Re-establishment of Native Riparian Plant Species After Reintroduction of River Dynamics Along the River Traisen

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Riparian ecosystems are threatened by habitat loss worldwide. Many river restoration projects have been launched to mitigate the negative impact of river regulation. The colonisation of, and succession dynamics along, river banks are important elements of successful ecological river restoration measures. The re-establishment of riparian plant species was observed during the vegetation period of 2016, after natural river dynamics of the river Traisen in Lower Austria had been re-established in 2014 and 2013 within the LIFE+ Traisen project, co-funded by the EU. After the reintroduction of river dynamics, two protected habitat types according to the EU FFH directive (habitat type 3270 and habitat type 91E0) established themselves. A total of 119 vascular plant species from 36 plant families were recorded; among them seven species of the genus *Salix*. The vitality of native *Salix* species was influenced by damage caused by the broad-shouldered leaf beetle *Chrysomela populi* and the browsing of Sika deer. Annual flooding events in June and August were a major driver for succession dynamics. The future development of the recorded invasive species can pose a risk to native riparian plant species, and the development of the riparian vegetation therefore requires further monitoring to ensure a sustained positive outcome of the LIFE+ Traisen river restoration project.

Lapin K., Hochauer A., Schindler A. & Bernhardt K.-B., 2017: Wiederansiedelung einheimischer Uferpflanzenarten entlang des Flusses Traisen nach Wiederherstellung der Flussdynamik.
Vom globalen Habitatsverlust sind auch Auwaldökosysteme betroffen. Zahlreiche Flussrenaturierungen wurden durchgeführt, um die negativen ökologischen Auswirkungen der Flussregulierungen zu kompensieren. Im Jahr 2016 wurde die Etablierung heimischer Pflanzenarten an den Ufern des neu angelegten Mündungsabschnitts der Traisen in Niederösterreich beobachtet. Die Flussdynamik wurde in den untersuchten Abschnitten 2014 und 2013 im Rahmen des, von der EU teilfinanzierten, LIFE+ Traisen Projektes wiederhergestellt. Zwei FFH-Lebensräume (Lebensraumtypen 3270 „Flüsse mit Schlammbänken mit Vegetation des *Chenopodion rubri* p.p. und des *Bidention* p.p.“ und der prioritäre Lebensraum FFH 91E0) haben sich etabliert. Es wurden 119 Gefäßpflanzenarten aus 36 Pflanzenfamilien beobachtet. Sieben Arten der Gattung *Salix* wurden aufgenommen. Die Vitalität der *Salix* Arten wird durch den Pappelblattkäfer *Chrysomela populi* und das Sika-Wild stark beeinflusst. Die zukünftigen Vegetationsentwicklungen können durch die beobachteten invasiven Neophyten beeinflusst werden. Ein Monitoring ist für die Sicherung und positive Entwicklung der Ziele des LIFE+ Traisen Projekts von hoher Priorität.

Keywords: Donau-Auen, river Traisen, floodplain, genus *Salix*, river mud banks, Lower Austria.

Introduction

Freshwater systems are threatened by human activity on a global and local scale (Dudgeon et al. 2006, Vörösmarty et al. 2010). River regulation and modifications to river habitats resulting from the construction of flood-prevention dams are drivers for riparian habitat loss worldwide (Poff et al. 2007). The negative impact of river regulation measures on global biodiversity, in particular, is widely recognised (Nilsson & Berggren 2000, Davies 2010). Riparian habitats are especially threatened by river regulation because their ecology depends on natural seasonal fluctuations in the dynamics of the respective river: regular disturbance creates species-rich riparian ecosystems. The riparian zone includes all habitats in the area between the stream channel and the high water marks, including the floodplains that are affected by flooding events (Niman et al. 1993). Changes in the water flow regime of regulated rivers affect species from almost all taxonomic groups adapted to riparian ecosystems (Lynn et al. 1998, Osmundson et al. 2002, Uowolo et al. 2005, Paetzold et al. 2008).

For over two decades, mitigation of biodiversity loss has been on the agenda of international conventions (United Nations 1992, Ramsar Convention Secretariat 2013) and has been gaining importance for national and regional legislation (Palmer et al. 2005). Within the European Union, the Water Framework Directive (Kallis & Butler 2001), the Habitats Directive (Council Directive (EU) 92/43/EEC) and the Birds Directive (Council Directive (EU) 07/147/EC) support the protection of riparian ecosystems and their species and habitats directly, e.g. by legitimising the protection status of riparian plant species, or indirectly, e.g. by safeguarding sustainable freshwater usage. Many ecological river restoration projects aiming to improve the natural conditions of rivers have been undertaken (Buijse et al. 2002, Bernhardt et al. 2005, Nakamura et al. 2006, Kondolf et al. 2007, Palmer et al. 2007). However, the positive impact of these projects at the European regional level is scarcely or not sufficiently documented (Buijse et al. 2002). The Austrian freshwater resources are subject to a large number of ecological stress factors caused by various economic sectors (Muhar et al. 2000). Less than 39% of all Austrian rivers provide good ecological conditions including a high riparian habitat quality. To counteract the negative developments in the past, an integrative management programme aiming to improve riparian ecosystems (Bundesministerium für Land- und Forstwirtschaft 2014) was developed.

While the hydrological and limnological changes resulting from river restoration measures are widely understood, there is yet scant experience with other ecological aspects of such projects, such as the re-establishment of native plant species in terrestrial riparian habitats. The key biological processes that shape riparian ecosystems along river channels are colonisation and succession (Hughes et al. 2005, Beechie et al. 2010). Following the colonisation process, during which plant species settle on vegetation-free soil surfaces, the process of succession causes a development towards floodplain forests. Physical disturbances like annual flooding events create loops between these two biological processes (Beechie et al. 2010). Species compositions and habitat structures also differ depending on geographical location and regional ecological conditions (Hupp & Osterkamp 1996). The inclusion of biological processes in river restoration management and planning efforts is considered to support the self-regulation and self-regeneration of riparian habitats (Muhar et al. 1995).

This study documents the results of natural succession dynamics regarding floodplain vegetation. Its goal is to assess the establishment of native riparian plant species following restoration of the outlet of the river Traisen in Lower Austria. We assumed that (1) the reintroduction of river dynamics promotes the establishment of native riparian plant species, that (2) typical plant communities of floodplain habitats become established along the newly created river course, that (3) invasive non-native plant species occur in the succession process of the riparian vegetation, and that (4) the indicator species of the genus *Salix* successfully re-establish themselves naturally.

