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ORIGINAL PAPER

To graze or to mow? The influence of grassland management on grasshoppers (Orthoptera) on a flood protection embankment in the Donau-Auen National Park (Austria)

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Abstract

Introduction Most Central European grasslands crucially depend on land use, and thus there is a need to comparatively analyse the impacts of different types of land use management on grassland biota.

Aims and methods We use grasshoppers (Orthoptera), which are the most important insect herbivores in grasslands, and assess the differences of grazing (sheep) and mowing on species abundance, richness, and composition. We use a river embankment in the National Park Donau Auen as study site, where we have established 28 transects. Orthoptera abundance was surveyed 13 times between May and September 2019 in each transect.

Results We recorded 24 Orthoptera species, of which 12 species are listed in the national Red List. The most abundant non-threatened species is *Pseudochorthippus parallelus* in mown transects, while in grazed transects *Euchorthippus declivus* is most abundant. Eight of the ten most abundant Orthoptera species differed significantly in abundance between mown and grazed transects. Total abundance of Orthoptera was higher in mown transects, while grazed transects had higher species richness. Most xero-thermophilic species were more abundant in grazed transects, while some species of mesic grassland were more abundant in mown transects. These species-level differences resulted in clearly separated Orthoptera species assemblages between grazed and mown transects. Our findings suggest that the less dense vegetation in grazed transects better fulfilled the habitat requirements of xero-thermophilic species compared to mown transects

Discussion Given that mown and grazed transects are located adjacent to each other, that the complete study site was mown for many decades and grazing was only started one year before field data collection, the scale of differences in species richness, composition and abundances between grazed and mown transects is surprising. Thus, our findings indicate that grasshoppers respond rapidly to changing land use.

Implications for insect conservation We conclude that river embankments can be important secondary habitats for species-rich grasshopper communities. We recommend that grazing should be continued at the river embankment, ideally as rotational pasture as currently done. Mowing should be changed towards mowing parts of the river embankment at different times and leaving small strips of vegetation unmown.

Keywords Abundance · Conservation · Dyke · Grasshoppers · Grazing · Mowing · Sheep · Species community · Species richness

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Introduction

Low-intensity land use is essential for preserving species-rich grasslands that harbour rare and threatened biota (Achtziger et al. 1999; Chiste et al. 2016). Basically, two contrasting types of land use management exist for grasslands, i.e. mowing and grazing. Both land use types create specific microhabitats with spatio-temporal differences in sward height and structure (Chiste et al. 2016). Mowing creates spatially homogenous swards which are characterized

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by pulsed and large-scale removal of above-ground biomass, while grazing results in a spatially heterogeneous mosaic of differently grazed patches, often including patches of open soil due to trampling (Rada et al. 2014). The vegetation structure of pastures is dependent on the behaviour of grazers. Each livestock has specific dietary preferences resulting in specific structural heterogeneity of the sward (Rook et al. 2004). The ability of grazing animals to express their dietary preferences, however, strongly differs with grazing pressure (Fonderflick et al. 2014). Under low-intensity grazing, selective grazing 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. 2017).

In the last two centuries, 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, 10,000 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 exist (Via donau 2015). To prevent the encroachment of woody species, flood protection embankments are usually mown or grazed (Rook et al. 2004). Given their substantial spatial extent and because they are not fertilized and usually covered by species-rich grasslands, dykes have become important secondary habitats for many grassland species. Further, they also serve as important dispersal corridors for biota in river valleys (Bátori et al. 2016).

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 (Báldi and Kisbenedek 1997; Fargeaud and Gardiner 2018; Gardiner et al. 2005; 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). Finally, Orthoptera species—particularly rare and threatened ones—have specific micro-habitat preferences, are thus highly sensitive to different types of land use and therefore excellent indicators for the effects of contrasting land use regimes on species assemblages (e.g. Fartmann et al. 2012; Gardiner et al. 2005).

Here, we assess the effects of the type of management (grazing vs. mowing) on the abundance, species richness and species composition of Orthoptera on a flood protection embankment in the Donau-Auen National Park in eastern Austria. We established 28 transects that were surveyed 13 times between May and September 2019. Specifically, we address the following questions: (1) How does land use affect species composition, abundance and species richness of Orthoptera? (2) Which species are preferentially associated with one of the two land use types? (3) Do threatened species respond differentially to the two land use types? (4) How do vegetation height and density change seasonally on mown and grazed grasslands?

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 (Via donau 2015). The Marchfeldschutzdamm from Vienna to the “Schönauer Schlitz” was finished in 1884 and is well-known for its semi-dry grasslands (Wesner 1995). 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 (Via donau 2015). The dyke has been mown since it was created, however, sheep grazing has been introduced in 2018 on a section of the dyke. Orthoptera were sampled in 28 transects on a 2.5 km long section of the embankment, 15 established in mown and 13 in grazed embankment sections (Fig. 1). Except for the differences in current land use, all transects have an identical land-use history and identical environmental factors such as exposition and inclination.

A total of 50 sheep grazed the embankment over a length of 2 km from May to July. For this, starting at the embankment section where the easternmost transect was located, 100–150 m long embankment sections were fenced with an electrical fence and equipped with a water tank. The width of the grazed area mostly comprised the whole dyke including the crest. Exceptions were the transects 4 and 5 which were only partly grazed, because of an adjacent flooded patch, whereas section D (see Fig. 2) was not grazed in the first grazing round in 2019. After approximately four days of grazing, sheep where moved to the next embankment section further west (Fig. S1).

