settlement in the region and the first historical reference to the region (as "Vuachua") is dated at 972 CE (Sickel 1879). Viticulture is first mentioned in 482 CE, some evidence for wine consumption dating back as early as 3000 BCE (Friedl 2014). Other crops could only have been planted in the flood area of the Danube making vineyards and orchards the dominant crops in the region.

Located at the northern border of the Roman Empire, the region originally used Roman viticulture techniques, after the decline of the Western Roman Empire in the 5th century these were replaced by Bavarian techniques (Friedl 2014) brought by the Benedictinian order, also founders of various abbeys (e.g. Melk and Göttweig) in the region. In less prosperous times, vineyards and orchards were abandoned and left to fallow (Friedl 2014) and in part used as communal pastures only to be reclaimed when times became more prosperous. Factors for such cycles of decline could be very different in nature: (i) geopolitical, e.g. the Thirty Years War 1618-1648 (Friedl 2014); (ii) economical, e.g. the increasing Hungarian competition in the wine market (Kerner von Marilaun 1863); (iii) climatic, e.g. periods of cooler climate (Kerner von Marilaun 1863); (iv) due to pests, e.g. the Grape Phylloxera Crises at the beginning of the last century or (v) technical developments, e.g. the mechanization of agriculture during the 20th century. Historically as much as 3450 ha (Friedl 2014) have been used as vineyards, change of land use due to reasons (i)-(v) above reduced that area to 1350 ha in 2014 (Friedl 2014). This mosaic of collapsing and (re-) expanding agricultural systems has shaped the character of the region to the present, vineyard (orchard?) terraces in various stages of decay and overgrowth being a prominent feature in the landscape (Kerner von Marilaun 1863, Friedl 2014, Denk & Kraus 2008).

The region was declared a UNESCO world heritage site in 2000 and conservation of its natural diversity was the focus of a Life Project from 2003 - 2008. Parts of the region are protected as Special Areas of Conservation (SAC, Habitats Directive) (Council of the European Union 2007) and Special Protection Area (SPA, Birds Directive) (Council of the European Union 2009), amounting to a protected area of 26520 ha in the "Europaschutzgebiete Wachau und Wachau-Jauerling" (Amt der NÖ Landesregierung 2009). Additionally, parts of the region were declared "natural monuments or features", IUCN cat. III. Conservation measures are coordinated by two NGOs (LANIUS, Arbeitskreis Wachau) - numerous volunteers aid regional management action.

The invasive tree *Robinia pseudacacia* (Fabaceae)

Robinia pseudacacia L., also known as Black Locust or False Acacia, is a deciduous tree in a genus of four to twelve (Fischer et al. 2008, USDA United States Department of Agriculture n.d.) species and some hybrids in the Fabaceae family. Like many other species in this family it forms symbiotic root nodules for nitrogen fixation.

In its native habitat, *R.pseudacacia* is a species of early forest regeneration (Boring & Swank 2016) after natural and artificial clearing. Though abundant seeds are produced, seedlings are competitively weak (Basnou 2006), some sources state that seeds actually require scarification to germinate (Rédei, Osvath-Bujtas & Veperdi 2008) and seedlings require open habitats free from shading to thrive (Cierjacks *et al.* 2013). Like many species of earlier succession/regeneration stages Black Locust exhibits vigorous vegetative reproduction from both root and stem suckers making it easy to cultivate and hard to eradicate. Human uses include timber (replacing tropical hardwoods in some cases), firewood, apiculture, ornamental planting and soil stabilization (Denk & Kraus 2008, Cierjacks et al. 2013).

Fig 1: First known map of Black Locusts native range (Munns 1938)

Historic accounts of *R.pseudacacia*s distribution (e.g. Munns (1938) shown above (Fig 1) and E. L. Little (1971)) show a disjoint range, suggesting its spread pre-dates records of North American plant distribution. At present, *R.pseudacacia* can be found in the lower 48 US states; the Canadian provinces Quebec, Ontario and British Columia; temperate Europe, Asia, Africa, Australia and New Zealand (Basnou 2006). Its current distribution in Austria (Walter *et al.* 2005) shows most occurrences in the east of the country and only some occurrences in Alpine valleys. Black Locust can tolerate a wide variety of soil conditions regarding soil acidity and phosphorous/nitrogen availability. It is claimed to be limited by water supply and soil aeration/drainage (Vítková, Tonika & Müllerová 2015b), however Austrian occurrences in floodplain and riverine forests make this limitation questionable. In its invasive range Black Locust increases mineral nitrogen in soils, with a shift in soil microbial communities possibly occurring in later stages of the invasion (Medina-Villar *et al.* 2016). 75 species of herbivorous insects feed on Black Locust in its native range (Cierjacks *et al.* 2013), exerting strong pressure on stands (Boring & Swank 2016), some of which have reached the Austrian introduced range (Essl & Rabitsch 2004). Their ecological influence remains unknown. Furthermore there is little evidence for native animals exerting meaningful herbivore pressure on Black Locust stands, which may in part be due to toxins present in all parts of the plant except its flowers (Cierjacks *et al.* 2013).

Discovered in the late 16th century by Jean Robin and described mid-18th century (Linnaeus 1753), early plantings of Black Locust in European gardens and parks were primarily ornamental (Vítková, Kolbek & Vetvicka 2015a), the earliest planting in Vienna/Austria said to be during the reign of Emperor Josef I. (1678-1711, Theresianum n.d.). Economic use as soil stabilizer beginning around 1750 in Hungary (Tiborcz *et al.* 2008) played a large role in changing the landscape (Kerner von Marilaun 1863).

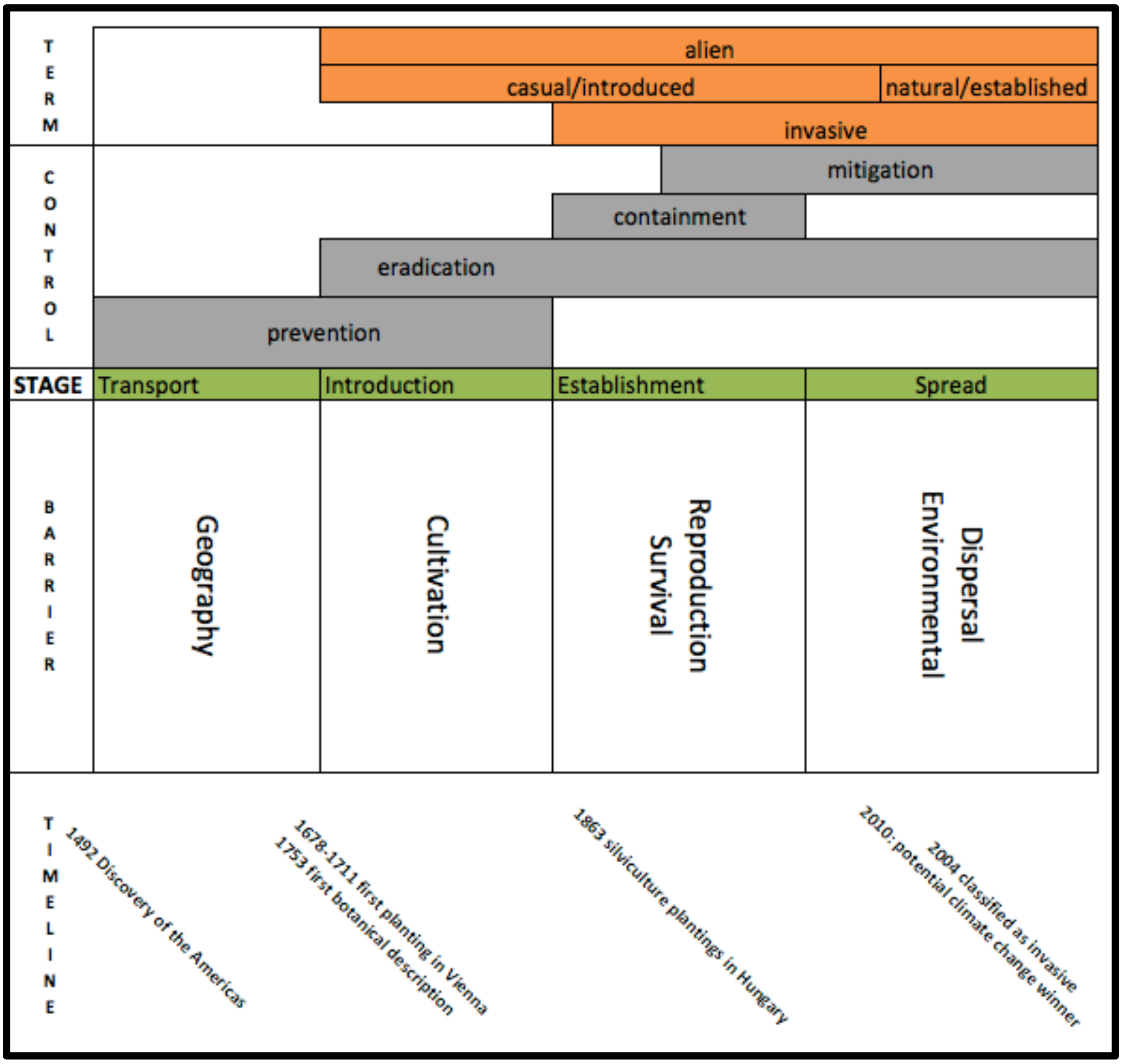

Fig 2: Timeline of Black Locust invasion in Austria with terminology following Blackburn et al. (2011)

Following Blackburn et al. (2011) the *R. pseudacacia* invasion in (eastern) Austria is in its late stages, earlier stages of the invasion process continuously reoccurring as new habitats become colonized (see Fig. 2 for timeline). In this case, limitations to its spread are mainly factors of dispersal and environmental barriers, climate change eroding the latter and thus benefiting further range expansion (Kleinbauer *et al.* 2010). In Austria, *R.pseudacacia* is characterized as invasive, economically harmful and simultaneously economically important (Essl & Rabitsch 2004). It has however not been included in the list of invasive species of European concern (Council of the European Union 2014). Many concepts identifying key traits of invasive species have been proposed (Baker 1974, Williamson & Fitter 1996, Cronk & Fuller 2001, Sakai et al. 2001). These traits can be grouped into 7 types (see Tab. 1 below):

Tab 1: Types of invasion hypotheses from (Hierro, Maron & Callaway 2005) and their potential to explain *Robinia pseudacacias* invasivity

hypothesis	**invasivity due to**	***Robinia pseudacacia***	
natural enemies	loss of natural enemies	yes	herbivore pressure in invaded range low due to fewer natural enemies in invaded range (Cierjacks *et al.* 2013), some herbivores from native range can be found in introduced areas (Essl & Rabitsch 2002)
evolution of invasiveness	genetic adaptation linked to new selection pressures	unknown	unlikely, due to evolutionarily short time period (400 a) of invasion, invasivity may be due to better ability to respond to natural selection (Lee 2002)
empty niche	use of unused resources, use of resources in a novel way	yes	a tree with root nodule symbiosis may exploit an empty niche in many European ecosystems
novel weapons	type of biochemical interaction unknown to the invaded area	yes	allelopathy (Korda *et al.* 2013)
disturbance	better adaptation to current disturbance regime which may be novel to natives	yes	changes in grassland use over the past century (Mucina & Kolbek 1993a)
species richness	low species richness of the invaded area	yes	species richness varies greatly within the introduced range
propagule pressure	pressure from multiple invasives	yes	Co-occurrences with other invasives (e.g. *Ailanthus altissima*, Vítková & Kolbek 2010)

Concepts of invasivity are also influenced by their account for a habitats' susceptibility to invasion, called invasibility (sensu Lonsdale 1999). Eltons (1958) argument that diversity and invasibility are inversely linked (less diverse ecosystems having more empty niches) have been conceptually criticized (Levine & D'Antonio 2015) yet are still supported empirically, with paradoxical effects on different scales (Levine 2000; Fridley *et al.* 2007). Furthermore, niche conservativism may not be a valid assumption for some invasive plant species (Guisan *et al.* 2014), as a niche shift (Pearman *et al.* 2008) may have occurred making the study of invasives in their introduced and native ranges important (Hierro *et al.* 2005). That considered, assuming the current distribution of a species represents the entire range of environmental conditions for survival may still lead to an underestimation of the potential range (Sax, Early & Bellemare 2013). The evolutionary biology of invasive species offers insights regarding competition and fitness, with Fridley & Sax (2014) offering an entirely Darwinian alternative framework for the field of invasion biology. With an invaders' colonization of a new habitat a change of selective pressures occurs, more successful invaders should be able to adapt to these pressures (Lee 2002), through their adaptive potential or relative pre-adaptation (Stockwell, Hendry & Kinnison 2003) - genetic admixture, inbreeding and outcrossing playing a not yet well-understood role in this process as well (Rius & Darling 2014).

Studied habitats

The investigated habitats in terms of plant communities and the (main) syntaxa they belong to are given in the following:

(i) Molinio-Arrhenateretea are "Anthropogenic managed pastures, meadows and tall-herb meadow fringes on fertile deep soils at low and mid-altitudes (rarely also high altitudes) of Europe" (Mucina et al. 2016). These grasslands, rich in nutrients and of moist to wet conditions, are of secondary origin and show up on potential sites of deciduous forests, which have been kept open by mowing or grazing. Mowing and grazing reduces biomass, which can facilitate species turnover by withdrawal of nutrients into stands of Festuco-Brometea or Calluno-Ulicetea (Ellmauer & Mucina 1993). Within this class a special status of conservation is given to some species-rich stands under the Flora Fauna Habitat (FFH) Directive (Council of the European Union 2006) if they correspond to habitat types 6510 and 6520 (Ellmauer & Mucina 1993; Denk & Kraus 2008).

(ii) Festuco-Brometea are "Dry grassland and steppe vegetation of mostly base- and colloid-rich soils in the submediterranean, nemoral and hemiboreal zones of Europe" according to Mucina et al. (2016). Arguments supporting their autochtonous character are locally extreme conditions and endemism, yet most of the currently recorded formations are of secondary origin (Mucina & Kolbek 1993a). Continuous extraction of biomass (through grazing and mowing), a medium to shallow soil layer and limiting water and nutrient supply are the main factors for development (Mucina & Kolbek 1993a). Within this class some stands correspond to the habitat types 6190, 6210, 6240, 6250, and 6260. (Ellmauer 2005; Denk & Kraus 2008; European Commission 2013) and are thus of European conservation interest.

(iii) Koelerio-Corynephoretea are "Dry grasslands on sandy soils and on rocky outcrops of the temperate to boreal zones of Europe, the North Atlantic islands and Greenland." (see Mucina et al. 2016). In the study area they occur as acidophytic rock-outcrops of the Hyperico perforati-Scleranthion perennis but their species can also occur as secondary formations on vineyard terrace stone-walls and as patches within stands of Festuco-Brometea (Denk & Kraus 2008). Stands within this class that correspond with FFH-Directive types 6110, 8220, 8230 (Mucina & Kolbek 1993b; Denk & Kraus 2008) are of European conservation interest (European Commission 2013).