Material and Methods

Study Area

The outlet of the river Traisen is situated in the northern part of the Danube floodplains in the municipality of Zwentendorf an der Donau. The flow rate of the river Traisen exhibits peaks of 75 to 90 m³/s in spring and early summer, and has an average MQ of 4 m³/s. The study area is in the continental biogeographical region of Lower Austria and ranges from 48.3689741° N and 15.8032604° E to 48.3726408° N and 15.8257183° E at an average altitude of 170 m above sea level. The nearby municipality of Tulln reaches an annual mean temperature of 9.6° C and average annual rainfall of 616 mm (Bernhardt et al. 2010). The study area is part of the Natura 2000 area "Tullnerfelder Donau-Auen", which has a total size of 17.990 ha. Human activity heavily altered the dynamics of this floodplain region in the past: In 1973/74 the outlet of the Traisen was regulated and relocated – a modification of the riverine landscape that caused damage to the connected riparian habitats and resulted in habitat loss and extinction of riparian species. The current economic use of the area is dominated by sylvicultural use of the poplar plantations

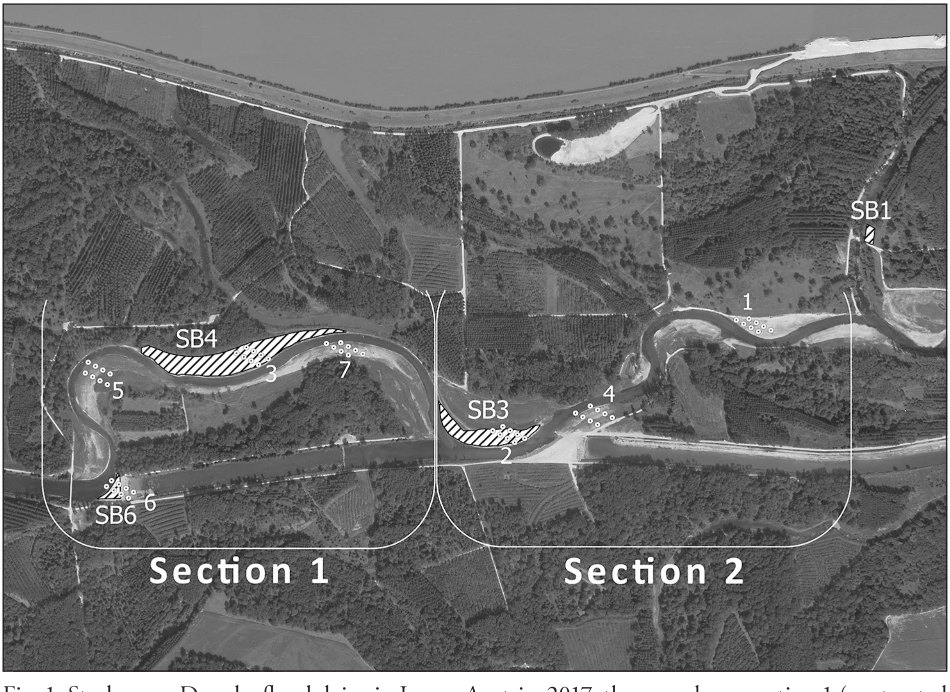

Fig. 1: Study area. Danube floodplains in Lower Austria, 2017; the map shows section 1 (contracted 2013) and section 2 (contracted in 2014) of the newly created river course. The vitality and occurrence of the genus *Salix* was recorded along 25 transects in locations no. 1 to no.7 . The vegetation dynamics along the river bank were assessed in the newly created transition zone SB3, SB4, SB6 and SB1 (along a feeder stream in near distance). – Abb. 1: Untersuchungsgebiet. Donauauen in Niederösterreich, 2017; Die Karte zeigt die Bauabschnitte 1 und 2 (2013 und 2014). Die Vitalität und das Vorkommen der *Salix*-Arten wurde an den Standorten Nr. 1 bis 7 aufgenommen. Die Vegetationsentwicklung entlang der Uferlinie wurde in SB3, SB4, SB6 und SB1 (Standort an einem Zubringer der Traisen) erfasst.

as well as hunting licenses for the large populations of Sika deer (Zentralstelle Österreichischer Landesjagdverband 2003).

Life+ Traisen Project

From 2009 to 2017 a large-scale river restoration project was conducted in the study area. The aim of this restoration of the outlet section of the Traisen was to construct a meandering river course and re-establish the natural river dynamics. In contrast to many European river restoration projects, the project did not follow the historic river course. Instead, a new river course based on landscape modelling with a total length of 12 km was constructed. Besides the river course, floodplain lakes with a total size of 12.5 ha were established to assure connectivity with the floodplain area of the river Danube. Within the LIFE+ Traisen project, the 60-80 m wide HQ 1 river bed, which corresponds to the bankfull discharge profile, was separated from the surrounding lower ground by ridges (about 1.5 m higher than the mean water level) to ensure sufficient flow dynamics and prevent excessive sedimentation (Eberstaller et al. 2016). This formation of the river bed only represents an initial state, which will eventually be further developed and changed over the long term by the natural river dynamics and their morphological effects. As the original terrain lay several metres above the mean water line, the ground along the inner banks next to the HQ 1 bed was lowered to form a depression over a width of around 100-300 m. This created an area of around 60 ha in size that is connected to the river Traisen and represents a typical floodplain containing standing water bodies, areas with reed growth and a white willow forest (priority FFH habitat type 91E0).

The objectives of the LIFE+ Traisen project are (1) accessibility for fish over the entire river course, (2) increase in typical floodplain and river habitat areas, (3) establishment of variegated structures in the transition zone between water and land along the banks of the new Traisen, and (4) creation of a floodplain with regularly flooded areas along the new river course (Verbund 2017). One of the major goals is the establishment of 82 ha of riparian softwood forest of habitat type 91E0 according to the Habitats Directive.

