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„Influence of grazing on Orthoptera on the flood protection embankment at the Donau-Auen National Park (Austria)"

verfasst von / submitted by

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Zusammenfassung
Extensive Bewirtschaftung, ob durch Mahd oder Beweidung, zur Förderung von Biodiversität in europäischen Kulturlandschaften steht im Diskurs der Naturschutzpraxis. Schutz- und Rückstaudämme haben sich zu wichtigen Rückzugsorten für diverse Lebensgemeinschaften des Grünlandes nahe der Feuchtgebiete entwickelt, gleichzeitig sind sie abhängig von regelmäßigem Management. Heuschrecken (Orthoptera) sind die wichtigsten Herbivoren des Grünlands Europas. Sie wurden in dieser Studie als Modellorganismen verwendet, um Effekte von Beweidung- und Mahdregime zu erfassen. Das Untersuchungsgebiet im Donau-Auen National Park (Ostösterreich) umfasst seit kurzem durch Schafe beweidete und gemähte Wiesenflächen auf dem Marchfeldschutzdamm. Unterschiede in Abundanz, Artenreichtum, Artenzusammensetzung und artspezifische Auswirkungen des Managements auf dem Marchfeldschutzdamm wurden bewertet. Die Artenzusammensetzung der beiden Abschnitte des Dammes unterschied sich signifikant. Einige Arten zeigten gravierende Unterschiede in ihrer Abundanz, meist mit einer höheren Abundanz auf den gemähten Flächen. Besonders als „nicht gefährdet“ geltende Arten waren häufiger auf gemähten Wiesen. Dennoch wurde eine signifikant höhere Artenvielfalt auf den beweideten Flächen festgestellt. Das graduelle Beweidungsmanagement bot über die Saison weitaus variablere Vegetationsstrukturen als das Mahdregime. Daher wird eine Weiterführung der Beweidung oder alternativ ein Mahdregime in mehreren Abschnitten empfohlen, um eine Migration in ungestörte Abschnitte zu ermöglichen.

Abstract
A widely discussed practice in conservation is the use of extensive grazing and mowing to enhance biodiversity in European cultivated landscapes. Flood protection embankments in riverine landscapes have become important refugia for grassland communities, but also highly dependent on regular management. Grasshoppers (Orthoptera) are the most important herbivores in European grasslands. Here, they were used as model organisms to assess effects of the management measures grazing and mowing. The study sites in the Danube Floodplain National Park (eastern Austria) include both mown meadows and meadows that have only recently been grazed by sheep. Changes in abundance, species richness, assemblage composition and the impact on individual species on the flood protection embankment were assessed. Species composition differed greatly between grazed and mown sections of the studied dyke. Several species differed substantially in abundance between treatments, showing an increased abundance of Orthoptera in the mowing treatment. Especially species listed as Least Concern showed significantly higher abundances in the mown meadows. However, a significantly greater species diversity was recorded in the grazing treatment. The gradual grazing management was less invasive than the mowing regime and provided a wide array of different vegetation structures during the season. Therefore, it is advised to continue grazing or, alternatively, to mow at a lower scale to allow migration to undisturbed patches.

Keywords: Danube, dyke, grasshoppers, grassland management, grazing, Marchfeldschutzdamm, mowing, nature conservation, sheep

Introduction

For grassland management aiming to maintain biodiversity there is not "one solution applies to all". For most biota, extensive land use is most beneficial for preserving communities rich in species, particularly rare and threatened ones (Achtziger et al. 1999, Chiste et al. 2016). Basically, two contrasting land use options exist, i.e. mowing versus grazing. Both land use types create specific microhabitats with spatio-temporal differences in sward height and structure (Chiste et al. 2016). Mowing, on the one hand, produces a spatially homogenous sward that is temporally characterized by pulsed and large-scale removal of the above-ground biomass. Grazing, on the other hand, leads to a spatially heterogenous mosaic of differently grazed patches, often including patches of open soil due to trampling (Rada et al. 2014).

In recent decades, flood protection embankments have been created along many European water courses to prevent flooding of the adjacent countryside and to protect human life. For instance, flood protection embankments sum up to 4200 km in Hungary, 10000 km in Germany, 3000 km in the Netherlands and 4000 km in the Czech Republic (Tourment et al. 2018). Along the Austrian Danube, about a total of 225 km of flood protection embankments are protecting adjacent villages and cities (viadonau, 2015). Given their substantial spatial extent and because they are not fertilized and usually covered by extensively used grasslands, dykes are important secondary habitats for many species. Further, they also function as important dispersal corridors for grassland species in river valleys (Bátori et al. 2016).

To prevent the encroachment of woody species, dyke management usually consists of some type of extensive land use such as mowing or grazing (Rook et al. 2004). This management potentially preserves this secondary habitat for many grassland species. In areas with great spatial extent of intensive agricultural land and forests, patches of extensively managed grassland, as for example semi-dry grassland on dykes, are essential to preserve local biodiversity. However, flood protection embankments are often intensively grazed or mown several times per year, which has a negative impact on the biodiversity of arthropods (Marini et al. 2009b, Humbert et al. 2010, Fabriciusová et al.2011, Fargeaud and Gardiner 2018).

Orthoptera are the most important herbivorous insects in grasslands and are recognized as excellent indicators for their conservation value (Fargeaud and Gardiner 2018), as they are sensitive to changes in structure, microclimate and plant species richness of their habitat (Báldi and Kisbenedek 1997, Fargeaud and Gardiner 2018, Gardiner et al. 2002, Sauberer et al. 2004). Further, Orthopteran species assemblages are sensitive to succession and their composition varies greatly between each successional stage (Fartmann et al. 2012).

During mowing, direct mortality through mowing machines, extraction of eggs (in removed plant material) and risk of predation as well as overheating are enhanced (Gardiner and Hassall 2009; Humbert et al. 2010). An experiment in Switzerland showed that 65-85% of Orthoptera individuals were killed during the mechanized mowing process with slight differences between methods. Mowing with a rotary mower had a mortality rate of 68±14% and with a conditioner added it was at 82±8%. Of all marked individuals, 5.7% emigrated during harvest (Humbert et al. 2010).

Less direct mortality was found through grazing because the process is slower (Chiste et al. 2016), but the response varies depending on the grazing species (Fargeaud and Gardiner 2018) and the considered Orthoptera species (Rada et al. 2014). As grazing animals move relatively slowly and often gather in patches, this allows grasshopper species to emigrate safely during grazing and to oviposit their eggs into plant parts in currently undisturbed sites (Chiste et al. 2016, Fartmann and Mattes 1997). Uneven vegetation coverage can result in patches with warmer microclimate, to the advantage of some Orthoptera species (e.g. *Gomphocerippus rufus*; Rada et al. 2014). Some species benefit when the vegetation is locally disturbed, providing patches of bare soil (Fartmann et al. 2012, Rada et al. 2014).

The main differences in vegetation structure of pastures are a result of the behaviour of grazers. Each species has specific dietary preferences resulting in a structural heterogeneity of the sward canopy (Rook et al. 2004). The ability of grazing animals to express their dietary preferences, however, strongly differs with grazing pressure (Fonderflick et al. 2014). With extensive or moderate grazing, selective defoliation is possible and often results in a more heterogeneous sward structure (Milne and Osoro 1997, Rook et al. 2004, Jerrentrup et al. 2014, Chiste et al. 2016, Ma et al. 20017). Although grazing decreases abundance and species richness of orthopterans (Ma et al. 2017), even intensive grazing can reduce Orthoptera species richness less then mowing (Chiste et al. 2016).