Thermophilous Oak Forests, syntaxonomically referred to as Quercetea pubescentis are "Oak, mixed deciduous and conifer open forests of warm regions in the cool-temporate and nemoral zone of Central and Southern Europe and in the supramediterranean belt of the Mediterranean, Asia Minor and Middle East" in Mucina et al. (2016). Some authors (e.g. Starlinger in Drescher *et al.* 2007, whose syntaxonomy of Austrian forests is used throughout this publication) include this class as an alliance Quercion pubescenti-petraeae within the class Querco-Fagetea, three orders (i)-(iii) being relevant within the scope of this publication: (i) Quercetalia roboris circumscribing stands on acidic soils with some fluctuation in the water regime dominated by *Qu. petrea* or *Qu. robur* (Drescher *et al.* 2007) being of little conservation interest and (ii) Quercetalia pubescentis, described as thermophilous forests in Willner & Grabherr (2007) and containing the aforementioned alliance Quercion pubescenti-petraeae which circumscribes stands with a tree layer mainly made up of *Quercus sp.* (mainly *Qu. cerris, Qu. petrea, Qu. pubescens*) with only low coverage of shade trees (e.g. *Fagus sylvatica*, *Carpinus betulus*, *Tilia sp)* corresponding to FFH-types 91H0 and 91G0 (European Commission 2013) and lastly - shade trees reaching higher coverage - (iii) Fagetalia sylvaticae, forests of a more mesophilous type (Starlinger in Drescher *et al.* 2007). These, depending on their composition, correspond to FFH-types 9110 9130 9150, 9170 and 9180 (European Commission 2013). Some connection to dry grassland exists via fringe vegetation, especially by species from the alliance Geranion sanguinei (Mucina & Kolbek 1993 in Mucina, Grabherr, & Wallnöfer, 1993), where environmental factors do not allow forest formation, yet individual trees may persist.

Robinia stands, syntaxonomically referred to as Robinietea are "Seral forest-clearing and anthropogenic successional scrub and thickets on nutrient-rich soils of temperate Europe" in Mucina et al. (2016). This definition contrasts with the definition by Vítková & Kolbek (2010) of Robinietea used in this publication where the class Robinietea circumscribes mesophilous to xerophilous stands with *R.pseudacacia* present in tree and/or shrub layer, wherein Chelidonio-Robinietalia pseudoacaciae represent mesophilous Black Locust stands with nitrophytes and Euphorbio cyparissiae-Robinietalia the xerophilous Black Locust stands of thermophilous habitats. Some debate exists about the syntaxonomy of this group as order per se (Mucina et al., 2016; Vítková & Kolbek, 2010) or as degradational stage of forests of various types. Grasslands under invasion are not mentioned by current literature as degrading towards vegetation of this type. In Austrian syntaxonomical literature (e.g. Exner in Drescher *et al.* 2007) Robinietea are regarded as a preliminary class pending further investigation. *Robinia* stands are generally viewed as a threat to plant communities of conservation interest especially threatening dry grasslands (Ellmauer 2005; Walter et al. 2005).

This investigation seeks to better understand the processes of invasions by *Robinia pseudacacia* locally and thus aid conservation efforts in mitigation and eradications. To achieve this research questions (i)-(iv) are posed: (i) What vegetation changes happen when *R.pseudacacia* invades dry grassland? (ii) What environmental changes occur during this process? (iii) What is the current impact/situation in invaded areas? (iv) What consequences does this have for conservation/management?

Material and Methods

Aim of this investigation was to identify key factors of *Robinia pseudacacia* - invasions and aid praciticioners' decision-making. The methods outlined in the following chapter were chosen due to their easy implementation in the field and their negliglble ecological impact on areas of conservation.

Data Collection and Site Choice

Using data from the life project (Denk & Kraus 2008) see above) and verbal input from experienced regional practitioners (Seehofer 2016: pers. comm.: pers. comm.) an outline for the research program was made. As a starting point data regarding areas of potential research interest were collected in March/April 2016 and a map of these areas was created with aerial fotographs provided by The Provincial Government of Lower Austria (Project ID: RU5-A-60/009-2016). The so-called "Upper Wachau" region (Spitz to Krems) was chosen based on accessibility and prevalence of sites according to stages of novel ecosystem development as sketched by Morse et al. (2014), see Fig. 3.

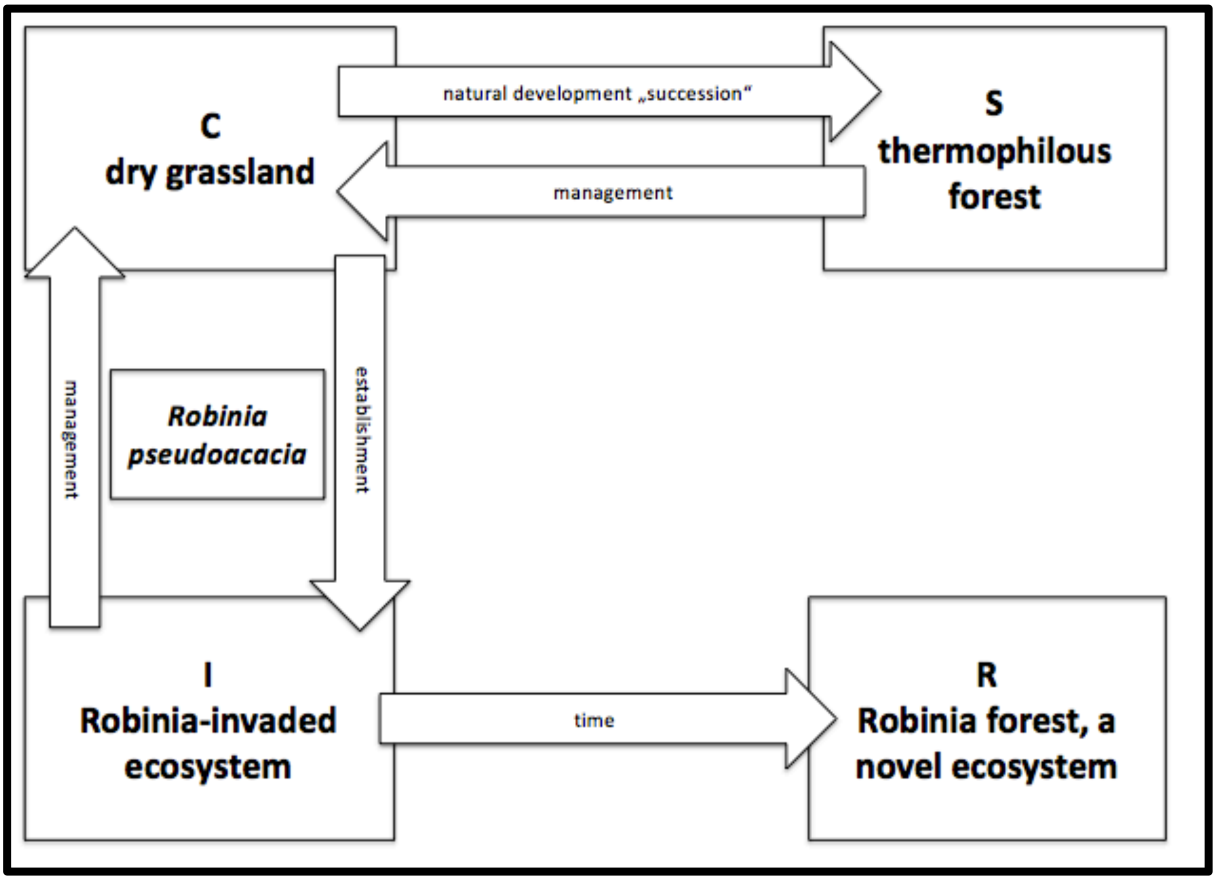

Fig 3: general schema of an invasion and novel ecosystem development by *Robinia pseudacacia* on dry grassland, modified from Morse et al. (2014), note that development from C to S takes place on a larger temporal scale than the C-I-R development of primary interest

Plots within these 4 types (I... Invasion, C... Control, R... *Robinia*, S... Succession) were chosen randomly in the field. A minimum distance of 10 m was chosen between C- and R-plots, I-plots were sampled at the intersection of C and R areas and S-plots were chosen in the immediate vicinity of C-plots. A plot size of 9x5 m corresponding to current suggestions for minimal sample sizes for fringe and shrub vegetation (Chytrý & Otýpková 2003) was chosen. For better comparability all plots were chosen to be equal in size.

Vegetation data

Basic geographical data (position, elevation, aspect and slope) were gathered for every plot along with a species list. Abundance and coverage was recorded on the Londo Decimal Scale (Londo (1976), modified for Braun-Blanquet-compatibility) due to its finer resolution for species with low abundance and better applicability in studies of succession (Mucina et al. 2016). Evidence of previous land use (vineyards, pastures) was also documented. To further describe and differentiate the *Robinia* stands, the number of ramets (stems over 2 cm in diameter and over 50 cm high), their height and diameter at breast height were noted to serve as estimators for age. To address soil characteristics in the field soil particle size class was determined by "the finger test" 3 times per plot and soil depth was measured 5 times per plot and bedrock data (Matura, Fuchs 1983) were obtained.

Historical data

Data regarding the previous management and evaluation of mapped areas was given by Denk & Kraus (2008) and officials in the region (Seehofer 2016: pers. comm.). Since *R. pseudacacia* has been in the area longer than present-day conservation efforts and land uses have changed over time 2 historical maps, the "Franziszeischer Kataster" dated 1817-1861 (Katastralmappenarchiv BEV Wien 2016) and the "Josefinische Landesaufnahme” dated 1806-1869 were obtained to gain insight in earlier vegetation ans land use.

Software

Map generation and editing was done with the software QGIS version 2.18 "Las Palmas" (QGIS Development Team 2016), data collected in the field were compiled in Microsoft Excel 2011 and analyzed with `RStudio` version 1.0.136 (RStudio Team 2016) and following packages: "`dave`" (Wildi 2014); "`labdsv`" (Roberts 2013); "`vegan`" (Jari Oksanen *et al.* 2017); "`wiqid`" (Meredith 2016) and "`rpart`" (Therneau, Atkinson & Ripley 2015).

Constancy Table

Species present in different strata (seedling, herb, shrub and tree layer) were treated as pseudo-species due to different informational value in different strata (e.g. *R.pseudacacia* coverage in seedling versus tree layer). To reduce noise within the data set, 2 general rules of species exclusion were applied: Species occurring only once with coverage less than five percent and species occurring three times or less with total coverage below one percent were omitted from cluster analysis. Furthermore, the seedling-layer - having overall low coverage - was unified with the herb layer to retain some information. An aggregate of common taxonomic confusion (*Achillea millefolium* agg., more precisely: *Achillea collina* and *A. pannonica*) was unified to one pseudospecies "*Achillea collina/pannonica*" to mitigate the effects of possible confusion in the field. The compliment of the similarity ratio (known as

Wishart Similarity Ratio or `distSimRatio`, Meredith 2016) was used as dissimilarity measure and clustering was performed via the unweighted pair group method with arithmetic mean (UPGMA, equivalent to average linkage clustering sensu Wildi 2013). Specificity, the product of a species' constancy and fidelity (Dufrêne & Legendre 1997), for cluster groups was used to identify species specific to cluster groups. Further sorting of species into groups according to their syntaxonomic characteristics was carried out manually with current literature (Ellmauer & Mucina 1993; Mucina & Kolbek 1993a; b; c; Drescher *et al.* 2007; Vítková & Kolbek 2010). These sorting parameters were combined into a constancy table (Dengler, Chytry & Ewald 2008).

Ordination and Multivariate Regression

The same exclusions and edits to reduce noise within the data were applied for the constancy table. The heat load index (hli) (McCune & Keon 2002) was calculated from the site data to obtain a measure of potential direct incidence radiation (PDIR). Geographical vicinity (defined as the hill the plots are located on) was added as variable to visualize geographic interdependency. The distances to the nearest settlements, streets, paths and agricultural land were used as a measure of hemeroby. Soil data proved to be mapped on too large a scale (1x1km, BFW (2016)), leading to obviously incorrect soil types (e.g. "Grauer Auboden" for the entire Dürnstein area). Thus this data was omitted from the analysis. Bedrock data were compiled as category. The soil particle density classes obtained per sample were tallied up to a majority type, if no clear majority could be found the particle density class was described as "complex". Median soil depth was used in analysis, since the minimum could be dependent on hitting rocks or roots. For *Robinia* stands dbh (diameter at breast height) and estimated maximal heights were used as estimators for stand age and the number of individuals (ramets) as a measure of invasion pressure. Management data were computed as binary variable for presence/absence of management measures such as grazing and mowing, which were addressed by the years of grazing and years since grazing ceased and the frequency of mowing (years of mowing X annual frequency) respectively. The "Josefinische Landeserhebung" a tactical map, denotes steep slopes through hatching lines drawn over the map, most of the plots being located on such slopes made precise interpretation impossible. The "Franziszeischer Kataster", a map made for taxation purposes based on land ownership and use proved more useful in this case. Non-metric multidimensional scaling (NMDS), using the same distance measure as for Clustering (see above), was chosen to visualize gradients within the data, since it allows the input of multiple types of variables (Wildi 2013). To reveal environmental variables with predictive capabilites of metric, ordinal and categorical variables a Multivariate Regression Tree (MRT) (De'ath 2002; Borcard, Gillet & Legendre 2011) was calculated.

Diversity and Indicator Values

Differences in diversity were compared between MRT groups as raw and rarefied species counts and with the Shannon index of diversity. Ellenberg indicator values (Ellenberg 1974) updated by Englisch & Karrer (2017 in prep) were calculated for the groups revealed by the MRT. To properly compare the indicator values calculation of the grouped Median was necessary (Englisch & Karrer 2001). The calculation was performed based on presence-absence data only, since the presence of a species indicates an environmental situation, irrespective of the species relative occurrence within the plot.

Results

Anthropogenic and semi-natural *Robinia*-stands occur commonly within the study area. Stands are spread throughout the region, with seedlings present in the undergrowth of forests, yet only in one invaded grassland site. Stand growth types ranged from low shrubs to tall trees so some variation of *Robinia* growth should be noted.

Constancy table

Clustering revealed a grouping of invaded areas grouped together with their uninvaded counterparts. Most sites of the C-group showed high coverages of *Arrhenatherum elatius*. Fringe vegetation (e.g. shrubs of Rhamno-Prunetea and Trifolio-Geranietea) was present in C and I groups, in the latter case sometimes overgrown by *Robinia*. Overall *Robinia* coverage ranged from five to 75%.

