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Habitat requirements of rare grasshopper species in a near-natural floodplain ecosystem in the Northern Alps (Tyrol, Austria)

by

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AIC..... Akaike's Information Criteria

a.s.l.....Above sea level

e.g.....for example

BIK.....Biotope type classification

Abstract

The Earth is facing a sixth mass extinction, given the extreme loss of biodiversity over the past decades on a global scale. Especially alarming is the decline of the insect fauna, which is mainly caused by habitat degradation. The loss of habitats is the main driver regarding the decline of several specialized insects inhabiting the gravel banks of wild Alpine rivers. Although the grasshopper fauna has been investigated at several Alpine rivers, no research has yet been carried out at river Rißbach. Therefore, an investigation on four endangered grasshopper species and their habitat preferences was conducted at the Tyrolean part of the Rißbach from "Oswaldhütte" to "Hagelhütten" in two periods in summer 2018. Data on the abundance of these species on 23 study plots and observations outside the study plots was gathered. The vegetation, the habitat types of the EU Habitats Directive as well as substrate and positional characteristics of the study plots were documented. In total, 228 grasshoppers could be detected during the 24th - 30th of July, of which 120 observations were made on the study plots. During the 27th - 29th of August 2018, 149 grasshoppers could be found of which 113 findings were made on the study plots. An analysis of the habitat preferences of the species along the gravel banks of Rißbach was performed. The results showed that *Psophus stridulus* preferred the elevated areas characterized by dry pine grassland which border the open gravel banks. *Tetrix tuerki* favoured plots with little streams characterized by rocks and moist fine sediment as well as areas with high pioneer shrubs and herbs cover. *Chorthippus pullus* preferred the open, stony and sunny study plots. More individuals of *Bryodemella tuberculata* could be detected on plots with a higher total vegetation cover. The compilation of these results enabled recommendations for the conservation management of the nature park Karwendel, targeting the preservation of these endangered species. This includes the implementation of environmental education programmes, well-designed signposting and the close collaboration with stakeholders involved with the Rißbach. Further, an Alpine-wide monitoring of *B. tuberculata* would not only allow the assessment of the conservation status of the species but also for many other specialized species of gravel banks, as *B. tuberculata* serves as an indicator species.

Zusammenfassung

Angesichts des extremen globalen Verlusts der biologischen Vielfalt befindet sich die Erde in einem sechsten Massensterben. Besonders beunruhigend ist der Rückgang der Insektenfauna. Dieser wird hauptsächlich durch die Veränderungen und Zerstörungen der Lebensräume verursacht. Der Verlust von Lebensräumen ist der Hauptgrund für den kritischen Zustand mehrerer spezialisierter Insekten, die an den Kiesbänken wilder Alpenflüsse leben. Obwohl die Heuschreckenfauna an mehreren Alpenflüssen erforscht wurde, wurden noch keine Untersuchungen am Rißbach durchgeführt. Im Sommer 2018 wurde daher im Tiroler Teil des Rißbachs von "Oswaldhütte" bis "Hagelhütten" eine Untersuchung vier bedrohter Heuschreckenarten und deren Lebensraum-präferenzen durchgeführt. Die Arten wurden auf den 23 Untersuchungsflächen sowie außerhalb der Flächen kartiert. Die Vegetation, die Lebensraumtypen der EU-Habitatrichtlinie sowie die Substrat- und positionellen Eigenschaften der Untersuchungsflächen wurden dokumentiert. Insgesamt konnten vom 24. - 30. Juli 228 Heuschrecken entdeckt werden, von denen 120 Beobachtungen auf den Untersuchungsflächen gemacht wurden. Vom 27. - 29. August 2018 konnten 149 Heuschrecken gefunden werden, von denen 113 Funde auf den Untersuchungsflächen notiert wurden. Die Analyse der Lebensraumeigenschaften und der Kartierung der Arten ergab die Lebensraumpräferenzen der Heuschrecken auf den Kiesbänken des Rißbachs. Die Ergebnisse zeigten, dass *Psophus stridulus* die höher gelegenen, durch spätere Sukzessionsstadien gekennzeichnete Bereiche bevorzugte, die an die offenen Kiesbänke grenzten. *Tetrix tuerki* saß vermehrt auf Flächen durchzogen von kleinen Bächen mit hohem Grobstein- und Feinsedimentanteil, sowie Flächen mit hoher Pioniersträucher- und Kräuterdeckung. *Chorthippus pullus* bevorzugte die offenen, steinigen und sonnigen Untersuchungsflächen. *Bryodemella tuberculata* konnte vermehrt auf Flächen mit höherer Vegetationsdeckung gefunden werden. Das Zusammenführen dieser Ergebnisse ermöglichte die Aufstellung von Empfehlungen für das Naturschutzmanagement des Naturparks Karwendel mit dem Ziel, diese gefährdeten Arten zu erhalten. Dazu gehört die Entwicklung von Umweltbildungs-programmen, eine gut durchdachte, informative Beschilderung und die enge Zusammenarbeit mit den verschiedenen InteressensvertreterInnen. Da die Gefleckte Schnarrschrecke als Indikatorart dient, würde ein alpenweites Monitoring dieser Art nicht nur Auskunft über ihren Zustand, sondern auch den vieler weiterer spezialisierter Arten der Kiesbänke geben.

1. Introduction

Given the human-induced species losses over the past few centuries and millennia, there is abundant evidence that we have entered the 6th mass extinction period in the history of Earth (Barnosky et al. 2011; Ceballos et al. 2017; Steffen et al. 2015; Wagler 2018; Wake and Vredenburg 2008). The pressures on biodiversity such as the nitrogen pollution, invasive species, overexploitation of resources, and impacts from climate change increase (Butchart et al. 2010). Although researchers have long focused on the biodiversity loss of terrestrial and aquatic vertebrates (Ceballos et al. 2017; Chaudhary and Mooers 2018; McCallum 2015; Wake and Vredenburg 2008), emphasis has been recently placed on the alarming decline of insects all over the globe (Hallmann et al. 2017; Lister and Garcia 2018; Sánchez-Bayo and Wyckhuys 2019). In 2017, a study by German and Dutch scientists revealed a decline in flying insect biomass of over 75 % over 27 years in several protected areas of Germany (Hallmann et al. 2017), which provoked considerable attention in the public discussion. Insects provide numerous ecosystem services such as pollination, decomposition, soil formation and biological control. Further, insects play an important role in food chains as they feed numerous vertebrates, especially amphibians, reptiles, birds, bats and small mammals (Wagner 2018). The decline in insect species diversity and abundance could set off wide-ranging cascading effects within several ecosystems. The most important drivers of the decline of insect species are habitat loss and the general shift to intensive agriculture and urbanisation. The second most important driver is the pollution by pesticides and fertilisers, followed by biological factors such as invasive species and pathogens and lastly, climate change (Sánchez-Bayo and Wyckhuys 2019).

The loss of habitats is surely the main driver regarding the critical conservation status and decline of several specialized insects inhabiting the gravel banks of wild Alpine rivers. Wild Alpine river systems are characterized by dynamic processes which create wide floodplains with massive gravel banks and alluvial forests. Floods, erosion, and rearrangement of sediments prevent the aging of habitats and ensure a constant renewal of environmental conditions. Floodplains and their gravel banks with sparse vegetation depend on these dynamics and provide habitats for many specialized species (Hofer 2009). In the past, many of the Alpine rivers were severely impacted by hydraulic engineering. With the regulation of running waters, the rearrangement processes on gravel banks with sparse vegetation are disrupted. Furthermore, the withdrawal of gravel, the recreation on gravel banks as well as scrub and forest encroachment lead to decreasing habitat. Once cohesive habitats are now separated into small segments through barriers like reservoirs. This led to the isolation of populations (Reich 1990). Therefore, the speckled grasshopper (*Bryodemella tuberculata*) is critically endangered in Austria (Reich 1991a) as well as the gravel bank grasshopper (*Chorthippus pullus*) and the alpine groundhopper (*Tetrix tuerki*) (Fischer et al. 2016). In Austria, the gravel bank grasshopper occurs mainly in North Tyrol as well as in South Carinthia, the Ennstal Alps and the edge of the Upper Austrian Limestone Alps whereas the speckled grasshopper only appears in North Tyrol (Zuna-Kratky et al. 2017). *Bryodemella tuberculata* and *Chorthippus pullus* are extremely specialized species which only occur on gravel banks with sparse vegetation. Due to their low dispersal potential, recolonization from outside the floodplains is almost impossible if local populations of these two species get extinct. The preservation of their remaining natural habitats is therefore critical for their protection (Reich 1991a).

The river Rißbach flows through the Rißtal valley, which is located in the Nature park Karwendel in North Tyrol, Austria. The Rißbach is one of the last remaining wild rivers with natural dynamics in Tyrol (Figure 1). On its floodplain, three endangered habitat types of the EU Habitats Directive occur. The habitat type "Alpine rivers and the herbaceous vegetation along their banks", "Alpine rivers and their ligneous vegetation with *Salix elaeagnos*" and "Alpine rivers and their ligneous vegetation with *Myricaria germanica*". Quality and extension of these habitats have decreased over the last decades due to various hydraulic engineering measures (Ellmauer 2005).

At the river Lech, *Bryodemella tuberculata* prefers gravel banks with a vegetation cover of 5 – 30 %. These sites can be assigned to the plant associations of the Myricario-Chondrilletum chondrilloides Br.-Bl. in Volk 1939 with transitions to Salici-Myricarietum Moor 1958 as well as light stages of Salicetum elaeagni Jeník 1955 (Reich 1990). *Bryodemella tuberculata* is adapted to these habitats with a special metapopulation strategy. Flooding of gravel banks can lead to the occasional extinction of parts of the population. Therefore, the existence of a metapopulation is shaped by local extinctions of populations and resettlements through remaining populations of neighbouring gravel banks (Reich 1991a). The investigated grasshopper species are forced to be well-camouflaged, as the open habitats offer few hiding possibilities. Locusts of the genus Oedipoda perfectly combine camouflage and attracting attention, since they appear inconspicuous while sitting and the rear wings shine colourfully while flying. In addition, the speckled grasshopper and the rattle grasshopper (*Psophus stridulus*) attract mates and at the same time scare off rivals through the rattling sounds of their wings during their flights (Landmann and Zuna-Kratky 2016). *Chorthippus pullus* does not favour a certain degree of vegetation cover on gravel banks (Zuna-Kratky et al. 2017). However, they prefer the open stony areas of gravel banks (Schwarz-Waubke 1997). At some places in the Northern Tyrolean Alps, *B. tuberculata* and *P. stridulus*

Figure 1: The river Rißbach and its floodplain. Natural river dynamics shape the landscape and lead to the creation of open, wide gravel banks and special endangered habitats.

occur together on gravel banks of Alpine rivers. Apart from that, *Psophus stridulus* occupies a variety of habitats but always requires some open bare ground areas at the sites for sunbathing and oviposition. On the other hand, *Tetrix tuerki* prefers the moist areas of gravel banks and a variable mosaic of different substrate grain sizes. Nevertheless, in Austria, they were also detected on areas with quite dense vegetation (Zuna-Kratky et al. 2017).

The appearance of a vital population of *Bryodemella tuberculata* at the Rißbach in the Karwendel mountains was firstly documented in the middle of the 19th century and still exists to this day (Zuna-Kratky et al. 2017). An investigation on the metapopulation of *B. tuberculata* at the Bavarian part of the Rißbach from "Oswaldhütte" to the mouth of the Isar counted 114 individuals in 2001 and 25 individuals in 2016 (Schödl, pers. obs.). Reich (1990) claims, that the population of *B. tuberculata* at the Tyrolean part of the Rißbach is small and strongly isolated from other populations. As the species *Bryodemella tuberculata* serves as an indicator species of gravel banks with sparse vegetation, a closer investigation on the occurrence of this species at the Tyrolean part of the Rißbach is crucial to support the preservation of endangered river habitats.

The spider fauna and their habitat requirements on the gravel banks is well documented at the wild alpine rivers of Tyrol and Germany (Lemke et al. 2010; Manderbach and Framenau 2001; Steinberger 1996). Furthermore, the habitat preferences and ecological niches of the grasshopper fauna on gravel banks have been studied e.g. at the floodplain in the Spanish Pyrenees (Löffler et al. 2016), the river Lech (Pfeuffer 2007), the river Tagliamento (Kuhn 2005), the river Alfenz (Kilzer 1996), rivers of Southern Bavaria (Lemke et al. 2010), the river Taugl (Schwarz-Waubke 1997) and the river Schwarzwasserbach (Pfeuffer 2004). A genetic study on the gravel bank grasshopper was conducted at the river Isar (Maag et al. 2013). While the beetle fauna of the Rißbach were investigated (Kahlen 1995), no studies have yet been carried out on the grasshopper fauna and their habitat preferences.

With the following research questions, I wanted to obtain an insight into the preferences of habitat and vegetation characteristics of all four grasshopper species as well as an overview of the condition of the metapopulation of *Bryodemella tuberculata* at the river Rißbach:

1) Which vegetation characteristics define the study plots?
    a. Which habitats of the EU Habitats Directive are represented on the study plots?
    b. Which plant associations and other vegetation features exist on the study plots?
2) How abundant are the four grasshopper species on the study plots on the gravel banks?
    a. What observations can also be made outside the study plots?
    b. What does the distinction between male and female individuals of *Bryodemella tuberculata* tell us about the features of the metapopulation?
3) What habitat characteristics do the four grasshopper species as well as female and male individuals of *B. tuberculata* prefer at river Rißbach? What vegetation, substrate and positional characteristics of study plots do they favour?

4) What can be done to preserve the populations of the grasshopper species *Bryodemella tuberculata, Chorthippus pullus, Tetrix tuerki* and *Psophus stridulus* at the river Rißbach?

From the results, recommendations for the practical management plan of the Nature park Karwendel will be drawn, which aim to improve and maintain these habitats and thereby the sustainable survival of these extremely specialized and rare species.

2. Methods and Materials

2.1 Study area

The river Rißbach is around 30 km long and located in Tyrol, Austria and borders with Bavaria, Germany. It is situated in the northern part of the mountain range Karwendel in the northern periphery of the Northern Calcareous Alps. The Nature park Karwendel was founded in 1928 and has a total size of 727 km². It is protected under the Tyrolean Nature Conservation Act and is the largest and oldest nature park in Austria. The valley Rißtal, where the Rißbach and therefore this study is located, is part of the 543 km² big nature conservation area (Naturpark Karwendel 2018a) (Figure 2). The Rhon-, Tor-, Johannis-, Laliderer valley and the "Eng" are part of the valley Rißtal. The nature park provides many natural habitats of wild forests and rivers and is home to numerous Europe-wide important animal and plant species such as the golden eagle, the white-backed woodpecker and the lady's slipper orchid (Naturpark Karwendel 2018a). The protected area takes up around 43 km from west to east and 25 to 30 km from north to south (Landmann 2013). The territory borders with the river Inn in the south, the river Isar in the north, the lake Achensee in the east and the Seefeld basin in the west. Its vertical extension is extreme as it ranges from roughly 560 m a.s.l. at the Inn Valley up to 2749 m a.s.l. with the highest peak Birkkarspitz (Landmann 2013).

