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Uncut grass refuges mitigate the impact of mechanical meadow harvesting on orthopterans

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ABSTRACT

Semi-natural grasslands require regular harvesting (cutting) or grazing to avoid vegetation succession, and this is well known to promote plant diversity. However, recent studies have shown that meadow harvesting has a severe direct negative impact on orthopterans and other grassland invertebrates. In view of this, leaving areas of uncut grass as refuges has often been recommended as a mitigation measure. Yet to date no studies have tested this hypothesis. We experimentally investigated the direct influence of leaving a 10% uncut grass refuge in the centre of 50 m diameter meadow plots on orthopteran population. During harvest, orthopteran densities dramatically declined within mown areas and doubled within refuges, showing that during the mowing stage some individuals actively moved to uncut areas, safe from the impact of post-mowing stages. After baling, final orthopteran population sizes were on average 53% higher in plots with an uncut refuge, compared to plots without. To maximise the benefit of refuges, we recommend mowing towards the refuge, as this is likely to drive field invertebrates into the refuge.

1. Introduction

Since the 1950s meadow and pasture agricultural systems have been considerably intensified, resulting in earlier and more frequent cuts or higher grazing intensities. These changes are, in general, detrimental to grassland biodiversity, with plant, bird and invertebrate populations and richness declining following intensification (Benton et al., 2002; Donald et al., 2006; Marini et al., 2008; Vickery et al., 2001; Wilson et al., 1999). In Europe, various agri-environment schemes (AESs) have been implemented to reverse such declines, but these have had limited success in restoring lost biodiversity, especially grassland invertebrates (e.g. Aviron et al., 2009; Kleijn et al., 2006; Knop et al., 2006; Taylor and Morecroft, 2009). The modest success of AES on field invertebrates highlights the need for research on grassland management practices that target, in addition to the plant community, invertebrates (Littlewood et al., 2012).

Grassland invertebrate communities are affected by both landscape and local factors (Marini et al., 2010; Robinson and Sutherland, 2002). Landscape factors, such as patch size, distance to the next source population, and habitat connectivity, are difficult to address in farm-scale restoration programs (Tscharntke and Brandl, 2004). On the other hand, local factors such as fertiliser inputs, time and frequency of harvests, can be shaped by individual farmers, and thus local management is the central focus of many AES guidelines (Kleijn and Sutherland, 2003). The meadow harvesting process is another important local element that has a direct and often substantial impact (in terms of mortality) on field invertebrates (Humbert et al., 2010a, 2010b, 2009). This impact depends on the machines used, the habitat, and the ecology and morphology of each species. It can be reduced using appropriate mowing techniques, but despite such precautions the impact of the whole harvesting process on field fauna remains substantial; 65–85% mortality for orthopterans (Humbert et al., 2010a). In view of this, leaving uncut grass areas within meadows has been recommended as a mitigation measure for field fauna (Dover et al., 2010; Gardiner and Hill, 2006; Humbert et al., 2009).

Reducing the area cut will correspondingly reduce direct mortality of beetles, orthopterans, spiders, lepidopteran caterpillars and other less mobile invertebrates (Baines et al., 1998; Humbert et al., 2010a, 2010b; Thorbek and Bilde, 2004). Furthermore uncut areas might also act as refuges to which invertebrates can move to from areas of the field that are mown. Beyond providing an opportunity to escape from mowing machinery, refuges might also offer protection from post-mowing harvesting stages (see definition below).

There is some indirect evidence to support this conjecture. For example, Guido and Gianelle (2001) showed a shift in the distribution patterns of four orthopteran species during the haying process (the harvesting of hay, from mowing to hay removal),