Robinia forests (the R-group) contained nitrophiles from various classes (e.g. Galio-Urticetea, Artemisietea vulgaris) with some species of Rhamno-Prunete, Querco-Fagetea and Festuco Brometea persisting in the herb and shrub layers. Since invaded areas, the focus of this study, contain both species of the original vegetation (mostly of Festuco-Brometea) but also species that belong to the syntaxon of the invading organism (Robinietea) I-plots defy a clear syntaxonomic circumscription. They were classified within Robinietea for the purpose of this study, yet their classification is "invaded Festuco-Brometea" is possible (see Discussion).

Tab 1: Constancy table with Relevés condensed into cluster groups and then sorted by *Robinia* occurence, species sorted by layer and syntaxonomic unit in cluster group, Class denoting the phytosociological class (or unit within a class) the species has a diagnostic value for, constancies above 60% are **bold**:

Rha...Rhamno-Prunetea, Rob...Robinietea (grey), Fes...Festuco-Brometea, Tri...Trifolio-Geranietea, Mol...Molinio-Arrhenateretea, Cal...Calluno-Ulicetea, Que...Querco-Fagetea, Eri...Erico-Pinetea, Gal...Galio-Urticetea, Koe...Koelerio-Corynephoretea, Ste...Stellarietea mediae, Art...Artemisietea vulgaris, Agr...Agropyretea, Epi...Epilobietea, Nar...Nardetea strictae

Plot types: S (natural succession to thermophilous forests), R (*Robinia* forests), I (invaded grasslands), C (grasslands, control group), A (other)

constancy /average coverage scale abbreviations		**Constancy Table**															
. absent	. absent	**Sampling Effort**															
		group/															
I > 0-20%	r > 0-0.2%	**Plot type**	**6**	**12**	**3**	**1**	**4**	**5**	**9**	**10**	**13**	**2**	**8***	**11***	**14***	**7***	**n=**
II > 20-40%	+ >0.2-1%	**S**	11	2	.	.	.	.	.	.	.	.	.	.	.	.	13
III > 40-60%	1 > 1-5%	**R**	.	.	9	1	.	.	.	.	.	.	.	.	.	.	10
IV > 60-80%	2 > 5-25%	**I**	.	.	.	8	5	2	2	1	1	.	.	.	.	.	19
V > 80-100%	3 > 25-50%	**C**	.	.	.	4	2	.	.	2	3	3	1	1	1	.	17
	4 > 50-75%	**A**	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1
	5 > 75-100%	**n=**	11	2	9	13	7	2	2	3	4	3	1	1	1	1	**60**

Species			**Cluster group (*single Relevé)**														
Layer	**Name**	**Occ**	**6**	**12**	**3**	**1**	**4**	**5**	**9**	**10**	**13**	**2**	**8***	**11***	**14***	**7***	**Class**

1 Tree Layer	*Carpinus betulus*	4	II / 2	.	I / 1	.	.	.	.	.	.	.	.	.	.	.	Que
1 Tree Layer	*Fagus sylvatica*	2	.	**V / 4**	.	.	.	.	.	.	.	.	.	.	.	.	Que
1 Tree Layer	*Acer campestre*	1	.	.	.	.	.	.	III / 1	.	.	.	.	.	.	.	Que
1 Tree Layer	*Acer pseudoplatanus*	1	.	.	.	I / +	.	.	.	.	.	.	.	.	.	.	Que
1 Tree Layer	*Crataegus laevigata*	1	.	III / 1	.	.	.	.	.	.	.	.	.	.	.	.	Que
1 Tree Layer	*Juglans regia*	1	.	.	I / +	.	.	.	.	.	.	.	.	.	.	.	Que
1 Tree Layer	*Robinia pseudacacia*	18	.	.	**V / 4**	II / 2	III / 1	III / 1	.	II / 1	.	.	.	.	.	.	Rob
1 Tree Layer	*Ailanthus altissima*	1	.	.	I / r	.	.	.	.	.	.	.	.	.	.	.	Rob
1 Tree Layer	*Crataegus monogyna*	1	I / +	.	.	.	.	.	.	.	.	.	.	.	.	.	Rob, Que
4 Shrub Layer	*Pinus sylvestris*	1	.	.	.	.	.	.	.	.	.	.	.	.	.	* / 2	Eri
4 Shrub Layer	*Quercus petraea*	15	**V / 1**	III / r	I / r	.	I / r	.	.	II / +	.	.	.	.	.	* / 2	Que
4 Shrub Layer	*Acer campestre*	9	I / +	.	**IV / 1**	.	.	.	III / 1	.	.	.	.	.	.	.	Que
4 Shrub Layer	*Tilia platyphyllos*	7	II / +	III / 1	II / 1	.	.	.	.	.	.	.	.	.	.	.	Que
4 Shrub Layer	*Carpinus betulus*	5	II / +	.	I / 1	.	.	.	.	.	.	.	.	.	.	.	Que
4 Shrub Layer	*Crataegus laevigata*	5	I / +	.	I / r	.	I / +	.	III / +	.	.	.	.	.	.	.	Que
4 Shrub Layer	*Cornus sanguinea*	3	.	.	II / 1	.	I / r	.	.	.	.	.	.	.	.	.	Que
4 Shrub Layer	*Juglans regia*	3	.	.	II / 1	.	.	.	.	.	.	.	.	.	.	.	Que
4 Shrub Layer	*Fagus sylvatica*	2	.	**V / 2**	.	.	.	.	.	.	.	.	.	.	.	.	Que
4 Shrub Layer	*Acer pseudoplatanus*	1	.	.	.	I / +	.	.	.	.	.	.	.	.	.	.	Que
4 Shrub Layer	*Berberis vulgaris*	15	I / 1	III / +	II / r	I / r	III / 1	III / 1	III / +	II / r	.	.	.	.	.	* / 1	Rha
4 Shrub Layer	*Ligustrum vulgare*	14	II / 1	III / r	II / 1	II / +	I / r	III / +	III / 1	.	.	.	.	.	.	* / r	Rha
4 Shrub Layer	*Rosa glauca*	5	.	.	I / 1	II / 1	.	.	.	.	.	.	.	.	.	* / r	Rha
4 Shrub Layer	*Prunus fruticosa*	3	.	.	.	I / 1	I / 1	.	.	.	.	II / 2	.	.	.	.	Rha
4 Shrub Layer	*Rosa rubiginosa*	1	.	.	.	.	.	.	III / r	.	.	.	.	.	.	.	Rha
4 Shrub Layer	*Rosa jundzilii*	3	.	.	I / r	.	I / +	III / 2	.	.	.	.	.	.	.	.	Rha, Que
4 Shrub Layer	*Rhamnus catharticus*	1	.	.	I / r	.	.	.	.	.	.	.	.	.	.	.	Rha, Que
4 Shrub Layer	*Robinia pseudacacia*	30	.	.	**V / 2**	**IV / 2**	**IV / 2**	**V / 2**	**V / 2**	II / +	II / +	.	.	.	.	* / 2	Rob

4 Shrub Layer	*Ailanthus altissima*	2	.	.	II / +	.	.	.	.	.	.	.	.	.	.	.	Rob
4 Shrub Layer	*Crataegus monogyna*	7	II / r	.	I / +	I / r	I / 1	III / +	.	.	.	.	.	.	.	.	Rob, Que
4 Shrub Layer	*Prunus spinosa*	5	.	.	.	I / r	.	.	III / 1	.	II / r	.	.	* / 2	* / 2	.	Rob, Que
4 Shrub Layer	*Rosa canina s.str.*	15	I / +	.	I / 1	II / 1	III / 1	.	**V / 1**	II / r	.	.	.	.	* / 1	.	Rob, Rha
4 Shrub Layer	*Sambucus nigra*	1	.	.	I / 1	.	.	.	.	.	.	.	.	.	.	.	Rob, Rha
4 Shrub Layer	*Sorbus aria agg.*	4	I / +	.	I / r	I / +	.	.	.	.	.	.	.	.	.	.	
4 Shrub Layer	*Rubus caesius*	2	I / r	.	I / 1	.	.	.	.	.	.	.	.	.	.	.	
4 Shrub Layer	*Ilex aquifolium*	1	.	.	.	.	.	.	.	.	.	.	.	.	.	* / r	
4 Shrub Layer	*Syringa vulgaris*	1	.	.	I / 1	.	.	.	.	.	.	.	.	.	.	.	
6 Herb Layer	*Anthoxanthum odoratum*	19	I / r	.	II / +	**IV / 2**	I / +	**V / 2**	III / +	.	.	II / 1	.	.	* / 1	.	Cal
6 Herb Layer	*Hieracium pilosella*	14	.	.	.	III / +	III / r	.	III / +	II / +	.	II / r	* / r	.	.	.	Cal
6 Herb Layer	*Luzula campestris*	6	II / 1	**V / 2**	.	.	.	.	.	.	.	.	.	.	.	* / 2	Cal
6 Herb Layer	*Antennaria dioica*	5	II / r	III / r	.	.	.	.	.	.	.	.	.	.	.	.	Cal
6 Herb Layer	*Galium pumilum*	2	I / r	.	.	.	.	.	.	.	.	.	.	.	.	.	Cal, Nar
6 Herb Layer	*Pinus sylvestris*	1	.	.	.	.	.	.	.	.	.	.	.	.	.	* / +	Eri
6 Herb Layer	*Verbascum chaixii ssp. austriacum*	25	II / r	.	.	III / +	**IV / +**	III / +	.	**V / +**	**IV / 1**	II / +	.	* / r	* / 1	.	Fes
6 Herb Layer	*Centaura stoebe*	24	.	.	.	III / +	III / +	**V / r**	III / r	**IV / +**	**IV / +**	**V / +**	* / r	* / r	* / 1	.	Fes
6 Herb Layer	*Festuca rupicola*	23	I / 1	.	.	**IV / 2**	III / 1	.	III / +	II / 1	III / 1	**V / 2**	* / 2	* / +	* / 2	.	Fes
6 Herb Layer	*Sedum album*	17	.	.	.	III / r	III / r	.	**V / 1**	.	II / r	**IV / r**	* / r	* / r	.	.	Fes
6 Herb Layer	*Achillea cf. collina/pannonica*	15	I / +	.	.	II / r	II / +	.	III / r	II / r	**V / r**	II / r	.	.	.	.	Fes
6 Herb Layer	*Cusctua epithymum*	13	.	.	.	I / r	**IV / r**	.	**V / r**	II / r	III / r	II / r	.	.	* / r	.	Fes
6 Herb Layer	*Eryngium campestre*	13	.	.	.	III / 1	II / +	III / r	**V / +**	.	.	.	.	* / r	* / +	.	Fes
6 Herb Layer	*Salvia pratensis*	13	.	.	.	II / r	II / +	.	III / +	**IV / +**	**IV / +**	II / r	.	* / +	.	.	Fes
6 Herb Layer	*Melica ciliata*	13	.	.	I / +	II / +	**V / 3**	.	.	.	.	**IV / 1**	.	.	.	.	Fes
6 Herb Layer	*Thymus praecox*	12	.	.	.	II / r	I / r	.	**V / +**	II / r	III / +	II / r	* / r	.	.	.	Fes
6 Herb Layer	*Anthericum ramosum*	12	II / r	III / r	I / +	.	I / r	.	III / r	**IV / 1**	III / 1	II / +	.	.	.	.	Fes
6 Herb Layer	*Veronica spicata*	11	.	.	.	I / r	II / r	III / r	III / r	II / r	II / +	II / r	* / +	.	* / r	.	Fes

6 Herb Layer	*Ranunculus bulbosus*	10	.	.	I / r	III / +	.	III / 1	.	.	.	II / r	.	* / r	.	.	Fes
6 Herb Layer	*Stipa pennata s.str.*	9	.	.	.	I / r	I / +	.	III / 1	.	III / 1	**V / 3**	.	.	.	.	Fes
6 Herb Layer	*Erysimum odoratum*	8	I / r	.	.	I / r	I / r	.	III / +	.	II / r	.	.	* / +	* / r	.	Fes
6 Herb Layer	*Koeleria macrantha*	8	.	.	.	II / +	I / r	III / r	III / 1	.	.	II / r	.	.	.	.	Fes
6 Herb Layer	*Thesium linophyllon*	7	I / r	.	.	I / r	.	.	III / r	II / r	.	II / r	.	* / r	* / 1	.	Fes
6 Herb Layer	*Koeleria pyramidata*	7	.	.	.	II / 1	.	.	.	.	II / r	II / r	.	* / 1	.	.	Fes
6 Herb Layer	*Festuca valesiaca*	7	I / +	.	.	I / +	I / +	.	**V / 2**	.	II / 2	.	* / r	.	.	.	Fes
6 Herb Layer	*Securigera varia*	6	.	.	.	I / +	I / r	.	.	**IV / +**	.	II / r	.	* / +	.	.	Fes
6 Herb Layer	*Dorycnium germanicum*	6	.	.	.	I / r	II / +	.	.	II / +	II / +	.	.	.	.	.	Fes
6 Herb Layer	*Helianthemum nummularium ssp. nummluarium*	6	.	.	.	.	I / r	.	.	**IV / r**	III / +	II / r	.	.	.	.	Fes
6 Herb Layer	*Galium verum*	5	.	.	.	I / r	I / r	.	.	**IV / +**	.	.	.	.	* / 1	.	Fes
6 Herb Layer	*Pulsatilla grandis*	5	.	.	.	I / r	II / r	.	.	.	.	.	* / 1	.	.	.	Fes
6 Herb Layer	*Bromus erectus*	5	.	.	.	I / +	.	.	.	.	**V / 3**	.	.	.	.	.	Fes
6 Herb Layer	*Globularia bisnagarica*	4	.	.	I / r	I / r	.	.	.	.	.	II / r	* / 1	.	.	.	Fes
6 Herb Layer	*Biscutella laevigata ssp. kerneri*	4	I / r	.	.	I / r	I / r	.	.	.	.	.	.	.	.	.	Fes
6 Herb Layer	*Galatella linosyris*	4	.	III / r	.	.	I / +	.	III / r	.	II / r	.	.	.	.	.	Fes
6 Herb Layer	*Achillea setacea*	3	.	.	.	I / r	.	III / +	.	.	.	.	.	.	* / r	.	Fes
6 Herb Layer	*Allium flavum*	3	I / r	.	.	I / r	.	.	III / r	.	.	.	.	.	.	.	Fes
6 Herb Layer	*Campanula glomerata*	3	.	III / r	.	.	II / r	.	.	.	.	.	.	.	.	.	Fes
6 Herb Layer	*Campanula moravica*	3	I / r	.	.	I / r	.	.	.	II / r	.	.	.	.	.	.	Fes
6 Herb Layer	*Centaurea scabiosa*	3	.	.	.	.	I / r	.	.	.	II / +	II / r	.	.	.	.	Fes
6 Herb Layer	*Festuca ovina*	3	.	.	.	.	I / r	III / 1	.	.	II / 1	.	.	.	.	.	Fes
6 Herb Layer	*Onobrychis viciifolia*	3	.	.	.	.	.	.	.	**IV / 1**	II / +	.	.	.	.	.	Fes
6 Herb Layer	*Stipa eriocaulis*	3	.	.	.	.	I / r	.	.	.	II / +	II / +	.	.	.	.	Fes
6 Herb Layer	*Verbascum speciosum*	3	I / r	.	.	.	I / r	.	III / +	.	.	.	.	.	.	.	Fes
6 Herb Layer	*Fragaria viridis*	2	.	.	I / r	.	.	.	.	.	.	.	.	.	* / +	.	Fes
6 Herb Layer	*Linum catharticum*	2	.	.	.	.	.	.	.	.	.	II / r	* / 2	.	.	.	Fes

