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# Hay harvesting causes high orthopteran mortality

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ABSTRACT

Knowledge on the direct impact of the meadow harvesting process on field invertebrates has long been limited to studies that investigated impacts due to mowing. This study demonstrates that raking coupled with baling impacts orthopteran populations to a similar degree as mowing followed by tedding. At the end of the harvesting process, orthopteran surviving rate was 32% (SD = 14) when meadows were mown with rotary mowers without conditioner and lower, 18% (SD = 8), when mown with rotary mowers with conditioner. Conversely, given the strong impact of tedding, raking and baling, no evident advantages were found for the use of tractor bar mowers over rotary mowers without conditioner. Reduction in orthopteran densities observed after harvesting was slightly higher than the estimated mortality caused by the machineries, presumably because orthopteran reduction includes a small emigration and natural mortality. If conservation is the primary objective of the meadow, no conditioner should be used, uncut grass refuges should be left when mowing, and the number of time the meadow is harvested per year should be the minimum required to maintain the habitat.



## 1. Introduction

The relative influence of local vs. landscape factors is scale and species dependent, as taxa respond differently according to their trophic level, body size and habitat specialization (Tscharntke et al., 2005). For orthopterans specifically, local factors such as management intensity, vegetation structure and microclimate, appear to be more important than landscape factors with regard to abundance and species composition (e.g. Van Wingerden et al., 1992; Wettstein and Schmid, 1999; Gardiner et al., 2002; Marini et al., 2008). It is on this basis that Orthoptera are considered to be good indicators for habitat change (Baldi and Kisbenedek, 1997). Nevertheless, at scales of around 100 m, the proportion of woody vegetation adjoining a meadow increases orthopteran species richness presumably by providing a refuge when the meadow is mown (Marini et al., 2009a), and at larger scales (radius 500 m) urban elements in the surrounding landscape negatively affect orthopteran richness (Marini et al., 2008). Landscape pattern is therefore also important in determining patterns of grassland orthopteran richness and abundance.

Although orthopterans react negatively to grassland intensification, the underling mechanisms are not clear. For example Van Wingerden et al. (1992) argued that nitrogen input increases vegetation density and height which decrease temperatures near the soil surface where orthopteran eggs are usually located. Lower temperatures delay hatching and increase exposure of eggs to predation and mortality. Increase in vegetation biomass due to fertilizer input also allows more frequent harvests which have been shown to reduce orthopteran diversity, mostly due to mortality caused by the harvesting machines (e.g. Gardiner, 2006; Marini et al., 2008; Braschler et al., 2009).

Reductions in orthopteran density due to the direct impact of mowing ranges between 9 and 60% (Humbert et al., 2009). These results do not, however, disentangle mortality from emigration. Additionally, mowing is usually followed by tedding, raking and baling, with each operation likely to impact orthopterans that survived the initial mowing intervention (Humbert et al., 2009). Each harvesting step has a negative impact simply because of the tractor running over the field (Humbert et al., 2010a). Indeed it has been suggested that orthopteran mortality resulting from the whole harvesting process can exceed 70% (Oppermann et al., 2000).

To our knowledge, no quantitative assessments of orthopteran mortality caused by the whole meadow harvesting process exist. Therefore, the aim of this study was to investigate orthopteran mortality resulting from the sequential harvesting stages of mowing, tedding, raking and baling. Specifically, the mortality rates of each single or combined harvesting stage were measured, and then the

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total mortality was calculated. In addition different mowing techniques were compared; in particular we investigated the impact of rotary mowers with conditioner as there are evidences that conditioners have strong negative impacts on field invertebrates (Humbert et al., 2009, 2010a).

The meadow harvesting process, often referred to as "cutting" in the literature, includes several mechanized stages (in brackets are abbreviations used in this paper):

1. Mowing the grass (M).
2. Conditioning the grass (C).
3. Tedding the grass for drying (T).
4. Raking the grass (R).
5. Baling or loading the grass (B).