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suggesting that some orthopterans actively moved to the adjacent undisturbed microhabitats. Meadow orthopteran species richness has also been correlated with the proportion of woody vegetation adjoining meadows, possibly because such vegetation provides a refuge when meadows are mown (Marini et al., 2009). Moreover net movements of arthropods have been recorded from cut to uncut plots in a lucerne (*Medicago sativa*) crop pest control experiment (Hossain et al., 2002). However, no study has experimentally investigated the influence of uncut refuges on invertebrate populations during the harvesting process, that is whether invertebrates actively move to uncut areas during harvesting. The present study investigated this question with orthopterans. The hypothesis was that leaving uncut grass areas when mowing mitigates the direct negative impact of harvesting by providing refuges to which invertebrates can retreat. Orthopterans were chosen because they are semi mobile organisms known to suffer mortality as a result of the mechanical harvesting process; they get killed by the machines (Humbert et al., 2010a). In addition, orthopterans are good indicators for grassland ecosystems health as they respond strongly to management intensification, both by decreasing species number and population density (Baldi and Kisbenedek, 1997; Fischer et al., 1997; Marini et al., 2008; Van Wingerden et al., 1992). Orthopterans are also an important food source for many birds (Bretagnolle et al., 2011).

To investigate the response of orthopterans to meadow harvesting process and the role of refuges, we determined orthopteran population densities in plots where a refuge area equivalent to 10% of the whole plot size was left uncut when mowing, and compared it with plots where the whole area was mown. Note that in this paper the meadow harvesting process is separated in two stages: the mowing stage and the post-mowing stages which include tedding, raking and baling the hay. Thus, the term “mowing” restrictively refers to the actual mowing event (i.e. the first harvesting stage). Tedding refers to the spreading of the grass to facilitate drying, while raking plus baling refer to the gathering of the dried grass in lines before baling and removal.

2. Materials and methods

2.1. Study sites

The study was carried out in Switzerland in 2008 and 2009 in extensively managed meadows under Swiss AES regulations that stipulate no fertiliser application and a first cut not before June 15th or July 1st according to site elevation. Two meadows were located in the municipality of Illnau ZH (labelled Il1 and Il2; Il1 47°25′7″N/8°44′13″E, and Il2 47°25′14″N/8°44′2″E), at about 580 m elevation. These meadows were used in 2008 and 2009. A third meadow used in 2009 was located in the municipality of Pfäffikon ZH (Pf1 47°21′30″N/8°47′26″E, elevation 550 m), and a fourth meadow used in 2008 was located in the municipality of Doppleschwand LU (Do1 47°1′2″N/8°3′41″E, elevation 730 m). All meadows were at least 115 m × 60 m, mostly flat and homogenous regarding vegetation structure. Their vegetation communities were associated between *Arrhenatherum elatius* and *Bromus erectus* grasslands (Delarze and Gonseth, 2008). All experiments in 2008 and 2009 were undertaken between June 17 and July 3 during the first annual harvest of the meadow. Except once in meadow Il2, the experiment took place during the second harvest between August 26th and 28th 2008.

2.2. Experimental design

To investigate the influence of leaving uncut grass refuges on orthopterans during the haying process, we adopted a randomized block design with two 50 m diameter plots per meadow: a treatment and a control plot (Fig. 1a). When mowing the treatment plot, a 16 m diameter circle was left uncut at the centre. A circular design was adopted to avoid any orthopteran directional movement effects across replicates. This uncut grass refuge corresponded to 10% of the plot area. Control plots were entirely mown, although we delimited a similar-sized central zone for comparison. Mowing machines without conditioners were used because conditioners have a dramatic impact on field invertebrates (Humbert et al., 2010a, 2010b). Conditioners roll or crimp the grass immediately after mowing to accelerate the drying process. In all plots mowing was undertaken in a circular motion starting at the perimeter of the 50 m plot and moving towards its centre. Tedding, raking and baling were implemented linearly across the plot, but refuges were left untouched during the whole harvesting process. A 5 m minimum buffer zone was maintained between the plots in each meadow. Meadows Il1 and Il2 were used twice (once in 2008 and once in 2009), though plots did not overlap. We assume that the replicates are independent as the experimental unit is not the field, but rather the haying event.