6 Herb Layer	*Campanula sibirica*	2	I / r	.	.	.	.	.	.	.	.	.	.	.	.	.	Fes
6 Herb Layer	*Carex caryophyllea*	2	.	.	.	I / r	.	.	.	.	.	.	.	.	.	.	Fes
6 Herb Layer	*Hieracium bauhinii*	2	I / +	.	.	.	.	.	.	II / r	.	.	.	.	.	.	Fes
6 Herb Layer	*Stipa capillata*	2	.	.	.	.	.	.	III / +	.	II / +	.	.	.	.	.	Fes
6 Herb Layer	*Jurinea mollis*	1	.	.	.	.	I / +	.	.	.	.	.	.	.	.	.	Fes
6 Herb Layer	*Ononis spinosa*	1	I / r	.	.	.	.	.	.	.	.	.	.	.	.	.	Fes
6 Herb Layer	*Orobanche alsatica*	1	.	.	.	.	.	.	.	.	II / r	.	.	.	.	.	Fes
6 Herb Layer	*Hypochaeris maculata*	5	.	.	.	I / r	I / r	.	.	.	.	.	* / 1	* / r	.	.	Fes, Cal
6 Herb Layer	*Phleum phleoides*	8	I / +	.	.	II / +	.	**V / 2**	.	.	.	.	* / +	* / +	.	.	Fes, Koe
6 Herb Layer	*Alyssum montanum*	3	.	.	.	.	I / r	.	III / r	II / r	.	.	.	.	.	.	Fes, Koe
6 Herb Layer	*Orobanche alba*	3	.	.	.	.	.	.	.	.	**IV / r**	.	.	.	.	.	Fes, Koe
6 Herb Layer	*Cerastium arvense ssp. arvense*	20	.	.	I / +	III / +	III / 1	III / r	.	**IV / +**	**IV / r**	**IV / +**	.	.	.	.	Fes, Koe, Agr
6 Herb Layer	*Echium vulgare*	24	I / r	.	.	III / +	III / +	**V / +**	**V / 1**	.	III / +	**V / +**	* / r	* / r	* / 1	.	Fes, Koe, Gal
6 Herb Layer	*Hypericum perforatum*	27	I / +	.	I / r	**IV / 1**	III / +	**V / +**	III / 1	II / r	III / +	**IV / r**	* / +	.	* / 1	.	Fes, Nar
6 Herb Layer	*Seseli libanotis*	20	I / +	.	.	II / 1	III / 1	**V / 2**	**V / r**	**IV / +**	II / 1	**IV / 1**	.	.	.	.	Fes, Tri
6 Herb Layer	*Centaurea triumfettii*	16	I / r	.	.	III / +	I / r	III / +	.	**IV / +**	II / +	**IV / +**	.	* / r	* / r	.	Fes, Tri
6 Herb Layer	*Primula veris*	7	II / r	.	II / r	.	I / r	.	.	.	II / r	.	.	.	.	.	Fes, Tri
6 Herb Layer	*Tanacetum corymbosum*	4	I / +	.	.	I / r	.	.	.	II / r	.	.	.	.	.	.	Fes, Tri
6 Herb Layer	*Isatis tinctoria*	11	I / +	.	.	I / r	I / +	III / r	III / +	II / r	**IV / +**	.	.	.	* / 2	.	Fes, Tri, Agr
6 Herb Layer	*Arabis auriculata*	5	.	.	.	I / r	.	.	III / r	.	II / r	.	* / r	.	.	.	Fes, Tri, Koe
6 Herb Layer	*Arabis hirsuta s.str.*	3	.	.	.	I / r	I / r	.	.	.	.	.	.	.	.	.	Fes, Tri, Koe
6 Herb Layer	*Stachys recta*	16	.	.	.	II / r	III / r	III / r	III / +	II / r	**IV / +**	II / +	.	.	* / r	.	Fes, Tri, Que
6 Herb Layer	*Inula hirta*	6	I / r	.	I / r	I / r	.	.	.	II / r	III / r	.	.	.	.	.	Fes, Tri, Que
6 Herb Layer	*Inula salicina*	1	.	.	.	I / r	.	.	.	.	.	.	.	.	.	.	Fes, Tri, Que
6 Herb Layer	*Sedum sexangulare*	18	II / r	.	.	II / r	**IV / r**	.	**V / +**	.	.	II / r	* / r	* / r	.	.	Koe
6 Herb Layer	*Trifolium arvense*	13	I / r	.	.	II / +	III / 1	III / 1	.	II / r	II / +	.	* / 3	.	* / 2	.	Koe
6 Herb Layer	*Petrorhagia saxifraga*	9	.	.	.	I / r	.	.	**V / r**	.	II / +	**IV / +**	* / 1	* / r	.	.	Koe

6 Herb Layer	*Potentilla argentea*	8	.	.	.	I / +	I / +	III / +	.	.	.	**V / 1**	.	* / r	.	.	Koe
6 Herb Layer	*Myosotis stricta*	8	.	.	.	II / r	.	III / +	III / r	.	.	II / r	* / 1	.	.	.	Koe
6 Herb Layer	*Arabidopsis thaliana*	7	.	.	.	I / r	.	III / r	III / r	.	III / r	II / r	.	.	.	.	Koe
6 Herb Layer	*Filago arvensis*	6	I / r	.	.	II / r	.	III / r	.	.	.	.	.	.	.	* / r	Koe
6 Herb Layer	*Rumex acetosella*	6	.	.	.	II / +	.	.	III / +	.	.	II / r	.	.	.	.	Koe
6 Herb Layer	*Sedum rupestre*	6	.	.	.	II / r	II / r	.	.	.	.	II / r	.	.	.	.	Koe
6 Herb Layer	*Myosotis ramosissima*	5	I / r	.	.	II / r	.	.	.	.	.	.	.	.	* / r	.	Koe
6 Herb Layer	*Alyssum alyssoides*	5	.	.	.	I / r	I / r	.	.	.	.	**IV / +**	* / r	.	.	.	Koe
6 Herb Layer	*Poa bulbosa*	3	.	.	.	I / r	I / +	.	.	.	.	.	* / 1	.	.	.	Koe
6 Herb Layer	*Arenaria serpyllifolia*	3	.	.	.	I / r	.	.	.	II / r	.	II / r	.	.	.	.	Koe
6 Herb Layer	*Clinopodium acinos*	3	I / r	.	.	.	I / r	.	.	.	.	II / +	.	.	.	.	Koe
6 Herb Layer	*Draba verna agg.*	3	I / r	.	.	I / r	.	.	.	.	.	II / r	.	.	.	.	Koe
6 Herb Layer	*Trifolium campestre*	2	.	.	.	.	I / r	.	.	.	.	.	.	.	* / +	.	Koe
6 Herb Layer	*Sedum acre*	2	.	.	.	I / r	.	.	.	.	.	.	.	.	.	.	Koe
6 Herb Layer	*Phedimus spurius*	10	I / r	.	.	II / r	II / r	.	.	.	.	II / r	.	.	.	* / r	Koe, Agr
6 Herb Layer	*Centaurea jacea*	9	.	.	I / r	I / r	III / r	.	.	**IV / +**	II / r	.	.	.	.	.	Mol
6 Herb Layer	*Phleum pratense*	8	.	.	.	I / r	III / +	.	.	II / r	II / r	.	.	.	* / +	.	Mol
6 Herb Layer	*Trifolium dubium*	6	.	.	.	I / r	I / +	III / 1	.	II / r	.	.	.	* / +	* / 2	.	Mol
6 Herb Layer	*Lotus corniculatus*	6	.	.	.	I / r	I / r	.	.	**IV / +**	.	II / +	.	.	* / +	.	Mol
6 Herb Layer	*Trifolium pratense*	3	.	.	.	I / r	.	.	III / 1	.	.	.	.	* / r	.	.	Mol
6 Herb Layer	*Poa pratensis*	3	I / r	.	.	I / +	.	.	.	.	.	.	.	.	.	.	Mol
6 Herb Layer	*Agrostis cf. capillaris*	1	.	.	.	I / +	.	.	.	.	.	.	.	.	.	.	Mol
6 Herb Layer	*Calamagrostis epigejos*	7	.	.	I / r	II / r	II / +	III / +	.	.	.	.	.	.	.	.	Mol, Art, Agr
6 Herb Layer	*Knautia arvensis*	3	.	.	.	I / r	.	III / +	III / r	.	.	.	.	.	.	.	Mol, Fes
6 Herb Layer	*Veronica officinalis*	2	.	.	.	I / r	.	.	.	.	.	.	* / r	.	.	.	Nar
6 Herb Layer	*Quercus petraea*	17	**V / +**	**V / +**	I / r	.	I / r	.	.	II / r	.	.	.	.	.	* / +	Que
6 Herb Layer	*Acer campestre*	9	I / r	.	III / r	I / r	.	.	III / r	.	.	.	.	.	.	.	Que

6 Herb Layer	*Asarum europaeum*	8	III / +	III / +	II / +	.	.	.	.	.	.	.	.	.	.	.	Que
6 Herb Layer	*Hedera helix*	8	II / 1	.	II / 1	I / r	.	.	III / +	.	.	.	.	.	.	* / r	Que
6 Herb Layer	*Tilia platyphyllos*	7	II / r	III / r	II / r	.	.	.	.	.	.	.	.	.	.	.	Que
6 Herb Layer	*Carpinus betulus*	6	III / +	.	I / r	.	.	.	.	.	.	.	.	.	.	.	Que
6 Herb Layer	*Crataegus laevigata*	6	II / r	.	I / r	.	I / r	.	III / r	.	.	.	.	.	.	.	Que
6 Herb Layer	*Juglans regia*	5	I / r	.	II / +	.	I / r	.	.	.	.	.	.	.	.	.	Que
6 Herb Layer	*Betonica officinalis*	3	I / r	III / r	I / r	.	.	.	.	.	.	.	.	.	.	.	Que
6 Herb Layer	*Cornus sanguinea*	3	.	.	II / r	.	I / r	.	.	.	.	.	.	.	.	.	Que
6 Herb Layer	*Fagus sylvatica*	2	.	**V / 1**	.	.	.	.	.	.	.	.	.	.	.	.	Que
6 Herb Layer	*Luzula luzuloides*	2	I / r	III / +	.	.	.	.	.	.	.	.	.	.	.	.	Que
6 Herb Layer	*Acer pseudoplatanus*	1	.	.	.	I / r	.	.	.	.	.	.	.	.	.	.	Que
6 Herb Layer	*Cyclamen purpurascens*	1	I / r	.	.	.	.	.	.	.	.	.	.	.	.	.	Que
6 Herb Layer	*Jasione montana*	1	I / r	.	.	.	.	.	.	.	.	.	.	.	.	.	Que
6 Herb Layer	*Hieracium murorum*	5	II / +	**V / 1**	.	.	.	.	.	.	.	.	.	.	.	.	Que, Eri
6 Herb Layer	*Ligustrum vulgare*	14	II / +	III / r	II / r	I / r	I / r	III / r	III / +	.	.	.	.	.	.	* / r	Rha
6 Herb Layer	*Berberis vulgaris*	13	I / r	III / r	I / r	I / r	III / +	III / +	III / r	II / r	.	.	.	.	.	* / +	Rha
6 Herb Layer	*Elymus hispidus*	9	.	.	I / +	II / +	III / 1	.	.	.	.	**IV / 2**	.	.	.	.	Rha
6 Herb Layer	*Rosa glauca*	5	.	.	I / 1	II / 1	.	.	.	.	.	.	.	.	.	* / r	Rha
6 Herb Layer	*Prunus fruticosa*	2	.	.	.	.	I / 1	.	.	.	.	II / 2	.	.	.	.	Rha
6 Herb Layer	*Rosa rubiginosa*	1	.	.	.	.	.	.	III / r	.	.	.	.	.	.	.	Rha
6 Herb Layer	*Agrimonia eupatoria*	1	.	.	.	.	.	.	.	.	.	.	.	* / 1	.	.	Rha, Fes, Tri
6 Herb Layer	*Clematis vitalba*	7	.	.	II / +	II / r	I / r	.	.	.	.	.	.	.	.	.	Rha, Que
6 Herb Layer	*Rosa jundzilii*	3	.	.	I / r	.	I / r	III / 2	.	.	.	.	.	.	.	.	Rha, Que
6 Herb Layer	*Rhamnus catharticus*	1	.	.	I / r	.	.	.	.	.	.	.	.	.	.	.	Rha, Que
6 Herb Layer	*Viburnum lantana*	1	.	.	.	I / +	.	.	.	.	.	.	.	.	.	.	Rha, Que
6 Herb Layer	*Bupleurum falcatum*	1	.	.	.	I / r	.	.	.	.	.	.	.	.	.	.	Rha, Tri
6 Herb Layer	*Robinia pseudacacia*	36	III / r	III / r	**V / +**	**IV / 1**	**IV / 1**	**V / 2**	**V / +**	II / r	II / r	.	.	.	.	* / +	Rob