In this paper the term "mowing" restrictively refers to the actual mowing event (i.e. the first harvesting stage). Conditioning (stage two) is a recent practice used to accelerate the drying of the grass by crushing it after mowing. Conditioners, which are directly fixed on the mower (mower-conditioner) or attached behind the tractor, perform a rolling or crimping mechanical action on the grass immediately after cutting. Thus, if a conditioner is used, mowing and conditioning are executed simultaneously. We henceforth indicate this process as MC. Implementation of tedding (stage three) depends primarily on the form in which the grass is to be stored, hay or silage. Raking (stage four) consists in gathering the mown grass in lines to allow a baler or self-loading wagon to remove the harvest (stage five).

While our study addresses impacts on Orthoptera specifically, the results have relevance to far more than just Orthoptera biodiversity and conservation in an agricultural matrix. Orthopterans are an important food sources for farmland birds, many of which have undergone alarming declines in recent decades (Vickery et al., 2001). Further, it is likely that orthopterans are effective surrogates for many other grassland invertebrates of similar size and mobility, including many beetles, spiders and larval forms of Lepidoptera. Our results will also help the evaluation of agri-environment schemes, and improve the management of extensively used meadows, field margins or any other grassland elements to deliver conservation objectives.

## 2. Material and methods

Orthopteran mortality due to harvesting was measured using a capture-mark-resight technique, wherein the mortality of a group of individuals exposed to one or more harvesting stage(s) was compared to a control group (not exposed). We also assessed the impact of the whole harvesting process by summing the impacts across each harvesting stage. All experiments were carried on farms to catch the impact of "real" meadow harvesting processes.

### 2.1. Study sites

The experiments were carried out in summers 2008 and 2009. In total 14 fields located in seven different municipalities throughout Switzerland were used for the experiments: six in Aadorf (Aa1–Aa6); two in Doppleschwand (Do1 and Do2); one in Illnau-Effretikon (I1); two in Le Vaud (Le1 and Le2); one in Pfäffikon (Pf1); one in Villigen (Vi1); and one in Zürich (Zu1). All meadows were managed for hay production with sometime a late season grazing. Elevation ranged from 460 to 760 m.a.s.l. Four meadows were selected for the density investigations and eleven were used for the mortality experiments (see sub-sections below).

The fields in the different municipalities belong to different farmers. While tedding, raking and baling machines were similar across the experiments, the farmers used different mowing machines. Thus, the mowing machines were classified as rotary mower without conditioner, rotary mower with conditioner, or tractor powered bar mower.

### 2.2. Mortality experiments

A capture-mark-resight method was used to measure orthopteran mortality. Two-three hours before mowing, tedding, raking or baling, 80–120 adult orthopterans of the same species were captured, marked and stored in net boxes. Orthopterans were captured with a sweep net and marked with *RADGLO* fluorescent pigments (Radiant Color NV, Europark 1046 B-3530, Houthalen Belgium) on their pronotum and wings using a small paint brush. The orthopterans were divided in two equal groups, a treatment and a control group marked with a different colour. All orthopterans were captured within the meadow used for the experiment or in its vicinity. Therefore, selection of the species was according to the species present in the meadow.

The first group of orthopterans (treatment group) was released about one hour before the start of the harvesting stage in the central zone (about 20 m × 20 m) of a 50 m × 50 m homogenous area of the meadow previously delimited. The second group (control) was released in that same zone just after the harvesting stage or the combined harvesting stages under investigation. The second group of orthopterans served as control for handling effects and refinding rate (cf. Fig. 1).

During the following night, orthopterans were located using a black-light lamp (20 W 230 V tube). First the 50 m × 50 m delimited plot was intensively searched by slowly turning the hay with a hayfork. Second, the area around the plot was inspected further and