The timing of grazing and associated structural changes of the plant cover have important indirect effects for grasshoppers via changes in habitat quality (Ma et al. 2017, Fargeaud and Gardiner 2018). Additionally, direct grazing mortality in orthopterans can be substantial, especially during cold-wet weather conditions and when grasshoppers are still in their relatively immobile nymph stages (Fartmann and Mattes 1997). Hence, traditional grazing strategies with a variety of different grazing periods and times can be beneficial, since they are creating a mosaic of habitat patches facilitating the requirements of different species and life stages of grasshoppers.

The aim of this study was to assess the effect of the type of management (grazing/mowing) and timing of grazing on the abundance, species richness and species composition of Orthoptera on a flood protection dam in the Donau-Auen National Park, eastern Austria. Specifically, I addressed the following questions: (1) How do vegetation height and vegetation density change seasonally on mown and grazed meadows? (2) Does the management type affect species composition, abundance and species richness differentially? (3) Which species benefit, which species are suppressed by the applied management measures? (4) Do threatened species respond differentially to the two management regimes?

Material and methods

Study area

The study area comprises a dyke situated in the Donau-Auen National Park east of Vienna, north of the Danube river (Fig. 1). This dyke is called “Marchfeldschutzdamm” and has a length of 38 km (viadonau 2015). The Marchfeldschutzdamm from Vienna to the “Schönauer Schlitz” was finished in 1884 and is well-known for its semi-dry grasslands (Wesner 1994). The topsoil layer of the dyke is very thin with a nutrient gradient from the riparian forest to the top of the levee. The elevation is at 150 m above sea level. The Donau-Auen are a hot spot of Orthoptera diversity in Eastern Austria and the secondary structure of the Marchfeldschutzdamm, which is surrounded by riparian forest and arable fields, is of great importance to orthopterans, particularly xerophilic species (viadonau 2015). The dyke has been mown since it was created, however, sheep grazing has been introduced in 2018 on a section of the dyke (Fig. 1).

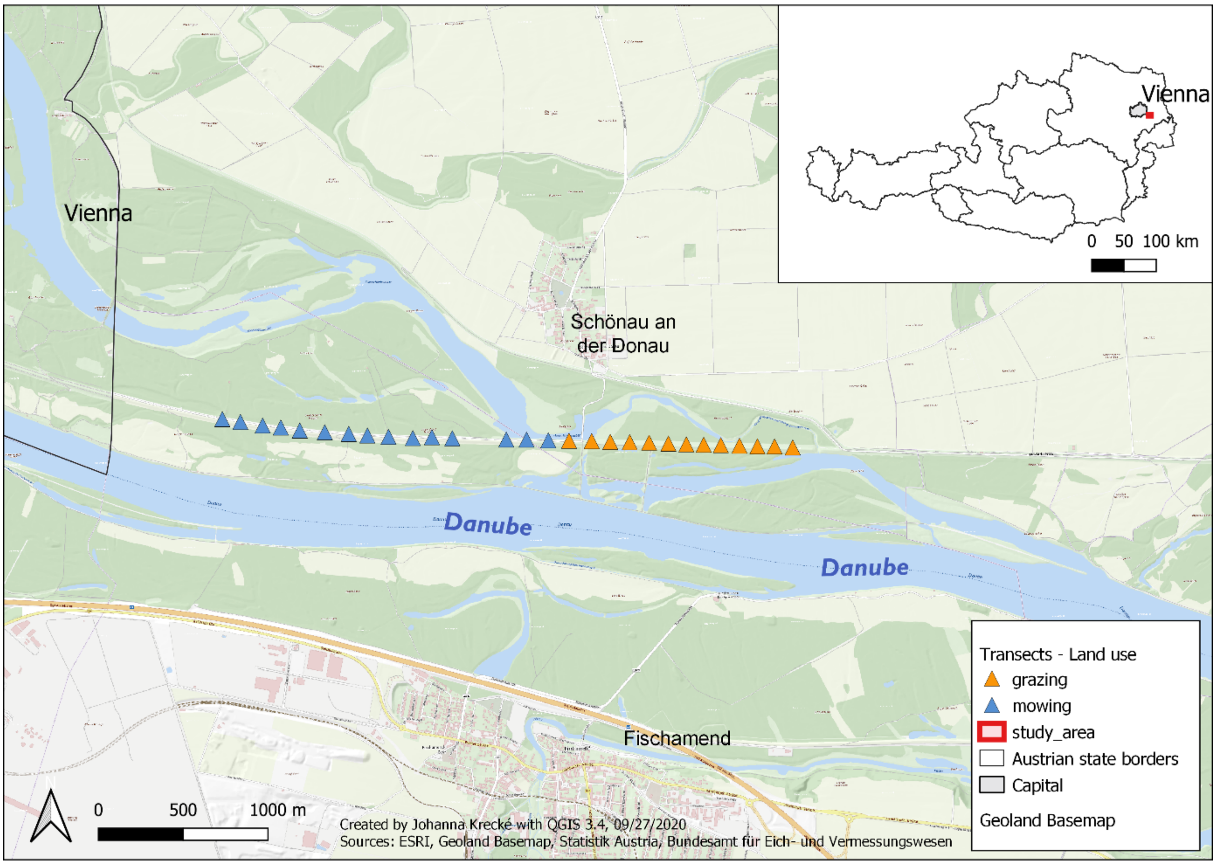

Figure 1: 28 Transects across dyke with different management practices and overview map of Austria. Study area (red). Transects of mown area in blue, grazed transects in orange.

The grazed section of 2 km length was grazed by a total of 50 sheep from May to July. The sheep where moved approximately every 4 days from East to West. The pasture was fenced with an electrical fence and equipped with a water tank and no additional fodder was given to the sheep during the field season. Depending on the weather conditions and fodder quality, the pasture length varied from 100 m to 150 m. The width mostly comprised the whole dyke section including the crest. Exceptions were the transects 4 and 5 which were only partly grazed, because of an adjacent flooded patch, whereas the southern slope "section D" (see Fig. 2) stayed unused during the first grazing round in 2019. The mown area was situated on the same riverside.

Field sampling

The recording of grasshoppers was done from May until September 2019 on warm dry days (T ≥ 20 °C) without strong wind. I used sweep netting as it is the most common method and appropriate for high population densities (Gardiner et al. 2005). All adults and nymphs were caught with a standardized number of sweeps per transect (see below) and subsequently counted and identified in the field, apart from early nymphs, which have been photographed and identified with the help of specialists as far as possible. We excluded all *Tetrix* species as they cannot be reliably surveyed with the used sampling method (Baur et al. 2006).

Orthoptera were sampled along 28 transects, each with a length of 30 m (modified after Jerrentrup et al. 2014, WallisDeVries et al. 2007). Each transect was divided in 3 sectors across the dyke (B: landside slope; C: crest; D: riverside slope) with a size of 10 m length and 4 m width (see Fig. 2). Sampling of each sector consisted of 10 single sweeps, resulting in 30 sweeps per transect. Sector A next to the landside slope of the dyke was excluded because of contrasting management.

The parameters time, temperature (°C), wind (Beaufort) and cloudiness (%) were noted. The mean vegetation height of sward canopy layer (cm) and vegetation density (%) of the sward were estimated separately for each section. The transects were semi-permanently marked by degradable tree marking paint on nearby stone riprap, trees or pavement. The sampling was done biweekly 13 times between May and September, to cover the full Orthoptera season; each survey was completed in two to three days.

Survey frequency was increased to weekly surveys during July and August, to closely monitor the effects of mowing. The first mowing was at the end of May including only sectors A and C. At the end of July all sectors were mown. Taxonomy and nomenclature of Orthoptera follow *Fauna Europaea* (De Jong et al. 2014).