Field data sampling

All 28 transects were 30 m long and 4 m wide (modified after Jerrentrup et al. 2014; WallisDeVries et al. 2007) and were divided in 3 sectors (each 10 m long) across the dyke (B: landside slope; C: crest; D: riverside slope) (see Fig. 2). The transects were semi-permanently marked by degradable

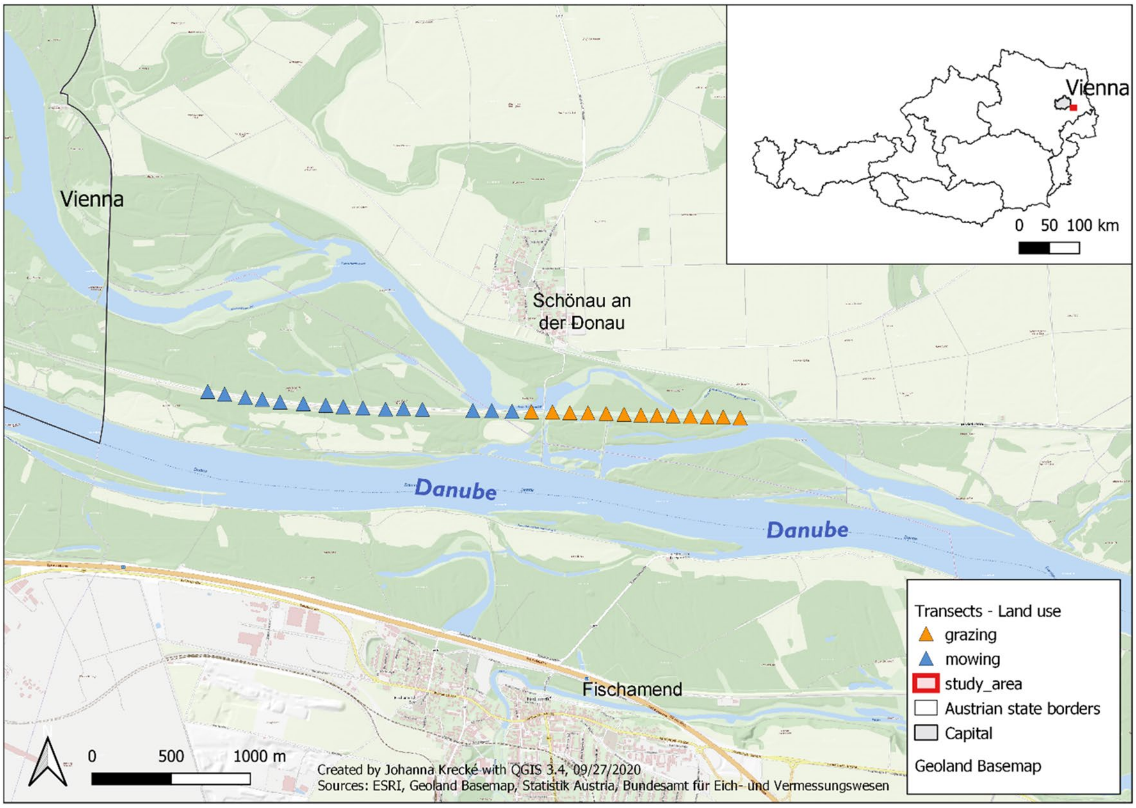

Fig. 1 Location of the 28 sampled transects at the dyke (Marchfeldschutzdamm) and location of the study area (red) in Austria (insert). Transects on mown dyke sections are indicated by blue triangles, grazed transects are indicated by orange triangles

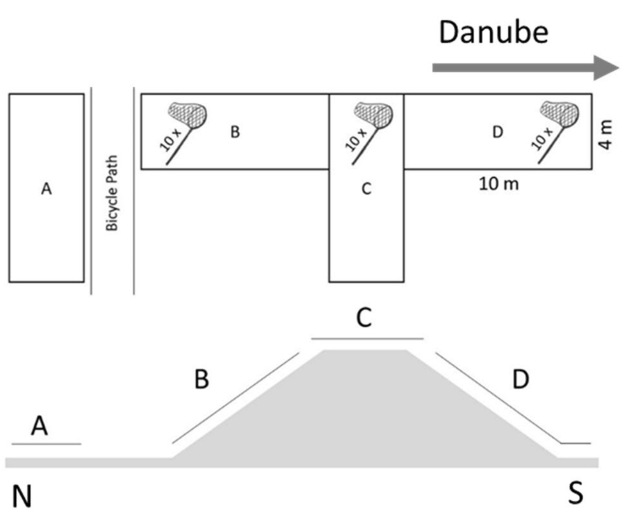

Fig. 2 Schematic overview of the transect design with sectors A–D. Sampling was done in sectors B–D; for analyses, data were pooled in the transect. On top, an aerial view is given, while below a lateral view is provided

tree marking paint on nearby stone riprap, trees or pavement. Sector A next to the landside slope of the dyke was excluded because of contrasting management.

Sampling of each sector consisted of 10 single sweeps, resulting in 30 sweeps per transect. We 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 above) 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). Taxonomy and nomenclature of Orthoptera follow *Fauna Europaea* (De Jong et al. 2014).

To cover the full Orthoptera season, sampling was done on warm dry days (T ≥ 20 °C) without strong wind between May and September 2019 with a biweekly sampling interval in May, June and September and—to closely monitor effects of mowing—a weekly interval in July and August. The first mowing was at the end of May including only sectors A and C. At the end of July all sectors were mown. Each of the 13 survey rounds was completed in two to three days. For each survey, mean vegetation height (in cm) and density (in % ground cover) of the sward were visually estimated separately for each transect sector; we then calculated mean vegetation height and density values for each transect by averaging across the sector values.

Statistical analyses

For analyses, we pooled the data of the different sectors of the transects as we were focusing on differences in Orthoptera species richness, abundance and composition among transects. We considered all adult individuals recorded in the transects, and for certain analyses, we also considered all nymphs that could be determined to the species level. For comparing the abundance of species between land uses, we summed up individual numbers per species and transects, and calculated the mean abundance per transect and use type.

