ABSTRACT: Semi-natural grasslands managed by mowing and grazing are an important part of European landscape. Orthopterans are considered to be an appropriate indicator to assess the impact of agricultural management on grassland ecosystems. We studied effects of mowing, grazing and two kinds of edges on Orthoptera of submontane hay meadows and pastures in the Hrubý Jeseník Mts. (Czech Republic). Using sweep netting and pan trapping, we sampled orthopteran assemblages associated with the farmland managed for at least five years under Czech agri-environmental schemes. In total we collected 2253 individuals of orthopterans representing 14 species. The short-term impacts of mowing and grazing were tested by multivariate ordination analyses. The results indicate that mowing significantly decreased Orthoptera species abundance. Conversely, the response of orthopterans to grazing was not statistically significant and appeared to be species-specific. The abundance of acridid Gomphocerippus rufus increased substantially with grazing, which is in contrast with its negative response to mowing. The negative influence of mowing on grassland inhabitants can be mitigated by lower mowing frequency and by providing temporary uncut refuges. The results of generalized linear models showed significant increase of both species richness and total abundance of Orthoptera towards the baulks. Therefore, the refuges should be established primarily along grass baulks or similar types of permanent grassy edges.

As a general rule an effort should be made when managing grasslands to ensure the highest habitat heterogeneity.

KEY WORDS: baulk, edge distance, grasshoppers, grassland ecosystems, management, meadow, pasture, Czech Republic

1. INTRODUCTION

Mowing and grazing are prevailing types of management essential for maintenance of semi-natural grasslands. Grasslands cover substantial part of European landscape and host large number of (often endangered) species (Stoate et al. 2009, Hoste-Danyłow et al. 2010), therefore grasslands are of crucial importance for biodiversity. Nevertheless, agricultural intensification and abandonment of land caused large-scale decline in grassland biodiversity in last decades (Benton et al. 2003, Báldi et al. 2005, Batáry et al. 2007, Stoate et al. 2009, Čížek et al. 2012). Efforts have been made to mitigate this damage, particularly through richly funded agri-environmental schemes [AES]. However, existing practises with these schemes and their contribution to improve biodiversity are doubtful (Kleijn and Sutherland 2003, Kleijn et al. 2006, Knop et al. 2006, Konvička et al. 2008, Blomqvist...
et al. 2009, Stoate et al. 2009). Thus there is an urgent need to study the response of grassland ecosystems to performed management and to obtain knowledge on how to manage grasslands aiming to maintain diversified invertebrates communities. These play the key role in provision of essential ecosystem services like pollination, decomposition and sustainable soil fertility (Tscharntke et al. 2005, Balvanera et al. 2006, Potts et al. 2009).

Orthopterans are one of the major groups associated primarily with grassland ecosystems (Marini et al. 2009a, Keßler et al. 2012) and represent an important part of the food chain. They consume substantial amounts of plant biomass (Köhler et al. 1987, Blumer and Diemer 1996, Zhong-Wei et al. 2006) and are also a common source of food for other invertebrate and vertebrate predators (Belovski and Sláde 1993, O’Leske et al. 1997, Gardner and Thompson 1998, Danner and Joern 2004). According to numerous studies, orthopterans are good indicators of the ecosystem health (Báldi and Kisbenedek 1997, O’Leske et al. 1997, Andersen et al. 2001, Kruess and Tscharntke 2002, Kampmann et al. 2008, Fartmann et al. 2012). The bioindicative potential of Orthoptera can be used for the assessment of various types of management conducted on agricultural grasslands; the resultant findings will contribute to the knowledge of how to maintain grassland ecosystems taking into account the conservation of biodiversity.

Both grazing and mowing provoke aboveground biomass removal, although grazing is a selective pressure while mowing affects the vegetation equally (Catorci et al. 2011). Moreover, the grazing can create small patches with bare ground as a result of cattle movement across the pasture (Mládek et al. 2006, Rosenthal et al. 2012). Therefore, the responses of plant and animal communities to each treatment were found predominantly distinctive (Stammel et al. 2003, Oertli et al. 2005, Saarinen and Jantunen 2005, Kampmann et al. 2008, Catorci et al. 2011, Fabriciusová et al. 2011, Rosenthal et al. 2012). Catorci et al. (2011) have even found characteristic pattern in the distribution of plant functional traits between grazed sites and those treated with mowing.