6 Herb Layer	*Poa nemoralis*	10	III / 2	**V / 1**	II / +	.	.	.	.	.	.	.	.	.	.	* / 1	Rob
6 Herb Layer	*Chelidonium majus*	9	I / +	.	**IV / 1**	.	I / r	.	.	.	.	.	.	.	.	.	Rob
6 Herb Layer	*Impatiens parviflora*	3	I / +	.	II / +	.	.	.	.	.	.	.	.	.	.	.	Rob
6 Herb Layer	*Geum urbanum*	3	.	.	II / r	.	I / r	.	.	.	.	.	.	.	.	.	Rob
6 Herb Layer	*Ailanthus altissima*	2	.	.	II / r	.	.	.	.	.	.	.	.	.	.	.	Rob
6 Herb Layer	*Elymus repens*	7	I / +	.	.	I / 1	I / 1	.	.	II / +	III / +	.	.	.	* / +	.	Rob, Agr
6 Herb Layer	*Alliaria petiolata*	6	I / +	.	III / 1	.	.	.	.	.	.	.	.	.	.	.	Rob, Art
6 Herb Layer	*Euphorbia cyparissias*	35	II / +	III / r	I / r	**V / 1**	**V / 1**	III / +	**V / +**	**IV / +**	III / +	**V / 1**	* / 1	.	* / +	.	Rob, Fes
6 Herb Layer	*Teucrium chamaedrys*	29	I / r	.	I / r	III / 1	**V / 1**	**V / 1**	**V / 2**	**IV / 1**	**V / 2**	**IV / 1**	.	.	* / r	.	Rob, Fes
6 Herb Layer	*Artemisia campestris*	20	I / r	.	.	III / +	**IV / +**	III / +	**V / +**	II / r	II / +	**IV / +**	* / +	.	.	.	Rob, Fes
6 Herb Layer	*Dianthus carthusianorum*	18	I / r	.	.	II / r	II / r	III / r	III / r	**IV / r**	II / r	**IV / r**	.	* / r	* / r	.	Rob, Fes
6 Herb Layer	*Seseli osseum*	13	.	.	.	II / +	II / +	.	**V / r**	.	II / r	**IV / 1**	* / r	.	.	.	Rob, Fes
6 Herb Layer	*Carex humilis*	12	I / r	.	.	II / +	II / r	.	**V / 1**	II / 1	.	II / 1	* / 1	.	.	.	Rob, Fes
6 Herb Layer	*Festuca pallens*	11	II / 1	.	.	I / r	II / 1	.	III / 1	.	.	**IV / +**	.	* / +	.	.	Rob, Fes
6 Herb Layer	*Pulsatilla pratensis ssp. nigricans*	10	.	.	.	I / r	I / r	.	III / r	**IV / r**	**IV / 1**	II / r	.	.	.	.	Rob, Fes
6 Herb Layer	*Brachypodium pinnatum*	9	.	.	.	I / r	I / r	III / 1	.	**V / 3**	.	.	.	* / +	* / r	.	Rob, Fes
6 Herb Layer	*Thymus pulegioides*	8	.	.	.	I / r	II / +	.	.	II / r	II / 1	**IV / +**	.	.	.	.	Rob, Fes
6 Herb Layer	*Viscaria vulgaris*	6	.	.	.	III / +	.	.	.	.	.	.	.	.	.	.	Rob, Fes
6 Herb Layer	*Pimpinella saxifraga*	4	.	.	.	I / r	.	.	.	II / +	III / +	.	.	.	.	.	Rob, Fes
6 Herb Layer	*Aurinia saxatilis*	4	.	.	I / r	I / r	I / r	.	.	.	.	.	.	.	.	* / r	Rob, Fes
6 Herb Layer	*Poa angustifolia*	3	.	.	.	I / r	.	.	.	.	II / +	.	.	.	* / 1	.	Rob, Fes
6 Herb Layer	*Bromus sterilis*	13	.	.	**IV / 2**	II / 2	II / +	III / +	.	II / 1	.	.	.	.	.	.	Rob, Fes, Mol
6 Herb Layer	*Galium aparine*	19	I / r	.	**IV / 2**	III / 1	I / +	III / r	.	II / +	II / r	.	.	.	.	.	Rob, Gal
6 Herb Layer	*Urtica dioica*	5	I / r	.	III / 1	.	.	.	.	.	.	.	.	.	.	.	Rob, Gal
6 Herb Layer	*Holosteum umbellatum*	3	.	.	.	.	I / +	.	.	.	.	**IV / 1**	.	.	.	.	Rob, Koe
6 Herb Layer	*Arrhenatherum elatius*	35	I / 1	.	III / 2	**V / 3**	**IV / 2**	III / 1	III / 1	**V / 2**	III / 2	II / +	.	* / 2	* / 1	.	Rob, Mol
6 Herb Layer	*Dactylis glomerata*	9	I / +	.	II / 1	I / +	.	.	.	II / r	III / +	.	.	* / r	.	.	Rob, Mol

6 Herb Layer	*Crataegus monogyna*	7	II / r	.	I / r	I / r	I / r	III / +	.	.	.	.	.	.	.	.	Rob, Que
6 Herb Layer	*Prunus spinosa*	5	.	.	.	I / r	.	.	III / r	.	II / r	.	.	* / +	* / 2	.	Rob, Que
6 Herb Layer	*Rosa canina s.str.*	16	II / r	.	I / r	II / +	III / +	.	**V / +**	II / r	.	.	.	.	* / 1	.	Rob, Rha
6 Herb Layer	*Sambucus nigra*	1	.	.	I / r	.	.	.	.	.	.	.	.	.	.	.	Rob, Rha
6 Herb Layer	*Polygonatum odoratum*	33	II / 1	III / r	III / +	III / 1	III / +	**V / +**	**V / 2**	**IV / 2**	**V / 2**	II / r	.	* / +	.	* / r	Rob, Tri
6 Herb Layer	*Sedum telephium*	7	I / r	.	I / r	I / r	.	.	.	.	.	**IV / r**	.	.	.	.	Rob, Tri
6 Herb Layer	*Vincetoxicum hirundinaria*	24	I / r	.	II / r	II / r	III / +	III / r	III / +	**V / r**	III / +	II / r	.	* / +	* / 1	* / r	Rob, Tri
6 Herb Layer	*Melica transsilvanica*	3	.	.	.	.	.	.	III / 2	II / 1	II / +	.	.	.	.	.	Rob, Tri, Agr
6 Herb Layer	*Viola arvensis*	17	I / r	.	II / r	**IV / r**	II / r	III / r	.	II / r	.	II / r	.	.	* / r	.	Ste
6 Herb Layer	*Convolvulus arvensis*	5	II / +	.	I / r	I / r	.	.	.	.	.	.	.	.	.	.	Ste
6 Herb Layer	*Papaver dubium*	4	.	.	.	I / r	I / r	.	III / r	.	.	.	.	.	.	.	Ste
6 Herb Layer	*Myosotis arvensis*	3	.	.	.	I / r	.	.	.	.	II / r	.	.	.	.	.	Ste
6 Herb Layer	*Stellaria media*	1	.	.	.	.	.	.	III / +	.	.	.	.	.	.	.	Ste
6 Herb Layer	*Trifolium alpestre*	11	I / +	.	.	II / +	III / +	III / r	.	.	II / +	II / +	.	.	.	.	Tri
6 Herb Layer	*Galium glaucum*	10	I / +	.	.	.	II / r	.	III / +	**IV / +**	**IV / r**	.	.	.	* / r	.	Tri
6 Herb Layer	*Vicia cf. tenuifolia*	9	.	.	.	I / r	I / 1	III / r	III / +	**IV / 2**	III / 1	.	.	.	.	.	Tri
6 Herb Layer	*Geranium sanguineum*	6	I / +	.	I / r	I / r	I / +	.	.	II / +	.	.	.	* / 3	.	.	Tri
6 Herb Layer	*Geranium sylvaticum*	3	I / +	.	I / r	.	.	.	.	.	.	.	.	.	.	* / +	Tri
6 Herb Layer	*Veronica chamaedrys ssp. chamaedrys*	2	.	.	.	I / r	.	.	.	.	II / r	.	.	.	.	.	Tri
6 Herb Layer	*Fragaria moschata*	1	.	.	.	.	.	.	.	.	.	.	.	.	* / 1	.	Tri
6 Herb Layer	*Fragaria vesca*	10	.	.	I / r	II / r	I / +	**V / r**	.	**IV / r**	II / 1	.	.	.	.	.	Tri, Koe, Epi
6 Herb Layer	*Scabiosa ochroleuca*	5	I / r	.	.	I / r	.	.	.	II / r	.	.	* / r	.	.	.	
6 Herb Layer	*Allium lusitanicum*	5	.	.	.	I / r	III / r	.	III / r	.	.	.	.	.	.	.	
6 Herb Layer	*Potentilla incana*	5	I / r	.	I / r	I / +	II / r	.	.	.	.	.	.	.	.	.	
6 Herb Layer	*Viola kitaibelliana*	5	.	.	.	I / r	II / r	.	.	.	.	II / r	.	.	.	.	
6 Herb Layer	*Ononis pusilla*	4	.	.	.	.	II / r	.	.	.	II / +	.	.	.	* / 1	.	
6 Herb Layer	*Sanguisorba minor*	4	.	.	.	II / r	.	.	.	II / r	.	.	.	.	.	.	

6 Herb Layer	*Sorbus aria agg.*	4	I / r	.	I / r	I / r	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Carex digitata*	3	II / 1	.	.	.	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Fumaria officinalis*	3	.	.	II / r	.	.	.	.	II / r	.	.	.	.	.	.
6 Herb Layer	*Jovibarba globifera ssp. globifera*	3	I / r	.	.	I / r	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Scleranthus perennis*	3	.	.	.	I / r	.	.	.	.	III / r	.	.	.	.	.
6 Herb Layer	*Vicia angustifolia*	2	.	.	I / r	.	.	.	.	.	.	.	.	.	* / +	.
6 Herb Layer	*Carduus nutans*	2	.	.	.	I / r	.	.	.	.	II / r	.	.	.	.	.
6 Herb Layer	*Hepatica nobilis*	2	I / r	.	I / r	.	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Hieracium piloselloides*	2	I / +	.	.	.	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Medicago lupulina*	2	.	.	.	.	I / r	.	.	.	.	II / r	.	.	.	.
6 Herb Layer	*Myosotis sylvatica*	2	.	.	.	.	I / r	.	III / r	.	.	.	.	.	.	.
6 Herb Layer	*Orobanche sp.*	2	.	.	.	I / r	.	.	.	.	.	II / r	.	.	.	.
6 Herb Layer	*Ranunculus acris*	2	.	.	II / r	.	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Salvia verticillata*	2	I / r	.	.	I / r	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Scabiosa canescens*	2	I / r	.	.	.	I / r	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Silene vulgaris*	2	.	.	.	I / r	I / +	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Veronica praecox*	2	.	.	I / r	I / r	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Medicago falcata*	1	.	.	.	.	.	.	.	.	.	.	.	.	* / +	.
6 Herb Layer	*Anchusa arvensis*	1	.	.	I / r	.	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Asparagus officinalis*	1	.	.	.	.	.	.	.	.	II / r	.	.	.	.	.
6 Herb Layer	*Aster amellus*	1	.	.	.	I / r	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Astragalus glycyphyllos*	1	.	.	.	.	.	.	.	.	II / +	.	.	.	.	.
6 Herb Layer	*Campanula sp.*	1	I / r	.	.	.	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Centaurea cf. diffusa*	1	.	.	.	.	.	.	.	.	.	II / r	.	.	.	.
6 Herb Layer	*Eupatorium cannabinum*	1	.	.	.	I / r	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Falcaria vulgaris*	1	I / r	.	.	.	.	.	.	.	.	.	.	.	.	.
6 Herb Layer	*Galium spurium*	1	.	.	.	.	I / +	.	.	.	.	.	.	.	.	.

6 Herb Layer	*Helichrysum arenarium*	1	.	.	.	.	.	III / r	.	.	.	.	.	.	.	.	
6 Herb Layer	*Ilex aquifolium*	1	.	.	.	.	.	.	.	.	.	.	.	.	.	* / r	
6 Herb Layer	*Medicago minima*	1	.	.	.	.	.	.	.	.	II / +	.	.	.	.	.	
6 Herb Layer	*Orobanche bartlingii*	1	.	.	.	I / r	.	.	.	.	.	.	.	.	.	.	
6 Herb Layer	*Orobanche coerulescens*	1	.	.	.	.	I / r	.	.	.	.	.	.	.	.	.	
6 Herb Layer	*Plantago lanceolata*	1	.	.	.	I / r	.	.	.	.	.	.	.	.	.	.	
6 Herb Layer	*Prunella grandiflora*	1	I / r	.	.	.	.	.	.	.	.	.	.	.	.	.	
6 Herb Layer	*Ranunculus sp.*	1	.	.	.	I / r	.	.	.	.	.	.	.	.	.	.	
6 Herb Layer	*Syringa vulgaris*	1	.	.	I / r	.	.	.	.	.	.	.	.	.	.	.	

The following cluster groups appear according to their sequences in Tab. 1. Group 6 consists of eleven S-plots; all dominated by *Quercus petraea* with shade trees (e.g. *Tilia platyphyllos*, *Carpinus betulus*) only reaching low coverages. These characteristics clearly show this group to be part of the Quercion pubescenti-petreae. Contrary to this, group 12 (two S-plots) is dominated by *Fagus sylvatica*, *Q. petraea* making up only a small portion of the tree layer in one of the relevés making this group part of the Fagion sylvaticae. Shrub and herb layer of these two groups are of similar composition and coverage was generally low in these. Group 3 is made up of nine (of ten) R-plots with *Robinia pseudacacia* coverages ranging from 50-75%. The only other tree present in the tree layer was *Tilia platyphyllos* in 2 relevés, with *Acer campestre* regularly present in the shrub layer, otherwise made of of species from the Rhamno-Prunetea (e.g. *Berberis vulgaris*, *Ligustrum vulgare*). The herb layer had higher coverage compared to the aforementioned groups and was made up of *Arrhenatherum elatius*, *Bromus sterilis*, sometimes with *Dactylis glomerata* and nitrophiles (e.g. *Chelidonium majus*, *Galium aparine*) reaching their highest constancies within the data set. This group predominantly belongs to the order Chelidonio-Robinietalia, with some aspects of Euphorbio cyparissiae-Robinietalia (e.g. *Euphorbia cyparissias*, *Rosa canina* agg.) occuring in light patches. Group 1 contained three of four plot types (one R-, eight I-four C-plots). Due to its mixed composition this group cannot be circumscribed by a single syntaxon (see above). The R-plot is part of the Euphorbio cyparissiae-Robinietalia, whereas I-plots contained vegetation of Balloto nigrae-Robinion (e.g. *Anthoxanthum odoratum*, *Bromus sterilis*). The C-plots show vegetation from the "*Melica transsilvanica-Festuca rupicola*-(Festucion valesiacae)-Gesellschaft" and the "*Verbascum austriacum-Festuca rupicola*-(Euphorbio-Callunion)-Gesellschaft. It must be noted that all relevés contained in this group show high coverage of *Arrhenatherum elatius*, irrespective of their invasion status. Group 4 contained 5 I-plots, 2 C-plots with herb layer dominated by *Melica ciliata*, suggesting the association Fumano-Stipetum eriocaulis, other species of Festuco-Brometea (e.g. *Teucrium chamaedrys*, *Cerastium arvense* ssp. *arvense*, *Seseli libanotis*) and Koelerio-Corynephoretea (e.g. *Sedum sexangulare*) showed high constancies within this group. Group 5 contains 2 I-plots with shrub layer made up mainly of *Robinia pseudacacia*. The herb layer contains a mixture of species syntaxonomically indicating the Euphorbio cyparissiae-Robinietalia (e.g. *Dianthus carthusianorum*) as well as groups within the Chelidonio-Robinietalia (e.g. *Anthoxanthum odoratum*). Species of the Rhamno-Prunetea (e.g. *Berberis vulgaris*) are present in only one of the two relevés. Group 9 contained 2 I-plots, both small occurences of *Robinia pseudacacia* within grassland stands, with no associated *Robinia* forests, compared to the previous groups signs of disturbance (e.g. *Arrhenatherum elatius*) and nitrophiles present in the previously discussed stands are largely absent, more xerotherm vegetation of Robinietea (e.g. *Melica transsilvanica*) is however present leading to classification as part of the Melico transsilvanicae-Robinietum. Group 10 contained one I- and two C-plots the invaded site had only little *Robinia*-coverage in the shrub layer. The dominant grass species were *Brachypodium pinnatum* and *Arrhenaterum elatius*, which places the vegetation within the Cirsio-Brachypodion, underscored by occurrence of *Scabiosa ochroleuca*. Vegetation of the Robinietea (e.g. *Galium aparine*, *Bromus sterilis*) only occurred within the invaded relevé. Group 13 contained one I- and three C-plots, the invaded site had only low *Robinia*-coverage in the shrub layer. The dominant grass species was Bromus erectus, indicating vegetation of the Bromion erecti, which can be corroborated by occurences of *Onobrychis viciifolia*. Group 2 consisted of three C-plots with lower vegetation cover and a rockier situation compared to other groups. Species of the Koelerio-Corynephoretea (e.g. *Alyssum alyssoides*) occur with higher constancies in this group, however the dominant grass species, *Stipa pennata* s.str., indicates vegetation of the *Verbascum austriacum-Festuca rupicola*-(Euphorbio-Callunion)-Gesellschaft with some elements of the Fumano-stipetum eriocaulis (e.g. *Stipa eriocaulis*). 4 cluster groups (8, 11, 14, 7) were represented only with one Relevé each (* asterisk in Tab 1). Group 8 contains high coverages of *Trifolium arvense*, indicatig vegetation of the Ranunculo illyrici-Festucetum valesiacae. However with only low coverage of other species of this association (e.g. *Festuca valesiaca*), assignment to any association remains tentative. Group 11 is a stand of Geranion sanguinei, untypically far from a forest fringe, surrounded by grassland. Group 14 stood out with large coverages of *Trifolium dubium* and *Prunus spinosa*, the latter indicating a shrubby fringe of the Prunetalia spinosae. Group 7 is an invaded pine forest belonging to the class Erico-Pinetea and was excluded from further analysis. It however may represent an alternative pathway of invasion.