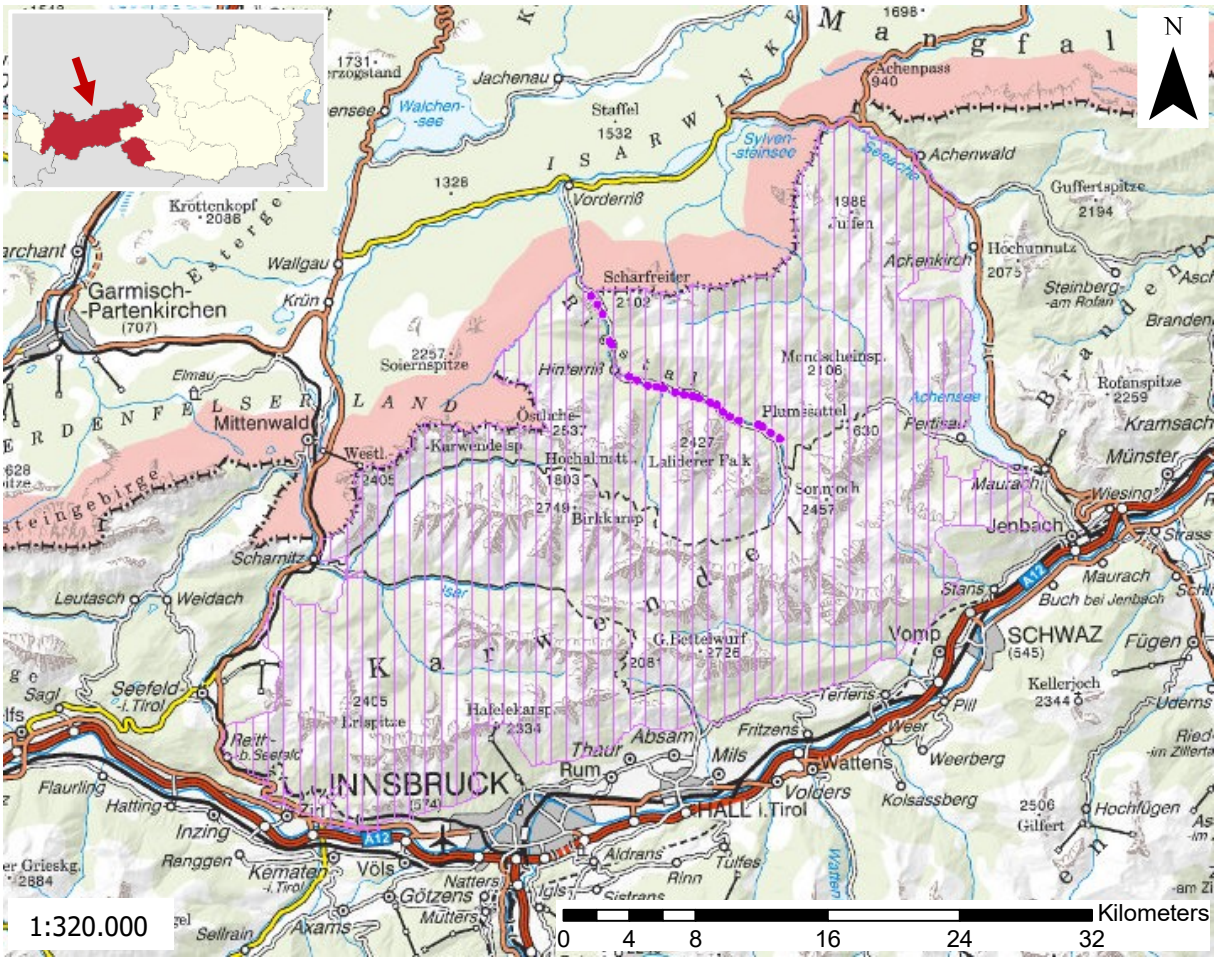
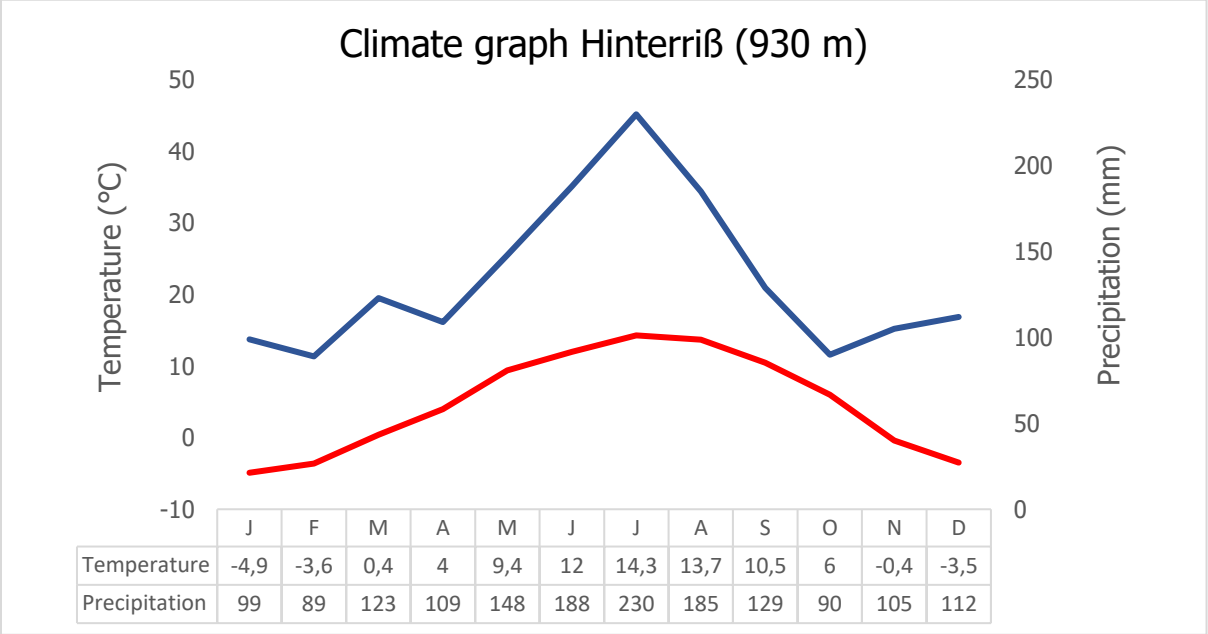


Figure 2: Map in the left corner displays the location of Tyrol and East Tyrol in Austria. Red arrow indicates the location of the Rißbach. Map of the location of the study plots along river Rißbach (purple dots) in the Nature park Karwendel (dashed purple area).

The Rißtal is characterized by an Atlantic, cold and wet climate. Due to its location north of the Karwendel's main mountain range, it is extremely exposed to the wind currents which bring precipitation. From September until June frosts are likely. The temperatures in winter can drop to -30°C and temperatures in summer can rise up to around 32°C (Tappeiner et al. 2007). The daily mean temperature is around 5°C. The mean annual precipitation lies at around 1600 mm (Tirol Atlas 2013). Figure 4 displays the monthly mean temperature and the monthly mean precipitation. It presents the wet, hot summers and cold, dry winters of the Rißtal with highest mean precipitation rates of 185 – 230 mm per m² in the months June, July and August and highest mean temperatures of 12 – 14,3 °C in the same months.



	J	F	M	A	M	J	J	A	S	O	N	D
Temperature	-4,9	-3,6	0,4	4	9,4	12	14,3	13,7	10,5	6	-0,4	-3,5
Precipitation	99	89	123	109	148	188	230	185	129	90	105	112

Figure 3: Climate graph visualizing the monthly temperature and precipitation for the measuring station at Hinterriß (930 m). The red line indicates the monthly mean temperature in °C, the blue line shows the monthly mean precipitation rate in mm per m². Data basis are long-term climate series covering the years 1990 – 2000 (Tirol Atlas 2013).

The Karwendel mountains consist mainly of Wetterstein limestone which reposes on dolomite pedestal. Through physical weathering and erosion, this limestone and dolomite rock forms the gravel and debris of the gravel banks of the floodplains. The vegetation growing on the gravel banks of river Rißbach is adopted to the extreme conditions of these habitats. Some of the plants growing on the gravel banks can be assigned to the group of so-called "Alpenschwemmlinge". These specialized plants, adapted to the rough conditions of mountain habitats, are washed out from high elevations and establish at the gravel banks of Alpine rivers. Their seeds disperse with the water flow into river Rißbach. On the gravel banks of the floodplains of the river, they find a similar climate to the one in high mountain regions: cold winters, hot summers and in general dry and windy conditions. The brightly coloured gravel has a high UV radiation, which is also a characteristic of high altitude habitats. Examples for "Alpenschwemmlinge" are plants like *Campanula cochleariifolia, Dryas octopetala*, *Saxifraga caesia, Atocion rupestre or Leontopodium nivale* (Verein Naturpark Tiroler Lech 2019). Generally, plants growing on the gravel banks require high regenerative capability as an adaptation to recurring floods. Their xeromorph and low-growth characteristics allow these plants to survive drought periods.

The "Eng", visited yearly by thousands of tourists, is famous for its mountain pastures and up to 400-year-old maple trees. The only village in the Rißtal is Hinterriss, which belongs to the municipality of Vomp and had 46 inhabitants in the year 2005. One single road coming from Germany leads all the way up into the valley. Shortly behind Hinterriss a toll is due for the continuation of the journey. For centuries, the Rißtal has been famous for its exclusive hunting grounds, which were mainly appreciated by aristocrats. In early centuries, mining was practiced. Tourism in the Rißtal is restricted to max. 15 000 – 25 000 overnight stays per year as there are only 13 accommodation possibilities. However, day tourists play a much more important role. Around 162 000 tourists passed the toll station on their way to the "Eng" and the "Großer Ahornboden" in the year 2005. Most of the tourists are coming from the Munich agglomeration in search of recreation (Mayer et al. 2008). In the summertime, numerous day visitors go hiking, climbing, kayaking, or enjoy the cool water and the rare sight of the wild floodplains of the Rißbach. These activities are facilitated by the signposted parking spaces along the river. Important agricultural areas bordering with the Rißbach are the Weitgries-Alm, the Angerl-Alm, agriculture at the Brandau and the Gasthof Alpenhof, the Fuggeranger-Alm and the Garberl-Alm. The remaining river segments neighbour with forests and sometimes with forest roads or the boundary of the main road.

The Rißbach river runs in its northern part 6 km through Bavarian territory and in its southern part 23 km through Tyrolean territory. In this study, only the Tyrolean part of the Rißbach was investigated. The catchment area of the Rißbach is 216,60 km² large (LfU Bayern 2016). The mountains Birkarspitze (2749 m), Grubenkarspitze (2663 m), Sonnjoch (2457 m), Östliche Karwendelspitze (2537 m), Scharfreiter (2102 m) and Fleischbank (2026 m) edge this catchment area. The Rißbach has its source in the "Enger Grund" at the very end of the valley where several brooks confluence. As the river shares its valley bottom with the main road, forestry roads and pastures for agriculture, bridges were built here and there, and the floodplain is slightly constrained in some places. Nevertheless, the Rißbach is one of the last wild rivers in the Karwendel, and the natural dynamics are especially distinctive in its Tyrolean part, its upper and middle course. In its lower course at "Oswaldhütte", the Rißbach is dammed and piped into the hydroelectric plant Walchensee around 6 km above the mouth of the river Isar. Only during floods, the dam opens and the Rißbach can feed the Isar.

During snow melt in spring and early summer, the Rißbach carries a lot of water. Heavy rainfalls in the summer months also lead to a rapid increase of water discharge within a few hours (Naturpark Karwendel 2018b). In the investigation time frame from July to August 2018, there were no major flood events detected by the measuring station of the Bavarian hydrology office at river Rißbach (LfU Bayern 2019) (Figure 7). For the river Rißbach, the mean flood discharge is at 82.1 m³/s (LfU Bayern 2019). Consequently, the investigations of the grasshopper species and their habitat preferences on the gravel banks did not come under the influence of a flood event. However, a higher discharge value of 51.5 on the 8th of August was measured. This higher discharge value is related to the high precipitation rates in summer and was probably caused by a strong summer thunderstorm with heavy rainfall.

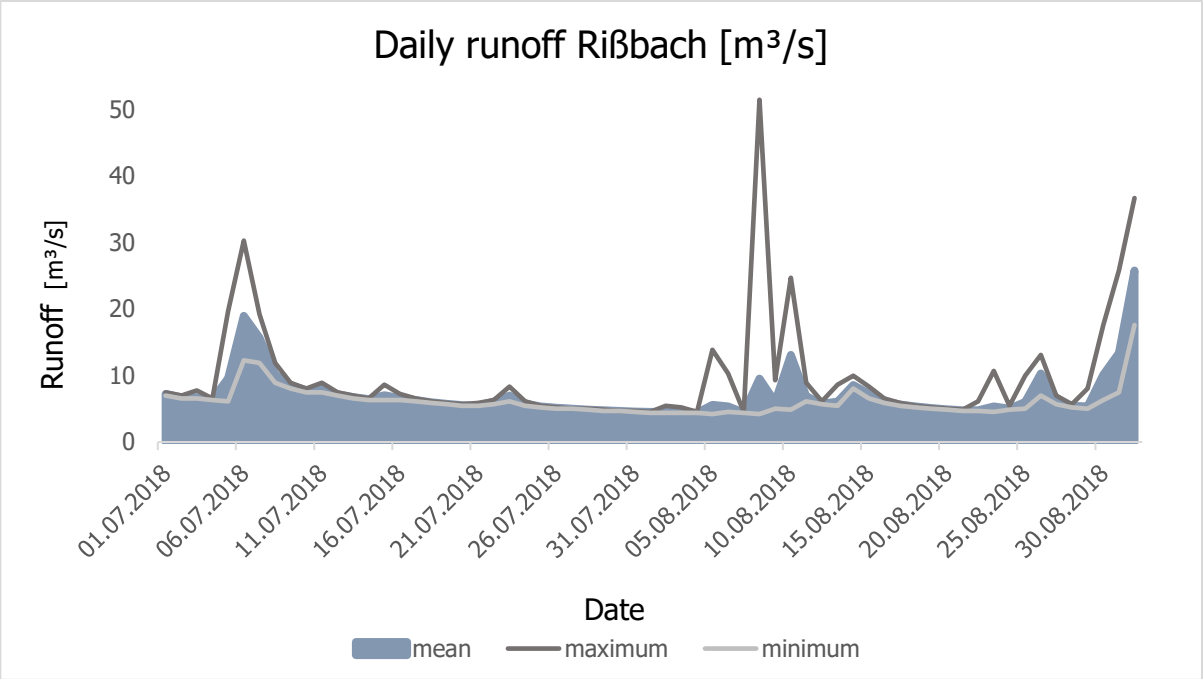


Figure 4: Daily runoff data between 01.07.2018 and 01.09.2018 for Rißbach [m³/s] (LfU Bayern 2019)

Within the framework of the restoration project of the Rißbach in the years 2012 – 2014, measures were carried out on three different areas of the floodplain (Figure 8). The first measure was located close to the bridge at parking area number 4, the second measure was placed opposite to the Garberl-Alm and the third measure was situated near the mouth of the Laliderer stream. The first two measures were implemented in late autumn 2012, the third measure in late autumn 2013 and early spring 2014. On the area of measure one, a neighbouring forest road was destroyed during a flood event. This was taken as an oppurtunity to remove a control structure and relocate the forest road. As a result of this, the river can now take up the floodplain in his whole width. Measure two involved the destruction of a gravel rampart with a size of around 150 m. In order to secure the neighbouring forest road, installations at the embankment of the road were implemented on a length of around 100 m. This measure has more than doubled the functional width of the river. At measure area three, a gravel rampart with a length of around 200 – 250 m was removed. This led to an improvement of the surface characteristics of involved gravel banks, as they now show various grain sizes and sediment structures. A greater area is now available for the Rißbach at this river segment. Further measures have been identified and are to be realised in the coming years (Sonntag and Zika 2014).

2.2 Study plots

The 23 study plots are distributed over gravel banks along around 19 km of the Tyrolean part of the river Rißbach from "Hagelhütten" in the south up to "Oswaldhütte" at the border to Germany in the north (Figure 5). The smaller Enger Grund stream develops into the stronger Rißbach at the Hagelhütten in the south. Shortly after "Oswaldhütte" at the border, the Rißbach is dammed and piped towards the hydroelectric plant at Walchensee. The river gradient of the investigated segment of the river lies at around 1%.

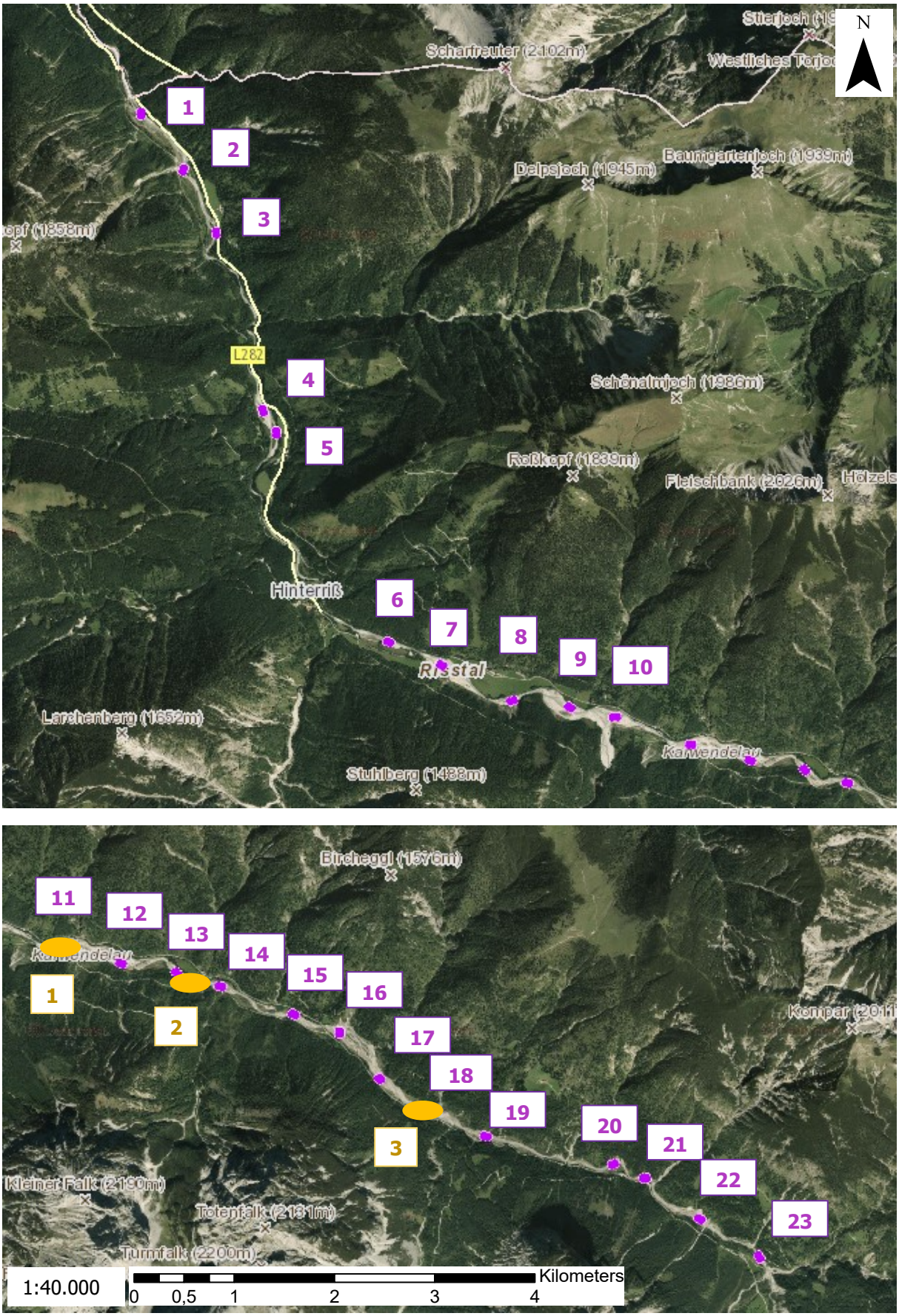


Figure 5: Location of the 23 study plots along River Rißbach (purple). Orange areas and numbers indicate the locations of the restoration measures (map produced by Land Tirol – tiris)

The study plots were selected by choosing gravel banks with the most suitable habitat for speckled grasshoppers. With help of literature research and the findings of speckled grasshoppers by the Nature park team in 2017, the plots could be realised on relevant gravel banks, representing the habitat of the grasshopper species. Each plot has roughly the size 25 × 50m, with around 1250m². Only plots number 2 and 3 are around 1000m² large with an extension of approximately 20 × 50 m, as this was the maximum possible plot size due to the specific terrain situation. The extensions of the plots were captured in a GIS-Shapefile.