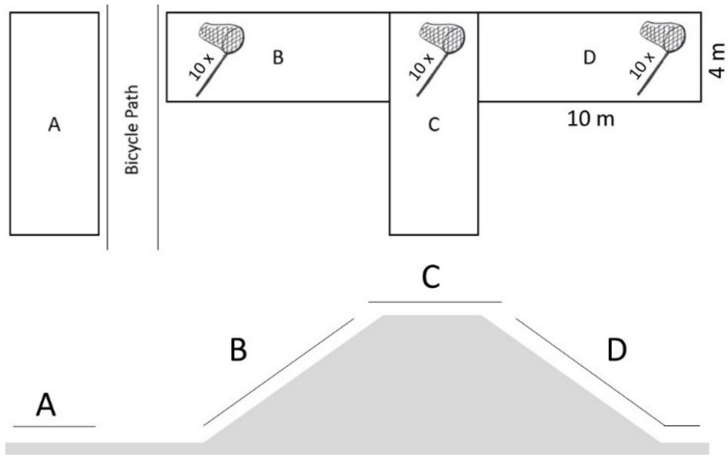

Figure 2: Transect with sectors A-D. Top: top view, bottom: cross section dyke

Statistical analysis

Similarities in species composition between transects were quantified using Bray-Curtis similarities. Based on the resulting similarity matrix, a one-way ANOSIM was calculated to test for differences in species composition between mowed and grazed transects. Further, the Bray-Curtis values were used to visualize the similarity relationships between species assemblages of sampled transects using a non-metric multidimensional scaling (NMDS) ordination. An associated *stress* value of <0.2 was accepted as reliably reflecting the observed similarity relationships. To test for differences in individual numbers of Red List Species (Red List Austria, Berg et al. 2005) two categories were made: RL (vulnerable, near threatened and endangered species) and LC (least concern species). A two-sample t-test and a Welch two sample t-test were done in R to test for differences in abundance of RL and LC in both treatments. The additional R package ggplot2 was used for visualising data and the package vegan was used to calculate the Shannon index. Differences in abundance were tested via students t-test and Welch-test. Tests on abundance and species composition were done with Past (Hammer et al. 2001). Species diversity assessment was calculated with Anne Chao's iNEXT online tool (Chao et al. 2016), visualized as sample-size-based rarefaction and extrapolation sampling curve (Settings: diversity: species richness; bootstrapping: 50 replications; confidence interval 0.95).

Results

A total of 24 Orthoptera species consisting of 12,448 individuals (including 3,486 adult individuals and 8,962 nymphs) were recorded in the 28 transects. In total 5,090 nymphs (57% of all nymphs) could not be identified on species level and were thus excluded from analyses. The most abundant species on the sites were *Pseudochorthippus parallelus* with 1,010 adult individuals (29%), followed by *Calliptamus italicus* with 731 adult individuals (21%) and 2,731 nymphs (30% of juveniles), *Euchorthippus declivus* with 654 adults (19%), *Chorthippus biguttulus* with 229 adult individuals (7%), *Chorthippus brunneus* with 208 adult individuals (6%), *Chorthippus dorsatus* with 134 adult individuals (4%), *Leptophyes albovittata* with 107 adult individuals (3%), *Conocephalus fuscus* with 84 adults and *Chorthippus mollis* with 80 adult individuals (each 2%).

Effects of management on vegetation height and vegetation density

Seasonal changes in vegetation height and vegetation density were dependent on phenology and land use. Interestingly, the mown transects had mostly higher, but extremely variable vegetation heights from May to July (Fig. 3). In the mown transects, there was a major decrease of mean (± 95% CI) vegetation height from 40 ± 10 cm to 6 ± 1 cm after mowing (from survey 5 to 6). In contrast, the mean height of the sward canopy of grazed transects changed relatively little over the season, at the same time as mowing was done in the other transects, it decreased from 31 ± 8 cm to 25 ± 61 cm, with big variation between transects and sectors (Fig. 3). In late summer, the mean vegetation height converged, with heights of 24 ± 4 cm in the grazing treatment and 18 ± 4 cm in the mowing treatment during the last survey.

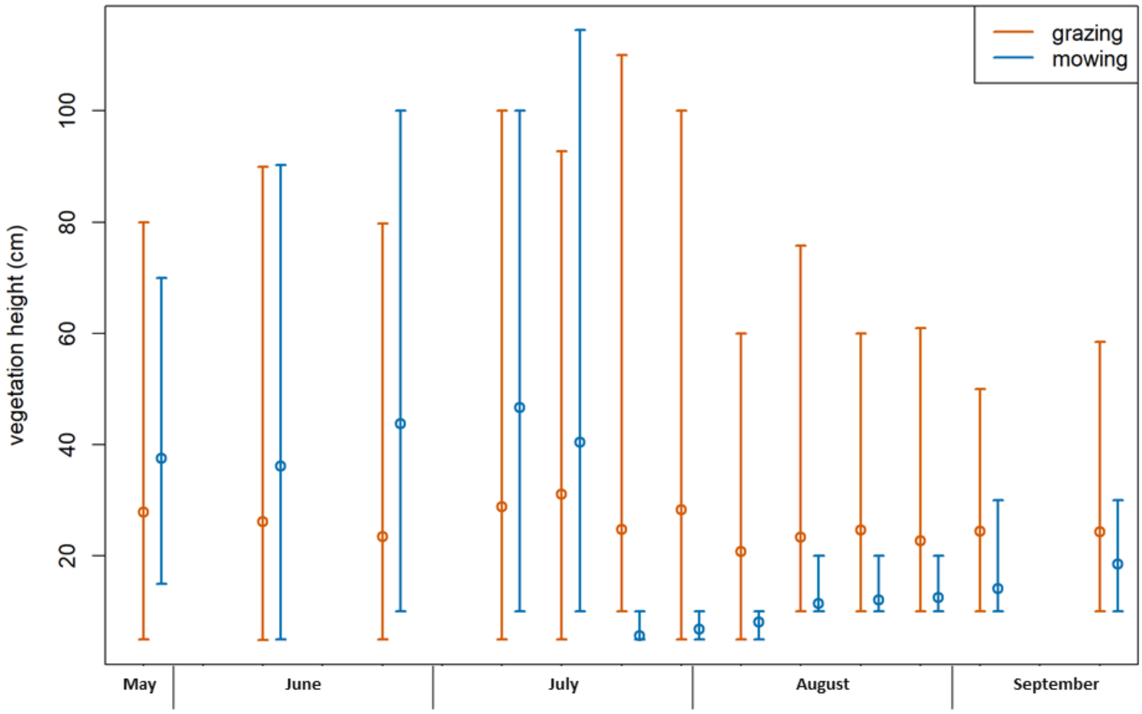

Figure 3: Mean vegetation height (± 95 % CI) of grazing treatment (orange, n=13) and mowing treatment (blue, n=15) during 13 survey rounds.

Also, vegetation densities (vegetation cover of sward in %) decreased and slowly converged towards mid-summer (Fig. 4). After mowing, mean vegetation densities (± 95% CI) in mown transects decreased from 60 ± 3 % to 43 ± 2 %. Among grazed transects vegetation density decreased during the grazing period from 51 ± 5 % during the first survey at the end of May to 42 ± 5 % during the fourth survey at early July. In the last six survey rounds, mean vegetation densities of the two management types were similar, with somewhat higher values and greater variability in grazing treatment. During the last survey in September vegetation densities were 50 ± 7 % in grazing treatment and 48 ± 4 % in the mowing treatment.