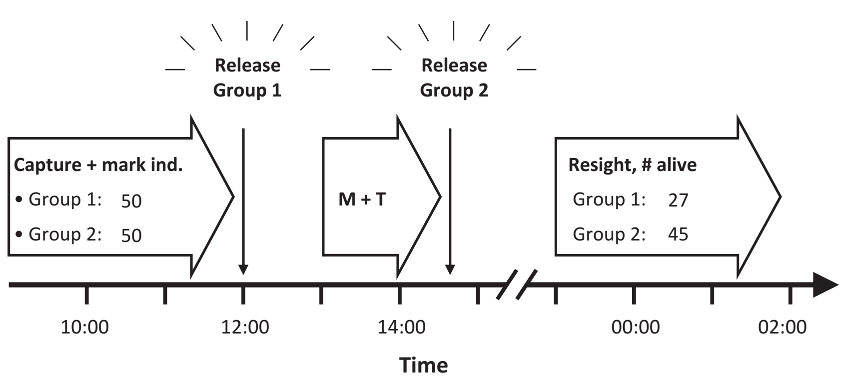


**Fig. 1.** Chronology of the capture-mark-resight method used to measure orthopteran direct mortality due to harvesting. The figure shows a hypothetical example for mowing (M) plus tedding (T), but the same methodology applies for other combined or single harvesting stages. In this example, orthopteran mortality due to mowing + tedding = (45 − 27)/45 = 40% (see text Section 2.2).

**Table 1**
Orthopteran mortality rates for mowing with a rotary mower plus tedding (M + T) and for raking plus baling (R + B). The last column (M + T + R + B) show the calculated cumulative mortality rates of R + B added to M + T. Mean values ± SD are given.

| Meadow and year | Species | % mortality | | |
|---|---|---|---|---|
| | | M + T | R + B | Calculated M + T + R + B |
| Do2 2008 | *C. parallelus* | 30 | 72 | 80 |
| Le1 2008 | *C. parallelus* | 40 | 32 | 59 |
| Aa5 2009 | *C. parallelus* | 39 | 40 | 63 |
| Aa6 2009/le2 2009 | *C. parallelus* | 52 | 30 | 67 |
| Aa6 2009/Il1 2009 | *C. biguttulus* | 37 | 22 | 51 |
| Le1 2009 | *S. lineatus* | 24 | 34 | 50 |
| Do2 2008 | *M. roeselii* | 58 | 78 | 91 |
| Le1 2008 | *M. roeselii* | 44 | 57 | 76 |
| Le1 2009 | *M. roeselii* | 50 | 48 | 74 |
| | Mean | 42 ± 11 | 46 ± 20 | 68 ± 14 |

further away (20–50 m) until no more marked orthopterans where seen. Potential nearby refuges, such as uncut field margins, were also inspected. The individuals were recorded as dead or alive, and their fluorescent colour marking was noted. The mortality rate was calculated as follows: the number of resighted orthopterans alive from the control group minus the number of resighted orthopterans alive of the treatment group divided by the number of resighted orthopterans alive of the control group (Fig. 1).Missing orthopterans of the treated group were assumed to be dead as they were often crushed, cut in pieces or packed in the bales, and were therefore not detectable using the methods described. Live orthopterans, by contrast, were easily located: mean resight rate of control group orthopterans across all experiments was 91.6%.

### 2.2.1. Rotary mower without conditioner

In fields mown with rotary mower without conditioner, the mortality rate due to mowing and tedding together was measured because these two harvesting stages took place one after another. In those cases the design followed exactly the example in Fig. 1. The following day, raking and baling also took place one after another and thus the combined impact of R + B was estimated. The design also followed Fig. 1, except that instead of “mowing + tedding” it was “raking + baling” and that different colours were used to avoid confusion with the orthopterans marked and released the day before. Nine replicates were performed.

In three fields (Aa5, Do2 and Le1) the hay was not baled, but removed with a self-loading wagon. The mechanism that removes the hay is the same for a baler or a self-loading wagon, therefore the two techniques were not differentiated in the analyses. For notation simplification in the tables and the text we talk only about baling, but imply the same for loading. Because of weather and logistic constraints, in two cases the impact of M + T and R + B had to be estimated in different fields (see Table 1). Some fields were used for more than one replicate. Though, we assume independence because the set of orthopterans were independent of each other.

### 2.2.2. Rotary mower with conditioner

In 2008, in Aadorf, the mortality rate due to mowing with a rotary mower with conditioner plus tedding was measured (four replicates). In those cases, an extra group of orthopterans marked with a third colour was released between mowing and tedding, which allowed also to estimate the separated impacts of mowing and tedding. The impact of raking and baling was not measured in those cases. Otherwise the methodology was the same as describe in Section 2.2.