The elevation of the sites along Rißbach range from 873 m a.s.l. for plot number 1 up to 1072 m a.s.l. for plot number 23. The elevation of each site was measured with the GPS device Garmin GPSMap 60CSx. The approximate width of each floodplain, where the plot was located, was measured in the ArcGIS software. Further, the latitude and longitude of each study plot was calculated with the ArcGIS software. The floodplain width of the Tyrolean part of the Rißbach ranges from 60 meters to a maximum width of 200 meters. The sea level, size, floodplain width and location in decimal degrees of each plot can be taken from Table 1.

Table 1: Area (m²), sea level (m a.s.l.), floodplain width at location of study plot (m) and longitude and latitude in decimal degrees of the 23 study plots

Study plot	Area (m²)	Sea level (m a.s.l.)	Floodplain width (m)	Longitude	Latitude
1	1230	873	135	11.4507889	47.5067385
2	1031	883	120	11.4550336	47.5028195
3	1006	890	95	11.458288	47.498425
4	1269	908	145	11.4628074	47.486079
5	1318	913	100	11.464122	47.4845428
6	1252	935	70	11.4752812	47.4699379
7	1321	939	140	11.4806519	47.4682811
8	1307	945	90	11.4877829	47.4657461
9	1241	953	190	11.4936613	47.4652315
10	1314	968	200	11.5059457	47.4625233
11	1186	959	165	11.5119609	47.4613677
12	1256	966	160	11.5175035	47.4606567
13	1196	978	100	11.5218422	47.459708
14	1233	977	100	11.5291193	47.4577411
15	1304	989	80	11.5376003	47.453291
16	1211	992	155	11.5481022	47.4492793
17	1245	1003	125	11.5607773	47.4472613
18	1226	1007	120	11.5693186	47.4434447
19	1283	1018	70	11.5751886	47.4408096
20	1243	1037	60	11.5420744	47.4511095
21	1267	1048	100	11.4982386	47.4645106
22	1206	1060	105	11.5638979	47.4462646
23	1286	1072	65	11.5336647	47.4564588

2.3 Study species

2.3.1 *Chorthippus pullus* (Philippi, 1830)

Figure 6: *Chorthippus pullus* male (Image from E. Pfeuffer)

The gravel bank grasshopper males reach sizes of 12 – 15 mm and females sizes of 17 – 21 mm. Therefore, it is one of the smallest species of the genus *Chorthippus* in Austria. Apart from its unobtrusive grey, grey-brown, sometimes red or yellow basic colouration, it has very remarkable rear legs maculation (Figure 6). Especially eye-catching are the black knees and the bright red metatibia (Landmann and Zuna-Kratky 2016). The wings are shortened, with this shortening being more distinct in female individuals. Their stridulation is soft and whirring and only one to four seconds short. Small *Chorthippus pullus* populations can be found in the Alps and in the sub-Atlantic dry sand heaths in Eastern Germany (Fischer et al. 2016). In Austria, some extant and scattered populations exist in North and East Tyrol, in South Carinthia, the Ennstal Alps and the edge of the Upper Austrian Limestone Alps (Zuna-Kratky et al. 2017). The distribution of the xerothermophile gravel bank grasshopper in the Alpine range is restricted to the gravel banks of Alpine rivers (Maas et al. 2002). Other than *Tetrix tuerki* and *Bryodemella tuberculata*, *Chortippus pullus* are not exclusively bound to natural riverbanks but can also be found further away from rivers e.g. in open pine meadows. This species feeds on various grass species, especially *Calamagrostis pseudophragmites*. As the gravel bank grasshopper is unable to fly, its low dispersal capability contributes to its endangerment. Once abandoned habitats can hardly be recolonized (Landmann and Zuna-Kratky 2016).

2.3.2 *Tetrix tuerki* (Krauss, 1876)

Figure 7: *Tetrix tuerki* (Image from E. Pfeuffer)

A lot easier to overlook is the alpine groundhopper, which has a size of 7 – 10 mm for males and 9 – 13 mm for females. This species has a light to dark grey, sometimes brown or black ground colour with various patterns and does not stridulate (Landmann and Zuna-Kratky 2016). The distinguishing mark to other *Tetrix* species is the corrugation underneath the middle thigh (Figure 7). In Austria, the most important refuge is the Tyrolean river Lech, all other findings in Austria are located in Tyrol at some relict single habitats along natural rivers and streams (Landmann and Zuna-Kratky 2016). Further sites in Austria exist in East Tyrol, Upper Carinthia and few relict single sites at e.g. the basin of Klagenfurt (Zuna-Kratky et al. 2017). *Tetrix tuerki* is only found on gravel banks of Alpine rivers and requires between the gravel some amount of fine sediment for the oviposition. As an adaptation to this habitat, the alpine groundhopper can swim and remain under water for some minutes (Fischer et al.

2016). Therefore, the strategy of drift for dispersion seems possible (Zuna-Kratky et al. 2017). It feeds on leaves of low-growing plants and on plant residues (Landmann and Zuna-Kratky 2016).

2.3.3 *Bryodemella tuberculata* (Fabricius, 1775)

Figure 8: *Bryodemella tuberculata* male

The speckled grasshopper is, with a size of up to 4 cm, the biggest of the four species. Males reach sizes of up to 31 mm and are smaller than females, which get slightly larger (Landmann and Zuna-Kratky 2016). While sitting they are well-camouflaged with their grey, black, brown or green coloration (Figure 8). However, while flying, they appear quite conspicuous with bright pink wings. The distinctive feature are the yellow metatibia (Fischer et al. 2016). Individuals make a rattling sound during the flight and males can fly up to several hundred meters far. The flight of males takes place wave-like and often in curves over the gravel bank. Regularly, they land only a few meters away from the launch site after several hundred meters of flight. Females fly almost exclusively in case of disturbance. They appear quite clumsy and fly only several meters, exceptionally 10 – 20 m far (Reich 1991b). *Bryodomella tuberculata* is a xerothermophile organism and appears on nearly vegetation-free pioneer habitats such as gravel banks along Alpine rivers or large-scale natural debris areas. Most habitats are characterized through rearrangement processes and floodings. These events prevent the advancing succession on gravel banks which decreases the habitat quality. In case high waters occur, new gravel banks are formed, and existing gravel banks are repositioned, whereby new habitats emerge. Floodings can lead to the occasional extinction of parts of the population. Therefore, the existence of a metapopulation is shaped by local extinctions of populations and resettlements through remaining populations on neighbouring gravel banks (Reich 1991a). The speckled grasshopper feeds on herbs and grasses. Females prefer for their oviposition gravel surfaces which have lacunar plant cover (Landmann and Zuna-Kratky 2016). Populations of this species have been declining over the last 100 years. Today, only a few big populations with a size of several hundred up to over thousands of individuals remain in Central Europe. All other populations are strongly isolated, appear on small areas, have small population sizes and therefore constitute relict occurrences (Reich 1990). In Austria, this species only occurs insular at rivers in North Tyrol (Zuna-Kratky et al. 2017). Regarding the Alpine range, large populations of *B. tuberculata* exist on the gravel banks of the Isar between Krün and Vorderriß, at the Friederlaine near Griesen and at the Lech near Forchach. Apart from that, smaller populations can be found at the Linder, Elmau, Neidernach, Rißbach, Pupplinger Au and at the Isar south of Mittenwald and north of the Sylvenstein reservoir (Reich 1990).

2.3.4 *Psophus stridulus* (Linnaeus, 1758)

Figure 9: *Psophus stridulus* male (Image from S. Hölscher)

The rattle grasshopper appears similar to the speckled grasshopper, although it is a bit smaller with males reaching a size up to 25 mm and females 38 mm. The basic colouration of male rattle grasshoppers is black and the one of females is grey, brown or brown-yellow (Figure 9). Only males are able to fly, that is when they show their bright orange-red wings. In contrary to the speckled grasshopper, the metatibia of the rattle grasshopper have a dark colour. The vocal expression is a rattling noise which is harder, louder and less melodic than the one of *Bryodomella tuberculata*. *Psophus stridulus* is a geophile species and has, other than the three grasshopper species from above, a broader variety of habitats. Its conservation status is not as critical as the other species because it is not strictly bound to the habitats of wild Alpine rivers. The habitats range from nutrient-poor grassland, sunny pine stands and Alpine meadows to rock- and raw soil habitats and gravel banks of Alpine rivers (Fischer et al. 2016). This species feeds mainly on leaves of herbs and requires spaces of open, bare ground for sunbathing and oviposition (Landmann and Zuna-Kratky 2016).

Table 2 lists the investigated four grasshopper species with their conservation status for some regions in the Alps, where populations still remain.

Table 2: Conservation status of four grasshopper species in selected countries (Fischer et al. 2016; Landmann and Zuna-Kratky 2016; Zuna-Kratky et al. 2017). 0 = extinct; 1 = critically endangered; 2 = endangered; 3 = vulnerable 4 = near threatened

Species	Austria	Switzerland	Germany	South Tyrol
Chorthippus pullus	2	1	1	1
Tetrix tuerki	2	1	1	1
Bryodemella tuberculata	2	0	1	0
Psophus stridulus	4	3	2	4

2.4 Data collection and processing

The first data collection took place from the 24th - 30th of July and the second from 27th - 29th of August 2018. These dates were selected to ensure investigations in the main appearance time frame of adult individuals of the grasshopper species. The gravel bank grasshopper for instance appears mainly in early summer and the speckled grasshopper end of August (Landmann and Zuna-Kratky 2016). In addition, these dates were chosen in consultation with the rangers of the Nature Park to avoid disturbing the incubation of the sandpiper *Actitis hypoleucos*. During the two investigation periods, the maximum daily air temperature ranged from 25 – 33°C and the minimum air temperature from 13 – 18°C (Accuweather 2019). Data collection was realised from mornings to afternoons when the weather was altogether sunny.

After visiting the sites in July together with the rangers of the Nature park Karwendel, the locations of the study plots were marked in aerial images. Findings of the speckled grasshopper by the rangers in summer 2017 were considered. Each plot has roughly the size 25 m × 50 m (1250 m²), minor changes were applied due to different terrain situations. Grasshopper species were counted by walking over the plots in a loop-like manner for around 30 minutes. For this, a hand net helped to flush hidden grasshoppers as well as a magnifier cup to identify species. Counted grasshoppers were noted into a tally as well as additionally for *Bryodemella tuberculata* the sex of detected individuals. Each located grasshopper was assigned to one waypoint in the GPS device. Apart from the search for grasshoppers on the 23 study plots, findings of the relevant grasshopper species along the river on the way to the study plots were also recorded. Data was collected with the Garmin GPSMap 60CSx and these GPX files were later transferred into the ESRI ArcGIS software. Then the attribute table of the grasshopper findings was adjusted in the ArcGIS software in a way to fit into the national fauna databank of the Tyrolean government.

Also, for the habitat characteristics, a precise datasheet was filled out, documenting the characteristics of vegetation, substrate types and the plot in general (Table 3). The mapping of the habitat characteristics and the mapping of the vegetation took place during the first investigation period from 24th – 27th of July 2018. The sheet concerning the habitat characteristics was based on the monitoring of ripicolous grasshoppers in the frame of the river Lech LIFE project to allow standardized methodology of species monitoring across different regions (Landmann 2017). The different characteristics describing the habitat on each plot are estimations. For measuring the max. height of vegetation and the height of plot centre over summer waterline, a measuring stick was utilised. Further features of the plots were noted in a "comment" field on the datasheet.

2.5 Vegetation mapping

For the vegetation mapping, plant species were identified by using the identification key Flora Helvetica (Lauber et al. 2018). The identified plant species and the estimated coverage were noted into a separate datasheet. The vegetation coverage was estimated through the original Braun-Blanquet scale (Braun-Blanquet 1964). In order to calculate the Evenness and the Shannon index, the values of the Braun-Blanquet scale were transformed into values of the mean percent coverage scale after Gigon et al. (2004). With these converted values, the Shannon's diversity index and the Evenness were calculated in Excel.

Plant associations, biotope types and Annex I habitat types of the EU Habitats Directive on each study plot were identified using the habitat identification key of the Tyrolean government (Tiroler Landesregierung 2018). To facilitate the classification into the habitat types of the different study plots, photographs of the specific areas were considered. If coverages of the vegetation mapping remained lower than 10%, plots were assigned to the habitat type "Alpine rivers and the herbaceous vegetation along their banks", BIK (biotope type) code WWG (Tiroler Landesregierung 2018). As soon as the coverages of the vegetation mapping of the lavender willow (*Salix elaeagnos*) and the purple willow (*Salix purpurea*) on the study plots exceeded 10%, the plots were assigned to early stages of the habitat types "Alpine rivers and their ligneous vegetation with *Salix elaeagnos*" (Code 3240) and "Alpine rivers and their ligneous

vegetation with *Myricaria germanica*" (Code 3230). The habitat type "Alpine rivers and their ligneous vegetation with *Salix elaeagnos*" is divided into the biotope type WWWO, lavender willow shrubbery, where *Salix elaeagnos* is at least sub-dominant and WWWP, purple willow shrubbery, where *Salix purpurea* dominates the trees and shrubs (Tiroler Landesregierung 2018).

Table 3: Datasheet on habitat characteristics filled out for each of the 23 plots. Based on (Landmann 2017).

Plot number:		
Date:		
Location:		
GPS Position:		
Vegetation cover	No vegetation	
	<10%	
	10-25%	
	25-50%	
	>50%	
Max. height of vegetation	<10cm	
	Up to 25cm	
	Up to 50cm	
	50-100cm	
	>1m	
Category of vegetation (in %)	Trees	
	Pioneer shrubs	
	Cushion plants	
	Herbs	
	Grass	
	Mosses	
Types of substrate (in %)	Rocks	
	Gravel	
	Grit	
	Sand	
	Deadwood	
	Fine sediment (moist)	
	Clay	
Distance from plot edge to (in m)	Waterline	
	Forest	
	Shrubs	
	Embankment	
Height of plot centre over summer waterline	<25cm	
	25-50cm	
	50-100cm	
	100-200cm	
	<200cm	

As *Salix elaeagnos* was always at least sub-dominant, the habitat type WWWP does not occur on the investigated study plots. Therefore, whenever the plots are allocated to the habitat type 3240, they are allocated to the biotope type WWWO.

Due to the furcation of the river, channels with sand and mud deposits which are frequently flooded are formed on the surfaces of the floodplain. Here, the plant association Juncetum alpino-articulati (Oberd. 57) Phil. 60 occurs on small areas and is closely interlinked with the associations Salicetum eleagni Jeník 1955 and Chondrilletum chondrilloides Moor 1958 (Werhonig 1997). As a pioneer society, Juncetum alpino-articulati colonises channel systems which are exposed to prolonged summer floods and are fed by pressurised water in times of low water levels. Mostly, these sites are represented by a high amount of sand (Müller and Bürger 1990). The species *Juncus alpinus, Carex flacca* and *Equisetum variegatum* are typical for this plant association (Braun 1970). Braun (1970) describes the ecology of this association as calcareous sand and silk in flood channels of rivers in the Alps.