Ordination

The following diagrams show NMDS-results of the investigated sites (Fig 4), environmental values were added to the same NMDS to visualize the data structure (Fig 5-7).

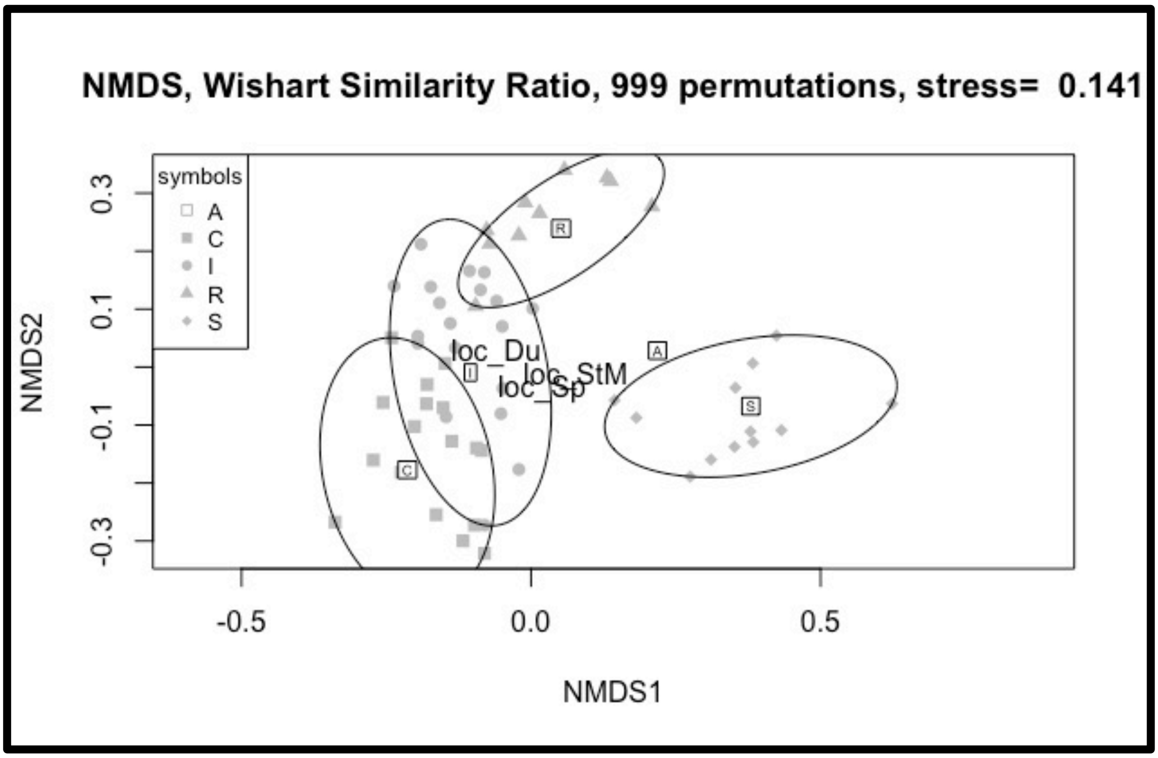

Fig 4: NMDS of plot groups; loc_ shows vicinity (Du=Dürnstein, loc_StM=St. Michael, loc_Sp=Spitz), ellipses are minimum spanning ellipses

As shown in Fig 4, the S-group of thermophilous forests was most distinct from the others, with the two plots closest to the center respresenting forest steppes. R-, I- and C-plots show some similarity and overlap in terms of species composition. This was to be expected since C and R represent the beginning and the final stage of plot type I (see Fig 3). Vicinity showed very little connection to plot types/groups. With a stress value of 0.141 the NMDS remains interpretable, however the plot positions do not resemble positions potentially obtainable by metric ordination.

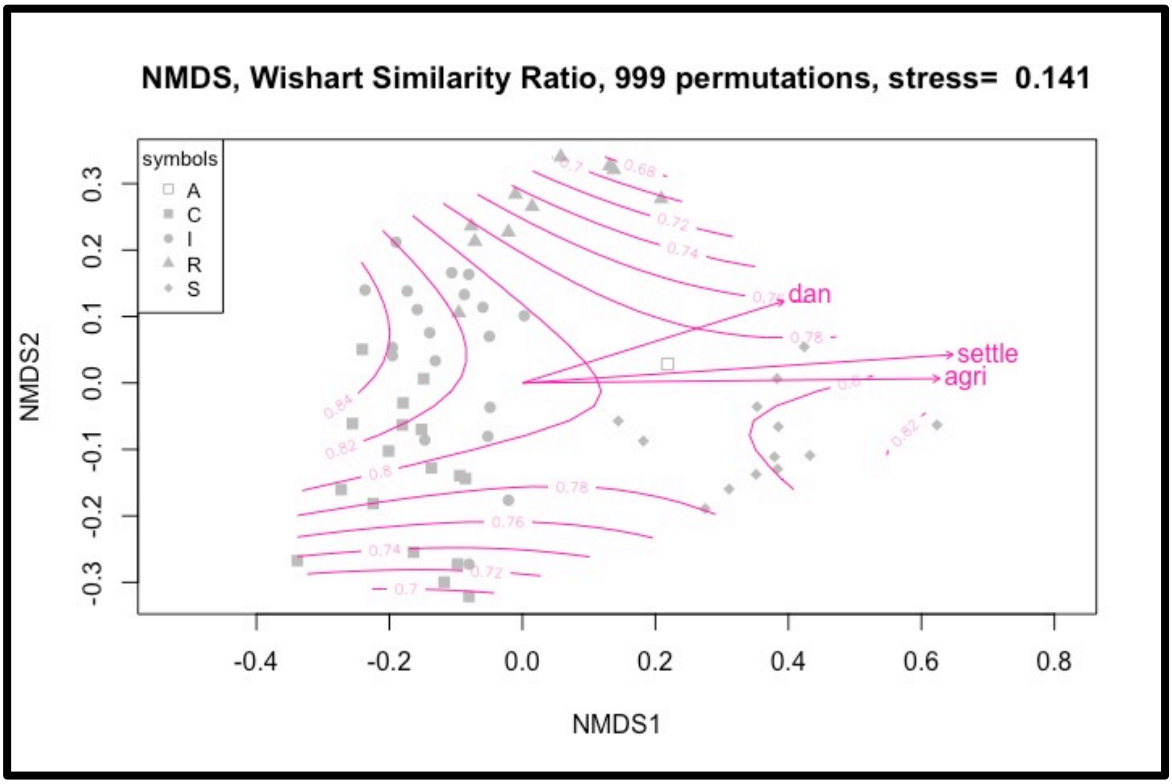

Fig 5: NMDS with plot types, contour lines show hli=heat load index, arrows show distances from: dan=distance from Danube river, settle=distance from nearest settlement, agri=distance from nearest agricultural site

The hli (contour lines in Fig. 5) shows a similar range of values for each plot group, thus the combination of folded aspect, latitude and slope shows only little connection to the different plot groups. Distance from the Danube River, agricultural land and settlement as surrogates for hemeroby indicate that S-plots had the lowest hemeroby.

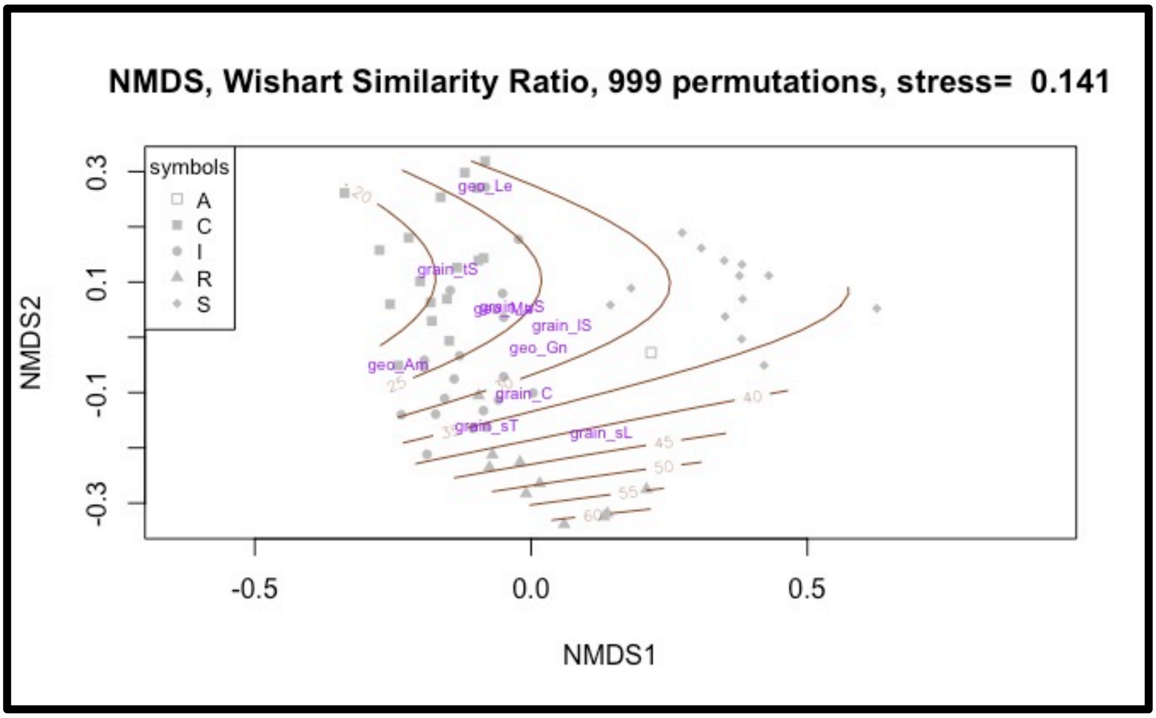

Fig 6: NMDS with plot types; contour lines show median soil depth in cm; grain_ shows grain type (C=complex, sL=sandy loam, sT=sandy clay, tS=loamy sand, uS=silty sand); geo_ shows bedrock (Gn= gneiss, Le=loam, Am=amphibolite, Ma=marble)

Fig. 6 demonstrates R-plots were located on the deepest soils, with median depth above 30 cm, whereas C-plots could be found with median depths below 20 cm, I-plots overlapping both these ranges. Loam and clay soil grains with some sand were present predominantly in R-plots along with some complex grains, whereas in C-plots the predominant grain type was sand with some loam and silt fractions.

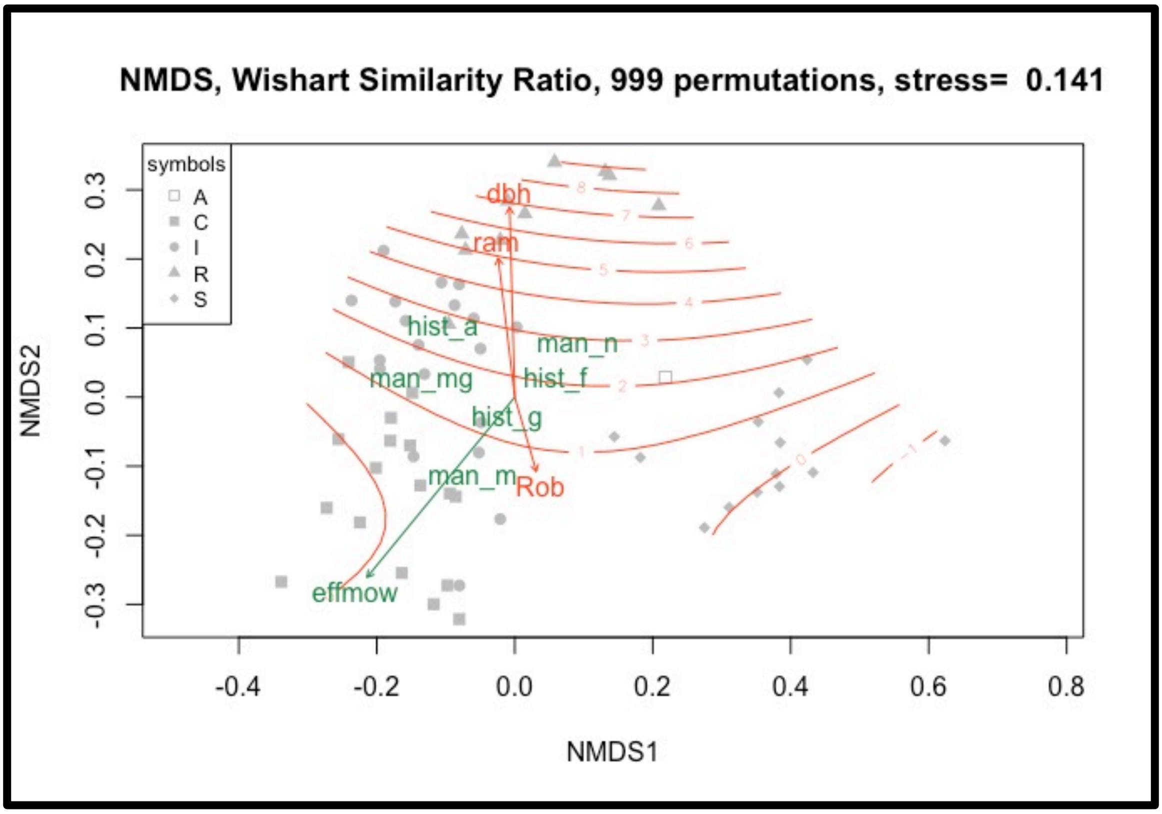

Fig 7: NMDS with plot types; contour lines show maximum Black locust stand height; Rob= distance from nearest Black Locust stand, dbh= maximum diameter at breast height for Black Locust stands, ram= number of Black Locust ramets; man_ shows management type (n= none, m=mowing, mg=mowing and grazing); effmow shows annual mowing frequency; hist_ shows historical land use (a=agricultural, f=forest, g=grassland/pasture)

Stand height (Fig. 7) shows increasing values with increasing dbh, an indicator of stand age, and a tendency to increase from I-plots to S-plots. The number of ramets increases somewhat with stand age as well. Historical land use as grassland/pasture and forest is not particularily associated with any group. The historical record shows the predominant forest type in the past to have been coniferous. Past agricultural use, exclusively viticultural in this case shows some connection to I-plots.