Genus *Salix*

The genus *Salix* includes species spread across the northern hemisphere. The seeds are adapted to wind dispersal over short distances of 30 to 70 m, with waterways being responsible for their wider dispersal (Venturas et al. 2013). *Salix* species are often pioneer plants and are well-adapted to abiotic disturbances like flood events (Graiss et al. 2008); most of them are also capable of vegetative reproduction (Neumann 1981). At altitudes below 1000 m, willows establish themselves along river banks that are regularly flooded. They have the advantage that their flexible wood and excellent regenerative capacity allow them to withstand the mechanical stresses of flowing water (Mleczek et al. 2010, Wu et al. 2015). The following species of the genus *Salix* are considered indicator species for evaluation of the re-establishment success and vitality of native plant species in the context of Traisen river restoration: *Salix alba, Salix* x *rubens, Salix fragilis, Salix triandra, Salix cinerea, Salix purpurea* and *Salix eleagnos*.

Vegetation Assessment

The development of the riparian vegetation was surveyed five times during the vegetation period from May to August of 2016. A total of 105 plots of 1 m² each were used to evaluate section 1 (constructed in 2013) and section 2 (constructed in 2014). Initially, 25 transects (78 plots of 1 m^2) were marked out to record indicator species and assess the development of the vegetation over the entire length of the newly created river course. An additional 27 plots of 1 m^2 were subsequently marked out in the direct transition zone by the waterline (SB3, SB4, SB6, SB1; see Fig. 1) to assess the vegetation dynamics along the river bank under the direct influence of seasonal water level dynamics. In one of the seven locations, willow cuttings of the species *Salix alba* and *Salix eleagnos* were planted. The individuals were marked and assessed separately from the non-planted individuals of the same species. An index adapted from Braun-Blanquet and Londo (Moore 1962, Londo 1976) was used to evaluate the total vegetation cover and the abundance of each species. Fischer et al. (2008) was used for the nomenclature of the vascular plants, and the willows were identified according to Hörandl et al. (2002). Soil type, sedimentation, inclination and humidity of each plot were assessed; the existing gravel fraction was found to consist of grain sizes between 2 mm und 63 mm (Rinklebe et al. 2007). The occurrence of adult trees of the genus *Salix* at distances of up to 200 m from the river course, as well as in the river course itself, was recorded. The occurrence of willows in the river course was classified into three densities: dense stands (> 10 individuals/m^2), intermediate occurrence (2-9 individuals/m^2), and dispersed occurrence (0-1 individuals/m^2). The soil properties (structure and humidity) were determined using the finger test (Blum 2007). In each location, the average grain size in 20 cm depth was assessed within the depression, the HQ1 bed and next to the waterline. We differentiated between mud (clay or silt, < 0.002 mm), sand (0.063 to 2 mm) and gravel (2 to 63 mm).

Data Analysis

The transformed cover ratios were subsequently used for calculations with the statistics programme SPSS Statistics 24. Distribution was tested for normality using a Shapiro-Wilkes Test, and equality of variances was examined with a Levene Test. Finally, the mean values were compared using a multifactorial ANOVA (analysis of variance) and the significance of the possible differences was calculated.

Vitality Assessment Key

The vitality of species of the genus *Salix* was assessed (Tab. 1). A vitality key covering all the requirements of the assessment of floodplain vegetation in restoration projects was developed (Erler et al. 2017). The key indicates whether a species exists within its optimal ecological range or on the fringe. The following categories were used in accordance with Murmann-Kristen (1991): very weak, randomly germinated, not reproducing; weakened, stunted; weakened, stunted by visible damage; normal; strong. The vitality key incorporates the visible reproduction scale (Frey & Lösch 2004), and the vitality levels were adapted to the scale to include growth, leaf colour and physical damage (Erler et al. 2017). A further defined criterion of vitality was leaf loss. The criterion of physical damage through external influences was expanded and adapted according to the requirements and goals of the study and includes feeding damage from insects (e.g. leaf beetle feeding marks on leaves), bark chewed and shoots browsed by deer, and damage caused by beavers and hares. Observed damaging fungi, bacteria and insects were determined according to Hörandl et al. (2002). The vitality assessments were conducted in early June and late August 2016.

Tab. 1: Vitality key for the assessment of the species of the genus *Salix*, covering all the requirements of the assessment of floodplain vegetation in restoration projects, adapted from FREY & LÖSCH 2004: 41ff. – Tab. 1: Vitalitätsschlüssel für die Bewertung der Arten der Gattung *Salix*, der alle Anforderungen für die Bewertung der Auvegetation in Restaurierungsprojekten abdeckt, adaptiert nach FREY & LÖSCH 2004: 41ff.

Level	Description
Vitality Level **1**	**Very good:** lush green leaf colour, slightly lower leaf mass (<10 % leaf loss), good shoot and longitudinal growth, no physical damage
Vitality Level **2**	**Good**: lush green leaf colour, slightly lower leaf mass (<25 % leaf loss), good shoot and longitudinal growth, light physical damage (<25 %)
Vitality Level **3**	**Poor:** yellow-green leaf colour, low leaf mass (<60 % leaf loss), weak shoot or longitudinal growth, significant physical damage (<60 %)
Vitality Level **4**	**Very poor:** Plant dead or dying; yellow-green to brown leaf colour, very low leaf mass (up to 100 % leaf loss), no shoot or longitudinal growth, massive physical damage (up to 100 %)

Results

Re-established Endangered Habitat Types

After the reintroduction of river dynamics, two protected habitat types according to the EU Habitats directive established themselves. Firstly, a total of 2.8 ha of the habitat type 3270 (Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation) appeared on the mud banks along the newly created river course in sections 1 and 2. The areas forming this habitat were influenced by the annual flooding events in May and June, and the soil consisted of fine sediments only. Secondly, plant species of habitat type 91E0 established themselves in the newly created river course in sections 1 and 2. The plant communities of this habitat type exist immediately above the mean water line, and the tree species occurring in them, e.g. *Salix purpurea* or *Salix eleagnos*, tolerate annual flooding. The soil structure of this area met the characteristics of habitat type 91E0, with the raw soils visible and consisting of sand and gravel fractions. In 47 plots, the proportion of gravel in the top soil layer was 70 to 80%, while sediment was dominant in 59 plots.