Similarly, in 2009, in Villigen, the impact of mowing with a conditioner was first measured. Then the impact of tedding plus raking was measured. In that case, tedding and raking were executed over a period of two days. And finally the impact of baling was measured. Three replicates were performed with different species.

### 2.2.3. Tractor bar mower

Using the same methodology, the impact of mowing (solely) with a bar mower powered by a tractor was investigated. Only one trial was done because only one farmer used that mowing technique.

### 2.2.4. Statistical analyses

The impact of the whole harvesting process was calculated by “adding” the impact of the different harvesting stages. The added impacts were calculated as follow: suppose mortality of M + T = $1 - x$, and mortality of R + B = $1 - y$, so that $x$ and $y$ are the surviving rates of M + T and R + B respectively, then the mortality of the whole harvesting process = $1 - (x{\cdot}y)$, which is one minus the multiplication of the surviving rates. The variance of $(x{\cdot}y)$ is: $V(x \cdot y) = [E(x)]^2 \cdot V(y) + [E(y)]^2 \cdot V(x) + V(x) \cdot V(y)$.

To test if harvesting with a rotary mower without conditioner affected differently some species or group of species Wilcoxon rank sum tests were used. To test if harvesting with a rotary mower with or without a conditioner led to different mortalities at the end of the harvesting process (after baling), the following routine was done. First, the 2008 rotary mower with conditioner experiment (four first rows in Table 2) was completed with R + B mortality rates sampled with replacement from the rotary mower experiment. The mortality rates were sampled from *Chorthippus* spp. R + B values (five first rows Table 1). Second, the mortalities due to the whole harvesting process were calculated by adding MC + T and R + B as described before. This is possible because in Table 1 the mortality rates of R + B were independently measured from the mortality rates of M + T. Similarly in the field, the proportion of orthopteran killed during raking and baling is not influenced by the proportion killed before. We, therefore, assume the same impact of R + B whatever the mowing technique used. Finally, a *t*-test on arcsin square root transformed data was performed. With nine estimates for the mortality due to a harvesting process without using a conditioner (column M + T + R + B in Table 1) and seven estimates when a conditioner was used (columns MC + T + R + B in Table 2). This routine was repeated 10,000 times to get all possible bootstraps, and the median of all *p*-values was used as final *p*-value.

## 2.3. Density experiment

Reduction in the abundance of orthopterans due to harvesting was investigated in three meadows both in 2008 and 2009. The density of orthopterans was measured two hours before the grass was mown and again just after baling using a biozoenometer. A biozoenometer is a one metre high canvas mesh attached to a solid circle of exactly 1 $m^2$. The circle was thrown in the grass, and all trapped juvenile and adult orthopterans from the Tettigonioidea and Acridoidea super-families were counted (24–32 samples of 1 $m^2$ regularly placed per meadow). This technique is

**Table 2**
Mortality rates for mowing with a rotary mower with conditioner (MC), tedding (T) and both combined (MC + T), or mowing with a rotary mower with conditioner (MC) and tedding plus raking plus baling (T + R + B). The last column (MC + T + R + B) show the calculated cumulative mortality rates. Mean values ± SD are given.

| Meadow and year | Species | % mortality | | | | |
|---|---|---|---|---|---|---|
| | | MC | T | MC + T | T + R + B | Calculated MC + T + R + B |
| Aa1 2008 | *C. parallelus* | 57 | 13 | 63 | | ** |
| Aa2 2008 | *C. biguttulus* | 66 | 30 | 76 | | ** |
| Aa3 2008 | *C. para.* + *C. bigu** | 56 | 46 | 76 | | ** |
| Aa4 2008 | *C. para.* + *C. bigu** | 35 | 21 | 49 | | ** |
| Vi1 2009 | *M. bicolor* | 53 | | | 66 | 84 |
| Vi1 2009 | *P. albopunctata* | 69 | | | 63 | 88 |
| Vi1 2009 | *S. lineatus* | 65 | | | 49 | 82 |
| | Mean | 57 ± 12 | 27 ± 14 | 66 ± 13 | 59 ± 09 | 82 ± 8 |

* Here *C. parallelus* and *C. biguttulus* had to be pooled because there were not enough individuals of a single species to do the experiment.
** R + B values were sampled with replacement from Table 1, species *C. parallelus* and *C. biguttulus* (see statistical analyses section).

equivalent to the 1 m$^2$ box quadrat approved sampling methodology by Badenhausser et al. (2009), except that the biozeonometer is circular. Among the meadows, the harvesting processes differed in the number of times the grass was tedded, and the number of days between mowing and baling. Therefore, no harvesting-process-specific analyses were done, but all the data were combined to get an estimate of orthopteran density reduction during slightly different, but common meadow harvesting processes (Table 3).