Short-term responses of orthopteran assemblages to mowing were studied in several places in Europe and were found to be predominantly negative (Gardiner and Hill 2006, Gardiner and Hassall 2009, Humbert et al. 2010, Čížek et al. 2012). In long-term view, higher intensity of mowing management negatively affects both orthopteran species richness and abundance (Marini et al. 2008, 2009a, b). In contrast, the negative influence of abandonment (complete absence of mowing) was also observed (Marini et al. 2009c). Impacts of grazing on Orthoptera were analysed several times, but often with mixed or ambiguous outcomes (Fielding et al. 2001, Krueß and Tscharntke 2002, O’Neill et al. 2003, Batáry et al. 2007, O’Neill et al. 2010). The influences of grazing appear to depend on a diversity of factors, including the weather (Fielding et al. 2001) and grazing intensity (Kruess and Tscharntke 2002, Fabriciusová et al. 2011).

Edge effects are a broad problem which have been often studied and discussed from different points of view (Ries et al. 2004). Some studies examined the topic of edges with Orthoptera as targeted taxa (e.g. Guido and Gianelle 2001, Ewers and Didham 2006). However, to our knowledge, there are no studies based on the analysis of the effects of edge character and distance from the edge, on orthopterans, in relation to the grassland management.

The aim of this study was to evaluate the short-term impacts of mowing and grazing on Orthoptera assemblages of submontane grasslands and to analyse the influences of edge character and distance. We expected the impact of mowing to be predominantly negative (by causing decline in the abundance; e.g. Humbert et al. 2010), whereas the impact of grazing moderately positive (according to Mládek et al. 2006). We were further interested in the role of edges in this relation. Positive influence of both grassy and tree edges was expected, since the beneficial effect of landscape features is largely accepted (Merckx et al. 2009, Ryszkowski et al. 2009). Based on our findings, we propose recommendations for a “biodiversity-friendly” management of grasslands. These proposals are novel since the management effects were assessed in combination with edge impacts on orthopteran abundance and species richness.
2. STUDY AREA

This study was performed in the submontane area of the Hrubý Jeseník Mts., in the north-eastern part of the Czech Republic, neighbouring Poland. The altitude varied from 730 to 830 m above sea level. The mean annual temperature is 6.5°C and long-term annual average rainfall is 900 mm (Tolasz 2007). All study patches were situated close to each other in a grassland area of approximately 180 ha, almost completely surrounded by forest (GPS: 50°6’37.91”N, 17°3’17.48”E).

We selected 12 study patches which differed in management (mowing, grazing or both) and in timing of the treatments. As the agricultural management of the area was financially supported by the Czech AES, each type of management fulfilled its conditions, meaning that the grazing intensity had to be lower than 1.5 cattle ha\(^{-1}\) (specifically it fluctuated from 0.82 to 0.84 cattle ha\(^{-1}\)) and the meadows were not fertilised. The meadows are managed by a single local farmer; all of them were cut once a year using rotary mower without conditioner (cutting height 6 cm). The majority of patches lied on gentle slopes, but two were on plain grounds. The patches were delimited by distinct boundaries – belts of trees, forest edges or baulks. For purpose of our study we considered two types of edge: 1) “baulks”, i.e. grassy edges (these were formed by strips of set-aside land, which was mown only sporadically, often with recently planted trees; 2) “tree edges”, i.e. belts of grown trees or forest edges. Average size of the individual patches was about 3 ha (the smallest covered the area of 0.6 ha, the largest the area of 6.7 ha).

The area was mown gradually in six steps between 29\(^{th}\) of June 2010 and the 25\(^{th}\) of August 2010. The cattle grazing started at the experimental pasture sites in mid-June and lasted for 30 days. Part of the patches was mown earlier, in the first week of July, and then grazed for approximately one month from the last term of August to the last week of September. The grassland area has been treated by the same way of management constantly for at least 5 years.