2.6 Habitats of the Annex I Habitats Directive

Table 4: Summary of the EU habitat types and their characteristics, typical plant species of the herbaceous and shrub layer and plant associations (Ellmauer 2005) (Tiroler Landesregierung 2018)

Habitat type	Habitat characteristics	Herbaceous layer	Shrub layer	Plant associations
3220	Open vegetation of mosses, herbs and low-growing woody plants of less than 10% cover	*Arabis alpina, Bupthalmum salicifolium, Dryas octopetala, Hieracium piloselloides, Hutchinsia alpina, Linaria alpina, Petasites paradoxus*	*Salix eleagnos, Salix purpurea, Myricaria germanica*	Chondrilletum chondrilloides or Epilobietalia fleischeri Moor 1958
3230	Bushes reach a height from 2 – 4 m, herbaceous layer has a low coverage	*Agrostis stolonifera, Calamagrostis pseudophragmites, Campanula cochleariifolia, Dryas ocotopetala, Saxifraga aizoides, S. caesia* and *S. paniculata*	*Myricaria germanica, Alnus incana, Picea abies, Pinus sylvestris, Salix elegnos, Salix purpurea*	Myricario-Chondrilletum Br.-Bl. In Volk 1939 or Salici-Myricarietum Moor 1958
3240	*Salix eleagnos* grows 2 – 15 m high, herbaceous layer grows loosely	*Aegopodium podagraria, Eupatorium cannabinum, Petasites hybridus, P. paradoxus, Urtica dioica*	*Salix eleagnos, S. daphnoides, S. purpurea*	Salicetea purpureae Moor 1958 for type WWWP, Salicetum eleagni Jeník 1955 for type WWWO

Habitat type 3220 "Alpine rivers and the herbaceous vegetation along their banks" appears along the running waters of mountains. Especially weaker river currents promote the accumulation of gravel banks and the deposition of sands and silts. On these alluvions, floods occur regularly, usually in early summer. The rearrangement processes lead to a sparse vegetation consisting of pioneer plants and plants with high regenerative capacity. These specialised plants can resist floods and dry periods. The "Alpenschwemmlinge" are typical for this habitat type. Usually, the geology of the habitat type 3220 consists of limestone or dolomite, the soils are raw alluvial soils composed of gravel, sand and silt. Bird species like *Charadrius dubius* and *Actitis hypoleucos* breed on the gravel banks. The structure is shaped by the dynamics of the river and underlies strong alterations through floods. Deadwood, debris and channels repeatedly change the face of these alluvial habitats. If the flood frequency declines due to a deepening of the river or the accumulation of alluvions, succession proceeds and other habitat types develop. Firstly, the coverage of drought resistant plant species increases (e.g. *Rhacomitrium spp.*). Then, with advancing soil formation, plant associations with shrubs and forest species emerge (Ellmauer 2005).

Habitat type "Alpine rivers and their ligneous vegetation with *Salix elaeagnos*" with code 3240 develops on gravel banks of alpine rivers, where summer floods occur intermittently. These areas protrude above the mean waterline and are whelmed with sand or gravel from time to time. The drought-resistant willows *Salix eleagnos, S. daphnoides* and *S. purpurea* grow on fine-grained substrate. This habitat type mostly occurs on limestone or dolomite, but also silicate. Depending on the site characteristics, it either forms loose shrubbery, shrub forests or dense forests. Under favourable conditions, *Salix eleagnos* can grow 10 – 15 meters high. However, under dry conditions bushes grow 2 – 3 meters high. Between the bushes, the herbaceous layer grows loosely and contains several species of dry grasslands. If severe floods occur, this habitat type can degrade to habitat type 3220 (Ellmauer 2005).

Finally, habitat type "Alpine rivers and their ligneous vegetation with *Myricaria germanica*", a species from the Tamaricaceae family, emerges on gravel banks at river segments with low flow rates, where fine sediments are deposited. *Myricaria germanica* requires a high ground-water table throughout the year. This habitat type depends on regular floods to avoid further successional stages. For germination, the tamarisk needs full light conditions. If soils dry out over a longer period, the tamarisk is not able to rejuvenate. The quality and extension of these habitat types have been decreasing over the last decades and are therefore threatened in Austria. Hydraulic engineering measures, the establishment of hydro power, gravel withdrawal and recreational use contributes to the degradation of these habitats (Ellmauer 2005).

2.7 Statistical Analysis

The parameters from the datasheet on habitat characteristics build up the independent variables. Before starting the statistical analysis, the independent variables "Trees", "Clay", "Distance from plot edge to shrubs", "Distance from plot edge to embankment" were excluded due to insufficient data. The estimated values of the independent variables "Height of plot centre over summer waterline" and "Max. height of vegetation" were transferred into numeric values to facilitate the statistical analysis (Table 5).

Table 5: Transformation of the estimated values of the two variables "Height of plot over summer waterline" and "Max. height of vegetation" into numeric classes

Numeric value	Height of plot over summer waterline	Max. height of vegetation
1	<25cm	<10cm
2	25-50cm	Up to 25cm
3	50-100cm	Up to 50cm
4	100-200cm	50-100cm
5	<200cm	>1m

The estimated values of the categories "Trees", "Pioneer shrubs", "Cushion plants", "Herbs", "Grass" and "Moss" were added up and summarized into an additional variable "Total vegetation cover". This variable replaced the variable "Vegetation cover" from the datasheet on habitat characteristics, as it appeared to be a more precise information of the total vegetation cover on each plot.

For the statistical analysis, the abundances of the species *Bryodemella tuberculata, Chorthippus pullus, Tetrix tuerki* and *Psophus stridulus* were tested against 18 independent variables. Additionally, for *Bryodemella tuberculata*, analysis for females and males were carried out to detect gender related differences of habitat preferences. The final list of independent variables can be taken from Table 6.

Table 6: List of 18 independent variables for the multiple linear regressions

Independent variables
Pioneer shrubs
Cushion plants
Herbs
Grass
Moss
Total vegetation cover
Rocks
Gravel
Grit
Sand
Deadwood
Fine sediment (moist)
Vegetation evenness
Max. height of vegetation
Height of plot centre over waterline
Elevation
Distance from plot edge to waterline
Distance from plot edge to forest

A dummy variable 0 for the first investigation and 1 for the second investigation was added to increase the dataset from 23 to 46 observations. To test for the effects of the independent variables on the abundance of detected grasshoppers, multiple linear

regressions for each grasshopper species were calculated with the statistic programme RStudio version 1.0.136. Before calculating the multiple linear regressions, a stepwise model selection by AIC was conducted in RStudio using the MASS package (Venables and Ripley 2002). Models were selected by applying first the backward selection and then the selection in both directions. Then, multiple linear regressions were computed with the remaining independent variables from the selection processes. The significance level was set at $p \leq 0.05$. Collinearities between the various independent variables were detected by calculating the collinearity diagnosis with the programme IBM Statistics SPSS Version 24. Further, bivariate correlations after Pearson helped to explain multicollinearity. After the backward and stepwise model selection processes, some collinearities between independent variables remained. Whenever the variance inflation factors were too high (> 10), an additional selection of independent variables by educated guess was conducted. Therefore, best model fits remained with minimized collinearity between the independent variables.

3. Results

3.1 Vegetation

The assignment of the different plots to the habitat types of the EU Habitat's Directive, the number of plant species, the plant species Evenness and special features can be taken from Table 7. The investigation of vegetation on the study plots resulted in highest plant species richness on plot number 4 with a total count of 26 species. On contrary, the lowest counts of plant species of 11 were detected on plots 7 and 9. On study plots number 7 and 9, the lowest values for evenness can be found. Here, the species *Atocion rupestre* for plot 7 and *Salix eleagnos* for plot 9 dominate all other plant species. Highest values for the vegetation evenness were calculated on plot 13, where all 15 detected plant species show consistent coverage values.

Table 7: Number of detected plant species, Evenness, EU Habitat's Directive habitat types and special features for the vegetation on the 23 study plots

Plot	Number of plant species	Evenness (E)	Habitat type code	Special features
1	21	0.54	3220	Mixed with Juncetum alpino-articulati
2	15	0.64	3220	
3	15	0.53	3220	Mixed with Juncetum alpino-articulati, *Calamagrostis pseudophragmites*
4	26	0.50	3230	*Myricaria germanica* >20cm & >1% coverage*, Calamagrostis pseudophragmites*
5	15	0.49	3220	
6	21	0.64	3220	*Calamagrostis pseudophragmites*
7	11	0.26	3220	
8	16	0.42	3220	*Calamagrostis pseudophragmites*
9	11	0.42	3220	*Myricaria germanica <1%*
10	12	0.26	3220	*Myricaria germanica <1%*
11	13	0.53	3220	Mixed with Juncetum alpino-articulati, *Calamagrostis pseudophragmites*
12	19	0.55	3220	
13	15	0.72	3220	Mixed with Juncetum alpino-articulati
14	14	0.41	3220	Mixed with Juncetum alpino-articulati
15	20	0.61	3220	
16	20	0.59	3220	
17	16	0.47	3220	*Calamagrostis pseudophragmites*
18	14	0.59	3240	
19	15	0.66	3240	
20	16	0.70	3240	
21	16	0.62	3240	Mixed with Juncetum alpino-articulati
22	15	0.58	3220	
23	13	0.47	3240	

The endangered and rare plant species *Calamagrostis pseudophragmites* appeared on study plots 3, 4, 6, 8, 11 and 17. Further, larger specimen of the indicator species *Myricaria germanica* were found on plot 4, and smaller specimen on plots 9 and 10. The dominant habitat type on the study plots was the Annex I habitat type "Alpine rivers and the herbaceous vegetation along their banks", code 3220. Early stages of the habitat type "Alpine rivers and their ligneous vegetation with *Salix elaeagnos*" occurred on the study plots 18, 19, 20, 21 and 23. Only on plot number 4, the habitat type "Alpine rivers and their ligneous vegetation with *Myricaria germanica*" appeared with the plant association Salici-Myricarietum. Here, the two individuals of *Myricaria germanica* were > 20 cm tall and made up a coverage of > 1 % (Figure 10). The plant associations of the study plots 18, 19, 20, 21 and 23 were allocated to the Salicetum eleagni. All other plant associations of the habitat type "Alpine rivers and the herbaceous vegetation along their banks" were assigned to the Chondrilletum chondrilloides Moor 1958, even though the characteristic *Chondrilla chondrilloides* could not be detected on the plots along river Rißbach. However, combinations of species of the "Alpenschwemmlinge" and the ecology of this habitat enabled the assignment to this plant association. "Alpenschwemmlinge" like *Campanula cochleariifolia, Dryas octopetala* and *Saxifraga caesia* appeared often and with high coverage values. *Leontopodium nivale* and *Atocion rupestre* were also found on some of the study plots (Figure 11).

Figure 10: *Myricaria germanica* on study plot 4

Values for the total vegetation cover on all plots never exceeded 60%. Plots 20 and 21 reached with 60% highest values for total vegetation cover. Although the plant associations Salicetum eleagni and Chondrilletum chondrilloides dominated the plots, the third plant association Juncetum alpino-articulati (Oberd. 57) Phil. 60 was detected on some smaller wetter areas of the study plots or alongside channels, puddles and creeks. On study plots 1, 3, 11, 13, 14 and 21 plant species like *Juncus alpinus, Equisetum variegatum, Carex flava, Carex flacca* and *Molinia caerulea* indicated the occurrence of small areas of the association Juncetum alpino-articulati (Figure 12).

Figure 11: "Alpenschwemmlinge" *Dryas octopetala* (left picture) and *Campanula cochleariifolia* (right picture) (Pictures from E. Pfeuffer)

These transition zones of Juncetum alpino-articulati seemed to attract the species *Tetrix tuerki*, as it prefers the muddy and wetter areas of the gravel banks. Also, *Chorthippus pullus* was often found sitting in this plant association, probably because it provides many different grass species to feed on. *Psophus stridulus* individuals were almost entirely detected outside the study plots. This reflects the differences between the habitat of *Psophus stridulus* and the three other grasshopper species. *Psophus stridulus* was often found further away from the waterline, at the edges of the gravel banks on heightened habitats. These habitats are denser vegetated with grasses and are represented by the plant association Erico carneae-Pinetum prostratae Zöttl 51 (Werhonig 1997). *Bryodemella tuberculata* was largely found on plots which were represented by the habitat type "Alpine rivers and their ligneous vegetation with *Salix elaeagnos*". Here, on plots 18, 19 and 20, most counts of *B. tuberculata* individuals were noted. Nevertheless, numerous individuals were also detected on plots of the habitat types "Alpine rivers and the herbaceous vegetation along their banks" and "Alpine rivers and their ligneous vegetation with *Myricaria germanica*". In conclusion, the habitats of the four investigated grasshopper species are represented by the habitat types 3220, 3230 and 3240 of the EU Habitats Directive.

Figure 12: Transition zone of plant association Juncetum alpino-articulati and Chondrilletum chondrilloides and Salicetum eleagni

3.2 Detected grasshoppers

During the first investigation period between the 24th – 30th of July 2018 a total of 228 grasshoppers were counted along the gravel banks of river Rißbach. 120 out of these 228 grasshoppers were detected on the 23 study plots. At the second investigation period between the 27th – 29th of August 2018, a total of 149 grasshoppers were found along the Rißbach, of which were a total of 113 grasshoppers found on the 23 study plots. Figure 13 displays the counted grasshoppers within the 23 study plots as well as the total count of grasshoppers, including the observations outside from the study plots. Almost twice as many total findings of all grasshopper species could be noticed during the first investigation at the end of July. Especially the species *Chorthippus pullus* and *Psophus stridulus* could be found more often during the first investigation.

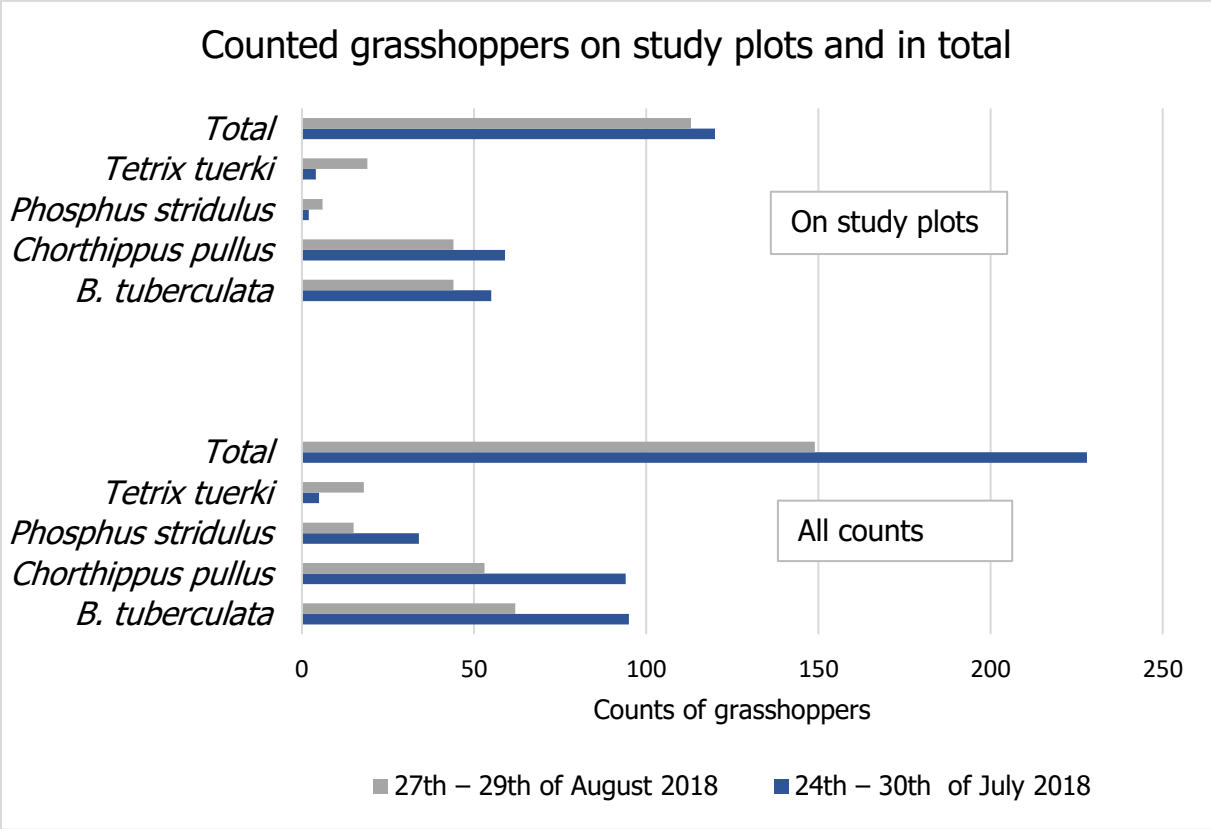


Figure 13: Number of detected grasshoppers on the 23 study plots (above) and counted grasshoppers in total, including the observations outside the study plots (below)

3.3 Statistical Analysis

All four target species could be detected on the investigated plots. The speckled grasshopper could be found on 17 out of 23 plots. As the habitat requirements of the rattle grasshopper do not totally comply with the characteristics of the investigated habitats, this species could be only found on 3 out of 23 plots. The gravel bank grasshopper was the most prevalent species, as it occurred on 18 out of 23 plots. The smallest grasshopper, the alpine ground hopper, was spotted on 9 out of 23 plots.