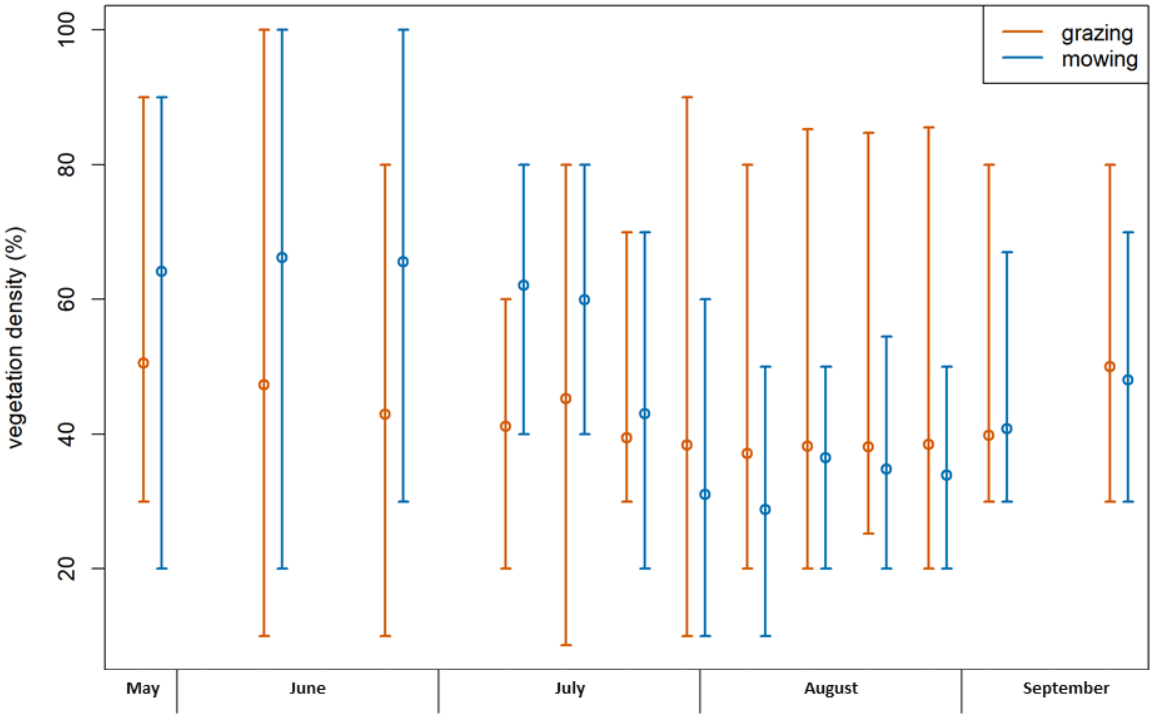

Figure 4: Mean vegetation density (± 95% CI) of grazing treatment (orange, n = 13) and mowing treatment (blue, n = 15) during 13 survey rounds.

Effects of grassland management on species composition, abundance and species richness

Although Orthoptera species composition was heterogenous between transects of the same treatment, differences were still bigger between grazing and mowing treatments (see Fig. 5). Species composition significantly differed between both treatments (one-way ANOSIM: Global $R = 0.61$, $p < 0.001$). Similarly, mean total abundance of adult grasshoppers differed significantly between grazed and mown transects ($t = -3.297$, $p = 0.003$). Mean abundance (± 95% CI) in grazed transects was a third lower (68 ± 19 individuals) than in mown transects (105 ± 15 individuals). In contrast, the mean species number (± 95% CI) of mown transects (11 ± 1 species) and grazed transects (10 ± 1 species) was very similar ($t = -0.684$, $p = 0.500$). In total, 21 species were found in grazed meadows, whereas 19 species were found in the mown meadows. The species accumulation curves indicate higher species diversity for grazed meadows although even three more transects were sampled on mown meadows (Fig. 6). Also, the mean Shannon index (± 95% CI) of transects was significantly lower ($t = 2.743$, $p = 0.005$) in the mowing treatment (1.50 ± 0.09) than in the grazing treatment (1.68 ± 0.11).

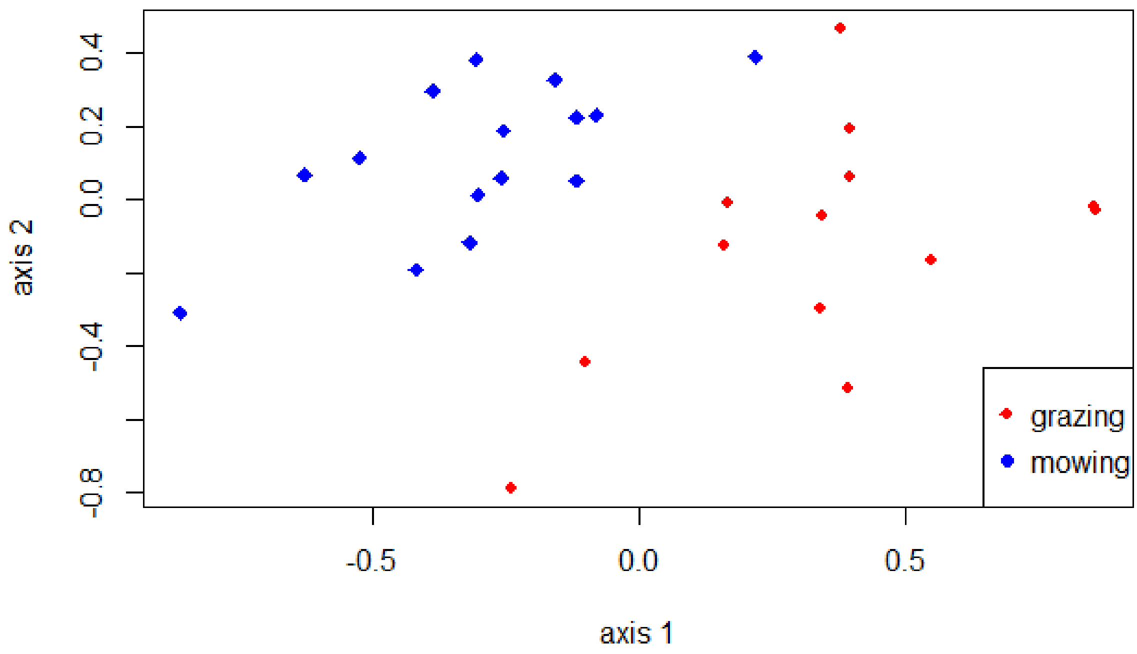

Figure 5: NMDS ordination (based on Bray-Curtis dissimilarities) visualizing similarity relationships of grasshopper species assemblages sampled on grazed (red, n=13) and mowed sections of the flood protection dam (blue, n=15) (stress = 0.153).