Vegetation Development

A total of 119 vascular plant species from 36 plant families were found; the most abundant species were those from the families *Compositae* (19 species), *Poaceae* (18 species) and *Salicaceae* (12 species). The most abundant plant species was *Agrostis stolonifera*, with an average occurrence of 10.3% of the average plant cover. Species occurrence and abundance changed between the recordings. The most significant changes in species composition occurred between the 1st (May) and 2nd (June) recordings, during a period of large water level fluctuations. The species *Populus* x *canadensis* showed the highest increase in average cover, from 3.8% during the 1st recording to 5.7% during the 2nd recording, while the indicator species *Salix alba* decreased from 4.0% during the 1st recording to 2.8% during the 2nd recording. The invasive species *Solidago gigantea* decreased from 1.8% to 0.9%, and the average cover of *Juncus articulatus* showed no significant changes (Annex).

In the vegetation survey of the protected habitat type 3270 (Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation), conducted during the vegetation period of 2016, 97 plant species from 32 families were observed in the 27 plots of the habitat type, with the most abundant families being *Poaceae* (19 species) and *Asteraceae* (15 species). Two plant communities from the alliance *Bidention* p.p., whose members grow on ruderal sites, were found (Annex). The number of plant species was positively correlated with the size of the mud bank, and the total plant cover increased constantly over the five recording periods. The most abundant species were *Agrostis stolonifera*, *Echinochloa crus-galli, Populus xcanadensis, Persicaria dubia, Salix alba, Erigeron annuus* and *Solidago gigantea*. In all 27 plots, the plant cover reached between 75 and 100%, and the average growth height was 77.5 cm. A total of 63 species were hemicryptophytes, 19 were therophytes, 8 were phanerophytes, 7 were geophytes, and 1 species was a chamaephyte (*Lycopus europaeus)*. The following amphiphytes were recorded: *Alisma plantago-aquatica, Phragmites australis, Veronica anagallis-aquatica* and *Veronica beccabunga*. The most abundant plant classes were *Bidentetea tripartiti* R. Tx. et al. in R. Tx. 1950, *Polygono lapathifolii-Bidentetum* Klika 1935, *Bidenti-Polygonetum hydropiperis* Lohmeyer in R. Tx. 1950 nom. inv., and *Chenopodion glauci* Hejný 1974. Habitat type 3270 is on the Red List of endangered habitat types in Austria. It is referred to as "Schlammufer der Fließgewässer mit Pioniervegetation" ("Muddy banks of waterways with pioneer vegetation"), but nevertheless corresponds to the Natura 2000 habitat type 3270. 14 species from the national Red List of endangered species were observed.

Abundance of *Salix* Species

Seven species of the indicator genus *Salix* were observed in total (Fig. 2). The most abundant indicator species was *Salix alba*, which was recorded in all 7 locations. The average cover of *S. alba* in each plot differed, however. The average cover of planted cuttings of *S. alba* and *S. eleagnos* decreased from 3.0% during the 1st recording to 0.1% during the 2nd recording, and their total numbers decreased accordingly. The results of the mapping of

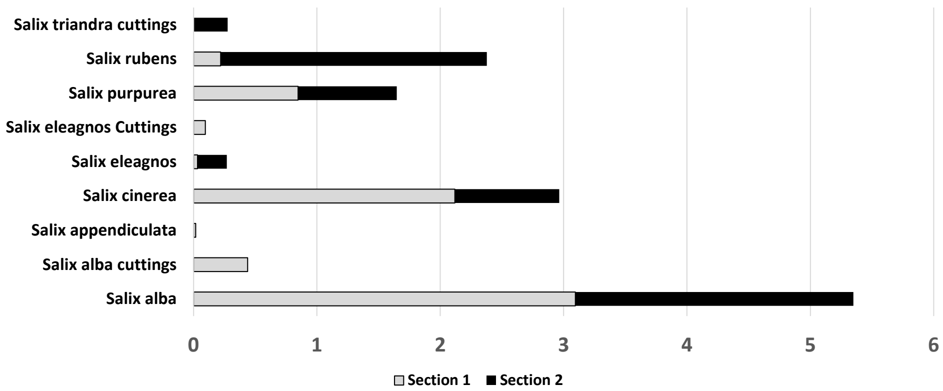

Fig. 2: Average cover of species of the genus *Salix* in sections 1 and 2 along 25 transects (78 plots of 1 m²). The species *Salix alba* shows the highest cover; *Salix cinerea* the second highest average cover. – Abb. 2: Durchschnittliche Deckung der Arten der Gattung *Salix* in den Abschnitten 1 und 2 auf 25 Transekten (78 Parzellen mit 1 m²). Die Art *Salix alba* weist die höchste Deckung auf; *Salix cinerea* die zweithöchste durchschnittliche Deckung.

Salix species in the study area showed that several of them had established themselves on 21.12 ha of the study area. Willow specimens were found in dispersed occurrence on 68% of the area, in intermediate occurrence on 18% of the area, and in dense stands on 14% of the area. At distances of up to 200 metres from the river course, a large number of adult trees of the species *Salix alba*, *Salix rubens*, *Salix eleagnos* and *Salix fragilis* were mapped (Hochauer 2017).

Vitality of the genus *Salix*

The vitality of the indicator species from the genus *Salix* was influenced by the browsing damage caused by Sika deer. Furthermore, the broad-shouldered leaf beetle *Chrysomela populi* (*Chrysomelidae*) also caused mechanical damage to the leaves of *Salix* specimens. The average vitality of *Salix alba* during the 1st recording was 2.02 in section 1 and 1.75 in section 2 (Fig. 3, 4). During the 2nd recording, it was 2.04 over the entire study area – according to the vitality scale, this corresponds to good development with lush green leaf colour, slightly low leaf mass (<25% leaf loss), weaker shoot and linear growth, and light physical damage (<25%). The average vitality of the second most abundant species, *Salix cinerea*, in section 1 during the 1st recording was 2.2, with the majority of damage caused by deer browsing and only about half as much damage caused by leaf beetles. During the first recording, the average vitality of planted cuttings of the genus *Salix* was assessed