Differences in species composition between transects were quantified using Bray–Curtis similarities (e.g. Clarke et al. 2006). Based on the resulting similarity matrix, a one-way ANOSIM was calculated to test for differences in species composition between mown and grazed transects. Further, the Bray–Curtis values were used to visualize the dissimilarity among species assemblages of transects using a non-metric multidimensional scaling (NMDS) ordination calculated with the function metaMDS from the R package *vegan*. In the NMDS, we accepted a maximum associated *stress* value of 0.2 as higher *stress* values indicate potentially spurious relationships (Dexter et al. 2018). To test for differences in individual numbers of red listed-species according to the Austrian Red List (Berg et al. 2005), we assigned all Orthoptera species to two categories: species that are threatened in Austria (i.e. vulnerable, near threatened, endangered) were assigned to the threatened category (RL), whereas species that are not threatened (i.e. least concern) were assigned to the least concern-category (LC). A two-sample t-test and a Welch two sample t-test were done in R (R Core Team 2020) to test for differences in abundance of RL species and LC species between grazed and mown transects. We used the R package *ggplot2* (Wickham 2016) for visualising data and the package *vegan* (Oksanen et al. 2020) for calculating Shannon indices for comparing assemblage richness among transects. Differences of individual species abundances between mown and grazed transects were tested by t-tests and Welch-test in R. Tests on abundance and species composition were done using the software Past (Hammer et al. 2001). Species richness accumulation curves for mown and grazed transects were calculated using the iNEXT programme (Chao et al. 2016) and visualized as sample-size-based rarefaction and extrapolation sampling curves using a bootstrapping approach (50 replications).

Results

A total of 12,448 individuals (including 3,486 adult individuals and 8962 nymphs) belonging to 24 Orthoptera species were recorded in the 28 transects. In total 5090 nymphs (57% of all nymphs) could not be identified on species level and were thus excluded from analyses. The most abundant species were *Pseudochorthippus parallelus* with 1,010 adult individuals (29%), followed by *Calliptamus italicus* with 731 adult individuals (21%) and 2731 nymphs (30% of all grasshopper nymphs), *Euchorthippus declivus* with 654 adult individuals (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. The mown transects had mostly higher, but extremely variable vegetation heights from May to July (see Fig. 3A). 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 large variations among transects (Fig. 3A). In late summer, mean vegetation heights converged, with heights of 24 ± 4 cm in the grazing treatment and 18 ± 4 cm in the mowing treatment during the last survey.

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 (Fig. 3B).

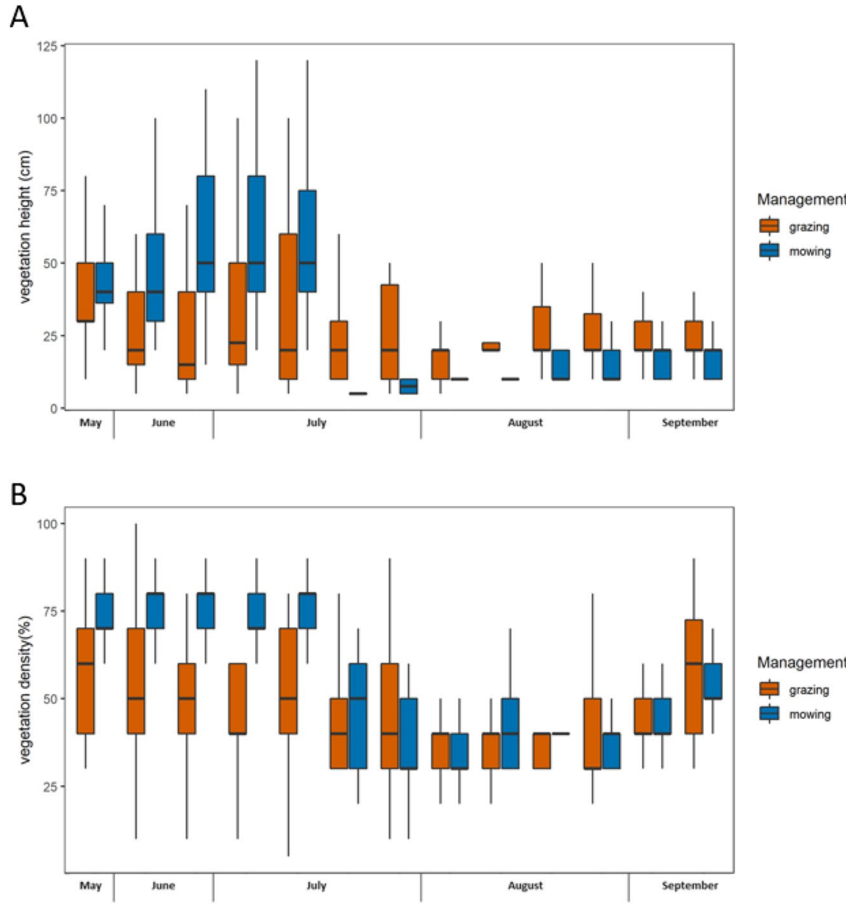

Fig. 3 Mean vegetation height (±95% CI) of grazed (orange, n = 13) and mown transects (blue, n = 15) (**A**) and mean vegetation density (**B**). Both vegetation indices were measured in 13 survey rounds between May and September 2019

Effects of grassland management on species composition, abundance and richness

Although Orthoptera species composition was heterogeneous between transects of the same treatment, it differed remarkably between grazing and mowing treatments, resulting in a clear segregation of sites in the NMDS ordination (Fig. 4). That mown and grazed transects were characterized by a distinct species composition is also indicated by the calculated one-way ANOSIM (Global $R = 0.61$, $p < 0.001$). Also, 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 by roughly one third lower (68 ± 19 individuals) than in mown transects (105 ± 15 individuals). In contrast, mean species numbers (± 95% CI) of mown transects (11 ± 1 species) and grazed transects (10 ± 1 species) were very similar ($t = -\ 0.684$, $p = 0.500$). In total, 21 Orthoptera species were found in grazed transects, whereas 19 species were found in mown transects. The species accumulation curves indicate higher species richness for grazed transects (Fig. 5). Also, mean Shannon index (± 95% CI) was significantly lower ($t = 2.743$, $p = 0.005$) for mown transects (1.50 ± 0.09) than for grazed ones (1.68 ± 0.11).