3.3.1 *Bryodemella tuberculata*

At the first investigation at the end of July 2018, a total of 55 speckled grasshoppers were detected. The findings consisted of 14 females and 41 males which results in a gender distribution of 1 : 2.93. The second investigation at the end of August 2018 resulted in altogether 44 counted speckled grasshoppers. This number is split into 15 females and 29 males, which generates a ratio of 1 : 1.93.

For the multiple linear regression testing for the effects of independent variables on *Bryodemella tuberculata* abundance, the selection processes by AIC excluded 6 out of 18 variables from the multiple linear regression model. Additionally, the variables "Pioneer shrubs, Cushion plants and Moss" were excluded from the model, as the collinearity statistics revealed high collinearities between these variables and the variable "Total vegetation cover". After subtracting these variables, 9 independent variables remained in the model. The multiple linear regression testing for the effects of 9 independent variables on *Bryodemella tuberculata* abundance achieved a significant level ($r^2_{multiple}$ = 0.5754, $r^2_{adjusted}$ = 0.4692, p = 0.000107). The output in Table 8 indicates that significant more individuals of *Bryodemella tuberculata* occurred on plots with a lower grass cover ($p \leq 0.01$) and a higher total vegetation cover ($p \leq 0.001$).

In a next step, statistical analysis was separately carried out for females and males of *Bryodemella tuberculata*. To avoid collinearities between the variables in the model for speckled grasshopper females, the variable "Moss" was additionally excluded after the selection processes. The multiple linear regression testing for the effects of 9 independent variables on the abundance of females of *Bryodemella tuberculata* showed a significant result ($r^2_{multiple}$ = 0.5429, $r^2_{adjusted}$ = 0.4286, p = 0.0003355). The results revealed that female individuals prefer plots with a higher total vegetation cover ($p \leq 0.01$) as well as plots which were located in farer distance to the forest ($p \leq 0.05$) (Table 9).

Table 8: Output of multiple linear regression model testing the counts of *Bryodemella tuberculata* on the plots against 9 independent variables (*p ≤ 0.05, **p ≤ 0.01 ***p ≤ 0.001)

	Coefficient	Std. error	t-statistic	p-value
(Intercept)	10.504260	12.770547	0.823	0.416186
Total vegetation cover	0.192887	0.046939	4.112	0.000217***
Grass	-0.362922	0.107628	-3.372	0.001795**
Distance to forest	0.007268	0.005648	1.287	0.206313
Herbs	-0.132269	0.201429	-0.657	0.515578
Elevation	-0.010371	0.011993	-0.865	0.392874
Height of plot centre	-0.881329	0.614453	-1.434	0.160108
Fine sediment	0.21942	0.048061	0.457	0.650741
Evenness	-0.210094	4.330418	-0.049	0.961573
Grit	0.024494	0.030158	0.812	0.422014

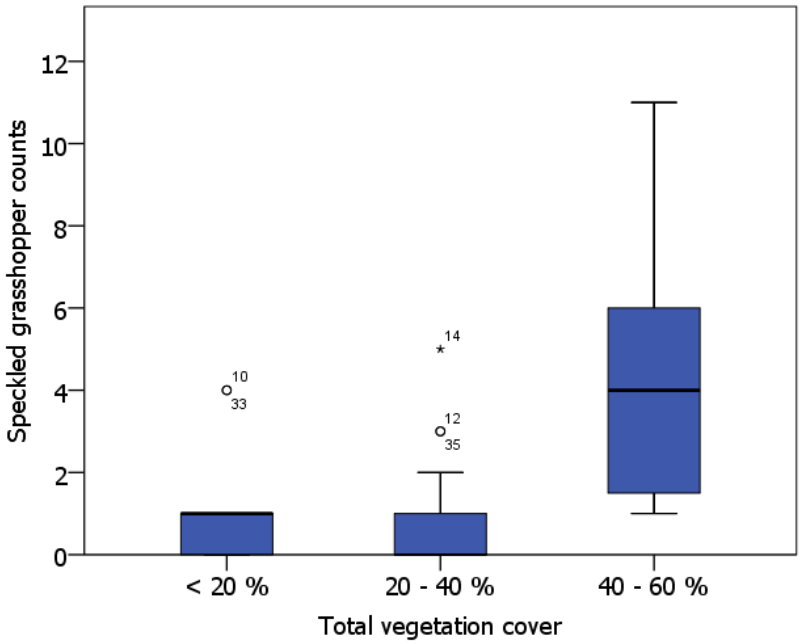


Figure 14: Boxplot of speckled grasshopper abundance and total vegetation cover classes (%)

Table 9: Output of multiple linear regression model testing the abundance of *Bryodemella tuberculata* females against 9 independent variables (*p ≤ 0.05, **p ≤ 0.01 ***p ≤ 0.001)

	Coefficient	Std. error	t-statistic	p-value
(Intercept)	6.415358	4.042529	1.587	0.12127
Total vegetation cover	0.053375	0.015787	3.381	0.00175**
Distance to forest	0.005682	0.002201	2.582	0.01405*
Elevation	-0.007882	0.003978	-1.981	0.05524
Fine sediment	-0.024791	0.015448	-1.605	0.11728
Rocks	-0.016783	0.012146	-1.382	0.17557
Grass	-0.040604	0.038864	-1.045	0.30309
Distance to water	0.012221	0.014454	0.846	0.40340
Evenness	0.614393	1.580883	0.389	0.69983
Grit	-0.002989	0.011601	-0.268	0.79814

The multiple linear regression testing for the effects of 3 independent variables on the abundance of males of *Bryodemella tuberculata* showed a significant result ($r^2_{multiple}$ = 0.3775, $r^2_{adjusted}$ = 0.333, p = 0.0001595). After the model selection processes, there were no collinearities between the independent variables detected, therefore all 3 variables remained in the model. The results showed that males significantly preferred plots with a higher total vegetation cover (p ≤ 0.001) and a lower grass cover (p ≤ 0.001) (Table 10).

Table 10: Output of multiple linear regression model testing the abundance of *Bryodemella tuberculata* males against 3 independent variables (*p ≤ 0.05, **p ≤ 0.01 ***p ≤ 0.001)

	Coefficient	Std. error	t-statistic	p-value
(Intercept)	-0.64011	0.74617	-0.858	0.395837
Total vegetation cover	0.08662	0.01857	4.665	$3.14e^{-05}$***
Grass	-0.22165	0.06148	-3.605	0.000821***
Distance to water	0.04114	0.03857	1.440	0.157301

3.3.2 *Chorthippus pullus*

The stepwise selection process by AIC included 13 independent variables in the multiple linear regression model testing for the effects of the variables on *Chorthippus pullus* abundance. The collinearity statistics displayed high collinearities between the variables, hence a model without the variable "Deadwood" was chosen. Hereby, collinearities were reduced, and 12 independent variables remained in the model. The multiple linear regression testing for the effects of 12 independent variables on *Chorthippus pullus* abundance achieved a significant level ($r^2_{multiple}$ = 0.6582, $r^2_{adjusted}$ = 0.5339, p = $6.789e^{-05}$). The output can be seen in Table 11. This species seemed to prefer plots which were in nearer distance to the waterline (p ≤ 0.01). Concerning the substrate-related predictors, the gravel bank grasshopper favoured plots with a higher rock (p ≤ 0.01), a higher grit (p ≤ 0.01), a higher gravel (p ≤ 0.01) and moist fine sediment (p ≤ 0.01) coverage. Regarding the vegetation predictors, more gravel bank grasshoppers could be found on plots with a higher evenness value (p ≤ 0.05), a higher coverage of herbs (p ≤ 0.01) and moss (p ≤ 0.05). Furthermore, *Chorthippus pullus* occurred to a higher rate on plots with a lower height of the plot centre over the waterline (p ≤ 0.05).

Table 11: Output of multiple linear regression model testing the abundance of *Chorthippus pullus* against 12 independent variables (*p ≤ 0.05, **p ≤ 0.01 ***p ≤ 0.001)

	Coefficient	Std. error	t-statistic	p-value
(Intercept)	-9.089455	5.077718	-1.790	0.08262
Distance to waterline	-0.125975	0.035008	-3.598	0.00103**
Fine sediment	0.165014	0.046310	3.563	0.00114**
Rocks	0.144358	0.040686	3.548	0.00119**
Gravel	0.122692	0.042525	2.885	0.00684**
Herbs	0.538777	0.193448	2.785	0.00879**
Grit	0.148806	0.044883	3.315	0.00223**
Evenness	8.977563	3.681847	2.438	0.02030*
Moss	0.457281	0.196145	2.331	0.02599*
Height of plot centre	-1.114207	0.532636	-2.092	0.04422*
Total vegetation cover	-0.091542	0.046039	-1.988	0.05512
Sand	0.110014	0.057635	1.909	0.06502
Distance to forest	-0.009731	0.005420	-1.795	0.08177

3.3.3 *Tetrix tuerki*

The multiple linear regression testing for the effects of 6 independent variables on *Tetrix tuerki* abundance achieved a significant level ($r^2_{multiple}$ = 0.3226, $r^2_{adjusted}$ = 0.2184, p = 0.01412). In this regression model, there were no collinearities between the 6 variables detected. All independent variables therefore remained in the linear regression model. The output can be seen in Table 12. The alpine groundhopper significantly preferred plots with a higher coverage of rocks ($p \leq 0.01$), pioneer shrubs ($p \leq 0.05$) and herbs ($p \leq 0.05$). Additionally, *Tetrix tuerki* occurred along Rißbach on more plots at a higher elevation ($p \leq 0.01$).

Table 12: Output of multiple linear regression testing the counts of *Tetrix tuerki* against 7 independent variables (*p ≤ 0.05, **p ≤ 0.01 ***p ≤ 0.001)

	Coefficient	Std. error	t-statistic	p-value
(Intercept)	-13.581580	4.846852	-2.802	0.00786**
Rocks	0.039940	0.013440	2.972	0.00505**
Elevation	0.015088	0.005312	2.840	0.00712**
Pioneer shrubs	-0.111633	0.041826	-2.669	0.01103*
Herbs	-0.215521	0.088297	-2.441	0.01930*
Fine sediment	0.028797	0.014929	1.929	0.06104
Total vegetation cover	0.028735	0.017336	1.658	0.10544

3.3.4 *Psophus stridulus*

For this linear regression model, the variables "Pioneer shrubs" and "Grit" were excluded from the model to avoid collinearities between the variables. The multiple linear regression testing for the effects of 9 independent variables on *Psophus stridulus* abundance showed no significant result ($r^2_{multiple}$ = 0.2008, $r^2_{adjusted}$ = 0.0009744, p = 0.4541). The output of this multiple linear regression can be taken from Table 13.

Table 13: Output of multiple linear regression testing the counts of *Psophus stridulus* against 9 independent variables (*p ≤ 0.05, **p ≤ 0.01 ***p ≤ 0.001)

	Coefficient	Std. error	t-statistic	p-value
(Intercept)	-1.0395901	0.8614137	-1.207	0.235
Deadwood	0.0014730	0.0179294	0.082	0.935
Evenness	-0.1429832	1.1324265	-0.126	0.900
Fine sediment	-0.0049319	0.0092959	-0.531	0.599
Total vegetation cover	-0.0096821	0.0190036	-0.509	0.614
Gravel	0.0009087	0.0099001	0.092	0.927
Moss	0.967100	0.0856257	1.129	0.266
Height of plot centre	0.3154469	0.2103986	1.499	0.143
Rocks	0.0091098	0.0106902	0.852	0.400
Sand	0.0188932	0.0143585	1.313	0.197

4. Discussion

4.1 *Bryodemella tuberculata*

In general, more males than females could be counted along river Rißbach. This can be explained by the cautious behaviour of females, who were harder to find as they tend to hide and show lower activity than the males. The first investigation from 24th – 27th of July 2018 found a gender ratio of 1 : 2.93. The second investigation from 27th - 29th of August 2018 showed a ratio of 1 : 1.93. These ratios reflect the statement of Reich (1991b) that the further the summer proceeds, the more females appear. This can be explained through the higher mortality of males and the higher life expectancy of females.

Typical habitat of *Bryodemella tuberculata* at river Rißbach can be seen in Figure 15. As succession on the gravel banks proceeds, a sparse pioneer vegetation develops which offers *B. tuberculata* a favourable microclimate and food. This habitat is gradually lost with increasing shrub encroachment (Reich et al. 1994). Whereas Reich (1991a) states that the abundance of *B. tuberculata* decreased on older and elevated locations of the gravel banks with vegetation covers of 25 – 50 %, the findings at the Rißbach show, that this species significantly preferred gravel banks with higher vegetation coverage ($p \leq 0.001$). The sites at the Rißbach with highest abundances of speckled grasshoppers were classified as early stages of the habitat type "Alpine rivers and their ligneous vegetation with *Salix elaeagnos*" and the plant association Salicetum eleagni as well as "Alpine rivers and the herbaceous vegetation along their banks" and

Figure 15: Typical habitat of *Bryodemella tuberculata* at the Tyrolean part of the Rißbach. Here, the habitat type "Alpine rivers and the herbaceous vegetation along their banks" occurs on plot 22.

the plant association Chondrilletum chondrilloides with vegetation coverages of 40 – 60 % (Figure 14). Nonetheless, individuals of the speckled grasshopper also occurred on sites with vegetation covers of 10 – 30 %. These findings agree with Reich (1990), where sites of *B. tuberculata* could be assigned to the Myricario-Chrondrilletum chondrilloidis and transitions to the Salici-Myricarietum, as well as at some sites at Friedergries as light stages of Salicetum eleagni. At the Rißbach, gravel banks with low vegetation cover were preferably occupied by male individuals. As low vegetation cover indicates a higher frequency of floods, the occurrence on these gravel banks might be too risky for the less mobile females. These findings correspond with the statement by Reich (1990), that areas which are strongly vegetated, completely vegetation-free or often flooded are only used sporadically and that reproduction does not take place on these areas. The lower, often flooded channels of the gravel banks are occasionally occupied by males for sunbathing (Reich 1990).

An explanation of higher abundances of the speckled grasshopper on denser vegetated areas of the gravel banks at the Tyrolean part of the Rißbach could be that these gravel banks are located at the upper and middle course of the river. Here, the gravel banks are more strongly interconnected than the gravel banks at the lower course of the Tyrolean part of the Rißbach. With proceeding succession, some of these gravel banks become uninhabitable, but at the same time, floods create new gravel banks and relocate existing gravel banks. The metapopulation of *B. tuberculata* can survive if these processes are balanced out and losses of subpopulations can be compensated with resettlements of subpopulations (Reich et al. 1994). These extinction and resettlement processes are better developed at the upper and middle course of the Tyrolean part of the Rißbach than at the lower course of the river up to "Oswaldhütte", where gravel banks are strongly separated from each other. Even though the gravel banks at the upper course of the Rißbach are more densely vegetated, their maximum position over the summer water line (at around 100 – 200 cm) ensures their occasional inundation and therefore the preservation of suitable habitats. A comparison of pictures of the study plots 6 and 21 show how the total vegetation cover increased from the Northern segments to the Southern segments of the river (Figure 16).

Still, the species requires gravel banks with open patches as oviposition occurs on gravelly areas free of vegetation. Here, the eggs are positioned several centimetres deep into the moist sand underneath the gravel (Reich 1990). This probably also

Figure 16: Study plot number 6 on the left side is less densely vegetated than study plot 21 on the right side.

explains the finding, that female individuals at the Rißbach significantly preferred plots which are in farther from forests, as areas closer to forests resulted in less suitable areas for oviposition. The results taken from the multiple linear regression showed that more *Bryodemella tuberculata* individuals could be found on plots with a lower grass cover. This displays the habitat preferences of this species, as it occurs rather on gravel banks which are characterized by plant associations of the Chondrilletum chondrilloides and Salicetum eleagni. These plant associations are not typical for high abundances of grass species. A high cover of grass species can indicate the appearance of the plant association Juncetum alpino-articulati, which often borders with the plant associations of the Salici myricaetum or Chondrilletum chondrilloides and is rather avoided by the speckled grasshoppers.

The metapopulation of *Bryodemella tuberculata* at the Tyrolean part of the Rißbach is divided into several small subpopulations, where each subpopulation occupies one gravel bank range. Subpopulations exist on gravel banks of plots 10 – 22, as only here, female individuals could be detected. Observations of male *B. tuberculata* on plots 4 – 10 and 23 represent marginal sites. Males have probably flown to these edge areas to scout them out since they can fly over extended distances and have home ranges of 5000 m² and more (Reich 1991a). A resettlement of subpopulations on these gravel banks is only possible if females also occur, as they oviposit (Reich et al. 1994). Females fly much shorter distances than males, move primarily by walking, and inhabit home ranges of around 500 m², although ranges of up to 1600 m² have been recorded (Reich 1991a). The edging gravel banks at the Rißbach can therefore only be populated by females if watercourses between gravel banks dry up, or if dense vegetation is overcome. Hence, new gravel banks will only be colonized intermittently (Reich 1991a). Between the subpopulations on gravel banks of plots 10 – 22 at the middle and upper course of the Tyrolean part of the Rißbach, an at least irregular genetic exchange seems likely. Gravel banks are close to each other and barriers can be overcome occasionally. Two individual females could be observed while "swimming" through small streams. Although this was expressed by a combination of drifting and kicking into the water, these observations suggest that females can overcome small creeks between gravel banks (Figure 17).