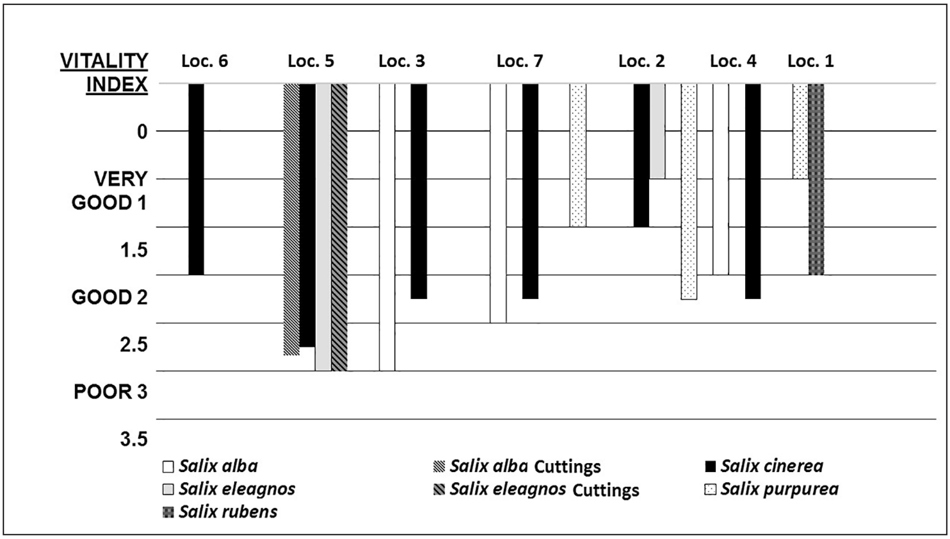

Fig. 3: Assessment of the vitality of the species *Salix alba*, planted *Salix alba* cuttings, *Salix cinerea*, *Salix eleagnos*, planted *Salix eleagnos* cuttings, *Salix purpurea* and *Salix rubens*. The vitality assessments were conducted in early June and late August 2016. The average cover of species of the genus *Salix* was higher in Section 1 (loc.6 (n=8), loc.5 (n=9), loc.3 (n=12), loc.7 (n=9)) than in Section 2 (loc.1 (n=15), loc.2 (n=14), loc.4 (n=11)), as was the total cover of non-native species. – Abb. 3: Beurteilung der Vitalität der Art *Salix alba*, gepflanzter *Salix alba* Stecklinge, *Salix cinerea*, *Salix eleagnos*, gepflanzter *Salix eleagnos* Stecklinge, *Salix purpurea* und *Salix rubens*. Die Vitalitätsbeurteilungen wurden Anfang Juni und Ende August 2016 durchgeführt. Die durchschnittliche Deckung der Arten der Gattung *Salix* war in Abschnitt 1 (loc.6 (n=8), loc.5 (n=9), loc.3 (n=12), loc.7 (n=9)) höher als in Abschnitt 2 (loc.1 (n=15), loc.2 (n=14), loc.4 (n= 11)), ebenso wie die durchschnittliche Gesamtbedeckung nicht heimischer Arten.

as 2.76, which corresponds to poor development: yellow-green leaf colour, low leaf mass (<60% leaf loss), weak shoot and linear growth, dead shoot ends and stunted growth, and high physical damage (<60%). 100% of the recorded cuttings showed browsing damage, and 33% showed damage caused by leaf beetles.

The average vitality of *Salix* specimens in section 2 was better at 1.3, a value indicating a level of development between good and very good (Fig. 3). In total (n=78 plots), the soil in 37 plots consisted of a high gravel content, in 32 plots of mud content and in 9 plots largely of sand. The cover of *Salix* specimens (p=0.88) and their vitality (p=0.910) did not differ between the soil properties. On substrates with a gravel content of 40 to 60%, *Salix purpurea* and *Salix cinerea* exhibited vitality levels between 1 and 2, while the vitality of *Salix alba* occasionally went down to level 2.5 in the mid-moist to dry areas – the lowest value for areas with this gravel content. On substrates with 70 to 80% gravel, the planted cuttings and *Salix pupurea* exhibited the lowest vitality (level 3). The best vitality levels (1 to 2.25) were found in areas with a high gravel content (90 to 100%). The vitality of willows on sandy soil lay between 1 and 2, with the best values achieved on soil with a sand content of 70 to 80%. On substrates with high mud content, *Salix* specimens also exhibited a vitality level of 1 to 2.

Non-native Plant Species

A total of 11 non-native plant species established themselves in the study area. The average occurrence of *Solidago gigantea* in the older section 2, constructed in 2013, was not significantly higher (1.6%) than that in the younger section 1 constructed in 2014 (1.6%). The most abundant non-native species, *Erigeron canadensis*, was significantly more dominant

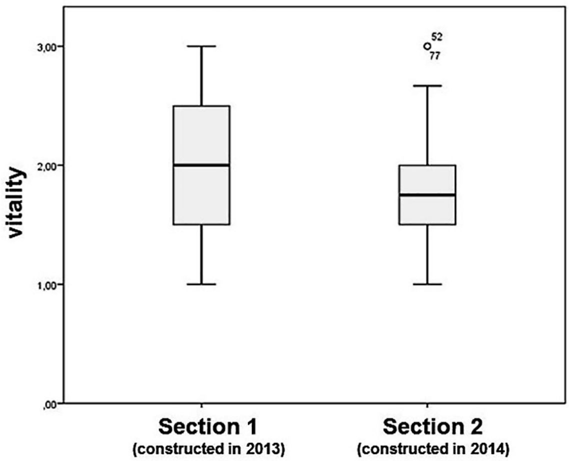

Fig. 4: The mean vitality level of *Salix* species in Section 1 (constructed 2013) differs significantly to Section 2 (constructed 2014) (multifactorial ANOVA, F0.05; 2, 137; = 10.43, p= 0.002). *Salix* species in Section 2 are performing better (vitality index: 1.5–2.0) than in Section 1 (vitality index: 1.5-2.5). – Abb. 4: Die mittlere Vitalität von *Salix* Arten im Abschnitt 1 (erbaut 2013) unterscheidet sich signifikant von Abschnitt 2 (erbaut 2014) (multifaktorielle ANOVA, F0.05; 2, 137; = 10.43, p = 0.002). *Salix*-Arten in Abschnitt 2 schneiden besser ab (Vitalitätsindex: 1,5-2,0) als in Abschnitt 1 (Vitalitätsindex: 1,5-2,5).

in section 2 (12.0% average cover) than in section 1 (2.8% average cover). The following non-native species were observed in the 27 plots of habitat type 3270: *Acer negundo, Erigeron annuus, Erigeron canadensis, Matricaria discoidea, Oxalis corniculata, Oxalis stricta, Panicum capillare, Solidago gigantea* and *Veronica persica*. The species *Erigeron annuus* (15 plots) and *Solidago gigantea* (14 plots) were the most frequent non-native species, and exhibited their greatest abundance in August.