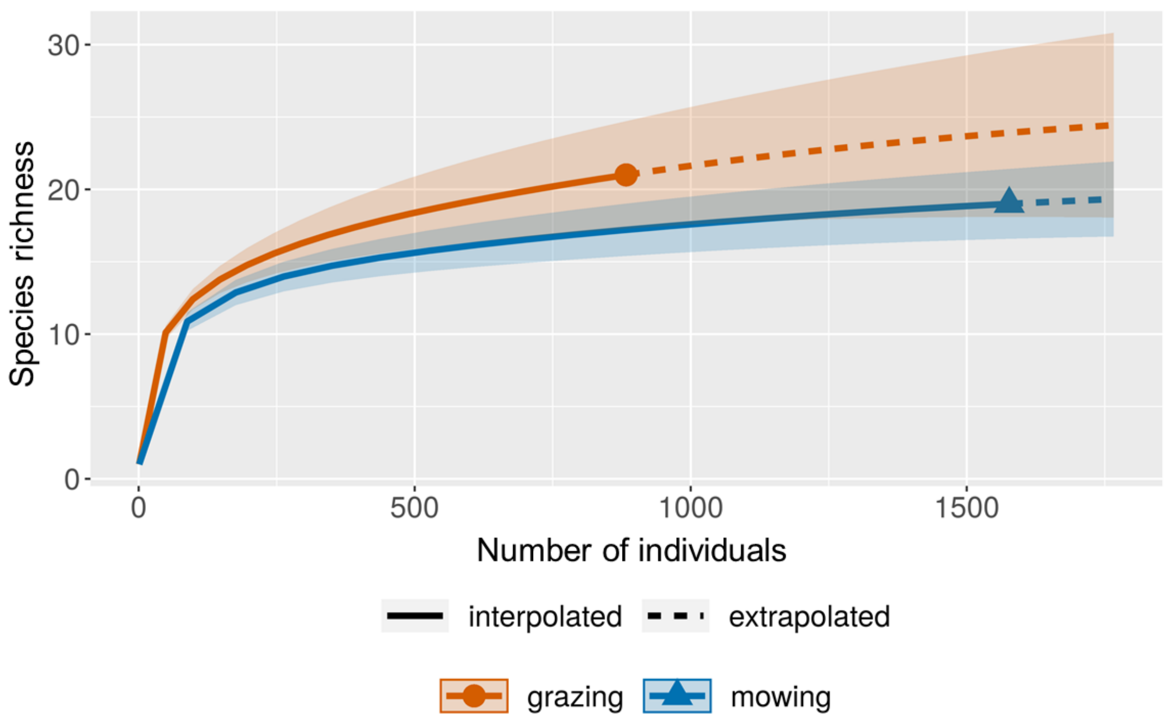

Figure 6: Species richness accumulation curves (± 95 % CI) for meadows managed by grazing (orange) and mowing (blue). The extrapolated part of the curve is indicated by a dotted line.

Differences in most abundant species

The mean total number of counted individuals differed significantly between mowed and grazed meadows in eight of the ten most abundant species in grazed meadows (Fig. 7). In the grazing transects, the most abundant species were *C. italicus, E. declivus, Ch. brunneus, P.*

parallelus, Ch. mollis, C. fuscus, Ch. biguttulus, L. albovittata, Ch. dorsatus and *Platycleis albopunctata grisea.* Most apparent were the almost tenfold higher mean number of individuals per transect (± 95 % CI) of *P. parallelus* (t =-10.643, $p \leq 0.0001$; 4.8 ± 2.7 individuals in grazing treatment vs. 46.9 ± 6.2 in mowing treatment) in mowing treatment and just under triple the amount of *E. declivus* (t = 1.981, p = 0.034; 20.2 ± 9.9 individuals in grazing treatment vs. 7.3 ± 1.9 in mowing treatment) in grazing treatment and the absence of *Ch. mollis* in the mowing treatment. Whereas *C. italicus* and *P. grisea* had no significant differences in abundances in both treatments (*C. italicus*: t = -0.744, p = 0.232; *P. grisea*: t = -0.690, p = 0.248), *Ch. brunneus* had almost twice (t = 2.512, p = 0.009) and *C. fuscus* had a more than four times greater abundance (t = 2.427, p = 0.014) in grazing treatment. Further, *Ch. biguttulus* showed a four times greater abundance (t = -3.566, p = 0.001), *L. albovittata* a three times greater abundance (t = -3.323, p = 0.002) and *Ch. dorsatus* a four times greater abundance (t = -4.223, p = 0.0002) in mowing treatment. In mown transects, the 10 most abundant species did not differ except *Bicolorana bicolor* (0.1 ± 0.2 in grazing treatment vs. 1.6 ± 0.9 in mowing treatment*) and Roeseliana roeselii* (t = -3.372, p = 0.002; 0.3 ± 0.6 in grazing treatment vs. 1.5 ± 0.8 in mowing treatment*)* were among the most abundant species, with a significantly higher abundance in mowing treatment, instead of *Ch. mollis* and *P. albopunctata grisea*.

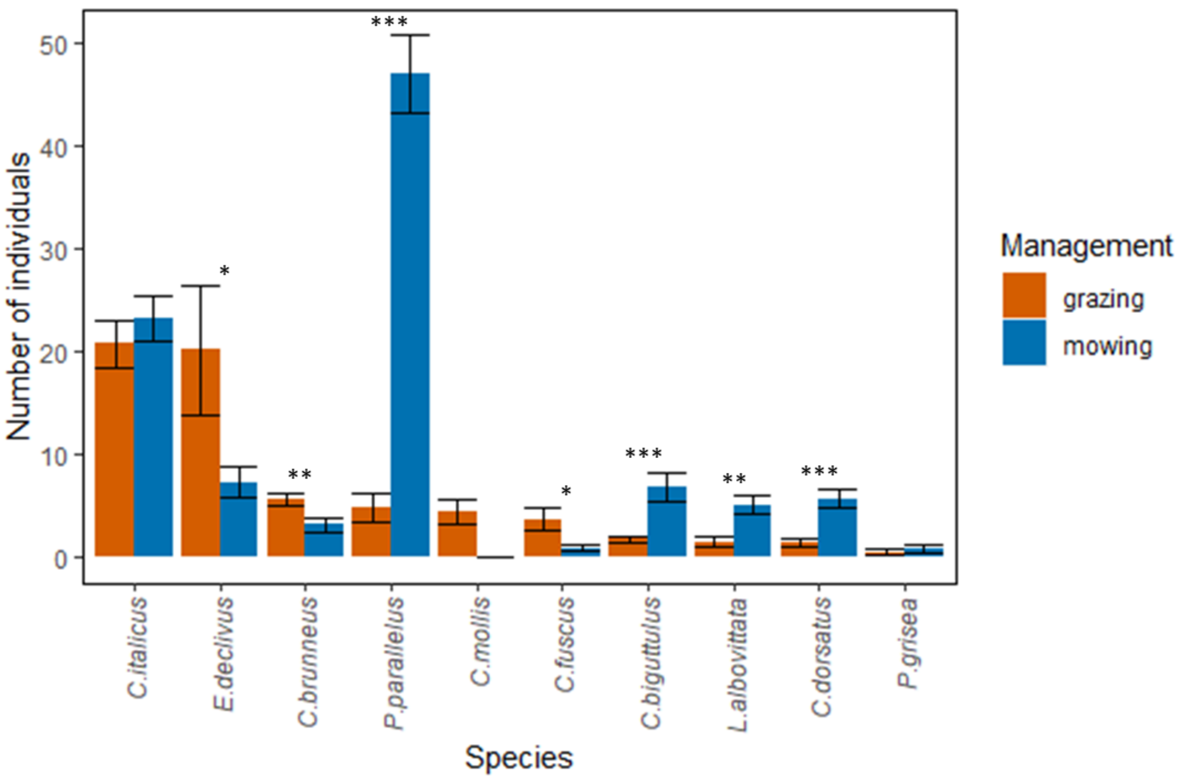

Figure 7: Mean number of individuals (±95% CI) per transect of the 10 most abundant species on grazed meadows shown separately for grazing (orange) and mowing treatment (blue). Differences in abundance tested via t-test: p ≤ 0.05(*), p ≤ 0.01(**), p ≤ 0.001(***), p ≤ 0.0001(****).