3. MATERIAL AND METHODS

3.1. Data collection

We sampled Orthoptera on the delimited patches in 2010. We recorded data on the performed management (i.e. timing of mowing and grazing) during regular field work. This information was supplied subsequently by the local farmer. The sampling was performed using two parallel methods: sweep netting and pan trapping.

Sweep netting is the most frequently used method for sampling Orthoptera (Gardiner et al. 2005). Representative numbers of sampling spots for each patch were derived from an area of particular patch (1 spot for 0.5 ha). For every sampling day we recorded 72 sampling spots in total, these were evenly and representatively spaced across the study patches. One sampling on a sampling spot comprised series of 10 sweeps. In the event of low and very low orthopteran numbers obtained, the number of sweeps was increased to 20 or 30, and then such outcomes were divided by 2 or 3, respectively. We used this technique in order to encompass all species. The diameter of the sweep net was 35 cm. The sweep netting was conducted during three visits (23\(^{rd}\) of July, 15\(^{th}\) of August and 19\(^{th}\) of September 2010), always between 10 a.m. and 5 p.m. All three visits were carried out in suitable weather conditions (none to mild wind, no rain, minimum temperature 17°C).

Pan trapping is frequently used to sample flying insects (Moerckie 1951, Duelli et al. 1999), but it can be successfully used also to sample Orthoptera (Evans and Bailey 1993). The principle of trapping is very similar to pitfall traps, also used to sample Orthoptera (Gardiner et al. 2005). The pan traps were plastic bowls 15 cm in diameter and 8 cm deep, half filled with preserving liquid (water solution of sodium chloride enriched with commercial detergent). They were placed on the ground and if necessary, the immediate surrounding was adjusted to avoid shading from vegetation. The pan traps were disposed in transects across all patches; totalling 77 traps. Transects ran from one edge of a particular patch to another, or directly through more patches and their edges together (formed by baulks or belts of trees). The distance between
each two traps was approximately 20 m; the distance in metres from the nearest grassy edge and the nearest tree edge was individually recorded for each trap. Some of the pan traps were placed directly into the edges. The samples were collected at approximately ten-day intervals (from 24th of July to 21st of September 2010; 10 collections in total).

Samples from pan traps were determined in the laboratory, adults were identified to the species level and nymphs to the family level. Sweep-netted individuals were determined directly in the field or later in the laboratory, the nomenclature follows Kočárek et al. (2005).

3.2. Statistical analyses

Multivariate analyses were performed with Canoco statistical software (version 4.5) for Windows (Ter Braak and Šmilauer 2002). Data sets obtained from sweep netting and pan trapping were analysed separately. We constructed both models calculating the sums of the numbers for each sample (sum of all adults, sum of all nymphs and total number of all orthopterans in the sample) and those based on numbers within individual species, to examine response of the whole assemblage in more detail. Consequently, four ordination models were constructed (model I: numbers of individuals of each species obtained by sweep netting, model II: numbers of individuals of each species obtained by pan trapping, model III: total numbers of orthopterans obtained by sweep netting, model IV: total numbers of orthopterans obtained by pan trapping).

The tested variables were mowing and grazing (explanatory variables) and numbers of individuals within orthopteran species (dependent variables). Mowing and grazing were scaled according to the gradual diminishing effect of the treatment. Therefore, the categories of the management variables were distinguished arbitrary by the number of days past after the treatment as follows: 3 (0–10 days after the treatment), 2 (11–30 days), 1 (31–60 days) and 0 (more than 60 days or without treatment). We defined these categories in an effort to depict approximate time of sward regrowth. The covariables included in the analyses were time (coded as the number of days passed from the beginning of the year) and the specific study patch (1 to 12) where the sampling took place.

Species with the number lower than 1% of the total number of individuals were excluded from the analyses (Table 1). Some pan...
traps were occasionally damaged by wild animals grazing on the meadows (e.g. deer, boars etc.). These samples reached less than 7% of total number of samples and were calculated as the average number of individuals of each species in the remaining pan traps at the correspondent sampling date.