Differences in most abundant species

We found significant differences in abundances for eight of the ten most abundant species between grazed and mown transects (Fig. 6). Most apparent were the almost tenfold higher abundance of *P. parallelus* with mean number of 46.9 individuals in mown transects and 4.8 adults in grazed transects ($t = -\ 10.643$, $p < 0001$), the almost three times higher abundance of *E. declivus* with mean numbers of 29.2 adults in grazed transects and 7.3 individuals in mown transects ($t = 1.981$, $p = 0.034$), and the absence of *Ch. mollis* in mown transects. Similarly, *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 grazed transects. On the other hand, *Ch. biguttulus* ($t = -\ 3.566$, $p = 0.001$) and *Ch. dorsatus* ($t = -\ 4.223$, $p = 0.0002$) were four times more abundant, and *L. albovittata* was three times more abundant ($t = -\ 3.323$, $p = 0.002$) in mown transects. Finally, the abundances of *C. italicus* ($t = -\ 0.744$, $p = 0.232$)

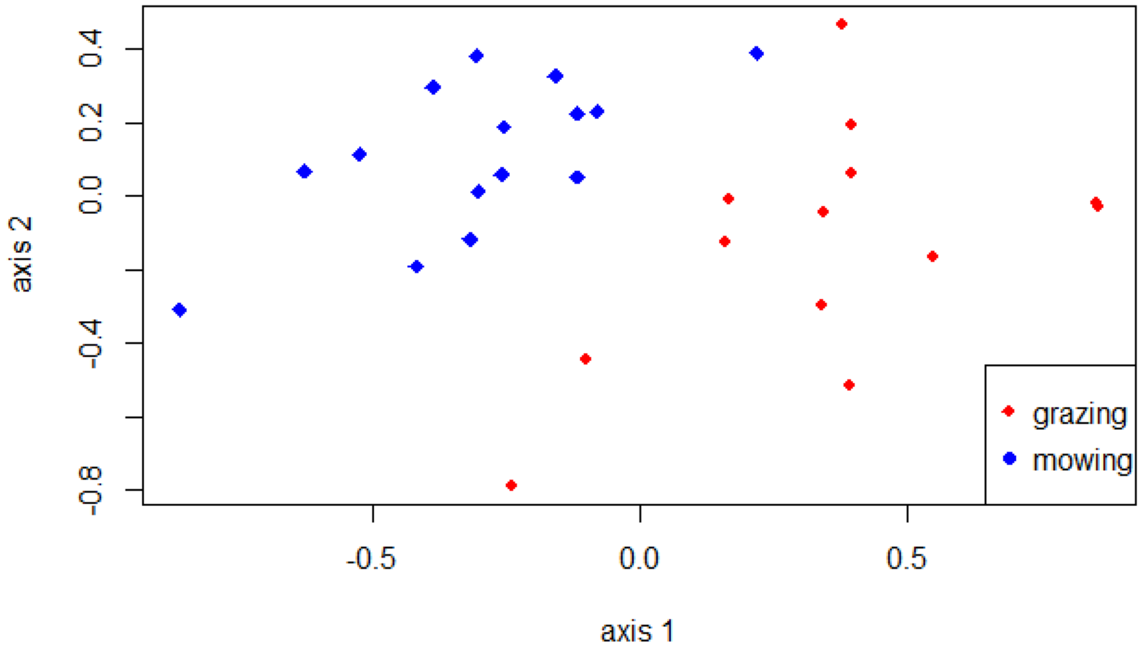

Fig. 4 NMDS ordination (based on Bray–Curtis dissimilarities) showing the similarity relationships of grasshopper species assemblages sampled in grazed (n = 13) and mown transects (n = 15) of the flood protection embankment (*stress* = 0.153)

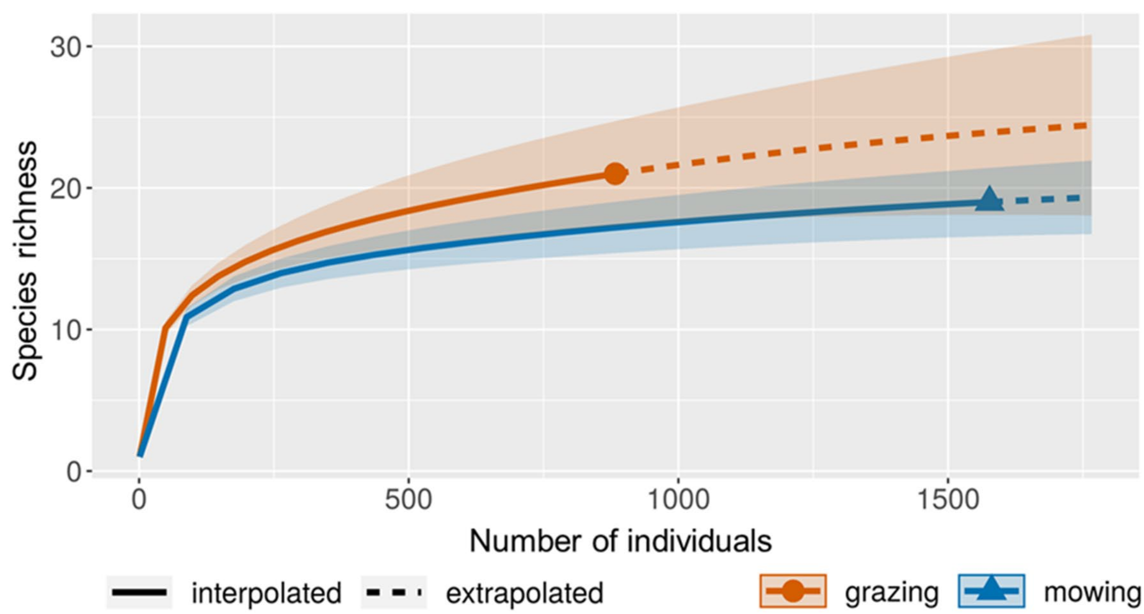

Fig. 5 Species richness accumulation curves (±95% CI) for grazed (n = 13) and mown transects (n = 15). The extrapolated part of the curve is indicated by a dashed line