Effects of management measures on threatened species

In this study 12 species listed as being of least concern (LC) in the national Red List (Berg et al. 2005) were recorded: Another 12 species are listed as vulnerable (VU), near threatened (NT) or endangered (EN). The abundance per transect of threatened species did not differ significantly between treatments (t-test: t = 1.684, p = 0.052) whereas the abundance of not threatened species was significantly lower in grazing treatment, compared to the mowing treatment (Welch two sample t-test, t = -2.739, p = 0.006). The most abundant RL species was

C. italicus comprising 70 % of RL individuals in grazing treatment and 78 % of RL individuals in mowing treatment.

Discussion

Effects of grazing vs. mowing

Several sources recommend extensive use of grasslands, as most orthopterans including scarce species showed higher abundances, especially if grazed, unfertilized or infrequently mown (Achtziger et al. 1999, Chiste et al. 2016, Fartmann and Mattes 1997). Grazing is often seen as the best solution to create a heterogenous sward height. By preferably consuming short, fresh patches and discarding patches with older or unpalatable vegetation, sheep and other livestock influence the spatial vegetation structure. But this is only the case in large pastures as well as during the earliest days in a new pasture. If livestock is kept on the same pasture, the heterogenous vegetation structure is reduced over time (Fonderflick 2014). Grasslands were found to be richer in biomass with a high plant coverage and height when grazed moderately, light or without grazing (Ma et al. 2017). Though this effect is highly grazer species-specific, therefore leading to differences in Orthoptera species richness, according to the type of livestock used (Chiste et al. 2016).

Contrary to results of this study, Oertli et al. (2005) and Bonari et al. (2017) could not find any significant effect of management on insect species richness. It can be argued that only very extensively used grasslands were compared in their studies and therefore only minor differences of effects were found, as the effect of management also depends on the disturbance gradient of the study sites (Oertli et al. 2005). Hence, it was suggested not only to scrutinize management practices, but also to consider the extent of disturbance.

In my study, significant differences in species richness were found and could be traced back to the already thin soil layer of the dyke, which was highly affected by trampling, creating a more heterogenous vegetation cover in a short period of time as well as the different timing and duration of management practises in both treatments. Since grazing was done as strip grazing in the Donau-Auen National Park, moving the pasture every three to five days with a movable electric fence, it will produce somewhat different effects on species richness and composition than large scale mowing done once a year (Humbert et al. 2010, Fabriciusová et al. 2011, Rada et al. 2014). Less significant differences in species richness and composition are likely if the scale of management is the same, e.g. mowing smaller patches or large-scale grazing with higher stocking rate (Fabriciusová et al. 2011, Rada et al. 2014). The current small-scale grazing treatment, with sheep in a mobile pasture, levelled out shifts in vegetation structures caused by defoliation. The mowing treatment, however, was drastically reducing the sward height and vegetation cover, since all transects were mown at once.

Large-scale mowing represents a high mortality risk for many insect groups and Orthopterans particularly. Since most grasshopper species are relatively large invertebrates and have limited mobility at least while juvenile, they are especially exposed to mowing. Additional to the direct mortality by harvesting machines, a change in microclimatic conditions with hostile temperatures is reached as sward height is drastically reduced (Wagner 2004, Gardiner and Hill 2006b, Gardiner et al. 2002). These negative effects could be aggravated by drought and heat during summer, climatic features which could get worse in the course of the progressing climate change.

Further, risk of predation is increased by large-scale mowing, since low sward height provides less plant biomass for shelter and with the distance to undisturbed patches the risk of predation enhances (Gardiner and Hassall 2009; Humbert et al. 2010). In my study only few individuals were left on the transects after mowing in August, in accordance to earlier findings which showed a decline of individuals both directly after mowing and later in the season after full recovery of the vegetation (Rada et al. 2014). With increasing time lag from the mowing event, a significant increase in abundance was found (Chiste et al. 2016), underlining the strong effect of mowing on grasshopper biomass.

To increase the numbers of Orthoptera in short farmland swards (<10 cm height) by mowing, it is important to tackle their main difficulties: The direct and indirect mortality caused by harvesting machines and the change of microclimatic conditions. Since the type of machine used for mowing can reduce mortality in Orthoptera, the use of tractor bar mowers is often advised. If solely the mowing process is regarded, the bar mower is less harmful to Orthoptera than rotary mowers (Humbert et al. 2009, 2010). To ensure the habitat quality for particularly scarce species, most studies strongly recommend a rotating mowing regime, leaving out some patches every season to allow migration to unmown patches (Fartmann and Mattes 1997, Achtziger et al. 1999). As a further option, I recommend mowing of different parts of the meadow at a time interval of several weeks. Hence, a gradient of sward height could be produced. This would allow Orthoptera and other insects to move from mown parts to unmown strips of grass (baulks) as mowing progressed. Baulks tend to have a significant positive interaction with orthopteran individuals and species numbers, numbers decreasing with increasing distance to baulks (Rada et al. 2014). Not only higher numbers of individuals in the baulks, but also directly next to them were found in the study by Rada et al. (2014).

Species diversity and composition

Although individual numbers were higher on mown dyke sections, Orthoptera species diversity proved being higher in the grazed part of the dyke. An explanation could be that grazing provides more spatial structures which benefit not only the common dominant species, but a wider variety of Orthoptera.

The abundance of LC species was higher in mowing treatment and the abundance of species classified as NT, VU and EN was similar in both treatments. Therefore, it is possible, that LC species are either less affected by the recent mowing regime or suppressed by grazing. The, by far, most abundant RL species in this study *C. italicus* did not show a significant difference in management, possibly producing less significant results. It was already discussed to review the Red List status of *C. italicus* in Eastern Austria because of recent increases due to warmer climatic conditions in the course of climate change (Zuna-Kratky et al. 2017). Therefore, also a comparison of LC and RL species excluding *C. italicus* could also be considered. The species composition was very heterogenous among transects of each treatment, but a greater divergence was found between both management types. This and the ratio of RL and LC species could also be caused by other factors than treatment such as different thickness of soil layer, nutrient input or slope, as the dyke was slightly less steep at the mown transects and had a higher cover of trees in the surrounding area. The protection of xerophilic and threatened species on the studied dyke by adequate management measures should be considered to meet their specific needs. Xerophilic species of conservation concern that were found during my study are *Bicolorana bicolor, Calliptamus italicus, Leptophyes albovittata, Oedipoda caerulescens, Omocestus haemorrhoidalis and Platycleis albopunctata grisea.*

Species abundance

My results show that several species differed substantially in abundance between treatments. The strongest difference showed *Pseudochorthippus parallelus*. On mown dyke sections, it was by far the most common species. Possibly *P. parallelus* is negatively affected by grazing, e.g. through trampling of its eggs. Also, abundances in the mown meadows could be enhanced by competitive release due to decreased abundances of other Orthoptera species with similar preferences. *Euchorthippus declivus* showed a clear preference to transects of grazing treatment. The high abundance of *E. declivus* can be explained by the stronger pronounced semi-dry grassland in the grazed part of the dyke, which is a preferred habitat of this species

(Zuna-Kratky et al. 2017). *Calliptamus italicus* was the most abundant species on the dyke crest of both mowed and grazed transects, as there is a gravelled trail, meagre soil layer and low vegetation cover. *Chorthippus mollis* was absent in mowing treatment, this could be caused by the preference of dry habitats and patches of bare soil, which were found more often in the grazed transects. *Conocephalus fuscus* was much more abundant in grazing treatment than in mowing treatment. This could be explained by its preference of extensively used grasslands with high sward heights (Zuna-Kratky et al. 2017).