Discussion

Floodplain habitats and species are endangered at the European, national, and regional level. The loss of riparian habitats owing to non-sustainable use of natural resources began during the last century and continues until today. Fortunately, the negative consequences of river regulations are by now well understood, and many efforts have been launched and tools developed to mitigate adverse impacts or even re-establish natural river dynamics. In this case-study of the river Traisen, we could document a large number of positive impacts in the context of a large-scale river restoration project while simultaneously highlighting challenges in regard to the re-establishment of native plant species.

The reintroduced dynamics of the Traisen affect vegetation development in the newly created river course. During the period between the first site inspection in May 2016 and the last vegetation recording in late August 2016, five flooding events occurred. One week after the onset of two of these flooding events in June and July, respectively, the water had receded and the second (early July) and fourth (early August) recordings could be performed. Following the flooding events, the vegetation in some parts of the mud banks was covered with dead plant matter, wood and mud; the affected areas were between one and several square metres in size. The sampled vegetation in all plots exhibited differences between the individual recordings. These differences were caused not only by the increase in vegetation cover and density within a seasonal vegetative and generative phenological development, but were also a result of the river dynamics, i.e. the flooding events and deposition of sediment. We observed that various plant species reacted differently to this disturbance, which thus resulted in a high diversity of plots with different plant species composition and vegetation cover. The following species were no longer found in some of the surveyed plots after flooding events: *Erigeron annuus, Phalaris arundinacea, Plantago lanceolata, Scrophularia nodosa, Stellaria* spec. and *Verbascum* spec. Conversely, the following species newly appeared in certain plots after flooding events: *Carex* spec., *Calamagrostis epigejos, Echinochloa crus-galli, Erigeron annuus, Erigeron canadensis, Eupatorium cannabium, Glechoma hederacea, Hieracium* spec., *Poa annua, Persicaria dubia, Rorippa palustris* and *Verbena officinalis*. We observed that species abundance and development are heavily influenced by the river dynamics, which create a high density of microhabitats in a relatively small area. While the flooding events decreased the numbers of some plant species in the mud bank habitat (habitat type 3270), other species reacted with an increase in individuals and greater coverage. The vegetation was composed not only of annual and perennial herbaceous plants, but also included some species from the alluvial forest, which may be an indication of a further successional stage (Selleck 1960, Frey & Lösch 2004).

The plant cover in the surveyed areas increased over the entire vegetation period, and there were no peculiarities to be found in the cover following the flooding events. A study by

Bernhardt (1993) along the river Ems found the plant cover to be constant or to exhibit strong fluctuations depending on the location along the river bank. Other surveys on the river Hunte (Bernhardt 1993) found greater stability. According to a meta-analysis on the influence of flooding on river vegetation, the survivability of seedlings as well as adult plants decreases, the longer they are flooded (Garssen et al. 2015). The recording after the flooding event in late July showed changes in the species composition: Out of the 27 surveyed plots, the number of observed species remained the same on 5 plots, while 12 plots held more species after the flooding and 10 plots held fewer species than before.

The occurrence of Natura 2000 habitat type 3270 is a major indicator for the positive effects of the successfully reintroduced Traisen river dynamics. This habitat type is critically endangered in Europe due to its dispersal and temporal occurrence along annually flooded river banks, which have become very rare as a result of the high regulation rate among European rivers (Nilsson et al. 2005, Artemiadou et al. 2008, Loos et al. 2009). Moreover, only fragmentary research results hitherto exist on the occurrence of habitat type 3270 (Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation) in Austria. Its key areas of occurrence in Austria are along the large rivers of the continental biogeographical region (e.g. Danube, Morava, Mur), with a total area likely measuring around 1,200 ha (Mucina et al. 1993a). The LIFE+ Traisen project supported the persistence of this endangered habitat type, and with it the survival of native riparian plant species.

One of the major threats to native riparian plants are invasive plant species that alter the species composition and compete with the native plant community (Richardson et al. 2007). We observed that certain non-native species can co-exist within the surveyed plant communities, while others like *Solidago gigantea* tend to dominate plant communities and can affect their natural development (Weber & Jakobs 2005, Schlaepfer et al. 2008). The incidence of non-native plant species in the study area was recorded. Future monitoring could help to observe the impact of biological plant invasions. Furthermore, invasive neophytes react more sensitively to hydrological changes, and their numbers can be reduced by regular flooding events (Tabacchi et al. 1995 in Casanova & Brock 2000, Lapin et al. 2016).

Surveying the vitality of species establishing themselves after the restoration measures is a useful tool for evaluating the success of restoration efforts. A semi-qualitative vitality key developed to assess species vitality allowed for determination of differences in spatial and temporal development by using simplified parameters of growth performance of indicator species. While the vitality of the naturally established *Salix* species was very good, the performance of planted willow cuttings in one location did not contribute to the re-establishment. Both the planted willow cuttings and also the naturally established *Salix* species were limited by damage due to Sika deer and insect pests. According to the results of this study, *Salix purpurea* and *Salix eleagnos* were least damaged by animals, while *Salix alba* was most heavily affected. This might be a result of the higher levels of salicin und bitter substances in *Salix purpurea* and *Salix eleagnos*, which are therefore less appealing to game (Patt 2016). Section 1 of the study area was experimentally fenced off for this reason, but the Sika deer were apparently able to find a way through the fencing, as the browsing damage was greater in section 1 than in section 2.

The observations and assessments also show that Natura 2000 habitat type 91E0 successfully established itself in the project area of the LIFE+ Traisen project. This habitat type had disappeared from the Tullnerfelder Donau-Auen region due to the transformation from softwood habitats to poplar plantations and the lack of river dynamics of the Danube (Kubíček et al. 2009, Hein et al. 2016). A large number of native *Salix* species re-established themselves naturally in the study area, likely through dispersal by wind or water. Potential seed trees of the genus *Salix* (*Salix purpurea, Salix fragilis, Salix alba, Salix eleagnos and Salix* × *rubens*) were recorded in close distance (200 to 400 Meters) to the newly created river course (Hochauer 2017). Further studies need to be undertaken to analyse the genetic source of the re-established *Salix* species. The new river bed of the Traisen currently offers an area of 80 ha for the re-establishment of typical softwood habitats. For the long-term survival of this habitat type in the study area, the vegetation development needs to be subjected to regular natural disturbances that create space for rejuvenation and ensure the natural regeneration of the habitat. In this context, the need for monitoring to ensure the sustained success of the current achievements must be highlighted.