Detrended correspondence analysis (DCA; Hill and Gauch 1980) was used to reveal a length of gradients in community dataset (using Canoco). The gradients in models I and II were long (> 3.5), hence a canonical correspondence analysis (CCA; Ter Braak 1986) was used for subsequent analyses and graphical exploration, according to Ter Braak and Šmilauer (2002). The gradients in models III and IV were short (< 3.5), therefore a redundancy analysis (RDA; Legendre and Anderson 1999) was used. CCA analyses were conducted with biplot scaling focused on inter-species distances; RDA analyses were conducted with scaling focused on inter-species correlations, species scores were divided by standard deviation and species were centred. We used the raw species data for the analyses. The ordination models were tested by Monte-Carlo permutation test as signed with restriction to temporal structure and block defined by covariables. Altogether 5000 permutations were used for full model. Forward selection procedure was used to test environmental variables. Furthermore, generalized linear models (GLM) with Poisson distribution and link function log were constructed to reveal individual responses of species. These analyses were computed by CanoDraw 4.0 for Windows; the best fitting models were selected according to Akaike’s Information Criterion (AIC).

To test the impacts of patch edges on number of species and total number of Orthoptera we used data obtained only by pan trapping. We tested the impacts of baulks (i.e. grassy edges) and tree edges (edges formed by a belt of grown trees or forest margins) separately, using generalized linear models with link function log. Standard errors were corrected by quasi-poisson model. The effects of the explanatory variables were tested by the analyses of deviance using F-test. These analyses were performed on the open source statistical computing environment R version 2.14.1 (R Development Core Team 2011).

4. RESULTS

The number of individuals caught by both sampling methods totalled 2253, representing 14 orthopteran species. The most abundant species were Omocestus viridulus (Linné, 1758) and Gomphocerippus rufus (Linné, 1758). For detailed information see Table 1.

To find out the impacts of grassland management on the total number of orthopterans and on the numbers of representatives within individual species we constructed four ordination models. Testing of the ordination axes revealed all the constructed models (I–IV) to be statistically significant. Testing of the explanatory variables (mowing and grazing) showed statistically significant influence of mowing but not grazing in all four models (P <0.05). For overall results of models, see Tables 2–5 and Figure 1.

3.1. Mowing and grazing

Response of orthopteran assemblage and individual reaction of species to mowing and grazing were explored by generalized linear models. These models were constructed for all species but only significant (P <0.05) results of GLMs are presented (Figs 2–3). Numerical characteristics of presented GLMs are listed in APPENDIX. According to the results of GLMs, the whole orthopteran assemblage, consisting of both adults and nymphs, showed an unimodal response to mowing (Fig. 3A). Number of individuals generally tended to decline both immediately after the mowing and later in the season after full recovery of the swards. In other words, orthopterans reached the maximum numbers in half-renewed vegetation. In addition, numbers of individuals within species declined with increasing effect of mowing in the majority of the cases (Figs. 2A, B, 3C), i.e. the effect of mowing was most apparent immediately after the treatment. The only exception of the latter mentioned trend represent the responses of two grasshopper species, Euthystira brachyptera (Ocskay, 1826) and Chorthippus paralellus (Zetterstedt, 1821), to which numbers increased towards the date of the treatment (Fig. 3C).

In contrast to mowing, we did not find general trends in grazing effect on the level of...
Table 2. Results of model I – CCA model of numbers of individuals within species (obtained by sweep netting) depending on the management (mowing and grazing). Statistically significant $P$-values are given in bold.