and *P. grisea* ($t = -0.690$, $p = 0.248$) did not differ significantly between grazed and mown transects.

In total, 12 of the recorded species are listed as least concern on the Austrian Red List (Berg et al. 2005). Another 12 species are listed as vulnerable, near threatened or endangered, and thus are threatened in Austria. The abundance of threatened species per transect did not differ significantly between grazed and mown transects (t-test: $t = 1.684$, $p = 0.052$), while the abundance of non-threatened species was significantly lower in grazed than in mown transects (Welch two sample t-test, $t = -2.739$, $p = 0.006$). The most abundant threatened species was *C. italicus* comprising 70%

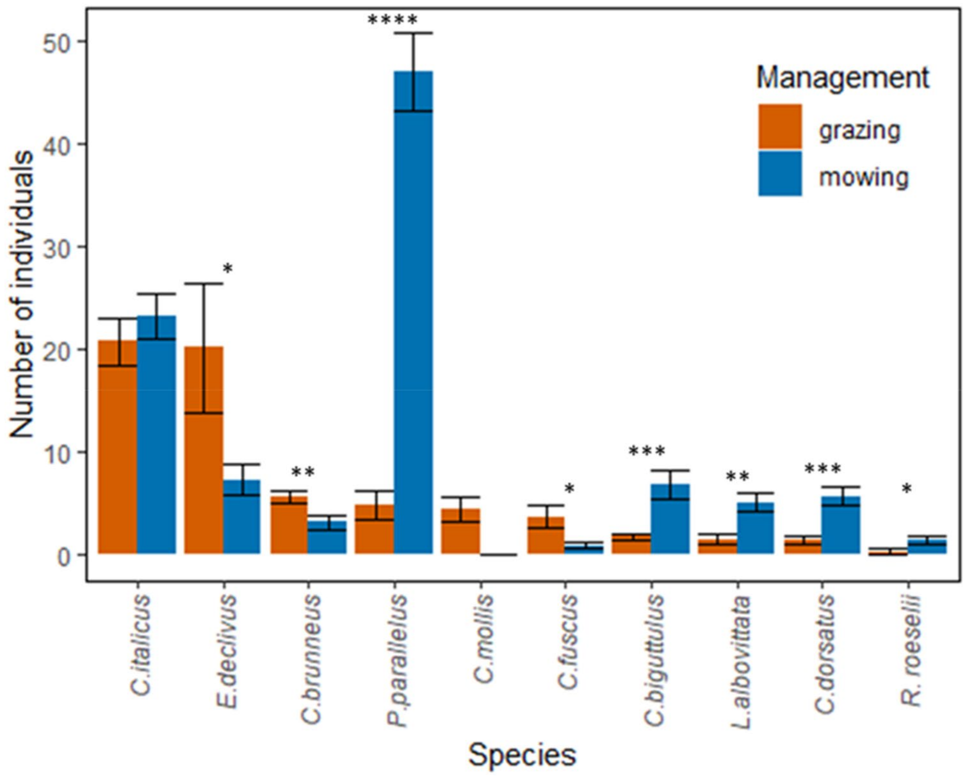

Fig. 6 Mean number of individuals (±95% CI) per transect of the 10 most abundant species shown separately for grazed and mown transects. Asterisks indicate significant differences in abundance between mown and grazed transects (t-test; $*p \leq 0.05$, $**p \leq 0.01$, $***p \leq 0.001$, $****p \leq 0.0001$)

of individuals of this species group in grazed transects and 78% in mown transects.

Discussion

The total number of 24 Orthoptera species (excluding species of the genus *Tetrix*, which were not sampled) recorded in this study shows that secondary grasslands such as river embankments can be of considerable conservation value. Twelve of the recorded species are listed on the national Red List (Berg et al. 2005), and several of these species have large populations on the study site. The most abundant non-threatened species is *Pseudochorthippus parallelus* in mown transects, while in grazed transects *Euchorthippus declivus* is the most abundant least concern-species. The most abundant red-listed species is *Calliptamus italicus*. Other species of conservation concern are also xerophilic ones (*Bicolorana bicolor, Leptophyes albovittata, Oedipoda caerulescens, Omocestus haemorrhoidalis, Platycleis albopunctata grisea*), and—surprisingly—one hydrophilic species (*Conocephalus fuscus*).

Effects of grazing vs. mowing on Orthoptera assemblages

While total abundance of Orthoptera was higher in mown transects, species-accumulation curves showed that Orthoptera species richness was higher in grazed transects. The most likely explanation for this result is that grazing leads to more heterogenous vegetation, and it is well-known that increased spatial heterogeneity in vegetation structures in grasslands is enhancing insect diversity in general and Orthoptera diversity in particular (e.g. Jerrentrup et al. 2014; Kruess and Tscharntke 2002). The presence of different microsites such as open soil, patches of low and open vegetation, and higher and denser vegetation allows species of different habitat preferences to coexist in a given habitat (Fartmann et al. 2012; Fonderflick et al. 2014).