Sites under no management correspond with R- and I-plots, management by mowing and grazing or just mowing show weak connections with C- and I-plots. S-plots are under no specific management and also show no connection.

Multivariate Regression tree (MRT)

The MRT (Fig. 8, Top) revealed five groups as most common optimal solution with a high cross-validated relative error of 0.869.

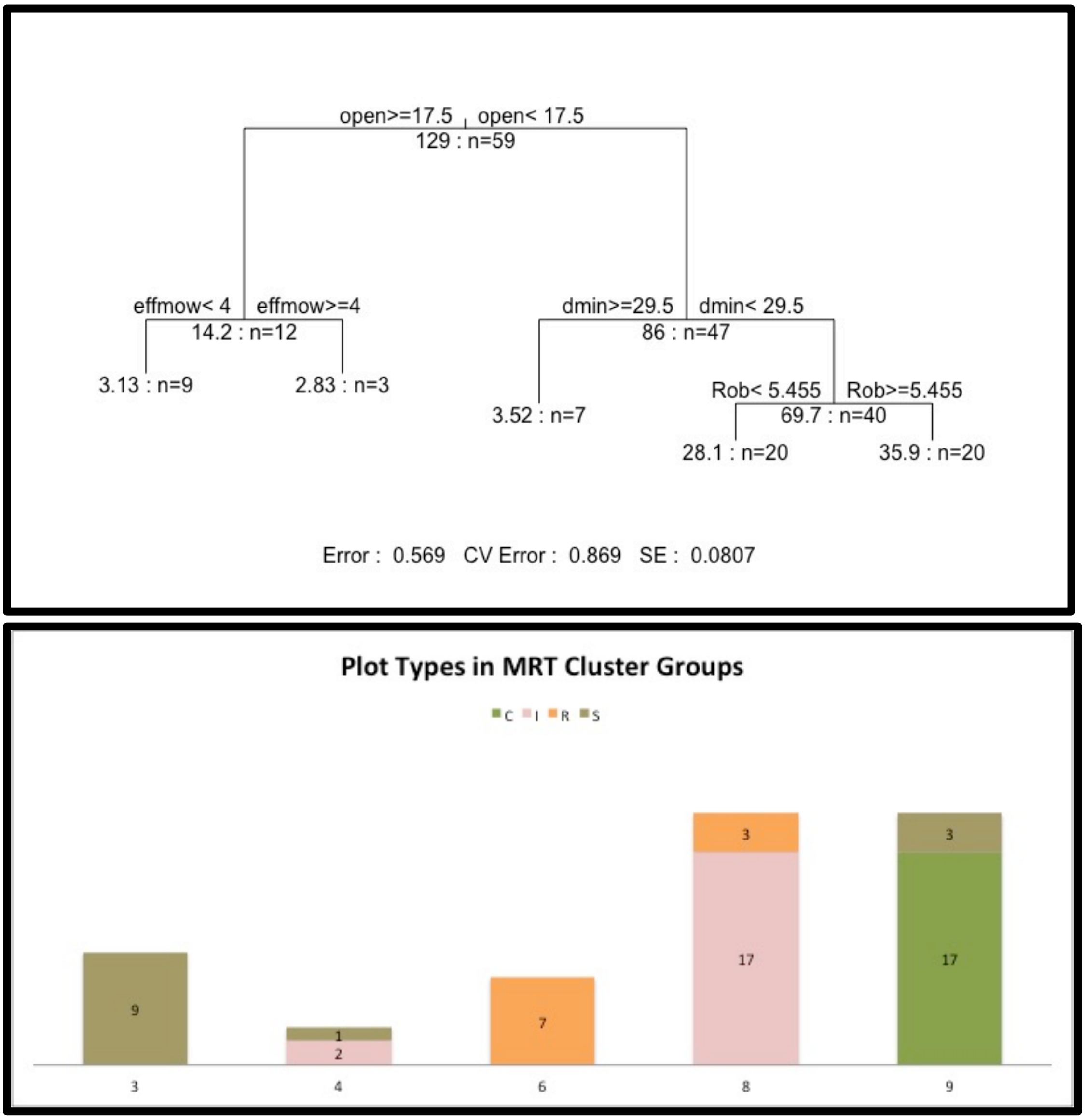

Fig 8: Top: Multivariate Regression Tree with numbers below cluster nodes denoting relative error of the node and numbers above denoting environmental values best predicting splits: open= percentage of uncovered topsoil, Rob=distance to nearest *Robinia* stand, dmin= minimum soil depth; CV Error= cross-validated error, SE= standard error; Bottom: Plot types as contained in MRT Cluster Groups

MRT groups 3 and 4 differentiate from MRT groups 6, 8 and 9 by a higher percentage of uncovered topsoil and consist mainly of S-plots. They are internally differentiated by their mowing regime, S-plots being unmowed by definition. MRT group six, consisting exclusively of R-plots, shows higher minimum soil depth than MRT groups 8 and 9. Their distance from the nearest *Robinia* stand differentiated the latter two groups. This distance is zero for group 8 (the group consists of R- and I-plots) and varies in MRT group 9, which consists mainly of C-plots with a controlled minimum distance from *Robinia* stands of 10 m. The three S-plots in this group were smaller forested areas, potentially closer to forest steppes.

Diversity

Consequences of invasion on elements of biological diversity are shown in Fig 9 below.

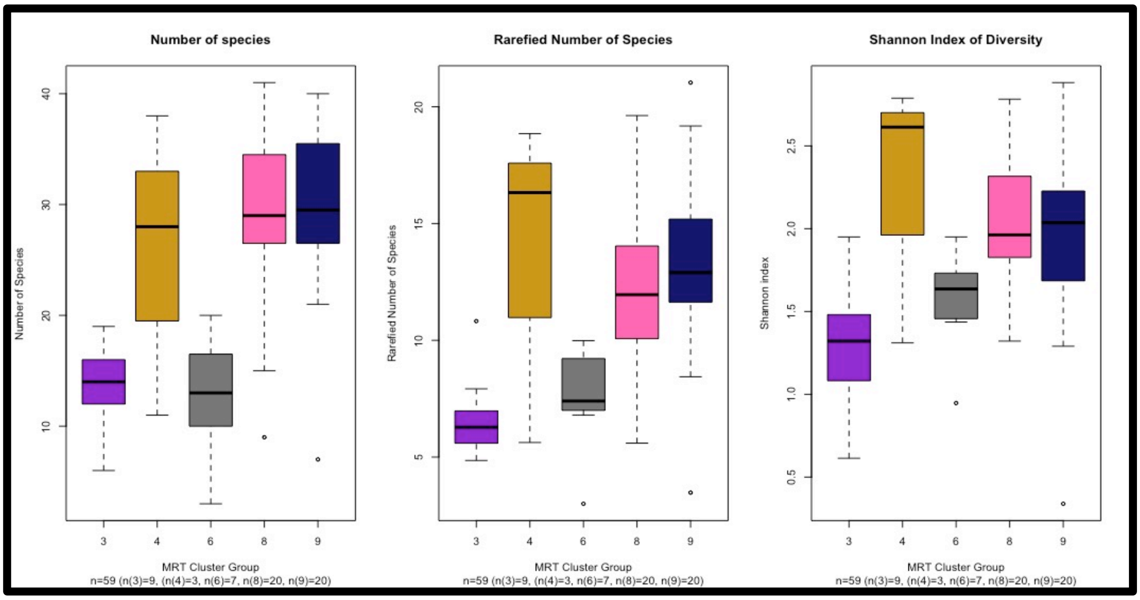

Fig 9: Number of species (left), rarefied number of species (middle), and Shannon index of diversity (right) for MRT cluster groups

Raw species count; rarefied species count and the Shannon index all follow a similar pattern with MRT groups 6 and 3 showing the lowest diversity. Predominantly invaded grassland with some *Robinia* stands (MRT group 8) and uninvaded grassland with some forest steppe stands (MRT group 9) show similar diversity.

Indicator Values

The indicator values presented in Fig 10 show some differences between the MRT site groups. The indicator values for salinity and heavy metal concentrations showed no differences between the sites.

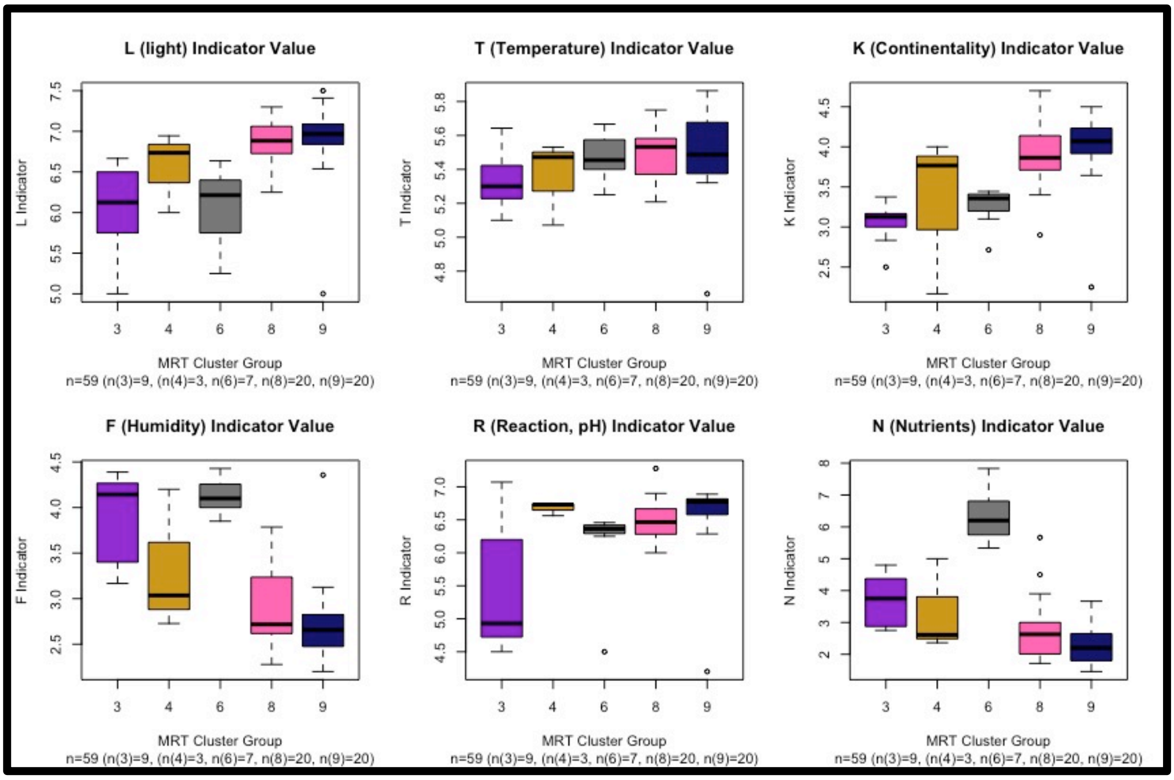

Fig 10: box whisker plots (bar represents median, whiskers represent 2 SD, points represent outliers) of grouped medians of indicator values for light (top left), temperature (top middle), continentality (top right), humidity (bottom left), pH (bottom middle), nutrients (bottom right),

Comparison of indicator values (Fig 10) showed some prominent changes under invasion. The light indicator shows similar values for all plots, with MRT groups 6 (*Robinia* forest) and 3 (thermophilous forest) being slightly lower than the others. The temperature indicator value shows similar values for all groups, the species being indicators of lower elevations and milder climate. The continentality indicator shows all groups between the oceanic and suboceanic range. MRT groups 8 and 9 show the lowest indicator values for humidity, with MRT group 8 (invaded grasslands with some

Robinia forests) showing a larger range. MRT groups 6 and 3 show higher values and MRT group four an intermediate humidity range. The reactivity indicator value for soil pH shows MRT group 3 (thermophilous forests) on somewhat acidic soils with the other groups with only weakly acid- or base-tolerant species. The nutrient indicator value shows MRT groups 3, 4, 8 and 9 to be in nutrient-poor environments, whereas group 6 represents stands in nutrient-rich environments. The largest overall differences could be found for the F and N indicator values, humidity positively influencing the availability of nutrients, especially nitrogen.

Discussion

With the data gathered and evaluated, some conclusions can be drawn to the research questions (i)-(iv). CVRE (see Fig 8 above) suggests a poor set of predictors to the MRT (Borcard *et al.* 2011). Additional research into environmental changes under *Robinia pseudacacia*-invasion is merited, ideally increasing the sample size while at the same time refining the research area to a specific subset of dry grasslands.

(i) What vegetation changes happen when *R.pseudacacia* invades dry grassland?

A high constancy and coverage of *Arrhenatherum elatius* - deemed a sign of degradation (Denk & Kraus 2008) - could be found in many sites, irrespective of their invasion status, suggesting and underlying trend towards dry grassland decline. This could in part be due to a change in management practices: grazing completely ceased in the region, management now being practiced by mowing.

Plots with low coverages around 10% of *Robinia pseudacacia*, especially in stands not bordering a fringe of a well-developed *Robinia* forest showed very similar species composition to uninvaded dry grasslands. With higher coverages (around 20% and above) a collateral invasion of plants of Molinio-Arrhenateretea, Artemisietea, Rhamno-Prunetea and other syntaxa occurs. Some of these syntaxa occur as natural degradational stages of dry grassland (e.g. Molinio-Arrhenatheretea, Mucina & Kolbek 1993a), their development possibly accelarated due to *R. pseudacacia*. Others (e.g. Artemisietea vulgaris, Galio-Urticetea) do not occur during dry grassland degradation, their species' establishment having only been made possible by invasion and possibly a change in the disturbance regime. This further underscores the need for early detection and monitoring of sites of high invasion risk. Initial changes in vegetation may only be in terms of species' abundance, undetectable in this study due to the differences in sampled grasslands.