## 3. Results

### 3.1. Rotary mower without conditioner

Mowing with a rotary mower without a conditioner plus tedding killed on average 42% orthopterans (Table 1). Assuming 27% mortality due to tedding, the mortality due to mowing solely is then equal to 21%. Raking and baling together killed 46% of the orthopterans. This does not correspond to 46% of the initial population, but 46% of the orthopterans present before raking. The impact of R + B is independent of the impact of M + T. The cumulative impact of (M + T) + (R + B) was on average 68% (last column, Table 1).

### 3.2. Rotary mower with conditioner

In 2008, the rotary mower with a conditioner killed 53, tedding alone 27, and the combined stages 66% orthopterans (Table 2). Note that the MC + T mortalities presented in Table 2 are the mortalities measured in the fields, not the calculated values from T added to MC. Since the impact of R + B was not measured in those fields, values bootstrapped from Table 1 were used to calculate the impact of the whole harvesting process (MC + T + R + B). One bootstrap consists of sampling with replacement (Table 1 *Chorthippus* spp.) an R + B value for each four replicates. In 2009, the rotary mower with conditioner killed 62, tedding plus raking plus baling 59, and baling itself (not shown in Table 2) 27% orthopterans.

The overall mortality of mowing with a rotary mower with conditioner across all replicates was 57%. The mean mortality of the whole harvesting process (MC + T + R + B) was 82%; this value and its associated SD were from the 10,000 bootstraps.

### 3.3. Tractor bar mower

In 2009, in field Il1, mowing with a bar mower powered by a tractor engendered a mortality of 13% on *Chorthippus biguttulus* population. To this mowing mortality, if we add an impact of T = 27 ± 14% (from Table 2), and an impact of R + B = 46 ± 20% (from Table 1), then the mortality of the whole harvesting process when mowing with a tractor bar mower adds to 66 ± 14%.

### 3.4. Statistical analyses

Orthopteran species were pooled in the analyses for two reasons. First, the data did not support any difference between species or groups of species. For example, mortality rates of M + T, R + B and M + T + R + B (Table 1), did not significantly differ between *C. parallelus* and *M. roeselii* (all Wilcoxon rank sum test outputs equal: $W$ = 2, $P$ = 0.229), and between Ensifera and Caelifera (all Wilcoxon rank sum test outputs equal: $W$ = 2, $P$ = 0.095). Additionally, no differences between mobile (*C. parallelus* and *C. biguttulus*) and less mobile species (*Stenobothrus lineatus* and *M. roeselii*) – mobility classes according to Reinhardt et al. (2005) – were found (Wilcoxon rank sum tests for M + T and M + T + R + B: $W$ = 2, $P$ = 0.557; for R + B: $W$ = 4, $P$ = 0.191). Finally, no qualitative interactions were observed, i.e. all species reacted in the same way to the different harvesting stages and mowing techniques.

The impact of the whole harvesting process when mowing with a rotary mower (M + T + R + B) is equal to 68 ± 14% (Table 1). The impact of the whole harvesting process when mowing with a rotary mower with conditioner (MC + T + R + B) is 82 ± 8% (Table 2). To test if these two harvesting processes led to different mortalities, a $t$-test was done for each single bootstrap. The median of the 10,000 $p$-

**Table 3**
Densities of orthopterans before mowing and after baling, and their associated reduction. All meadows were mown with rotary mower without conditioner. Mean reduction ± SD is given.