On the other hand, vegetation height and density were higher in mown transects, and these vegetation characteristics likely favoured a few widespread species of mesic grasslands (e.g. *P. parallelus*). Accordingly, Orthoptera species which are not threatened in Austria were more abundant in mown transects. The most abundant red-listed species (*C. italicus*) did not show a significant difference between grazed and mown transects, as it was restricted to patches of sparse vegetation associated with a trail at the crest of the dyke. This xero-thermophilic species has recently become substantially more abundant in eastern

Austria (Zuna-Kratky et al. 2017) and Central Europe in general (Poniatowski et al. 2020) in response to climate warming.

Differences in Orthoptera species abundance between mown and grazed transects

Our results show that eight of the ten most abundant Orthoptera species differed significantly in abundance between mown and grazed transects, including several species which exhibited impressive differences in abundance between both land use types. The strongest difference wasshown by *Pseudochorthippus parallelus*, which likely is the most abundant grasshopper species in Austria (Zuna-Kratky et al. 2017), and which was the by far most abundant species in mown transects. We argue that the on average denser and higher vegetation in mown transects better fulfilled the habitat preferences (mesic grasslands with dense vegetation) of this species.

On the contrary, *Euchorthippus declivus* showed a clear preference for grazed transects, where it was the most abundant species; this likely is a consequence of its preference for open semi-dry grasslands (Zuna-Kratky et al. 2017), as these habitat characteristics were better provided in grazed transects. Similarly, *Chorthippus mollis*, a typical species of semi-dry grasslands in eastern Austria (Zuna-Kratky et al. 2017), was absent in mown transects, while it regularly occurred in grazed transects. Overall, these findings suggest that the less dense vegetation in grazed transects better fulfilled the habitat requirements of xero-thermophilic species compared to mown transects.

Calliptamus italicus was the most abundant species on the dyke crest of both mown and grazed transects, and *Oedipoda caerulescens* was also mostly recorded there. Both species need patches of open soil and little vegetation cover (Zuna-Kratky et al. 2017), and this habitat requirements were provided on the crest by a gravel trail with a thin topsoil layer and sparse vegetation.

Finally, *Conocephalus fuscus* was regularly recorded in the transects, and was much more abundant in grazed transects than in mown ones. This was somewhat surprising, as this species prefers high, vertically structured herbaceous vegetation in wet grasslands and reed vegetation (Zuna-Kratky et al. 2017). This species is abundant in the reed vegetation of oxbow lakes of the Danube close to the studied river embankment (pers. obs.), and we argue that this mobile species migrates partly between the study site and its core habitats.

Implications for management

Many studies have shown that low-intensity grasslands harbour the most species-rich Orthoptera assemblages, especially when being grazed or infrequently mown (e.g. Achtziger et al. 1999; Bonari et al. 2017; Chiste et al. 2016; Essl and Dirnböck 2012; Fumy et al. 2021; Löffler et al. 2019; Mazalova et al. 2015). By preferably consuming palatable plant species and discarding patches with old or unpalatable vegetation, and by trampling, livestock shapes the spatial vegetation structure, and thus creates a heterogenous sward. However, if pastures are grazed intensively and over long time periods, vegetation heterogeneity decreases (Fonderflick 2014; Fumy et al. 2021). Since grazing at the study site was done as strip grazing, and the grazed part of the river embankment was moved every three to five days from one place to the next one, grazing was small-scale compared to the large-scale mowing, where the entire part of the river embankment was mown at once. This difference in scale of land management at the study site likely increases Orthoptera richness and is shaping species composition (Humbert et al. 2010; Fabriciusová et al. 2011; Rada et al. 2014). Less significant differences in species richness and composition between mown and grazed transects were to be expected if the scale of management would be the same, e.g. mowing smaller patches or large-scale grazing with higher stocking rate (Fabriciusová et al. 2011; Rada et al. 2014).

Large-scale mowing represents a high mortality risk for many insect groups and Orthoptera in particular. As a consequence of mowing, direct mortality of Orthoptera through mowing machinery, extraction of eggs (in removed plant material), risk of predation and overheating are increased (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 $68 \pm 14\%$ and with a conditioner added it increased to $82 \pm 8\%$ (Humbert et al. 2010).

As most grasshopper species are relatively large invertebrates and have limited mobility at least while juvenile, they are especially exposed to mowing. Additional to direct mortality caused by harvesting machines, extraction of eggs (in removed plant material) (Gardiner and Hassall 2009; Humbert et al. 2010), change in microclimatic conditions after mowing may have adverse effects on grasshoppers (Wagner 2004; Gardiner and Hill 2006). Further, risk of predation is increased by large-scale mowing, since low swards provide little shelter and the risk of predation increases (Gardiner and Hassall 2009; Humbert et al. 2010). In our study, only few individuals were recorded after mowing in August, because grasshoppers migrate to unmown grasslands nearby. This finding is in accordance with earlier studies which showed a strong decline of Orthoptera abundance directly after mowing (Rada et al. 2014). With increasing time lag from the mowing event, it is known that grasshopper abundance increases again (Chiste et al. 2016), as grasshoppers migrate back.

Less direct mortality occurs through grazing (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). Grazing animals move relatively slowly and often gather in patches, thus grasshopper species are able to migrate to ungrazed parts (Chiste et al. 2016; Löffler et al. 2019). Uneven vegetation cover can result in patches with a 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 (e.g. trampling), providing patches of bare soil (Fartmann et al. 2012; Rada et al. 2014).