Vegetation cover

One vital feature to enhance insect diversity is an increase in spatial heterogeneity and vegetation structures (Jerrentrup et al. 2014). A positive correlation of phytovolume and Orthoptera abundance can be found, especially in August when adult abundance is highest. Earlier in the year, this correlation is lower, because nymphs are less mobile than adults. Additionally, at an intermediate stage of grassland succession (30-40 cm mean sward height), still including bare ground and low-growing vegetation as well as tall-growing vegetation, a peak in Orthoptera abundance can be seen, this can be traced back to a compromise in the supply of food, favourable temperatures and protection against predation and trampling due to vegetation cover (Fartmann et al. 2012, Fonderflick et al. 2012). Although high abundance in medium vegetation height could also be biased by method, as sweep netting becomes less efficient in tall heterogenous vegetation (>50 cm sward height), according to a study on methods at different sward heights and climatic conditions (Gardiner et al. 2005). A greater density of Orthoptera was found on freshly abandoned arable land with high vegetation density and height in the study of Báldi and Kisbenedek (1997), whereas species richness and diversity were indicated to be greater on less disturbed meadows with lower, but more heterogenous vegetation. Jerrentrup et al. 2014 discuss that the greatest sward height, even though having a greater biomass, was not providing more microclimatic or feeding niches, than vegetation of medium height.

Effects of timing of management

Differences in species composition could be caused not only by type of management, but by different timing of management (Mazalová et al. 2015). Depending on the seasonal development of nymphs, the periodic defoliation could favour some species. An early defoliation might affect the hatching date, as higher soil temperatures are reached on patches with shorter vegetation (ONeill et al. 2003). To enhance the abundance of species, the specific hatching date could be an interesting factor. It should be considered which species are affected by earlier defoliation because they hatch early or late. The hatching date of vulnerable and endangered species could help coordinate the most suitable time of management practise, as there are several opinions on the right timing of mowing or grazing (Miller and Gardiner 2018). It is important to understand the positive effect of management for the development of eggs and early larval stages because of warmer ground temperatures as well as a disturbance both for relatively immobile nymphs, but also reproducing adults (Miller and Gardiner 2018).

Conclusions

This research addressed different effects of management on the Orthoptera community. My results show that species composition differed greatly between grazed and mown sections of the studied dyke. Also, a greater species diversity, including a higher percentage of threatened species, was recorded in the grazing treatment.

Nonetheless did several species differ substantially in abundance between treatments, showing an increased abundance of Orthoptera in the mowing treatment. Especially species listed as Least Concern showed significantly higher abundances in the mown meadows. Therefore, it can be argued that the higher vegetation density was more suitable for those common species or they are less affected by the mowing event than by grazing. As to the abundance of threatened species, no significant difference in overall abundance could be found. Though eight out of ten most abundant species in the grazing treatment, including unexpectedly high abundances of *Pseudochorthippus parallelus* and *Euchorthippus declivus in opposing treatments,* showed significant differences in abundance between treatments. Therefore, I recommend addressing possible habitat preferences, particularly of *P. parallelus* and *E. declivus* regarding management in further research.

The gradual grazing management was clearly less invasive than the abrupt mowing regime and provided a wide array of different vegetation structures during the season. The drastic change in biomass in the mowing treatment could be mitigated by leaving undisturbed strips of vegetation at each mowing event (Marini et al. 2008, 2009b, Humbert et al. 2010, Rada et al 2014). Consequently, it is essential to exclude parts of the dyke from management each season, or alternatively with several weeks distance, to allow Orthoptera to switch to an undisturbed patch during the management practise and provide shelter until mown or grazed patches have regrown (Achtziger et al. 1999). Therefore, either grazing or mowing as a rotational regime is recommended. To coordinate the management regime with the seasonal Orthoptera activity and, to minimise mortality, a late harvest in September is suggested (Gardiner and Hassall 2009, Humbert et al. 2010). To protect the xerophilic species, which are classified as Near Threatened or Vulnerable, the national park management should consider phenological differences of each species (see Supplementary Material, Table S5, Zuna-Kratky et al. 2017).

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Supplementary Material

Table S1: Coordinates of each transect listed by management practice and location from East to West.

Conservation Management	Transect Code	Coordinates	
		latitude	longitude
grazing	1	48.135905° N	16.630425° E
	2	48.135981° N	16.628991° E
	3	48.136004° N	16.627634° E
	4	48.136058° N	16.626214° E
	5	48.136108° N	16.624737° E
	6	48.136150° N	16.623379° E
	7	48.136188° N	16.622011° E
	8	48.136248° N	16.620587° E
	9	48.136319° N	16.619063° E
	10	48.136368° N	16.617528° E
	11	48.136403° N	16.615987° E
	12	48.136465° N	16.614514° E
	13	48.136505° N	16.612724° E
mowing	14	48.136552° N	16.611083° E
	15	48.136615° N	16.609363° E
	16	48.136643° N	16.607755° E
	17	48.136770° N	16.603483° E
	18	48.136850° N	16.601868° E
	19	48.136825° N	16.600353° E
	20	48.136920° N	16.598434° E
	21	48.137013° N	16.596765° E
	22	48.137117° N	16.595286° E
	23	48.137198° N	16.592913° E
	24	48.137351° N	16.591414° E
	25	48.137531° N	16.589914° E
	26	48.137656° N	16.588479° E
	27	48.137869° N	16.586723° E
	28	48.138041° N	16.585296° E

Table S2: Total species found during data sampling c~~h~~ategorized by habitat preference and Red List status of Austria (Berg et al. 2005).x = xerophil, h = hydrophil, i = indifferent, LC = least concern, VU = vulnerable, NT = near threatened, EN = endangered.

Species	Habitat Preference	Red List Austria
Bicolorana bicolor	x	**NT**
Calliptamus italicus	x	**VU**
Chorthippus albomarginatus	h	**NT**
Chorthippus apricarius	x	LC
Chorthippus biguttulus	x	LC
Chorthippus brunneus	x	LC
Chorthippus dorsatus	i	LC
Chorthippus mollis	i	**NT**
Chrysochraon dispar	h	**NT**
Conocephalus dorsalis	h	**EN**
Conocephalus fuscus	i	**NT**
Euchorthippus declivus	x	LC
Leptophyes albovittata	x	**NT**
Oecanthus pellucens	x	LC
Oedipoda caerulescens	x	**NT**
Omocestus haemorrhoidalis	x	**VU**
Phaneroptera falcata	x	LC
Phaneroptera nana	i	LC
Pholidoptera griseoaptera	i	LC
Platycleis albopunctata grisea	x	**NT**
Pseudochorthippus parallelus	i	LC
Roeseliana roeselii	i	LC
Ruspolia nitidula	h	**NT**
Stenobothrus lineatus	x	LC
Tettigonia viridissima	i	LC

Table S3: Adult individuals found during data sampling, ordered by sectors and management type.

species	grazing: adults per sector			total	mowing: adults per sector			total
	b	c	d		b	c	d	
bicbic			1	1	24			24
caelifera sp.	1	3		4		6		6
calita	107	137	26	270	94	234	19	347
choalb	1		1	2	1			1
chobig	12	9	2	23	27	51	25	103
chobru	31	23	19	73	12	22	14	48
chodor	5	2	12	19	29	24	33	86
chomol	30	16	12	58				
chorthippus sp.	2	1	3	6	3			3
chrdis						1	1	2
condor			1	1				
confus	3	5	40	48	6	3	4	13
eucdec	132	77	53	262	31	69	9	109
lepalb	3	6	11	20	41	4	32	77
oedcae	3	13	1	17	1	5	2	8
omohae	1			1				
phafal			1	1			1	1
phanan			5	5				
phogris					1			1
plagris	1	1	5	7	7	2	4	13
psepar	17	3	43	63	263	164	277	704
roeroe			4	4	4		19	23
rusnit			2	2	1	2		3
stelin	4		1	5	10	2		12
tetvir			1	1	1		1	2