Numerous authors agree that the implementation of a monitoring regime is necessary to ensure the positive outcome of river restorations projects (Bernhardt et al. 2005, Giller 2005, Palmer et al. 2005, Nakamura et al. 2006, Palmer et al. 2010, Bernhardt & Palmer 2011). The monitoring of river restoration areas is suggested to continue over a period of 10 years and should be budgeted in the planning stage of a project. Monitoring is not a luxury, but an essential requirement for a long-term successful outcome. Unfortunately, monitoring after the completion of construction work is often under-budgeted or not taken into serious consideration at all. One of the main reasons for post-monitoring of river restoration is the current lack of experience with large-scale restoration projects. Based on monitoring data, our knowledge and methods could be improved. A further important reason is the unpredictability of changing environmental conditions, which requires active monitoring to ensure the positive performance of the investment. Monitoring data can also support the efficient use of budgets for future restoration projects.

Acknowledgements

This project would not have been possible without the support of all co-authors at the Institute of Botany. The University of Natural Resources and Life Sciences is acknowledged for providing the authors with access and its resources. The financial support by VERBUND AG through the LIFE+ Traisen project is likewise gratefully acknowledged. We thank the three anonymous reviewers, who improved the text with their valuable comments. The authors thank Inga-Maria Besener for her help in formatting and reviewing the paper, as well as for her constructive comments. Finally, we would like to thank Stephan Stockinger, whose comments on English language and style helped to improve this paper.

Annex: Differentiated table of plant species in 2016 (adapted from Mucina et al. 1993a and 1993b, Schubert et al. 2001, Glaeser et al. 2009); Vegetation assessment of the direct transition zone by the waterline (SB3, SB4, SB6, SB1; see Figure 1) following the method of Braun-Blanquet (Moore 1962), showing species referring to the Natura 2000 habitat type 3270 (Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation). – Anhang: Differenzierte Tabelle der Pflanzenarten 2016 (adaptiert nach Mucina et al. 1993a und 1993b, Schubert et al. 2001, Glaeser et al. 2009); Vegetationsbewertung der direkten Übergangszone bei der Wasserlinie (SB3, SB4, SB6, SB1; siehe Abbildung 1) nach der Methode von Braun-Blanquet (Moore 1962) mit Arten, die sich auf den FFH-Lebensraumtyp 3270 beziehen (Flüsse mit Schlammbänken mit *Chenopodion rubri* p.p. und *Bidention* p.p. Vegetation).

		Continuity	**SB1** (by the feeder stream)					**SB3, SB3, SB6** (area of newly created transition zone by the waterline)																					
	plot (1m²)		**1a**	**1b**	**1e**	**1f**	**1g**	**3i**	**6a**	**6d**	**6f**	**4b**	**4c**	**3f**	**3g**	**3h**	**4g**	**4j**	**3a**	**4f**	**4h**	**4i**	**3c**	**4k**	**4l**	**4m**	**4a**	**4e**	**6c**
	total vascular plants (n)		4	7	5	5	11	15	17	12	16	17	17	16	20	25	21	19	13	15	19	21	7	22	6	9	14	8	7
Tree species																													
T	*Populus* Hybrid	19	-	-	-	-	-	r	1	-	2	+	1	+	+	r	1	3	+	+	1	2	+	2	1	+	2	-	-
T	*Salix alba*	17	-	-	-	-	-	-	+	-	+	+	1	-	r	r	1	1	r	+	1	2	+	1	r	r	2	-	-
T	*Salix cinerea*	13	-	-	-	-	-	-	-	-	-	+	+	r	+	+	1	1	-	r	+	1	-	+	1	-	+	-	-
T	*Populus alba*	10	-	-	-	-	-	+	r	-	-	r	+	+	r	+	-	-	-	-	r	+	-	-	-	1	-	-	-
T	*Corylus avellana*	5	-	-	-	-	-	-	r	-	-	r	+	-	-	-	-	-	-	-	r	-	-	+	-	-	-	-	-
T	*Salix purpurea*	5	-	-	-	-	-	-	-	-	-	+	-	-	r	r	-	-	-	-	-	r	-	+	-	-	-	-	-
nitrophile ruderal species																													
AR	*Calamagrostis epigejos*	13	-	1	r	3	+	1	-	+	-	1	+	-	-	+	+	+	-	-	-	-	-	1	-	-	1	2	-
PA	*Agrostis stolonifera*	22	-	4	-	-	1	-	3	5	4	5	4	1	+	+	3	+	1	+	4	4	1	+	r	1	4	-	3
AR	*Cirsium arvense*	5	-	-	-	-	+	-	-	-	-	+	-	-	-	r	+	-	-	-	-	+	-	-	-	-	-	-	-
AR	*Urtica sp.*	4	-	-	-	-	r	-	-	r	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-	-	-	-	+
AR	*Elymus caninus*	3	-	-	-	-	-	-	-	3	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
AR	*Equisetum arvense*	2	-	-	-	-	-	3	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AR	*Erigeron annuus*	15	-	-	-	-	-	r	-	-	-	+	+	r	r	r	+	+	-	+	+	r	-	+	-	1	+	+	-
AR	*Solidago gigantea*	14	-	-	-	-	-	-	+	+	+	-	+	+	+	1	-	+	+	r	+	r	-	+	-	-	+	-	-
AR	*Verbena officinalis*	4	-	-	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	r	-
AR	*Artemisia vulgaris*	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	r	+	-	-	r	-	-	-	-	-	-	-	-
AR	*Epilobium parviflorum*	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	-	1	-	-