The following assignment of cluster groups to syntaxa (Tab 2 below) shows the assignment of all invaded plots (except from forests invaded only in the herb layer) in a cluster group to the Robinietea (sensu Vítková & Kolbek 2010) and a tentative assignment to the original syntaxon preceding the invasion based on their non-invaded counterparts in the cluster group. Different invasion status created problems with proper assignment to syntaxonomic groups: assigning all groups to the syntaxa of the invading species reduces documentation of potentially endangered habitats and could skew the focus of future conservation efforts, assigning these plots to uninvaded syntaxa neglects the effect of the invasion and may be equally misleading if the invasion is not denoted in some way. A possible solution could be a notation of both the original vegetation and the invading species, e.g. "Fumano stipetum eriocaulis X Arrhenathero elatioris Robinietum".

Tab 2: Assignment of cluster groups to hierarchically lowest syntaxon possible, cluster groups are split into the invaded members of the group and the uninvaded, The **.** denotes all members of group were (un)invaded, ***** denotes a single relevé, group order matches Tab 1 above

Cluster group	uninvaded	invaded
6	Sorbo torminalis-Quercetum	only seedlings present
12	Melampyro-Fagetum	only seedlings present
3	.	Arrhenathero elatioris-Robinietum
1	*Melica transsilvanica-Festuca rupicola* (Festucion valesiacae)-Gesellschaft	Arrhenathero elatioris-Robinietum
4	Fumano-Stipetum eriocaulis	Arrhenathero elatioris-Robinietum
5	Carici humilis-Callunetum	Arrhenathero elatioris-Robinietum
9	Medicagini minimae-Festucetum valesiacae	Melico transsilvanicae-Robinietum
10	Onobrychido arenariae-Brachypodietum	Poo nemoralis-Robinietum-Cardaminopsietum arenariae
13	Bromion erecti	Poo nemoralis-Robinietum-Cardaminopsietum arenariae
2	Fumano stipetum eriocaulis	.
8*	Carici humilis-Callunetum	.
11*	Campanula bononiensis-Vicietum tenuifoliae	.
14*	Pruno-Ligustretum	.
7*	Erico-Pinetum sylvestris	Melico transsilvanicae-Robinietum

Invaded areas where the invasion was still ongoing (I-group) showed diversity similar to uninvaded areas. This can be explained by some of the species of the original habitat going locally extinct (e.g. *Alyssum alyssoides*) and being replaced by species due to the invasion while others (e.g. *Dianthus carthusianorum*) persist over a longer period of time. The *Robinia* forests on deeper soils showed a steep drop off in diversity (see Fig 9 above) with few species present compared to grassland sites. Thus longer lasting, uncontrolled *Robinia pseudacacia*-invasion reduces diversity by overgrowing many originally distinct and diverse types of vegetation and replacing them by a single vegetation type that retains little to none of the original diversity and distinguishing qualities (Hejda, Pyšek & Jarošík 2009).

(ii) What environmental changes occur during this process?

Primary change of an invasion by *Robinia pseudacacia*, which can occur as shrub or tree, is expected to cause an increase of shading, making it possible for more shade-tolerant species to outcompete species of the invaded dry grassland. This is shown in a slight reduction of the L indicator value for MRT group 8 and a stronger decrease in MRT group 6, both compared to MRT group 9. In turn an increase in shade is expected to cause an increase in humidity at least on a microclimatic level further opening the door for species better adapted to more humid microclimates. Here MRT group 6 shows the highest humidity indicator value, followed by MRT group 8, exhibiting the widest span suggesting a larger variety in available microclimates and MRT group 9 with the smallest span. Nitrogen fixation via root nodule symbiosis and remineralization via leaf litter (Lee, Nam & Kim 2011) are expected to increase soil nutrients, mainly nitrogen, which is better mobilized under more humid conditions. This is clearly expressed by the comparatively high nutrient indicator values of MRT group 6, yet only seen in the outliers of MRT group 8, MRT group 9 having the lowest nutrient indicator value. This suggests a lag in nutrient accumulation via nitrogen fixation during the early stages of invasions, possibly also lower humidity reducing nitrogen availability within the soil. In terms of conservation early invasions, with a lower nutrient indicator value indicate possibility to restore (or at least replace) an invaded habitat with proper management, whereas areas with higher *Robinia* coverage have already undergone a nutrient increase making their restoration doubtful.

(iii) What is the current impact/situation in invaded areas?

The scope of the invasion is quantitatively hard to discern, new remote sensing possibilities' (e.g. Somodi *et al.* 2012) detection is limited to flowering time, reducing the available amount of satellite images needed in this process. Additionally not all individuals may flower every year, heavy rainfalls and late frosts cutting flowering time short creating potentially biased maps. A comprehensive mapping of all *R. pseudacacia* populations within the region was beyond the scope of this study, however the areas surrounding sites were mapped showing clearly that multiple populations exist in the vicinity of most sites of conservation interest. Many of these sites being on privately owned land may further complicate their analysis beyond simple mapping. Furthermore, *Robinia pseudacacia* could be found growing in the undergrowth of native forests through seedling establishment (see Tab 1). These different occurrences are also seen in its native range (Boring & Swank 2016), where it is coupled with fast growth after disturbances closing the canopy outcompeting native trees (Essl, Milasowszky & Dirnböck 2011) and lastly succumbing to herbivore pressure and competition (Boring & Swank 2016). With this last stage missing in the study area *Robinia* can easily outcompete native species (Essl *et al.* 2011) in the long-term.

(iv) What consequences does this have for conservation/management?

Grassland diversity and species composition is largely upheld by *Robinia* management measures currently in place, however some areas are not managed regularly, increasing the risk of loss due to *R. pseudacacia* population growth - up to 10 m per year vegetatively (Seehofer 2016: pers. comm.), especially since there is currently no regular monitoring of these sites. At the same time most uninvaded areas showed signs of degradation unrelated to *Robinia*, which could in turn cause additional loss of protected habitats.

In the results of this study, seedlings were only found in locations with uncovered topsoil, making it likely that spread via seedling establishment is a lesser threat to grasslands. Uncovered topsoil can in part be a management goal for dry grasslands, increasing diversity through local disturbance, yet in can also increase the chances of *R. pseudacacia* establishment through seedlings. This creates a potential conflict with management goals. Historical and present agricultural use show ties to *Robinia* occurences, suggesting the main contributor to invasion is vegetative spread from anthropogenic plantings. A median soil depth below ca. 20 cm seems to inhibit or at least impede vegetative spread, creating zones potentially safer from invasion. This safety is relativated by seedling establishment still being possible and shallow soils in rocky terrain show a tendency towards openness due to disturbances. Distance to *Robinia* stands above five meters are in part explicable by the minimal distance chosen when sampling, however a buffer distance for vegetatively spreading inidividuals may be a goal for future conservation measures.

A detailed documentation of current management measures is not available for the region making it hard to evaluate their efficacy. Reinvasion and potential new invasions are not specifically monitored and forests, also sites of invasion are under no specific management.

Outlook

With the *Robinia* population still expanding in the region and regular management efforts focussed on a few sites of invasion and other invasives (e.g. *Ailanthus altissima*) spreading within the region (Denk & Kraus 2008) the need for a more stringent approach to regular monitoring and mapping of invasive taxa and their population dynamics is clear. Furthermore this monitoring has to go beyond the borders of the habitat in question, if not reducing the potential source populations than at least making them known. With seedling establishment seeming a rare event and the main threat to biodiversity being rapid vegetative (re)growth even partial eradication seems possible.

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Appendix

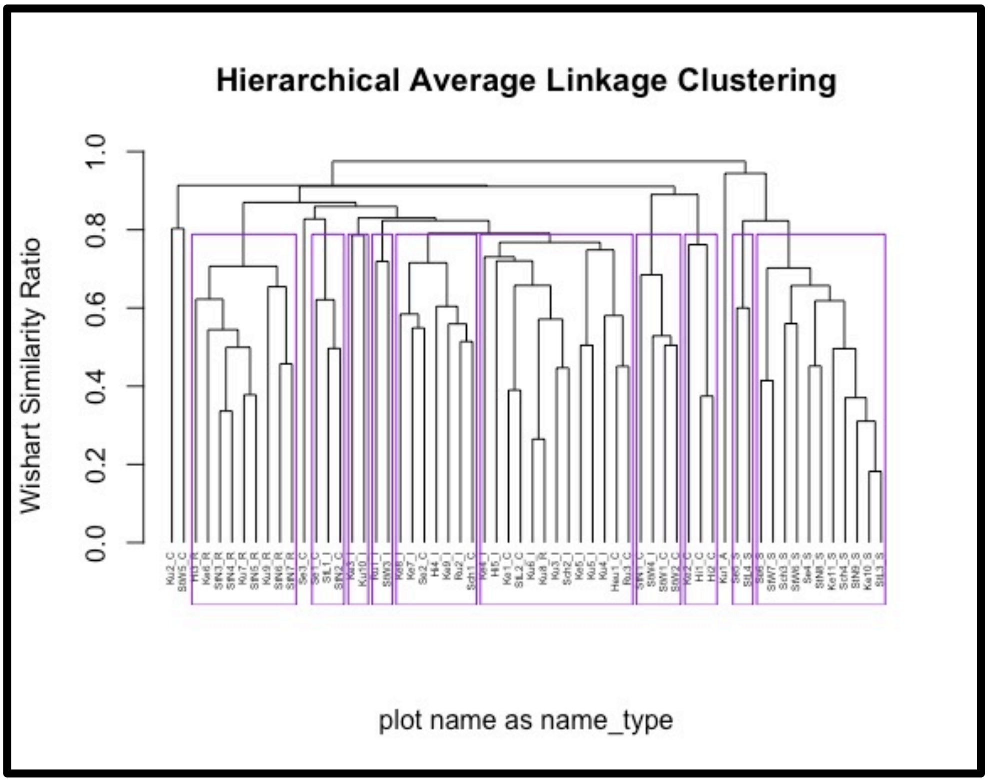
The following appendix represents additional information, please note additional information (App III relevé table and App IV R code) contained in the digital Appendix on CD-ROM.

App I: table of Plots with geographic coordinates and referenced areas from the previous life project, dd denotes areas previously uninvestigated

Area	code	type	coordinate N	coordinate E	referance area in Denk & Kraus (2008)
Heudürr	Heu1	C	48.41263889	15.50338889	dd
Hinterhaus	Hi1	C	48.35886111	15.40891667	6
Hinterhaus	Hi2	C	48.35875	15.40816667	6
Hinterhaus	Hi3	R	48.358359	15.407807	7
Hinterhaus	Hi4	I	48.35894444	15.40913889	6
Hinterhaus	Hi5	I	48.35880556	15.40783333	6
Kellerberg	Ke1	C	48.39447222	15.52616667	2
Kellerberg	Ke10	S	48.39713889	15.52755556	dd
Kellerberg	Ke11	S	48.39666667	15.52686111	dd
Kellerberg	Ke2	C	48.39497222	15.52630556	2
Kellerberg	Ke3	I	48.39555556	15.52619444	3
Kellerberg	Ke4	I	48.39516667	15.52641667	3
Kellerberg	Ke5	I	48.39583333	15.52727778	dd
Kellerberg	Ke6	R	48.39569444	15.52719444	dd
Kellerberg	Ke7	I	48.39555556	15.52591667	3
Kellerberg	Ke8	I	48.39558333	15.52605556	3
Kellerberg	Ke9	I	48.39541667	15.52747222	dd
Kuhberg	Ku1	A	48.39575	15.52402778	dd
Kuhberg	Ku10	I	48.39644444	15.52522222	dd
Kuhberg	Ku2	C	48.39522222	15.52391667	1

Kuhberg	Ku3	I	48.39611111	15.52483333	3
Kuhberg	Ku4	I	48.39616667	15.52522222	3
Kuhberg	Ku5	I	48.39625	15.52533333	3
Kuhberg	Ku6	I	48.39636111	15.52558333	3
Kuhberg	Ku7	R	48.39619444	15.52441667	1
Kuhberg	Ku8	R	48.39647222	15.52552778	dd
Kuhberg	Ku9	R	48.3975	15.52638889	dd
Ruinenberg	Ru1	I	48.39613889	15.523	29
Ruinenberg	Ru2	I	48.39677778	15.52275	29
Ruinenberg	Ru3	C	48.39633333	15.52291667	29
Schreiberberg	Sch1	C	48.4095	15.50908333	dd
Schreiberberg	Sch2	I	48.41055556	15.50972222	dd
Schreiberberg	Sch3	S	48.409975	15.50927	dd
Schreiberberg	Sch4	S	48.41111111	15.50697222	dd
Setzberg	Se1	C	48.36291667	15.39630556	18
Setzberg	Se2	C	48.36258333	15.39702778	18
Setzberg	Se3	C	48.36336111	15.3975	18
Setzberg	Se4	S	48.36436	15.396393	19
Setzberg	Se5	S	48.364855	15.396738	19
Setzberg	Se6	S	48.365581	15.398306	19
St. Michael Lanius	StL1	I	48.37041667	15.43033333	33
St. Michael Lanius	StL2	C	48.37013889	15.42591667	33
St. Michael Lanius	StL3	S	48.37216667	15.42841667	dd
St. Michael Lanius	StL4	S	48.37241667	15.42941667	dd
St. Michael Nord	StN1	C	48.37505556	15.43652778	11
St. Michael Nord	StN2	C	48.37563889	15.43594444	11

St. Michael Nord	StN3	R	48.37555556	15.43658333	dd
St. Michael Nord	StN4	R	48.37552778	15.43669444	dd
St. Michael Nord	StN5	R	48.37561111	15.43733333	dd
St. Michael Nord	StN6	R	48.37377778	15.43494444	dd
St. Michael Nord	StN7	R	48.37369444	15.43516667	dd
St. Michael Nord	StN8	S	48.376	15.43544444	dd
St. Michael Nord	StN9	S	48.37563889	15.43483333	dd
St. Michael West	StW1	C	48.3715	15.4365	8
St. Michael West	StW2	C	48.37161111	15.43766667	8; 10
St. Michael West	StW3	I	48.37122222	15.43736111	8
St. Michael West	StW4	I	48.37208333	15.43794444	8
St. Michael West	StW5	C	48.37208333	15.43266667	9
St. Michael West	StW6	S	48.37177778	15.4325	8
St. Michael West	StW7	S	48.37255556	15.43405556	dd



App II: Dendrogram of relevé Clustering, boxes denote groups as given ein Constancy Table (see Tab 1), single relevés with no box are cluster groups made up of only one relevé