Findings of male *B. tuberculata* on plots 4 – 10 and 23 could also indicate the presence of subpopulations on these gravel banks. Perhaps female individuals were just not found in the frame of this investigation. If this was the case, the genetic exchange between the local subpopulations 4 – 5 and the subpopulation 6 would occur extremely rarely. Between these subpopulations lie around 2.5 km of gorge-like river segments which are only overcome very infrequent for example through accidental drifting (Reich, pers. comm.). On study plots 1 – 3, no single individual of *B. tuberculata* could be detected. These gravel banks are probably unsuitable as they are strongly separated from the other gravel banks and too far away from the other subpopulations to be settled. Since the Tyrolean part of the river is separated from the Bavarian part of the river by a dam at "Oswaldhütte", it can be assumed that along river Rißbach, two metapopulations of *Bryodemella tuberculata* exist. One metapopulation occurs at the Tyrolean part of the Rißbach, from the south at "Hagelhütte" to the border at "Oswaldhütte" and one at the Bavarian part of the Rißbach from "Oswaldhütte" to the mouth of the Isar. This assumption is strengthened by the fact that a stretch of about 10 km lies between the findings of *B. tuberculata* in the frame of this investigation at

the Tyrolean part of the river and the findings of *B. tuberculata* at the Bavarian part of the river of M. Schödl in 2016. Therefore, genetic exchange between these two metapopulations is extremely unlikely. Accidental drifting of individuals would probably fail in most cases due to predation by river trout, drowning, or misplacement in unsuitable habitats. An exchange between these metapopulations could therefore be successful perhaps once in 100 years (Reich, pers. comm.).

The abundance of *Bryodemella tuberculata* on the areas where restoration measures were carried out in the years 2012 – 2014 confirms the success of these conservation efforts. At the first restoration measure area, one individual of *B. tuberculata* could be found directly on the measure area, and one individual in immediate vicinity of the measure area. At restoration area two, 2 speckled grasshoppers were found directly on the measure area in between the plots 13 and 14, and 2 individuals in the nearer distance of the measure area on plot 13. The removal of the gravel rampart had presumably a positive impact on the occurrence of the species, as river dynamics were restored. 31 individuals of *B. tuberculata* could be detected at measure area three around plot 18. As a larger subpopulation of *B. tuberculata* is located here, this restoration measure was most likely beneficial for the habitat quality of this species. After the removal of the gravel rampart, the dynamics of the river were restored, and therefore grain sizes and sediment structure diversified. This led to an improvement of the habitat characteristics as diversified substrate structures are more advantageous for the habitat demands of the species than areas made up by big boulders and rocks. The higher amount of fine sediment probably had a positive impact on the oviposition.

Figure 17: An individual *Bryodemella tuberculata* female "swimming" in a little stream, then arriving on the gravel bank

4.2 *Chorthippus pullus*

More gravel bank grasshoppers appeared at the first investigation period end of July. 59 individuals of *Chorthippus pullus* could be detected during the first investigation period on the study plots (94 individuals in total including observations outside the study plots) and 44 individuals (53 individuals in total including observations outside the study plots) during the second investigation period. This result confirms the research by Landmann and Zuna-Kratky (2016), which state that the gravel bank grasshopper appears mainly in early summer.

The gravel bank grashoppers prefer open and sparsely vegetated areas. These areas dominated by rock, gravel and grit strongly heat up during the day. Investigations of Schwarz-Waubke (1997) showed that areas without vegetation warm up quickly, as gravel absorbs and stores the heat. Thereby, temperatures at noon and afternoon reached higher values on open areas dominated by gravel than surrounding areas with higher vegetation density. Temperatures at open gravel areas got extremely high with an average of 30 – 32 °C, reaching a maximum of almost 40°C. *Chorthippus pullus* seemed to prefer these stony, sunny habitats (Schwarz-Waubke 1997). These findings are also reflected by the results at river Rißbach, where gravel bank grasshoppers favoured plots with a high rock, grit and gravel coverage, because of the mentioned microclimatic conditions (Figure 18).

Figure 18: *Chorthippus pullus* on rocky, sunny habitat

Schwarz-Waubke (1997a) discovered that in the field the gravel bank grasshopper mostly fed on the grass families Poaceae and Cyperaceae and also to some amount on moss. At the Rißbach, the species seemed to prefer plots with a higher coverage of moist fine sediment. Areas with high, moist, fine sediment coverage were often related to the plant association Juncetum alpino-articulati, which occurred on the muddy and wet areas of the gravel banks. Here, the gravel bank grasshopper finds grass species like *Molinia caerulea* and *Carex* spp. to feed on. The preference of plots with higher evenness values indicates that the grasshoppers choose areas with a higher diversity of plant species over areas covered with one dominating plant species. Probably because the former provides a larger variety of grass species to feed on. A significant preference of plots with a higher coverage of herbs and moss underlines the fact that this species requires aside from the warm, open and stony habitats also habitats with some vegetation to feed on. However, the degree of vegetation cover seems to not clearly explain the habitat preferences of this species, as the vegetation cover at sites of *Chorthippus pullus* in Austria varies considerably (Zuna-Kratky et al. 2017). The availability of open, sunny, and stony habitats appears to be of greater importance for the occurrence of the gravel bank grasshopper.

Schwarz-Waubke (1997b) states that the attachment of *Chorthippus pullus* to wild river landscapes is not related to the water itself but the sparsely vegetated habitat which is created by the river dynamics. Here, habiats with mostly stony surfaces create a favourable hot and dry microclimate. With advancing succession, these habitats

disappear. Significantly more individuals of *Chorthippus pullus* were found at lower heights of the plot centre over the waterline at river Rißbach. An explanation for this could be that these habitats are more frequently flooded than the habitats which are located higher above the summer waterline. This frequently inundation leads to the maintenance of open and gravelly habitats, which the gravel bank grasshopper prefers.

4.3 *Tetrix tuerki*

Zuna-Kratky et. al (2017) describe the habitat preferences of *Tetrix tuerki* as a variable mosaic of the substrates gravel, grit and sand. It favours the fine sediments in cool and humid hollows (Zuna-Kratky et al. 2017). This study's result that the species prefers rocky areas at the river Rißbach strengthens the fact that observations of *Tetrix tuerki* individuals were made at their favoured habitat, namely along little creeks framed with muddy fine sediment (Figure 19). These areas are composed of small low streams with high amounts of moist fine sediment and high amounts of rocks obstructing the flow. Additionally, they are vegetated by grasses like *Carex flava* and *Molinia caerulea* and smaller specimens of *Salix eleagnos.* A part of its diet contains of alges and mosses, which occur on these wet zones of the gravel bank (Roesti and Rutschmann 2018). In the case that predators appear, the alpine groundhopper can quickly dive into the water and swim away or hide under water. The preference of these areas with higher moist fine sediment coverage is not statistically significant, but still worth mentioning in this context.

Although this species was mostly found along the little creeks on the gravel bank, the results of the statistical analysis show that is was also detected on gravel banks with a higher cover of pioneer shrubs and herbs. Whenever *Tetrix tuerki* individuals were observed outside the small creeks desribed above, they sat on areas of the gravel banks with higher coverages of pioneer shrubs and herbs, probably to feed on them. These observations match to the ones from T. Kopf at Pinswang and B. Keist at the Lech, where *Tetrix tuerki* was found on places with quite dense vegetation (Zuna-

Figure 19: Habitat of *Tetrix tuerki* at river Rißbach. Little creeks flow through the gravel banks (left) and create muddy areas with moist fine sediment, mosses and grasses (right).

Kratky et al. 2017). Also, significantly more *Tetrix tuerki* individuals could be found on plots which were located at higher elevation above sea level. According to Zuna-Kratky et al. (2017), 73% of all findings of the alpine groundhopper in Tyrol were made between 600 and 1000 m. Only some single findings were made at 1224 m, 1330 m and 1380 m. In Switzerland, *Tetrix tuerki* could be detected at elevations up to 2000 m (Zuna-Kratky et al. 2017). Along river Rißbach, the alpine groundhopper showed up between 953 m and 1072 m which therefore lies in its usual range. An explanation for more individuals located at higher elevations could be that perceptional more suitable habitats of little creeks with fine sediment were available in the Rißbachs upper and middle course. *Tetrix tuerki* individuals are extremely unconspicous, which might be an explanation for the very few observations of this species on the study plots.

4.4 *Psophus stridulus*

According to Reich (1991a), *Psophus stridulus* replaces *B. tuberculata* and *Chorthippus pullus* on the gravel banks with a vegetation cover of 50 % or more. At the Rißbach, they seemed to prefer areas which were elevated, farer away from the river and denser vegetated than the habitats of gravel banks with sparse vegetation. Zuna-Kratky et al. (2017) describe the habitat of *Psophus stridulus* characterized by bare patches, e.g. on embankments (often on sunny forest paths), in neglected grasslands and especially in stony pastures. The species also appears on dry grasslands, fossil pine meadows and dry pine forests (Zuna-Kratky et al. 2017). This classification would be suitable for its occurrence at the floodplain of the Rißbach, as their favoured habitats could here be characterized by the plant association of dry pine grasslands Erico carneae-Pinetum prostratae Zöttl 51 (Werhonig 1997). In general, it preferred the later successional stages of gravel banks at the river. *Psophus stridulus* occurred on the plots 16, 18 and 19. *Psophus stridulus* could not be found on study plots where clear cuts between the elevated areas with denser vegetation and those areas with less vegetation cover existed. Once the boundaries were blurred, *Psophus stridulus* occurred on the study plots along with the species *Chorthippus pullus* and *B. tuberculata*. This was the case at plots 18 and 19. On the floodplain of plot number 16, several small elevated areas

Figure 20: Left picture: Clear cut between the gravel bank habitat on the left and the densely vegetated elevated habitat on the right at plot number 6. Right picture: Patch of densely vegetated dry pine grassland on the otherwise sparsely vegetated gravel bank at plot 16 in the right picture. On the left, no rattle grasshopper could be found on the gravel bank. On the right, some rattle grasshoppers were detected on the gravel bank.

with dense vegetation appeared, representing suitable habitat for rattle grasshoppers. Therefore, some individuals of the rattle grasshopper could be here found on neighbouring areas with less vegetation (Figure 20). Still, there were not enough observations of *Psophus stridulus* made on the study plots to run a significant multiple linear regression analysis.

Small differences in habitat preferences of the four endangered grasshopper species reflect the requirement of diverse floodplains shaped by natural dynamics. The speckled grasshopper favours sparsely vegetated, open gravel banks. The alpine groundhopper inhabits muddy areas alongside little creeks which traverse the gravel banks. The gravel bank grasshopper prefers the sunny, stony habitats. The rattle grasshoppers occurs on the elevated areas of the floodplain with later successional vegetation stages. These areas are characterized by dry pine grasslands and border the Rißbach. It is of great importance to preserve the natural dynamics of the river, as thereby several habitat niches evolve on the gravel banks. The floodplains of the Rißbach have a sufficient width to ensure the coexistance of little muddy creeks, grassy areas, sparsely vegetated areas or open, stony spaces. *Bryodemella tuberculata* is not directly dependent on regular or irregular flooding of its habitats. At the Upper Isar, gravel banks with highest abundances of the speckled grasshopper are not flooded every year – at least in the period from May to October. The decisive factor is rather that the natural dynamics of the water creates sufficient new habitats bevor the old habitats become unsuitable (Reich 1990). Therefore, it can be said that as long as the natural dynamics of the river do not become restricted, the balance between the destruction of old and the creation of new gravel banks and therefore the existence of the metapopulation of *B. tuberculata* at the Tyrolean part of the Rißbach is assured. The numerous findings of *B. tuberculata* on the study plots indicate a healthy state of the metapopulation as study plots only encompass around 1250 m² of the gravel banks and the entire gravel bank is inhabitated by many more individuals. High flood events reaching 161 – 346 m³/s at the Rißbach river were documented in the years 1985, 1999, 2005, 2010 and 2013 (LfU Bayern 2019). The recurring flood events every 3 – 14 years at Rißbach guarantee the occasional inundation of gravel banks and therefore the preservation of the diverse gravel bank habitats characterized by channels and varying vegetation patterns. As there are no hydraulic engeneering projects planned at the Rißbach, the natural river dynamics are preserved until further notice. Still, some conservation management suggestions are mentioned below, addressing the existing threats and challenges of gravel bank ecosystems at river Rißbach.

4.5 Management suggestions

(Sonntag and Zika 2014) state, that further restoration measures at the Rißbach have been identified and are to be carried out in the coming years. It was observed that elevated gravel ramparts on the gravel bank of study plot 19 restricted the natural flow of the Rißbach. The dismantling of these obstacles would likely enhance the natural dynamics at this river segment and lead to a widening of the floodplain and therefore to increased habitat quality. The same improvement would apply for the assigned river segments, where further restoration measures are planned.

Creating a connection between the metapopulations of *B. tuberculata* at the Tyrolean part of the Rißbach with the Bavarian part of the Rißbach at Vorderriß might be

beneficial for the genetic exchange and the survival of these two metapopulations. However, it is questionable if these two metapopulations were ever connected before the dam was built at "Oswaldhütte". Several kilometers of long gorge-like segments separate these two metapopulations despite this hydraulic engeneering measure. An exchange between the metapopulations would be very unlikely and rare, and could only be carried out in the direction of flow, namely from the Tyrolean part to the Bavarian part and very unlikely in the other direction. Still, a genetic exchange would probably have taken place more often in the time before the dam was built. The connection of these metapopulations by the creation of continuous gravelled areas along the river is undesirable because it would contradict the natural gorge-like characteristics of the Rißbach at the affected river segments. The destruction of the dam is unlikely, as it is necessary for the water supply of the hydroelectric plant at Walchensee.

The ecosystem of the gravel banks at Rißbach is considerably disturbed through recreational activities of visitors in the summertime. The close cooperation with local kayak clubs, farmers and fishing guides promotes respectful and cautious behaviour around the delicate gravel bank ecosystems. Arrangements must be negotiated to avoid disturbing the fauna at particularly critical times. Mostly in summer, numerous tourists enter the gravel banks. Signs and fences prevent visitors of entering sensitive areas on gravel banks in the time from 15th of April – 15th of August when the common sandpiper (*Actitis hypoleucos*) breeds. Furthermore, the fencing aims to prevent cows from entering the gravel banks and destroying the clutches of eggs. An overall interest in conservation efforts is shown by the local farmers, and the disturbance of the floodplains through livestock is restricted. This engagement should be sustained and fencing of sensitive areas should not be neglected. Eutrophication could lead to changes in vegetation compositions (Kortenhaus 1987). Grazing close to gravel banks should be delimited to preserve the natural vegetation and thus the riverine habitats.

The conservation measures in the frame of the *Actitis hypoleucos* project surely also benefit the investigated endangered grasshopper species, since their habitat is thereby less disturbed during the summer months. Nevertheless, disturbances can cause scattering and negatively affect populations of *Bryodemella tuberculata* (Reich 1990). This is especially true for small-scale and isolated populations, which is the case at the metapopulation at the Rißbach. The availability of easily accessible information is necessary to encourage conscious behaviour. For example, information flyers or signs with information about the gravel bank ecosystem could be set up at the parking areas which are often located directly at gravel banks. Sings indicating a ban on entering the area to protect the common sandpiper do not provide enough information. Outright bans can be misunderstood and therefore ineffective. However, well-designed information signs about the ecosystem of the gravel banks can arouse interest in the topic and raise awareness. Environmental education programmes targeting these ecosystems especially could be developed and implemented.

Monitoring of the common sandpiper already exists at the Rißbach and is carried out by the ranger team. The implementation of long-term monitoring of the speckled grasshopper could be valuable for observing changes in the metapopulation, allowing the assessment of its conservation status. As the speckled grasshopper serves as an indicator species of natural river systems and their gravel bank ecosystems, monitoring of this species would also delineate the conservation status of the endangered habitats

of the EU Habitats Directive 3230, 3240 and 3220. Monitoring of *Bryodemella tuberculata* at the Tyrolean part of the Rißbach would involve the participation by a team of 2 – 8, searching the entire suitable habitats on the gravel banks (Figure 21). One or two investigations every year in the months July or August would be sufficient to provide an overview on the state of the metapopulation (Reich 2018). This monitoring could also be implemented on an international basis and could include all remaining populations of *B. tuberculata* at the wild Alpine rivers of the Northern Alps. The establishment of an Alpine-wide network between the various environmental and nature conservation associations whose domains include wild rivers would be beneficial in terms of exchanging human resources and knowledge. Monitoring of *Bryodemella tuberculata* could be beneficial for the assessment of its conservation state across all remaining isolated sites allowing conclusions on the connectivity of populations and therefore promoting conservation efforts. Furthermore, the observation of alterations of the populations of *B. tuberculata* allows to draw conclusions on the conservation status of the habitats of Alpine river ecosystems, including several more endangered species.