		Continuity	**SB1** (by the feeder stream)					**SB3, SB3, SB6** (area of newly created transition zone by the waterline)																					
	plot (1m²)		**1a**	**1b**	**1e**	**1f**	**1g**	**3i**	**6a**	**6d**	**6f**	**4b**	**4c**	**3f**	**3g**	**3h**	**4g**	**4j**	**3a**	**4f**	**4h**	**4i**	**3c**	**4k**	**4l**	**4m**	**4a**	**4e**	**6c**
	total vascular plants (n)		4	7	5	5	11	15	17	12	16	17	17	16	20	25	21	19	13	15	19	21	7	22	6	9	14	8	7
AR	*Erigeron canadensis*	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	1	-	4	-
AR	*Epilobium tetragonum*	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-
AR	*Glechoma hederacea*	2	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	r	-	-	-	-	-	-	-
AR	*Tussilago farfara*	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	r	+	-	-	-	-	-	-	-	-
AR/PP	*Taraxacum officinale agg.*	8	-	-	-	-	-	-	-	-	r	+	+	-	+	+	-	-	-	-	-	r	-	1	-	-	1	-	-
mud bank species																													
IN	*Cyperus fuscus*	3	3	2	-	-	-	r	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI	*Echinochloa crus-galli*	20	3	2	-	-	-	1	r	-	+	+	-	+	1	2	1	+	2	+	3	1	1	+	3	+	-	3	-
BI	*Persicaria dubia*	18	1	3	-	-	r	2	3	3	3	-	+	+	+	+	r	r	3	+	1	1	+	-	-	-	-	-	-
BI	*Bidens tripartita*	8	-	-	-	-	-	r	r	+	1	r	+	-	r	-	-	-	-	-	-	-	-	1	-	-	-	-	-
BI	*Rorippa palustris*	3	-	-	-	-	-	-	+	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
BI	*Veronica anagallis-aquatica*	3	-	-	-	-	-	-	-	-	-	-	-	+	-	r	-	-	-	-	r	-	-	-	-	-	-	-	-
PA	*Mentha longifolia*	12	-	-	-	-	-	2	-	r	-	+	+	-	+	+	+	2	-	1	1	1	-	-	-	-	1	-	-
PA	*Juncus articulatus*	7	-	r	-	-	-	-	-	-	-	-	+	-	-	-	-	-	1	+	-	+	-	+	-	-	r	-	-
PA	*Juncus inflexus*	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	+	r	+	-	-	-	-	-
PA	*Rumex crispus*	5	-	r	-	-	-	-	+	-	r	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	r
Reed species																													
PH	*Lycopus europaeus*	11	-	-	-	-	-	-	3	2	1	+	+	-	-	r	-	-	+	1	r	-	-	1	-	-	+	-	-
PH	*Veronica beccabunga*	6	-	-	-	-	-	r	+	-	-	-	-	1	+	-	-	-	r	-	-	-	-	-	-	-	-	-	2
PH	*Phalaris arundinacea*	9	-	-	-	-	3	-	-	r	-	-	+	-	-	-	+	1	-	+	2	-	-	-	-	-	+	-	4
PH	*Lythrum salicaria*	7	-	-	-	-	1	-	-	-	-	+	r	-	-	-	+	-	-	-	-	+	-	-	-	-	+	-	1
PH	*Mentha aquatica*	5	-	-	-	-	3	-	-	+	-	-	-	3	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-
PH	*Iris pseudoacorus*	2	-	-	+	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PH	Phragmites australis	2	r	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PH	*Carex acutiformis*	1	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

		Continuity	**SB1** (by the feeder stream)					**SB3, SB3, SB6** (area of newly created transition zone by the waterline)																					
	plot (1m²)		**1a**	**1b**	**1e**	**1f**	**1g**	**3i**	**6a**	**6d**	**6f**	**4b**	**4c**	**3f**	**3g**	**3h**	**4g**	**4j**	**3a**	**4f**	**4h**	**4i**	**3c**	**4k**	**4l**	**4m**	**4a**	**4e**	**6c**
	total vascular plants (n)		4	7	5	5	11	15	17	12	16	17	17	16	20	25	21	19	13	15	19	21	7	22	6	9	14	8	7
PH	*Eupatorium cannabium*	4	-	-	-	-	-	-	-	-	-	-	-	-	-	+	r	+	-	-	-	-	-	+	-	-	-	-	-
PH	*Carex pendula*	2	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Verschiedene																													
PP	*Plantago major*	12	-	-	-	-	-	+	r	-	+	-	-	1	2	1	1	+	1	-	+	+	-	-	-	r	-	-	-
PP	*Poa annua*	7	-	-	-	-	-	-	-	-	-	-	-	+	2	+	1	2	-	1	-	-	-	+	-	-	-	-	-
PP	*Matricaria inodora*	3	-	-	-	-	-	-	-	-	-	-	-	+	-	r	+	-	-	-	-	-	-	-	-	-	-	-	-
PP	*Centaurium erythraea*	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	r	-	-	-	-	-
S	*Carex sp.*	3	-	-	-	+	+	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S	*Stellaria sp.*	3	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	r	-	-	-	-	r	-	-	-	-	-
S	*Euphorbia cyparissias*	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	r	-
S	*Poa trivialis*	2	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SM	*Panicum capillare*	2	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
SM	*Veronica persica*	2	-	-	-	-	-	r	-	-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	-	-	-	-
MA	*Agrostis sp.*	2	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Species of conituity 1																													
MA	*Agrostis capillaris*	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
O	*Acer negundo, Brachypodium pinnatum, Crataegus laevigata, Dactylis glomerata, Epilobium hirsutum,Filipendula ulmaria, Hieracium sp., Lotus corniculatus , Oxalis corniculata, Peucedanum sp., Plantago lanceolata, Poa sp., Potentilla reptans, Potentilla reptans, Sedum hispanicum, Stellaria aquatica, Tanacetum corymbosum, Trifolium repens, Verbascum nigrum*																												
Assosiantion: AR (Artemisietea vulgaris), BI (Bidentetea), T (Tree species), IN (Isoeto-Nanojuncetea), PA (Potentillion anserinae), MA (Molinio-Arrhenatheretea), PH (Phragmiti-Magnocaricetea), PP (Polygono-Poetea annuae), O (Other), SM (Stellarietea mediae);																													

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Received: 2017 10 26

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Zeitschrift/Journal: Verhandlungen der Zoologisch-Botanischen Gesellschaft in Wien. Frueher: Verh.des Zoologisch-Botanischen Vereins in Wien. seit 2014 "Acta ZooBot Austria"

Jahr/Year: 2017

Band/Volume: 154

Autor(en)/Author(s): Lapin Katharina, Hochauer Andrea, Bernhardt Karl-Georg, Schindler Andrea

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