Depending on the conservation goal, grazing and mowing have specific advantages and disadvantages, with grazing being advantageous for most xero-thermophilic species and most species of the Austrian Red List. We recommend that grazing should be continued at the river embankment, ideally as rotational pasture as currently done. Mowing should be changed towards mowing parts of the river embankment at different times (Achtziger et al. 1999) and leaving small strips of vegetation unmown in each mowing event (e.g. Marini et al. 2008; Humbert et al. 2010; Rada et al. 2014). Such a small-scale management allows migrations of Orthoptera between differently managed parts of the river embankment, and it increases the heterogeneity of the vegetation. Generally, late mowing (September) would be preferable for most Orthoptera species (Gardiner and Hassall 2009; Humbert et al. 2010), and species phenology of target species should be taken into account (see Table S5) (Zuna-Kratky et al. 2017). Mowing should be done with bar mowers, as insect mortality is substantially lower than caused by rotary mowers (Humbert et al. 2009, 2010).

Conclusions

Our study shows quite substantial differential effects of management on the Orthoptera community of a grassland on river embankment in eastern Austria. Given that mown and grazed transects are located adjacent to each other, that previously the complete study area was mown for many decades and grazing was only started one year before field data collection, the scale of differences in species richness, composition and abundances between grazed and mown transects is surprising. The total abundance of Orthoptera was higher in mown transects, while grazed transects had higher species richness. Eight of the ten most abundant species differed significantly in abundance between mown and grazed transects. Most xero-thermophilic species were more abundant in grazed transects, while some species of mesic grassland were more abundant in mown transects. Although we are lacking data on Orthoptera from the study site before grazing was established in 2018, as this would allow to directly compare Orthoptera assemblages before and after grazing was introduced, our findings clearly indicate that grasshoppers respond rapidly to changing land use.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10841-021-00337-4.

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Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

References

Achtziger R, Nickel H, Schreiber R (1999) Auswirkungen von Extensivierungsmaßnahmen auf Zikaden, Wanzen, Heuschrecken und Tagfalter im Feuchtgrünland. Schriftenr Bayer Landesamt Umweltsch 150:109–131

Báldi A, Kisbenedek T (1997) Orthopteran assemblages as indicators of grassland naturalness in Hungary. Agric Ecosyst Environ 66:121–129

Bátori Z, Körmöczi L, Zalatnai M, Erdős L, Ódor P, Tölgyesi C, Margóczi K, Torma A, Gallé R, Cseh V, Török P (2016) River dikes in agricultural landscapes: the importance of secondary habitats in maintaining landscape-scale diversity. Wetlands 36:251–264

Baur B, Cremene C, Groza G, Rakosy L, Schileyko AA, Baur A, Stoll P, Erhardt A (2006) Effects of abandonment of subalpine hay meadows on plant and invertebrate diversity in Transylvania, Romania. Biol Conserv 132:261–273

Berg H-M, Bieringer G, Zechner L (2005) Rote Liste der Heuschrecken (Orthoptera) Österreichs. In: Zulka KP (ed.): Rote Listen gefährdeter Tiere Österreichs. Checklisten, Gefährdungsanalysen, Handlungsbedarf. Teil 1: Säugetiere, Vögel, Heuschrecken, Wasserkäfer, Netzflügler, Schnabelfliegen, Tagfalter. Böhlau, Vienna, pp 167–209.

Bonari G, Fajmon K, Malenovský I, Zelený D, Holuša J, Jongepierová I, Kočárek P, Konvičkah O, Uřičář J, Chytrý M (2017) Management of semi-natural grasslands benefiting both plant and insect diversity: the importance of heterogeneity and tradition. Agric Ecosyst Environ 246:243–252. https://doi.org/10.1016/j.agee.2017.06.010

Chao A, Ma KH, Hsieh TC (2016) iNEXT (iNterpolation and EXTrapolation) Online: Software for interpolation and extrapolation of species diversity. Program and user's guide. http://chao.stat.nthu.edu.tw/wordpress/software_download/

Chisté MN, Mody K, Gossner MM, Simons NK, Köhler G, Weisser WW, Blüthgen N (2016) Losers, winners, and opportunists: how grassland land-use intensity affects orthopteran communities. Ecosphere 7(11):e01545. https://doi.org/10.1002/ecs2.1545

Clarke KR, Sommerfield PJ, Chapmann MG (2006) On resemblance measures for ecological studies, including taxonomic dissimilarities and a zero-adjusted Bray-Curtis coefficient for denuded assemblages. J Exp Mar Biol Ecol 330:55–80

De Jong Y, Verbeek M, Michelsen V, Bjørn P, Los W, Steeman F, Bailly N, Basire C, Chylarecki P, Stloukal E, Hagedorn G, Wetzel F, Glöckler F, Kroupa A, Korb G, Hoffmann A, Häuser C, Kohlbecker A, Müller A, Güntsch A, Stoev P, Penev L (2014) Fauna Europaea——all European animal species on the web. Biodivers Data J 2:e4034. https://doi.org/10.3897/BDJ.2.e4034

Dexter E, Rollwagen-Bollens G, Bollens SM (2018) The trouble with stress: a flexible method for the evaluation of nonmetric multidimensional scaling: the trouble with stress. Limnol Oceanogr Methods 16:434–443. https://doi.org/10.1002/lom3.10257

Essl F, Dirnböck T (2012) What determines Orthoptera species distribution and richness in temperate semi-natural dry grassland remnants? Biodiv Conserv 21:2525–2537

Fabriciusová V, Kaňuch P, Krištín A (2011) Response of Orthoptera assemblages to management of montane grasslands in the Western Carpathians. Biologia 66:1127–1133

Fargeaud K, Gardiner T (2018) The response of Orthoptera to grazing on flood defense embankments in Europe. J Orthoptera Res 27:53–60. https://doi.org/10.3897/jor.27.25183

Fartmann T, Krämer B, Stelzner F, Poniatowski D (2012) Orthoptera as ecological indicators for succession in steppe grassland. Ecol Indic 20:337–344

Fonderflick J, Besnard A, Beuret A, Dalmais M, Schatz B (2014) The impact of grazing management on Orthoptera abundance varies over the season in Mediterranean steppe-like grassland. Acta Oecol 60:7–16. https://doi.org/10.1016/j.actao.2014.07.001