<table>
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<th>Axis</th>
<th>1</th>
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<td>Eigenvalues</td>
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<td>0.007</td>
<td>0.550</td>
<td>0.454</td>
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<tr>
<td>Species-environment correlations</td>
<td>0.300</td>
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<td>0.000</td>
<td>0.000</td>
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<tr>
<td>Sum of all eigenvalues</td>
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<td>Sum of all canonical eigenvalues</td>
<td>0.039</td>
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Significance of the model (test on I. canonical axis)  $F = 2.377$  $P < 0.05$
Significance of the model (test on all canonical axes)  $F = 1.449$  $P = 0.121$
Permutation test on variable “mowing”  $F = 2.170$  $P < 0.05$
Permutation test on variable “grazing”  $F = 0.730$  $P = 0.561$

Fig. 1. Ordination diagrams of CCA model I (A), CCA model II (B), RDA model III (C) and RDA model IV (D) – numbers of individuals within species depending on mowing and grazing (represented by time past from treatment). Numbers of individuals were obtained by sweep netting (A, C) and pan trapping (B, D). ChoApr = Chorthippus apricarius, ChoBig = Chorthippus biguttulus, ChoPar = Chorthippus parallelus, ChrDis = Chrysochaon dispar, EutBra = Euthystira brachyptera, GomRuf = Gomphocerippus rufus, MetRoe = Metrioptera roeselii, OmoVir = Omocestus viridulus.
Table 3. Results of model II – CCA model of numbers of individuals within species (obtained by pan trapping) depending on the management (mowing and grazing). Statistically significant $P$-values are given in bold.

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<tr>
<td>Eigenvalues</td>
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<td>0.002</td>
<td>0.329</td>
<td>0.325</td>
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<tr>
<td>Species-environment correlations</td>
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<td>0.092</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Sum of all eigenvalues</td>
<td>1.986</td>
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<tr>
<td>Sum of all canonical eigenvalues</td>
<td></td>
<td></td>
<td></td>
<td>0.025</td>
</tr>
</tbody>
</table>

Significance of the model (test on I. canonical axis) \( F = 8.665 \) \( P < 0.05 \)
Significance of the model (test on all canonical axes) \( F = 4.721 \) \( P < 0.05 \)
Permutation test on variable "mowing" \( F = 8.640 \) \( P < 0.01 \)
Permutation test on variable "grazing" \( F = 0.810 \) \( P = 0.618 \)

Fig. 2. Generalized linear models of response of Orthoptera species to moving and grazing effect (represented by time past from treatment). GLM A was derived from RDA model IV (pan trapping); B, C, D were derived from CCA model I (sweep netting). Linear (A) or quadratic (B, C, D) function and Poisson distribution were used. ChoPar = *Chorthippus parallelus*, GomRuf = *Gomphocerippus rufus*, MetRoe = *Metrioptera roeselii*, OmoVir = *Omocestus viridulus*. 
Table 4. Results of model III – RDA model of sum of Orthoptera numbers (obtained by sweep netting) depending on the management (mowing and grazing). Statistically significant $P$-values are given in bold.

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<td>Sum of all canonical eigenvalues</td>
<td>0.044</td>
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</table>

Significance of the model (test on 1. canonical axis) $F = 12.40$ $P < 0.01$

Significance of the model (test on all canonical axes) $F = 6.480$ $P < 0.01$

Permutation test on variable "mowing" $F = 11.72$ $P < 0.01$

Permutation test on variable "grazing" $F = 1.220$ $P = 0.261$

Fig. 3. Generalized linear models of response of Orthoptera species to mowing and grazing effects (represented by time past from treatment). GLMs A, B were derived from RDA model III (sweep netting); C, D were derived from CCA model II (pan trapping). Linear (C) or quadratic (A, B, D) function and Poisson distribution were used. ChoBig = *Chorthippus biguttulus*, ChoPar = *Chorthippus parellus*, EutBra = *Euthystira brachyptera*, GomRuf = *Gomphocerippus rufus*, MetRoe = *Metrioptera roeselii*.
the whole orthopteran assemblage. GLM derived from RDA model III (Fig. 3B) depicts a bimodal response of orthopteran assemblage to grazing. Orthopterans reached maximum numbers both immediately after grazing and later in the season. Ordination diagrams (Fig. 1) indicate predominantly negative effect to the assemblage, but not clearly. In contrast, one of these models (Fig. 1A) also points to a positive response of O. viridulus to grazing. Nevertheless, this finding was not supported by GLMs which does not show statistically significant response of O. viridulus.