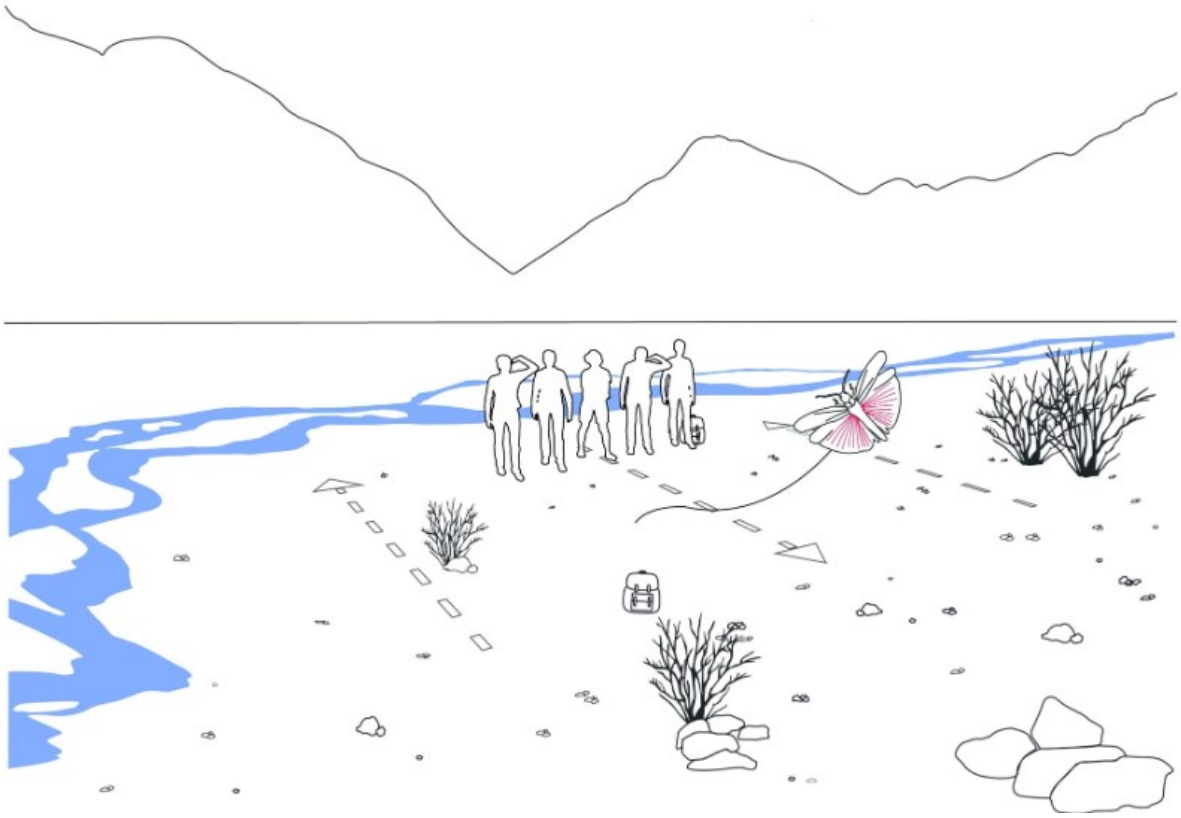


Figure 21: A team searching for *Bryodemella tuberculata* through walking in a loop-like manner over gravel banks. Backpacks can be deposited to mark edges of investigation area (Figure from Reich (2018), drawing by: M. Beiring)

5. Conclusion

In the context of the international decline of insects, this work is of importance regarding the critical conservation status of the investigated grasshoppers. As the study plots had a size of around 1250 m², they only represent a small area of the gravel banks. The assessment of total population sizes of the different grasshopper species of complete gravel banks of the river Rißbach could not be conducted due to limited personnel resources. A thorough investigation of entirety of thee gravel banks would not only give an estimate of the total population size but would probably also reveal more findings of hidden female individuals. This could contribute to more detailed conclusions on the features of the metapopulation of *B. tuberculata*. In addition, more specimens of the inconspicuous alpine groundhopper would be detected. However, this study offers an overview on the abundances of four endangered grasshopper species along river Rißbach. Additionally, it generates an insight into the different habitat preferences of the grasshopper species at the river Rißbach. The results enable suggestions for a management plan targeting the preservation of the endangered grasshopper fauna on the gravel banks of the Rißbach. Furthermore, assumptions were drawn on the state of the metapopulation of *Bryodemella tuberculata* at the Tyrolean part of the Rißbach. Suggestions for a future monitoring of this indicator species were also given.

The methodology of this study involved a sheet on habitat characteristics which was based on the sheet of the river Lech LIFE project. Further studies with similar methodologies would allow for an international comparison of the preferences of habitat characteristics of the endangered grasshopper species across wild Alpine rivers. This could promote the conservation efforts of this fauna which is adapted to gravel banks with sparse vegetation. Over the past decades, several hydraulic engineering measures restricted running waters in the Alpine region. The monitoring of species at the remaining natural rivers is of great importance as these ecosystems are highly threatened. Some conservation efforts at wild Alpine rivers indicate the increasing awareness of the decline of these habitats. Further investigations on the preferred habitat characteristics of endangered species can support more restoration or conservation projects and therefore the preservation of the gravel bank ecosystem.

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Attachments

Annex I

Table 14: Counts of grasshopper species at the first investigation 24th - 30th of July 2018. *B. tuberculata* divided into male and female counts.

	Bryodemella tuberculata	Males *B. tuberculata*	Females *B. tuberculata*	*Chorthippus pullus*	*Tetrix tuerki*	*Psophus stridulus*
Plot 1	0	0	0	3	0	0
Plot 2	0	0	0	7	0	0
Plot 3	0	0	0	0	0	0
Plot 4	1	1	0	5	0	0
Plot 5	1	1	0	5	0	0
Plot 6	0	0	0	2	0	0
Plot 7	1	1	0	1	0	0
Plot 8	0	0	0	1	0	0
Plot 9	0	0	0	3	0	0
Plot 10	4	2	2	0	0	0
Plot 11	1	1	0	2	2	0
Plot 12	3	2	1	2	0	0
Plot 13	1	1	0	5	0	0
Plot 14	5	5	0	2	2	0
Plot 15	1	1	0	4	0	0
Plot 16	1	1	0	0	0	0
Plot 17	8	6	2	0	0	0
Plot 18	11	9	2	1	0	1
Plot 19	6	3	3	4	0	1
Plot 20	6	3	3	1	0	0
Plot 21	1	1	0	5	0	0
Plot 22	4	3	1	6	0	0
Plot 23	0	0	0	0	0	0

Table 15: Counts of grasshopper species at the second investigation 27th - 29th of August 2018. *B. tuberculata* divided into male and female counts.

	Bryodemella tuberculata	Males *B. tuberculata*	Females *B. tuberculata*	*Chorthippus pullus*	*Tetrix tuerki*	*Psophus stridulus*
Plot 1	0	0	0	3	0	0
Plot 2	0	0	0	8	0	0
Plot 3	0	0	0	0	0	0
Plot 4	0	0	0	4	0	0
Plot 5	0	0	0	4	0	0
Plot 6	0	0	0	0	0	0
Plot 7	1	1	0	0	0	0
Plot 8	0	0	0	2	0	0
Plot 9	1	1	0	2	1	0
Plot 10	4	3	1	0	0	0
Plot 11	0	0	0	1	0	0
Plot 12	3	2	1	3	0	0
Plot 13	1	0	1	0	2	0
Plot 14	2	2	0	1	2	0
Plot 15	1	0	1	0	4	0
Plot 16	2	0	2	0	2	2
Plot 17	6	5	1	0	0	0
Plot 18	4	3	1	1	2	0
Plot 19	6	5	1	4	0	4
Plot 20	9	4	5	1	0	0
Plot 21	2	2	0	7	3	0
Plot 22	2	1	1	3	1	0
Plot 23	0	0	0	0	2	0

Annex II

Table 16: Data on habitat characteristics. Estimations of the various vegetation, substrate and location related characteristics of each study plot.

Height of plot centre over summer waterline (classes)	4	4	4	3	2
Height of plot centre over summer waterline	100-200cm	100-200cm	100-200cm	50-100cm	25-50cm
Clay coverage (%)	0	0	0	0	0
Fine sediment coverage (%)	40	10	50	30	10
Dead wood coverage (%)	30	5	10	5	0
Sand coverage (%)	0	5	20	0	10
Grit coverage (%)	10	25	0	50	15
Gravel coverage (%)	10	15	10	15	60
Rock coverage (%)	10	40	10	0	5
Moss coverage (%)	0	0	0	0	1
Grass coverage (%)	10	2.5	10	15	2
Herb coverage (%)	5	5	5	5	2
Cushion plants coverage (%)	2	10	0	1	1
Pioneer shrub coverage (%)	10	10	10	5	4
Tree coverage (%)	0	0	0	0	0
Vegetation height (classes)	4	5	5	4	3
Vegetation height	50-100	>1m	>1m	50-100	up to 50
Total vegetation cover	25	27.5	25	26	10
Sea Level	873	883	890	908	913
Plot	1	2	3	4	5

3	2	4	3	3	3	3	2	3
50-100cm	25-50cm	100-200cm	50-100cm	50-100cm	50-100cm	50-100cm	25-50cm	50-100cm
0	0	0	0	0	0	0	0	0
1	5	5	5	0	20	0	0	10
0	5	5	0	5	5	20	5	0
20	20	10	10	20	30	20	40	0
40	58	20	35	60	20	40	0	20
10	20	55	45	15	20	15	15	35
5	2	5	5	0	5	5	20	40
0	0	0	0	0	0	0	0	0
5	2.5	2.5	2	2.5	10	2.5	5	1
2.5	2.5	2.5	1	2.5	0	5	2.5	4
2.5	2.5	2.5	5	5	5	5	2.5	5
5	2.5	2.5	15	10	10	20	10	15
0	0	0	0	0	0	0	0	0
4	2	3	4	4	4	5	3	4
50-100	up to 25	up to 50	50-100	50-100	50-100	>1m	up to 50	50-100
15	10	10	23	20	25	32.5	20	25
935	939	945	953	968	959	966	978	977
6	7	8	9	10	11	12	13	14

4	4	4	4	4	4	3	4	4
100-200cm	100-200cm	100-200cm	100-200cm	100-200cm	100-200cm	50-100cm	100-200cm	100-200cm
0	0	0	0	0	0	0	5	0
0	0	0	0	0	0	10	15	0
10	10	10	5	10	20	10	5	5
0	20	5	5	15	0	10	15	0
30	35	30	40	20	30	20	30	35
30	30	40	40	20	30	20	10	30
30	5	15	10	35	20	25	20	30
5	5	2.5	5	5	5	10	2.5	0
15	5	2.5	2.5	5	10	15	5	5
5	2.5	2.5	2.5	5	5	5	10	5
15	15	15	15	10	10	5	5	5
10	15	20	20	25	30	25	20	25
0	0	0	5	0	0	0	0	0
4	5	5	5	5	5	5	4	5
50-100	>1m	>1m	>1m	>1m	>1m	>1m	50-100	>1m
50	42.5	42.5	50	50	60	60	42.5	40
989	992	1003	1007	1018	1037	1048	1060	1072
15	16	17	18	19	20	21	22	23

Annex III

Table 17: Results of the vegetation mapping of the 23 study plots. Coverage values after the original Braun-Blanquet scale

Study plot		1
Date		24.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Alpen-Pestwurz	*Petasites paradoxus*	1
Ahorn Keimling	*Acer pseudoplatanus*	+
Grau-Erle	*Alnus incana*	+
Fichten Keimling	*Picea abies*	r
Blaugrüner Steinbrech	*Saxifraga caesia*	r
Blutwurz	*Potentilla erecta*	r
Felsen-Leimkraut	*Atocion rupestre/Silene rupestris*	+
Grannen-Klappertopf	*Rhinanthus glacialis*	+
Mittleres Zittergras	*Briza media*	+
Violettes Rispengras	*Poa variegata*	r
Alpen-Straussgras	*Agrostis alpina*	+
Alpen-Klatschnelke	*Silene vulgaris subsp. glareosa*	r
Weiße Silberwurz	*Dryas octopetala*	+
Lavendel-Weide	*Salix eleagnos*	1
Bunter Schachtelhalm	*Equisetum variegatum*	r
Purpur-Weide	*Salix purpurea*	1
Gelbe Segge	*Carex flava*	+
Salzburger Augentrost	*Euphrasia salisburgensis*	r
Schlaffe Segge	*Carex flacca*	+
Alpen-Binse	*Juncus alpinus*	+
Blaues Pfeifengras	*Molinia caerulea*	+

Study plot		2
Date		24.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Alpen-Pestwurz	*Petasites paradoxus*	1
Grau-Erle	*Alnus incana*	+
Felsen-Leimkraut	*Atocion rupestre/Silene rupestris*	1
Alpen-Straussgras	*Agrostis alpina*	+
Alpen-Klatschnelke	*Silene vulgaris subsp. glareosa*	r
Weiße Silberwurz	*Dryas octopetala*	1
Lavendel-Weide	*Salix eleagnos*	2
Bunter Schachtelhalm	*Equisetum variegatum*	r
Purpur-Weide	*Salix purpurea*	1
Salzburger Augentrost	*Euphrasia salisburgensis*	+
Blaues Pfeifengras	*Molinia caerulea*	1

Fetthennen-Steinbrech	*Saxifraga aizoides*	1
Zwerg-Glockenblume	*Campanula cochleariifolia*	r
Florentiner Habichtskraut	*Pilosella piloselloides*	r
Weidenblättriges Ochsenauge	*Buphthalmum salicifolium*	r

Study plot		3
Date		25.07.2018
Associaton	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Alpen-Pestwurz	*Petasites paradoxus*	1
Grau-Erle	*Alnus incana*	+
Lavendel-Weide	*Salix eleagnos*	2
Bunter Schachtelhalm	*Equisetum variegatum*	r
Purpur-Weide	*Salix purpurea*	2
Blaues Pfeifengras	*Molinia caerulea*	1
Ufer-Reitgras	*Calamagrostis pseudophragmites*	1
Ahorn Keimling	*Acer pseudoplatanus*	+
Fetthennen-Steinbrech	*Saxifraga aizoides*	+
Alpen-Labkraut	*Galium anisophyllon*	+
Blutwurz	*Potentilla erecta*	r
Wiesen-Flockenblume	*Centaurea jacea*	r
Schlaffe Segge	*Carex flacca*	+
Alpen-Binse	*Juncus alpinus*	+
Mittleres Zittergras	*Briza media*	+

Study plot		4
Date		25.07.2018
Association	Salici-Myricarietum	
Species (German)	Latin	Coverage
Alpen-Pestwurz	*Petasites paradoxus*	1
Grau-Erle	*Alnus incana*	1
Felsen-Leimkraut	*Atocion rupestre/Silene rupestris*	+
Alpen-Straussgras	*Agrostis alpina*	+
Alpen-Klatschnelke	*Silene vulgaris subsp. glareosa*	r
Lavendel-Weide	*Salix eleagnos*	+
Bunter Schachtelhalm	*Equisetum variegatum*	r
Purpur-Weide	*Salix purpurea*	1
Salzburger Augentrost	*Euphrasia salisburgensis*	r
Zwerg-Glockenblume	*Campanula cochleariifolia*	+
Florentiner Habichtskraut	*Pilosella piloselloides*	+
Fichten Keimling	*Picea abies*	+
Violettes Rispengras	*Poa variegata*	r
Breitwegerich	*Plantago major*	r
Alpen-Leinkraut	*Linaria alpina*	+
Echter Dost	*Origanum vulgare*	r
Zwerg-Gänsekresse	*Arabis bellidifolia*	r
Wiesenklee	*Trifolium pratense*	1
Feld-Klee	*Trifolium campestre*	+

Rasen-Schmiele	*Deschampsia cespitosa*	+
Ahorn Keimling	*Acer pseudoplatanus*	r
Blutwurz	*Potentilla erecta*	r
Ufer-Reitgras	*Calamagrostis pseudophragmites*	2
Deutsche Tamariske	*Myricaria germanica*	1
Blaues Pfeifengras	*Molinia caerulea*	2
Sumpf-Herzblatt	*Parnassia palustris*	r

Study plot		5
Date		24.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Alpen-Pestwurz	*Petasites paradoxus*	1
Grau-Erle	*Alnus incana*	1
Alpen-Klatschnelke	*Silene vulgaris subsp. glareosa*	r
Weiße Silberwurz	*Dryas octopetala*	+
Lavendel-Weide	*Salix eleagnos*	1
Purpur-Weide	*Salix purpurea*	+
Blaues Pfeifengras	*Molinia caerulea*	r
Ahorn Keimling	*Acer pseudoplatanus*	+
Gewöhnliche Gämskresse	*Hornungia alpina*	r
Felsen-Kugelschötchen	*Kernera saxatilis*	r
Blutwurz	*Potentilla erecta*	r
Mittleres Zittergras	*Briza media*	+
Gemeine Scharfgabe	*Achillea millefolium*	r
Zwerg-Glockenblume	*Campanula cochleariifolia*	r
Violettes Rispengras	*Poa variegata*	r