Fumy F, Kämpfer S, Fartmann T (2021) Land-use intensity determines grassland Orthoptera assemblage composition across a moisture gradient. Agric Ecosyst Environm 315:107424. https://doi.org/10.1016/j.agee.2021.107424

Gardiner T, Hassall M (2009) Does microclimate affect grasshopper populations after cutting of hay in improved grassland? J Insect Conserv 13:97–102

Gardiner T, Hill J (2006) Mortality of Orthoptera caused by mechanised mowing of grassland. Br J Entomol Nat Hist 19:38–40

Gardiner T, Hill J, Chesmore D (2005) Review of the methods frequently used to estimate the abundance of Orthoptera in grassland ecosystems. J Insect Conserv 9:151–173

Hammer Ø, Harper DAT, Ryan, PD (2001) PAST: paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4: 9 pp. http://palaeo-electronica.org/2001_1/past/issue1_01.htm

Humbert J-Y, Ghazoul J, Walter T (2009) Meadow harvesting techniques and their impacts on field fauna. Agric Ecosyst Environ 130:1–8

Humbert J-Y, Ghazoul J, Richner N, Walter T (2010) Hay harvesting causes high orthopteran mortality. Agric Ecosyst Environ 139:522–527

Jerrentrup JS, Wrage-Monnig N, Rover K-U, Isselstein J (2014) Grazing intensity affects insect diversity via sward structure and heterogeneity in a long-term experiment. J Appl Ecol 51:968–977. https://doi.org/10.1111/1365-2664.12244

Kruess A, Tscharntke T (2002) Grazing intensity and the diversity of grasshoppers, butterflies, and trap-nesting bees and wasps. Conserv Biol 16:1570–1580

Löffler F, Poniatowski D, Fartmann T (2019) Orthoptera community shifts in response to land-use and climate change—lessons from a long-term study across different grassland habitats. Biol Conserv 236:315–323. https://doi.org/10.1016/j.biocon.2019.05.058

Marini L, Fontana P, Scotton M, Klimek S (2008) Vascular plant and Orthoptera diversity in relation to grassland management and landscape composition in the European Alps. J Appl Ecol 45:361–370

Mazalová M, Šipoš J, Rada S, Kasak J, Sarapatka B, Kuras T (2015) Responses of grassland arthropods to various biodiversity-friendly management practices: Is there a compromise? Eur J Entomol 112:734–746

Ma J, Huang X, Qin X, Ding Y, Hong J, Du G, Li X, Gao W, Zhang Z, Wang G, Wang N, Zhang Z (2017) Large manipulative experiments revealed variations of insect abundance and trophic levels in response to the cumulative effects of sheep grazing. Sci Rep 7:11297. https://doi.org/10.1038/s41598-017-11891-w

Milne JA, Osoro K (1997) The role of livestock in habitat management. In: Laker JP, Milne JA (eds), Livestock systems in European rural development. In: Proceedings of the 1st conference of the LSIRD network (Nafplio, Greece). Macaulay Land Use Research Institute, Aberdeen, pp 75–80

Oksanen J, Blanches FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O`Hara RB, Simpson GL, Solymos P, Stevens HH, Szoecs E, Wagner H (2020) Package "vegan". https://cran.r-project.org/web/packages/vegan/vegan.pdf

Poniatowski D, Beckmann C, Löffler F, Münsch T, Helbing F, Samways MJ, Fartmann T (2020) Relative impacts of land-use and climate change on grasshopper range shifts have changed over time. Glob Ecol Biogeogr 29:2190–2202

R Core Team (2020) R: A language and environment for statistical computing. Austria, Vienna

Rada S, Mazalová M, Šipoš J, Kuras T (2014) Impacts of mowing, grazing and edge effect on Orthoptera of submontane grasslands: perspectives for biodiversity protection. Pol J Ecol 62:123–138

Rook AJ, Dumont B, Isselstein J, Osoro K, WallisDeVries MF, Parente G, Mills J (2004) Matching type of livestock to desired biodiversity outcomes in pastures—a review. Biol Conserv 119:137–150

Sauberer N, Zulka KP, Abensperg-Traun M, Berg H-M, Bieringer G, Milasowszky N, Moser D, Plutzar C, Pollheimer M, Storch C, Trostl R, Zechmeister H, Grabherr G (2004) Surrogate taxa for biodiversity in agricultural landscapes of eastern Austria. Biol Conserv 117:181–190

Tourment R, Beullac B, Peeters P, Pohl R, Bottema M, Van M, Rushworth A (2018) European and US levees and flood defences characteristics, risks and governance. https://hal.inrae.fr/hal-02609228. Accessed 28 Jan 2021

Via donau (2015) Aktionsprogramm Donau des bmvit bis 2022. bmvit – Bundesministerium für Verkehr, Innovation und Technologie, Vienna

Wagner C (2004) Passive dispersal of *Metrioptera bicolor* (Phillipi 1830) (Orthopteroidea: Ensifera: Tettigoniidae) by transfer of hay. J Insect Conserv 8:287–296

WallisDeVries MF, Parkinson AE, Dulphy JP, Sayer M, Diana E (2007) Effects of livestock breed and grazing intensity on biodiversity and production in grazing systems. 4. Effects on animal diversity. Grass Forage Sci 62:185–197

Wesner W (1995) Flora und Vegetation des Marchfeldschutzdammes (Kartierungen 1992–1994). Diploma thesis, University of Vienna

Wickham H (2016) ggplot2: elegant graphics for data analysis. Springer, New York

Zuna-Kratky T, Landmann A, Illich I, Zechner L, Essl F, Lechner K, Ortner A, Weißmair W, Wöss G (2017) Die Heuschrecken Österreichs. Denisia 39