Table S4: Adult individuals found during data sampling, ordered by transects and management type.

species	grazing: adults per transect													total	mowing: adults per transect															total
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**		**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	
bicbic					1									1				3	1	1	4	3	6	1	1	2	1	1		24
caelifera sp.		1		1						1		1		4	1			1					4							6
calita	32	23	25	23	18	21	27	5	24	29	3	19	21	270	41	22	12	15	26	22	30	34	26	27	12	29	16	18	17	347
choalb	1									1				2								1								1
chobig	1	1	1	3	2	4	3	2	2	2	1	1		23	6	8	1	5	15	13	3	10	20	5	5	3	2	3	4	103
chobru	2	6	7	8	5	3	6	5	6	6	2	9	8	73	7	8	2	3	4	7	4	5	5			2	1			48
chodor	2	1	2	2			5	1	3	1		2		19	5		4	2	6	6	7	15	6	6	6	10	7	5	1	86
chomol		1	3	12	9	2	8	7	10	1	1	3	1	58																
chorthippus sp.	2					2	1	1						6			1	1	1											3
chrdis																											1	1		2
condor	1													1																
confus	5	5	14	8	4	6	3	1		1	1			48					1	1	1	4		1	1	1			3	13
ensspec																														
eucdec	86	41	23	24	19	6	10	2	12	25	5	2	7	262	22	17	9	10	4	2	6	10	4	2	6	2	2	8	5	109
lepalb	1	1			5	2	4			2	1	1	3	20	3	4	1	3	1	4	6	13	7	4	8	8	1	12	2	77
oecpel																														
oedcae	1			1	1			6	5	3				17	2	2		1	1									2		8
omohae													1	1																
phafal				1										1		1														1
phanan		1	1		1		1			1				5																
phogris																											1			1
plagris			2			2				3				7						4		1			1	4	1	2		13
plaspec																														
psepar	6	5		1	3	2	4	4	5	20	3	2	8	63	63	26	34	53	38	58	39	71	35	64	65	32	39	49	38	704
roeroe										4				4	4		1		1	1		2		4	3		1	3	3	23
rusnit	1			1										2					1							1	1			3
stelin						1	1		2				1	5	2		2	1	2	1			1	2					1	12
tetvir	1													1									1				1			2

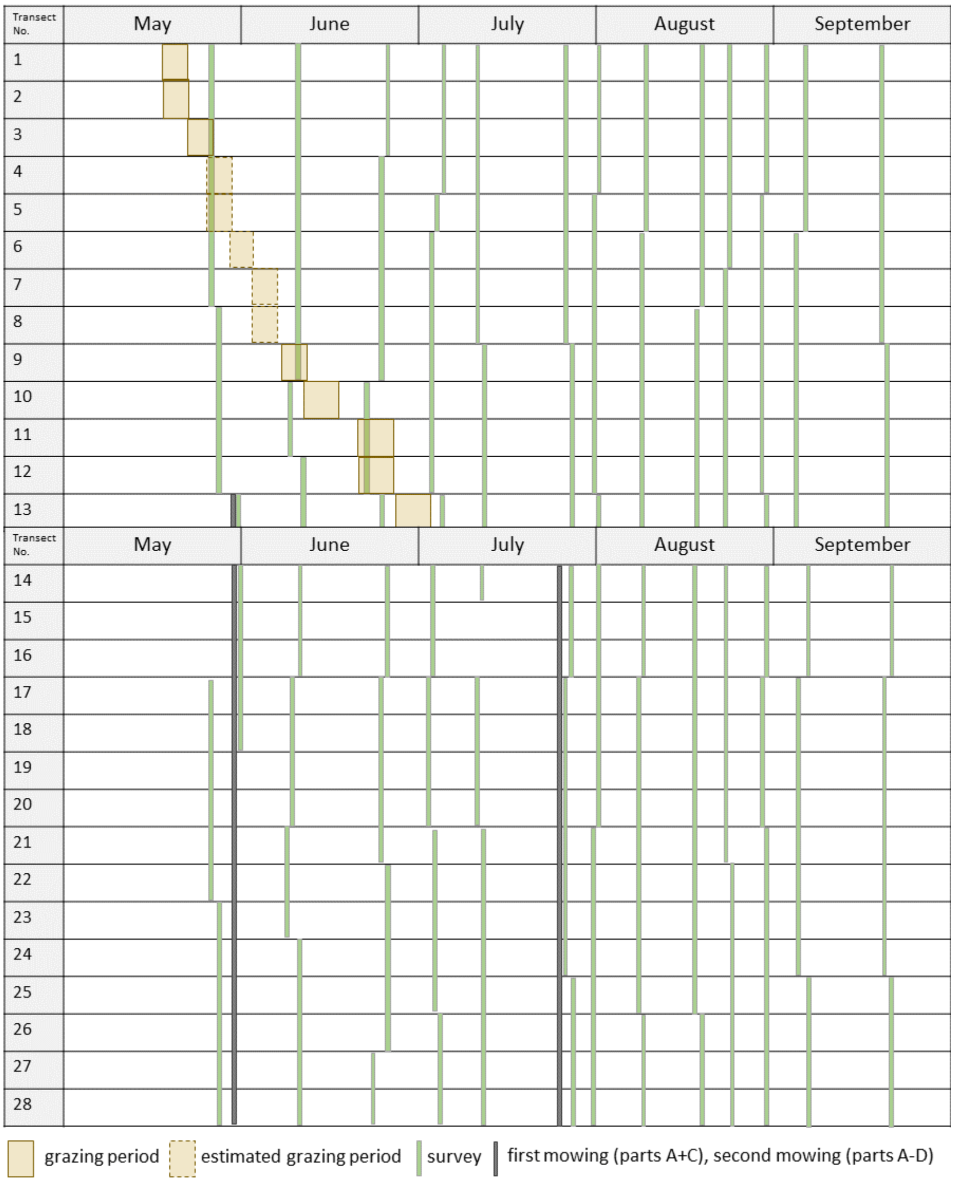

Figure S1: Timeline of both management strategies (up: grazing, bottom: mowing) and sampling of data in 2019

*Table S5: Phenology of Orthoptera species found in both treatments. Table altered after Zuna-Kratky et al. (2017). Grey = 1 to <5 % of data, green = 5 to <10 % of data, oange = 10 to <20 % of data, 20+ % of data, * = decade of most records.*

Orthoptera	MAY	JUN	JUL	AUG	SEPT	OCT	NOV
Chrysochraon dispar			*				
Pseudochorthippus parallelus			*				
Roeseliana roeselii			*				
Bicolorana bicolor			*				
Chorthippus apricarius				*			
Leptophyes albovittata			*				
Stenobothrus lineatus			*				
Chorthippus brunneus				*			
Euchorthippus declivus			*				
Platycleis albopunctata grisea			*				
Omocestus haemorrhoidalis				*			
Pholidoptera griseoaptera				*			
Calliptamus italicus				*			
Tettigonia viridissima				*			
Chorthippus albomarginatus				*			
Chorthippus biguttulus				*			
Oedipoda caerulescens				*			
Chorthippus dorsatus				*			
Chorthippus mollis				*			
Conocephalus dorsalis				*			
Conocephalus fuscus				*			
Phaneroptera falcata				*			
Oecanthus pellucens				*			
Phaneroptera nana				*			
Ruspolia nitidula				*			

Timeline

Figure S2: Seasonal changes of vegetation height and density depending on management practise during the field season.