| Meadow and year | Tedding events | Days for harvesting | [Orthopterans/m$^2$] | | % reduction |
|---|---|---|---|---|---|
| | | | Before mowing | After baling | |
| Pf1 2008 | 2 | 4 | 5.63 | 0.47 | 91.7 |
| Le1 2008 | 1 | 2 | 3.09 | 0.47 | 84.8 |
| Do1 2008 | 2 | 2 | 16.45 | 0.50 | 97.0 |
| Pf1 2009 | 2 | 4 | 6.66 | 0.56 | 91.5 |
| Le1 2009 | 1 | 2 | 1.71 | 0.33 | 80.5 |
| Zu1 2009 | 1 | 2 | 2.56 | 0.34 | 86.6 |
| | | Mean | | | 88.7 ± 5.9 |

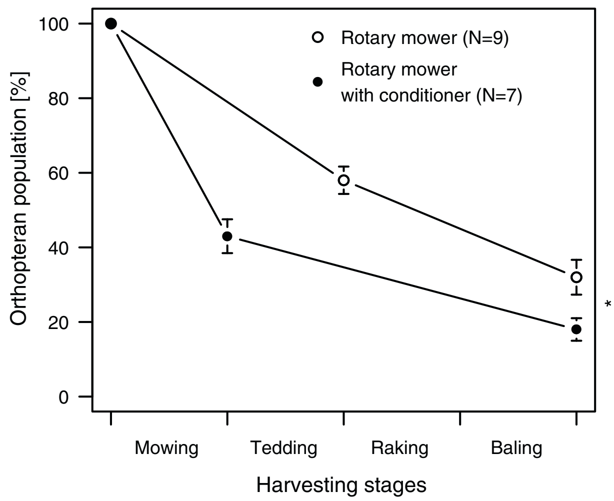


**Fig. 2.** Mean orthopteran population densities with standard error bars through the meadow harvesting process (data from Tables 1 and 2).

values obtained from all *t*-tests is 0.035. Thus, mowing with a rotary mower with conditioner led to a significantly higher mortality rate at the end of the harvesting process than mowing with a rotary mower without conditioner (Fig. 2).

Among 1642 marked orthopterans of the treatment groups, 86 were resighted outside the meadow, correcting for recovery rate (91.6%), it shows that 5.7% of the marked orthopterans moved out the meadow during the harvesting process (5.6% were Caelifera and 6% Ensifera).

### 3.5. Density experiment

Orthopteran population density before mowing varied between meadows and years, and ranged between 1.7 and 16.5 individuals per $m^2$. All populations experienced strong declines during harvesting; density after baling ranged between 0.3 and 0.6 orthopteran per $m^2$ (Table 3). Average orthopteran population reduction was $88.7 \pm 5.9\%$. Values include all individuals found of the Tettigonioidea and Acridoidea super-families. The grass was tedded one or two times and the harvesting processes lasted two or four days.

## 4. Discussion

The results show that, overall, the meadow harvesting process caused a direct mortality of 65–85% orthopterans. The variability was largely due to the different mowing machines adopted for the mowing stage. These results demonstrate the very substantial impact of the mechanical harvesting process on field invertebrates, a factor that has been largely overlooked by management policies that aim to enhance the biodiversity of meadow fauna. This is important for many European agri-environmental programs for which effectiveness has been questioned, especially regarding their ability to improve invertebrate diversity (Kleijn et al., 2006; Roth et al., 2008). In addition to agricultural grasslands, some open nature reserves and hotspots are also mown as a management strategy (e.g. Cattin et al., 2003). When conservation is the primary goal of such management, the harvesting techniques used should be considered carefully in the light of our results.

### 4.1. Mortality due to mowing

Mowing with rotary mowers killed about 21% of the orthopterans, while adding a conditioner increased mortality by almost three times (57%). These estimates are similar to other studies that used insect models (Humbert et al., 2010a), or orthopterans (Oppermann et al., 2000). While only adult orthopterans were used in this study, Oppermann et al.'s study showed that juveniles are less affected than adults. Our results also provide further evidence that for orthopterans, tractor bar mowers are slightly less damaging than rotary mowers (Oppermann et al., 2000). For larval butterfly, Humbert et al. (2010b) found no differences between tractor bar mowers and rotary mowers without conditioner.