In general terms, response of orthopterans to grazing was species-specific and mostly weak (Figs 2D, 3D). In the case of Ch. paralellus we found the opposite trends in numbers of individuals calculated by models I and II. The positive response of G. rufus to grazing (Fig. 2C) contrasts with its negative response to mowing (Figs 2B, 3C).

3.2. Distance to edges

Analysis of the interactions between both number of species and total number of orthopterans and distance to patch edges showed statistically significant effects of baulks (i.e. grassy edges). In contrast, the impact of distance from tree edges (i.e. belts of trees or forest edges) was not statistically significant (for overall results see Table 6). Figure 4 depicts a negative interaction between number of species and numbers of individuals respectively and increasing distance to the baulk. Both characteristics increased towards the grassy edges.

4. DISCUSSION

4.1. Impact of mowing

Our data show negative short-term impacts of mowing on Orthoptera. This finding concurs with results of other authors (Gardiner and Hill 2006, Braschler et al. 2009, Gardiner and Hassall 2009, Humbert et al. 2010, Fabriciusová et al. 2011). Decrease in numbers is caused mainly by immediate mortality during the process of mowing (Gardiner and Hill 2006, Humbert et al. 2010). According to Humbert et al. (2010), the mechanized mowing process kills 65–85% of orthopterans in an assemblage. Decrease in numbers after mowing is also caused by a higher risk of predation (Braschler et al. 2009) and unsuitable microclimatic conditions (Gardiner and Hassall 2009), which result in higher mortality and emigration (Gardiner and Hassall 2009, Humbert et al. 2010).

The unimodal response of Orthoptera assemblage (Fig. 3A) can be explained by the gradual change of the vegetation structure. Numbers of Orthoptera perhaps drop during the treatment and immediately after it. Then it may slowly increase together with gradual recovery of sward, enabling recolonization of previously abandoned patches. Moreover, higher probability of “being caught” in medium height vegetation may contribute to the trend, since sweep netting is much easier there, than in tall structured vegetation (Gardiner et al. 2005). This effect should be particularly strong for small nymphs (Fig. 3A). The explanation of the trend by means of methodical artefact is further supported by comparing Figure 3A with Figure 2A (which depicts results from pan trapping method).

Other models document clearer negative impact of mowing on orthopteran assemblage (Figs 1C, 1D, 2A) and on individual species (Figs 2B, 3C). According to our data, the most sensitive species to mowing appears to be G. rufus (Figs 2B, 3C). Negative responses of this grasshopper are interesting particularly in comparison with an inverse response to grazing (see next section). GLM conducted for data obtained by pan trapping (Fig. 3C) demonstrates an increase in numbers of two common grasshopper species E. brachyptera and C. paralellus towards the strongest mowing effect. Such trend immediately after mowing is questionable, because mowing causes high mortality and emigration (Gardiner and Hill 2006, Humbert et al. 2010). We suggest that surviving grasshoppers tried to escape from danger of predation and overheating (Gardiner and Hassall 2009), therefore they showed higher dispersal. Intensified mobility then may lead to higher probability of falling into pan traps. Therefore, we consider the increase in numbers shown on Figure 3C to be a methodical artefact.
4.2. Impact of grazing

The bimodal response of the assemblage to grazing shown on Figure 3B is probably caused by the species-specific impacts of grazing on Orthoptera, due to the increased numbers within some species and decline within others under the same grazing management. Different reactions of diverse orthopteran species to grazing had been previously noticed (O’Neill et al. 2003, 2010, Batáry et al. 2007).

Grasshopper species *G. rufus* showed a positive response to grazing (Fig. 2C), this species may benefit from a disturbed structure of the sward and from small patches of bare ground which are created by the movement of cattle. *G. rufus* typically prefers warmer and dryer habitats (Ingrisch and Köhler 1998), such conditions may be induced by cattle grazing. The vegetation is locally disturbed including sometimes the soil surface, this leads to severe warming and drying of particular patches. This could positively enhance the population of *G. rufus* and its activity. The positive response of this species to grazing contrasts with its negative response to mowing (Figs. 2B, 3C). Mowing creates different, probably not as suitable conditions as in grazing environments. In addition to this, high mortality was previously observed in mowed habitats (Humbert et al. 2010, 2012).