Study plot		6
Date		25.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Grau-Erle	*Alnus incana*	+
Alpen-Klatschnelke	*Silene vulgaris subsp. glareosa*	r
Lavendel-Weide	*Salix eleagnos*	+
Purpur-Weide	*Salix purpurea*	1
Fichten Keimling	*Picea abies*	r
Violettes Rispengras	*Poa variegata*	r
Blutwurz	*Potentilla erecta*	r
Blaues Pfeifengras	*Molinia caerulea*	1
Ufer-Reitgras	*Calamagrostis pseudophragmites*	1
Gemeine Scharfgabe	*Achillea millefolium*	1
Breitwegerich	*Plantago major*	r
Gewöhnliches Knäuelgras	*Dactylis glomerata*	r
Kleines Habichtskraut	*Hieracium pilosella*	r
Grannen-Klappertopf	*Rhinanthus glacialis*	+
Gewöhnlicher Hornklee	*Lotus corniculatus*	r
Wiesen-Flockenblume	*Centaurea jacea*	r

Wiesenklee	*Trifolium pratense*	r
Sumpf-Herzblatt	*Parnassia palustris*	1
Gelbe Segge	*Carex flava*	+
Zwerg-Glockenblume	*Campanula cochleariifolia*	1
Mittleres Zittergras	*Briza media*	+

Study plot		7
Date		25.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Fichten Keimling	*Picea abies*	+
Blaues Pfeifengras	*Molinia caerulea*	+
Zwerg-Glockenblume	*Campanula cochleariifolia*	r
Ahorn Keimling	*Acer pseudoplatanus*	+
Grau-Erle	*Alnus incana*	r
Felsen-Leimkraut	*Atocion rupestre/Silene rupestris*	1
Weiße Silberwurz	*Dryas octopetala*	+
Blaugrüner Steinbrech	*Saxifraga caesia*	r
Florentiner Habichtskraut	*Pilosella piloselloides*	r
Zwerg-Gänsekresse	*Arabis bellidifolia*	r

Study plot		8
Date		26.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Weiße Silberwurz	*Dryas octopetala*	+
Lavendel-Weide	*Salix eleagnos*	1
Purpur-Weide	*Salix purpurea*	1
Blaues Pfeifengras	*Molinia caerulea*	+
Mittleres Zittergras	*Briza media*	+
Zwerg-Glockenblume	*Campanula cochleariifolia*	r
Wiesenklee	*Trifolium pratense*	+
Feld-Klee	*Trifolium campestre*	+
Wiesen-Flockenblume	*Centaurea jacea*	r
Breitwegerich	*Plantago major*	r
Hundspetersilie	*Aethusa cynapium*	r
Ufer-Reitgras	*Calamagrostis pseudophragmites*	+
Fichten Keimling	*Picea abies*	r
Kleines Habichtskraut	*Hieracium pilosella*	r
Gemeine Scharfgabe	*Achillea millefolium*	r

Study plot		9
Date		26.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Weiße Silberwurz	*Dryas octopetala*	1

Lavendel-Weide	*Salix eleagnos*	2
Purpur-Weide	*Salix purpurea*	1
Blaues Pfeifengras	*Molinia caerulea*	+
Fichten Keimling	*Picea abies*	+
Deutsche Tamariske	Myricaria germanica	r
Ahorn Keimling	*Acer pseudoplatanus*	+
Zwerg-Gänsekresse	*Arabis bellidifolia*	r
Rundblättriges Hellerkraut	*Noccaea rotundifolia*	r
Alpen-Pestwurz	*Petasites paradoxus*	+
Gewöhnliche Gämskresse	*Hornungia alpina*	r

Study plot		10
Date		26.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Weiße Silberwurz	*Dryas octopetala*	+
Lavendel-Weide	*Salix eleagnos*	1
Purpur-Weide	*Salix purpurea*	+
Blaues Pfeifengras	*Molinia caerulea*	r
Fichten Keimling	*Picea abies*	r
Deutsche Tamariske	Myricaria germanica	r
Ahorn Keimling	*Acer pseudoplatanus*	+
Alpen-Pestwurz	*Petasites paradoxus*	r
Salzburger Augentrost	*Euphrasia salisburgensis*	+
Weidenblättriges Ochsenauge	*Buphthalmum salicifolium*	r
Zwerg-Glockenblume	*Campanula cochleariifolia*	r
Alpen-Klatschnelke	*Silene vulgaris subsp. glareosa*	r

Study plot		11
Date		26.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Weiße Silberwurz	*Dryas octopetala*	+
Mittleres Zittergras	*Briza media*	+
Blaues Pfeifengras	*Molinia caerulea*	+
Latschenkiefer	*Pinus mugo*	1
Lavendel-Weide	*Salix eleagnos*	1
Feld-Klee	*Trifolium campestre*	r
Alpen-Binse	*Juncus alpinus*	r
Kleine Braunelle	*Prunella vulgaris*	+
Trauer-Segge	*Carex atrata*	+
Weidenblättriges Ochsenauge	*Buphthalmum salicifolium*	r
Gebirgs-Thymian	*Thymus praecox subsp. polytrichus*	r
Ufer-Reitgras	*Calamagrostis pseudophragmites*	1
Deutscher Franzenenzian	*Gentianella germanica*	r

Study plot	12
Date	27.07.2018

Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Weidenblättriges Ochsenauge	*Buphthalmum salicifolium*	r
Alpen-Pestwurz	*Petasites paradoxus*	+
Besenheide	*Calluna vulgaris*	+
Lavendel-Weide	*Salix eleagnos*	1
Weiße Silberwurz	*Dryas octopetala*	+
Ahorn Keimling	*Acer pseudoplatanus*	+
Grau-Erle	*Alnus incana*	1
Florentiner Habichtskraut	*Pilosella piloselloides*	+
Sumpf-Herzblatt	*Parnassia palustris*	+
Fichte	*Picea abies*	1
Blaues Pfeifengras	*Molinia caerulea*	+
Wiesen-Flockenblume	*Centaurea jacea*	r
Gebirgs-Thymian	*Thymus praecox subsp. polytrichus*	r
Gemeine Scharfgabe	*Achillea millefolium*	r
Salzburger Augentrost	*Euphrasia salisburgensis*	+
Alpen-Silbermantel	*Alchemilla alpina*	r
Zwerg-Glockenblume	*Campanula cochleariifolia*	+
Blaugrüner Steinbrech	*Saxifraga caesia*	+
Kleiner Wiesenknopf	*Sanguisorba minor*	+

Study plot		13
Date		27.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Gewöhnliche Gämskresse	*Hornungia alpina*	r
Lavendel-Weide	*Salix eleagnos*	1
Purpur-Weide	*Salix purpurea*	+
Ahorn Keimling	*Acer pseudoplatanus*	+
Weiße Silberwurz	*Dryas octopetala*	+
Alpen-Pestwurz	*Petasites paradoxus*	+
Zwerg-Glockenblume	*Campanula cochleariifolia*	+
Trauer-Segge	*Carex atrata*	+
Blaues Pfeifengras	*Molinia caerulea*	+
Alpen-Binse	*Juncus alpinus*	+
Salzburger Augentrost	*Euphrasia salisburgensis*	+
Fichten Keimling	*Picea abies*	r
Mittleres Zittergras	*Briza media*	+
Gebirgs-Thymian	*Thymus praecox subsp. polytrichus*	r
Besenheide	*Calluna vulgaris*	r

Study plot		14
Date		27.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Lavendel-Weide	*Salix eleagnos*	2
Purpur-Weide	*Salix purpurea*	2

Weiße Silberwurz	*Dryas octopetala*	1
Fichten Keimling	*Picea abies*	+
Zwerg-Glockenblume	*Campanula cochleariifolia*	+
Ahorn Keimling	*Acer pseudoplatanus*	r
Alpen-Pestwurz	*Petasites paradoxus*	+
Latschenkiefer Keimling	*Pinus mugo*	r
Blaues Pfeifengras	*Molinia caerulea*	+
Alpen-Binse	*Juncus alpinus*	+
Gelbe Segge	*Carex flava*	+
Sumpf-Herzblatt	*Parnassia palustris*	r
Blaugrüner Steinbrech	*Saxifraga caesia*	+
Alpen-Fettkraut	*Pinguicula alpina*	r

Study plot		15
Date		28.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Blaues Pfeifengras	*Molinia caerulea*	1
Weiße Silberwurz	*Dryas octopetala*	2
Alpen-Pestwurz	*Petasites paradoxus*	1
Fichten Keimling	*Picea abies*	+
Ahorn Keimling	*Acer pseudoplatanus*	r
Latschenkiefer Keimling	*Pinus mugo*	r
Zwerg-Glockenblume	*Campanula cochleariifolia*	+
Weidenblättriges Ochsenauge	*Buphthalmum salicifolium*	+
Blaugrüner Steinbrech	*Saxifraga caesia*	+
Lavendel-Weide	*Salix eleagnos*	1
Purpur-Weide	*Salix purpurea*	+
Herzblättrige Kugelblume	*Globularia cordifolia*	+
Sumpf-Herzblatt	*Parnassia palustris*	1
Wiesen-Flockenblume	*Centaurea jacea*	+
Schlaffe Segge	*Carex flacca*	+
Mittleres Zittergras	*Briza media*	+
Besenheide	*Calluna vulgaris*	1
Salzburger Augentrost	*Euphrasia salisburgensis*	+
Polster-Segge	*Carex firma*	1
Alpen-Silbermantel	*Alchemilla alpina*	+

Study plot		16
Date		29.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Weiße Silberwurz	*Dryas octopetala*	2
Lavendel-Weide	*Salix eleagnos*	2
Fichten Keimling	*Picea abies*	+
Blaues Pfeifengras	*Molinia caerulea*	+
Florentiner Habichtskraut	*Pilosella piloselloides*	+
Alpen-Leinkraut	*Linaria alpina*	+

Alpen-Pestwurz	*Petasites paradoxus*	1
Besenheide	*Calluna vulgaris*	1
Zwerg-Glockenblume	*Campanula cochleariifolia*	+
Latschenkiefer Keimling	*Pinus mugo*	r
Ahorn Keimling	*Acer pseudoplatanus*	r
Purpur-Weide	*Salix purpurea*	r
Weidenblättriges Ochsenauge	*Buphthalmum salicifolium*	+
Alpen-Silbermantel	*Alchemilla alpina*	+
Fetthennen-Steinbrech	*Saxifraga aizoides*	1
Sumpf-Herzblatt	*Parnassia palustris*	+
Polster-Segge	*Carex firma*	+
Kleine Braunelle	*Prunella vulgaris*	+
Gelbe Segge	*Carex flava*	1
Schlaffe Segge	*Carex flacca*	1

Study plot		17
Date		29.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Weiße Silberwurz	*Dryas octopetala*	2
Lavendel-Weide	*Salix eleagnos*	2
Purpur-Weide	*Salix purpurea*	1
Alpen-Pestwurz	*Petasites paradoxus*	1
Fichten Keimling	*Picea abies*	+
Ahorn Keimling	*Acer pseudoplatanus*	+
Alpen-Silbermantel	*Alchemilla alpina*	r
Zwerg-Glockenblume	*Campanula cochleariifolia*	+
Weidenblättriges Ochsenauge	*Buphthalmum salicifolium*	+
Grau-Erle	*Alnus incana*	+
Latschenkiefer Keimling	*Pinus mugo*	+
Florentiner Habichtskraut	*Pilosella piloselloides*	+
Polster-Segge	*Carex firma*	+
Blaues Pfeifengras	*Molinia caerulea*	+
Ufer-Reitgras	*Calamagrostis pseudophragmites*	+
Sumpf-Herzblatt	*Parnassia palustris*	+

Study plot		18
Date		29.07.2018
Association	Salicetum eleagni	
Species (German)	Latin	Coverage
Sumpf-Herzblatt	*Parnassia palustris*	+
Bunter Schachtelhalm	*Equisetum variegatum*	+
Fichten Keimling	*Picea abies*	1
Lavendel-Weide	*Salix eleagnos*	2
Purpur-Weide	*Salix purpurea*	1
Weiße Silberwurz	*Dryas octopetala*	2
Zwerg-Glockenblume	*Campanula cochleariifolia*	+
Alpen-Pestwurz	*Petasites paradoxus*	+

Wiesenklee	*Trifolium pratense*	r
Wiesen-Flockenblume	*Centaurea jacea*	r
Blaues Pfeifengras	*Molinia caerulea*	+
Ahorn Keimling	*Acer pseudoplatanus*	r
Fichte	*Picea abies*	1
Latschenkiefer	*Pinus mugo*	1

Study plot		19
Date		29.07.2018
Association	Salicetum eleagni	
Species (German)	Latin	Coverage
Berg-Ahorn	*Acer pseudoplatanus*	r
Alpen-Pestwurz	*Petasites paradoxus*	2
Fichten Keimling	*Picea abies*	1
Ahorn Keimling	*Acer pseudoplatanus*	+
Grau-Erle	*Alnus incana*	+
Lavendel-Weide	*Salix eleagnos*	2
Purpur-Weide	*Salix purpurea*	2
Weidenblättriges Ochsenauge	*Buphthalmum salicifolium*	1
Weiße Silberwurz	*Dryas octopetala*	2
Sumpf-Herzblatt	*Parnassia palustris*	+
Wiesen-Flockenblume	*Centaurea jacea*	r
Blaues Pfeifengras	*Molinia caerulea*	1
Mittleres Zittergras	*Briza media*	+
Zwerg-Glockenblume	*Campanula cochleariifolia*	+
Florentiner Habichtskraut	*Pilosella piloselloides*	+

Study plot		20
Date		30.07.2018
Association	Salicetum eleagni	
Species (German)	Latin	Coverage
Gewöhnliches Rispengras	*Poa trivialis*	+
Alpen-Pestwurz	*Petasites paradoxus*	1
Weiße Silberwurz	*Dryas octopetala*	1
Fichten Keimling	*Picea abies*	1
Sumpf-Herzblatt	*Parnassia palustris*	+
Blaugrüner Steinbrech	*Saxifraga caesia*	1
Lavendel-Weide	*Salix eleagnos*	2
Purpur-Weide	*Salix purpurea*	1
Grau-Erle	*Alnus incana*	+
Zwerg-Glockenblume	*Campanula cochleariifolia*	+
Weidenblättriges Ochsenauge	*Buphthalmum salicifolium*	+
Mittleres Zittergras	*Briza media*	+
Besenheide	*Calluna vulgaris*	+
Polster-Segge	*Carex firma*	1
Latschenkiefer Keimling	*Pinus mugo*	+
Blaues Pfeifengras	*Molinia caerulea*	1

Study plot		21
Date		30.07.2018
Association	Salicetum eleagni	
Species (German)	Latin	Coverage
Trauer-Segge	*Carex atrata*	+
Gelbe Segge	*Carex flava*	1
Blaues Pfeifengras	*Molinia caerulea*	1
Alpen-Pestwurz	*Petasites paradoxus*	1
Fichte	*Picea abies*	+
Lavendel-Weide	*Salix eleagnos*	2
Purpur-Weide	*Salix purpurea*	2
Sumpf-Herzblatt	*Parnassia palustris*	+
Alpen-Binse	*Juncus alpinus*	+
Weiße Silberwurz	*Dryas octopetala*	1
Alpen-Leinkraut	*Linaria alpina*	+
Fetthennen-Steinbrech	*Saxifraga aizoides*	+
Polster-Segge	*Carex firma*	1
Alpen-Edelweiss	*Leontopodium nivale*	r
Besenheide	*Calluna vulgaris*	+
Latschenkiefer Keimling	*Pinus mugo*	+

Study plot		22
Date		30.07.2018
Association	Chondrilletum chondrilloides	
Species (German)	Latin	Coverage
Lavendel-Weide	*Salix eleagnos*	2
Purpur-Weide	*Salix purpurea*	1
Weiße Silberwurz	*Dryas octopetala*	2
Fichten Keimling	*Picea abies*	+
Alpen-Pestwurz	*Petasites paradoxus*	1
Besenheide	*Calluna vulgaris*	1
Gebirgs-Thymian	*Thymus praecox subsp. polytrichus*	+
Florentiner Habichtskraut	*Pilosella piloselloides*	+
Zwerg-Glockenblume	*Campanula cochleariifolia*	+
Blaues Pfeifengras	*Molinia caerulea*	1
Blutwurz	*Potentilla erecta*	r
Kleines Habichtskraut	*Hieracium pilosella*	r
Ahorn Keimling	*Acer pseudoplatanus*	+
Gewöhnliche Gämskresse	*Hornungia alpina*	+
Kleine Braunelle	*Prunella vulgaris*	+

Study plot		23
Date		30.07.2018
Association	Salicetum eleagni	
Species (German)	Latin	Coverage
Lavendel-Weide	*Salix eleagnos*	2
Purpur-Weide	*Salix purpurea*	1
Fichten Keimling	*Picea abies*	1

Alpen-Pestwurz	*Petasites paradoxus*	1
Ahorn Keimling	*Acer pseudoplatanus*	+
Kleines Habichtskraut	*Hieracium pilosella*	+
Weidenblättriges Ochsenauge	*Buphthalmum salicifolium*	+
Gewöhnliche Gämskresse	*Hornungia alpina*	+
Blutwurz	*Potentilla erecta*	r
Alpen-Leinkraut	*Linaria alpina*	+
Zwerg-Glockenblume	*Campanula cochleariifolia*	r
Alpen-Klatschnelke	*Silene vulgaris subsp. glareosa*	+
Latschenkiefer Keimling	*Pinus mugo*	r