### 4.2. Mortality due to the whole harvesting process

Mortality due to the mowing machines has usually been assumed to be the most damaging of meadow harvesting impacts on field fauna. Our results demonstrate that post-mowing interventions such as raking coupled with baling impact orthopteran populations to a similar degree as mowing followed by tedding (Table 1). Indeed, any benefits gained in terms of reduced orthopteran mortality by using a tractor-powered bar mower relative to a rotary mower are mostly lost by the cumulative impact of the subsequent harvesting stages (see also Oppermann et al., 2000). These results underline the need to consider the entire harvesting process for a complete assessment of harvesting impacts on field invertebrates.

Conditioner increased Orthoptera mortality to such an extent that at the end of the harvesting process, after baling, the cumulative mortality (82%) is significantly higher compared to harvesting without conditioner (68% mortality, see Fig. 2).

The variability found in the results may be due to different species mixtures among trials. While no significant differences were found between *C. parallelus* and *M. roeselii*, or between Ensifera and Caelifera or between mobile (*C. parallelus* and *C. biguttulus*) and less mobile species (*S. lineatus* and *M. roeselii*), the literature suggests that some differences may exist between species (Oppermann et al., 2000; Humbert et al., 2010a). Note that a power analysis indicates that the sample size ($N = 5$) does not allow detection of differences smaller than 20% between species or group of species. Additionally, different machine brands were used. For example, tedders might vary in their visibility to orthopterans, and tractor wheels, which can influence the impact of the process, might differ in size. The speed at which the tractors move across the field might also affect rates of mortality.

Across all six meadow harvesting processes using rotary mowers without conditioner, orthopteran population density decreased by 88.7% on average (Table 3). As expected, this value is higher than the mortality rate calculated for similar harvesting processes (68%), because this decrease represents the proportion of orthopteran missing after harvesting, and includes the ones that were killed by the harvesting machines, the ones that naturally died, as well as the ones that moved out the meadow. Emigration during harvesting is believed to be low. Daily movement and dispersal capacities of orthopterans are usually smaller than 10 m, although species specific (Reinhardt et al., 2005), and higher in unsuitable habitat (Hein et al., 2003; Berggren, 2004). During the mortality experiment, 5.7% of 1642 marked orthopterans moved out the meadows when harvesting. Whereas this proportion is linked to the size and form of the meadow, it gives a good daily emigration estimate for our 1 ha average size meadows. Daily adult natural mortalities haven been reported for several species in Grant et al. (1993) and range between 3 and 4%. In the density experiments, average harvesting process length was 2.7 days, thus average natural mortality can be estimated around 10%. Subtracting the emigration rate and natural mortality from the overall density reduction leads to the following: $88.7 - 5.7 - 10 = 73.0\%$, which correspond to the estimated proportion of orthopteran killed by the harvesting machines. While this is a rough estimation, it is nevertheless close to the mortality measured using the capture-mark-resight methodology and confirms the strong impact of the harvesting process.

### 4.3. Management recommendations

While the impact of harvesting is considerable whatever the type of process, it appears that using a conditioner significantly increases the total mortality. Therefore we recommend not using conditioner where biodiversity is of concern.

Our single replicate using a tractor bar mower corresponds with previous results that indicate bar mowers as being less damaging than rotary mowers (Humbert et al., 2009). Nevertheless, given the strong impact of tedding, raking and baling, the difference between tractor bar and rotary mowers at the end of the harvesting process is small. Therefore, there is no clear advantage to using tractor bar mowers over rotary mowers over the whole harvesting process.

Given the strong negative impact of harvesting, reducing the number of harvests per year, and considering the date of harvesting are probably the major issues. Where faunal abundance is a primary objective, we recommend that the number of cuts is reduced to the minimum required to maintain the plant community. In Europe, this is usually one or, at most, two cuts per year according to meadow location and conditions (Parr and Way, 1988; Jantunen et al., 2007). Harvesting late in the season, when most species have completed reproduction is also an option (Wettstein and Schmid, 1999). For Alpine meadows, Marini et al. (2009b) even recommended supra-annual mowing regimes of once every 3–5 years to reduce mortality of Orthoptera. Providing nearby refuges such as uncut grass strips is also likely to be important, as such refuges could act as source populations for recolonization of the meadow after the harvesting process, though the effectiveness of such refuges remains to be explored.

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