Weak and unclear responses of other species (Figs 1A, B, 2D, 3D) are in accordance with no statistical significance found from grazing in the ordination models for the whole assemblage and with low proportion of variability explained by this factor (Tables 2–5). The possible reasons for this may be the small proportion of plots managed by grazing compared to mowing. Another explanation, concurring with results of other recent studies, focused on the influence of arthropods by grassland management (Batáry et al. 2007, 2008), might be the low intensity of grazing performed in the study area.

Impacts of grazing are generally harder to assess than the ones of mowing. Some studies consider these impacts to be negative (Kruess and Tscharntke 2002), others found grazing to have positive effects on biodiversity (Holmes et al. 1979), but also insignificant impacts were observed by Batáry et al. (2007). We concur that the rate of influence can differ between particular orthopteran species (O’Neill et al. 2003, 2010, Batáry et al. 2007), with grazing intensity (Kruess and Tscharntke 2002, Fabriciusová et al. 2011) or along the gradients of external factors, for example weather in a season (Fielding et al. 2001).

4.3. Impact of edges

Our data uncovered a relationship between distance to the grassland edge and both the total number of orthopteran species and individuals. Whereas distance to the tree edge had no significant impact on orthopterans, distance to the baulk (i.e. grassy edge) significantly affected orthopteran assemblage (Table 6). Number of species and total number of Orthoptera tend to increase towards

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**Table 5. Results of model IV – RDA model of sum of Orthoptera numbers (obtained by pan trapping) depending on the management (mowing and grazing). Statistically significant *P*-values are given in bold.**

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<th>1</th>
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</thead>
<tbody>
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<td>Significance of the model (test on 1. canonical axes)</td>
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<tr>
<td>Significance of the model (test on all canonical axes)</td>
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<td></td>
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<tr>
<td>Permutation test on variable “mowing”</td>
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</tr>
<tr>
<td>Permutation test on variable “grazing”</td>
<td><em>F</em> = 1.420, <em>P</em> = 0.146</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Impacts of mowing, grazing and edge effect on Orthoptera of submontane grasslands

The baulk (Fig. 4). This novel finding indicates that baulks probably play the role of uncut refuge, i.e. the places where orthopterans can outlast the mowing event and from which they subsequently recolonize nearby grassland areas. The importance of uncut refuges to survive the mowing event has been recently reported (Humbert et al. 2012). Though, the detail view on the residuals (Fig. 4) reveals that the maximum numbers of orthopterans are not nested directly in the edge, but next to it. Thus we suggest that the value of baulks for Orthoptera consists not only as mowing refuges, but it also has other benefits for orthopterans. Most likely, the baulks promote orthopterans (and other invertebrate or vertebrate animals) by increasing habitat heterogeneity, this is widely accepted as a biodiversity booster (e.g. Benton et al. 2003).

Conversely, the impact of tree edges (i.e. belts of trees and forest edges) was found to be not significant. Here our results differ from those of Marini et al. (2009b) who regarded the presence of woody vegetation as beneficial for orthopterans. Marini et al. (2009b) saw the potential benefits of woody vegetation in providing refuges against mowing; however, the woody vegetation in that study was rather sparse, contrastingly in our investigations the woody edges were represented by dense formations of trees. Hence we believe that these edges hardly provide refuges for grassland species of Orthoptera.

5. CONCLUSIONS

Our study contributes to the knowledge of the effects of agricultural management on grassland invertebrates. Using the Orthoptera as a model taxa, we examined the role of mowing and cattle grazing in enhancing the community structure and species abundances in short time-scale. We found clearly negative response in the majority of orthopteran species manifested as a decline in numbers. In contrast, impacts of extensive grazing were not statistically significant. Although some ordination diagrams indicated negative influence,

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Table 6. Results of testing of dependence of number of species and total number of individuals of Orthoptera on distance to baulks (= grassy edges) and tree edges (= belt of trees or forest edge). Statistically significant P-values are given in bold.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variable</th>
<th>Value</th>
<th>SE</th>
<th>DF</th>
<th>t-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species richness</td>
<td>(intercept)</td>
<td>0.196</td>
<td>0.087</td>
<td>600</td>
<td>2.243</td>
<td>&lt;0.05</td>
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<td></td>
<td>baulk distance</td>
<td>−0.008</td>
<td>0.001</td>
<td>600</td>
<td>−4.868</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(intercept)</td>
<td>−0.202</td>
<td>0.095</td>
<td>600</td>
<td>−2.128</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>tree edge distance</td>
<td>0.001</td>
<td>0.002</td>
<td>600</td>
<td>0.317</td>
<td>0.751</td>
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<tr>
<td>Total abundance</td>
<td>(intercept)</td>
<td>0.899</td>
<td>0.112</td>
<td>600</td>
<td>7.999</td>
<td>&lt;0.001</td>
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<tr>
<td></td>
<td>baulk distance</td>
<td>−0.008</td>
<td>0.002</td>
<td>600</td>
<td>−3.859</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(intercept)</td>
<td>0.516</td>
<td>0.124</td>
<td>600</td>
<td>4.174</td>
<td>&lt;0.001</td>
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<tr>
<td></td>
<td>tree edge distance</td>
<td>0.000</td>
<td>0.003</td>
<td>600</td>
<td>0.012</td>
<td>0.990</td>
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the response of whole assemblage to grazing appeared to be species-specific, without uniform trend. Amongst all examined species the grasshopper *Gomphocerippus rufus* stood out, the species showed clear positive response to grazing and, simultaneously, negative response to mowing. Our study also brought evidence for the importance of local landscape structure. We found significant positive effect of baulks (grassy edges) on both number of Orthoptera species and individuals.


We have shown that number of species and individuals of Orthoptera increased towards grassy edges (baulks). The present study brought two fundamental findings: 1) we emphasized the importance of uncut refuges (recently established by Humbert et al. 2012); 2) our data support the hypothesis that orthopterans benefit from the presence of baulks as constituent of habitat heterogeneity. These findings can be related also to other less mobile arthropods (beetles, caterpillars or spiders) and might provide even general implication for other invertebrate and vertebrate taxa (Humbert et al. 2012).

Based on our findings, we recommend: (i) to leave uncut grass refuges until the next mowing event. These refuges should be placed primarily along baulks or another types of grassy edge. Leaving of the uncut strips along dense woody edge appears to be less effective for grassland fauna. However, it can be beneficial for ecotonal mechanisms (Ries et al. 2004) and it can be practical for farmers; (ii) to establish permanent linear features (e.g. grass baulks) which can substantially increase the biological value of agroecosystems, primarily in the conditions of Central European farmlands, recently affected by agricultural intensification. In our opinion, the most important target of modern environmental-friendly grassland management is to avoid uniformity and to ensure habitat heterogeneity.

ACKNOWLEDGEMENTS: We are much obliged to I. Pur, the nature-friendly-thinking owner of the farmland where the survey took place. A. Gouveia kindly checked our English. Last but not least we thank two anonymous referees and editor for useful suggestions. The research was partially supported by grant VaV SP/2D3/155/08 from the Ministry of the Environment of the Czech Republic.

6. REFERENCES


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Impacts of mowing, grazing and edge effect on Orthoptera of submontane grasslands


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### APPENDIX

Numerical characteristics of presented generalized linear models (statistically significant results only).

<table>
<thead>
<tr>
<th>Model</th>
<th>Predictor or group</th>
<th>Species*</th>
<th>Regression coefficients</th>
<th>F</th>
<th>P</th>
<th>AIC</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>for intercept</td>
<td>for predictor</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>B</td>
<td>B²</td>
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<td>mowing</td>
<td>GomRuf</td>
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<td>1.761</td>
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<td>II</td>
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