Orthopteran densities were measured 2–3 h before mowing in both types of plots. Before mowing 16 samples were taken per plot, where density within plot was assumed equal in the centre and periphery zones (Fig. 1b). One or two hours after mowing orthopteran density was no longer homogenous and measured separately in all four zones described in Fig. 1. Twelve samples were regularly taken in the uncut refuge (zone 1) and 16 samples were regularly taken around the refuge (zone 2). Sampling in the central zone was limited to twelve samples because the area was too small to accommodate 16 independent samples (Fig. 2b). Similarly, in the control plot, 12 samples were taken in the central zone (zone 3) and 16 samples were taken around it (zone 4). This was repeated once again 1 or 2 h after baling or the following morning when baling was late in the evening and conditions were no longer optimal for orthopteran sampling (i.e. too cold). First developmental stage larvae (<5 mm) were not included in the analyses because detectability may vary between cut and uncut zones.

2.3. Sampling method

The density of orthopterans (i.e. number of individuals/m^2) was measured using a biocenometer made of a net fastened around the circumference of a 1 m square hard circle. This technique is equivalent to the 1 m^2 box quadrat approved sampling methodology by Badenhausser et al. (2009), except that the biocenometer is circu-

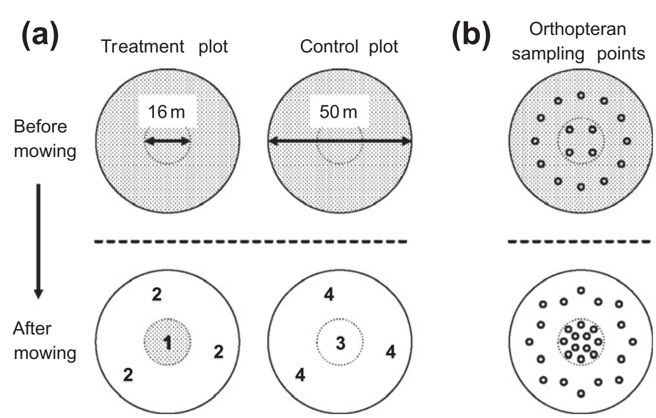

Fig. 1. Experimental design. (a) Orthopteran densities were measured before mowing, after mowing and again after baling. Before mowing orthopteran densities were assumed homogenous within plots. After mowing and after baling densities were measured separately in all four zones. Zone 1 is the uncut refuge, zone 2 is the cut zone around the refuge, zone 3 is the central zone of the control plot and zone 4 is the periphery zone of the control plot. (b) Orthopteran densities were measured using a biocenometer (circular net) of one meter square; taking 12 or 16 samples per zone. The same sampling scheme was applied on both plots.

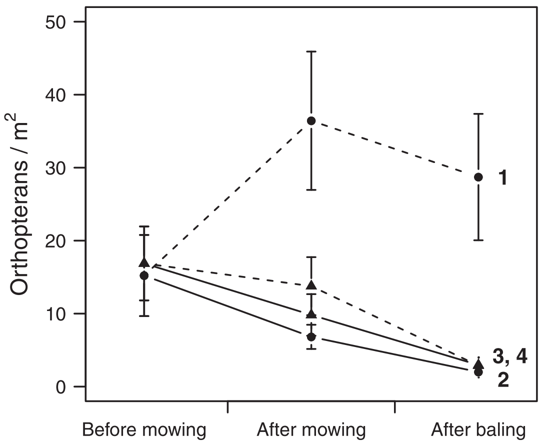

Fig. 2. Absolute orthopteran densities before mowing, after mowing and after baling with SE bars. Numbers correspond to the four different zones shown in Fig. 1. Dashed lines are for the treatment plots and solid lines for the control plots, while circles are the densities in the central zone 1 (uncut refuge) and central zone 3 (cut), triangle are the densities in the periphery zones 2 and 4 (cut). Figures with densities per replicate and per suborder (Caelifera vs Ensifera) are provided in Appendix A.

lar. The biocenometer was thrown in the grass, and all trapped orthopterans from the Tettigonioidea and Acridoidea super-families (juveniles and adults) were recorded visually.

2.4. Data analysis

Treatment effects were analyzed with linear mixed effects models as these models can take into account the different orthopteran initial population densities across replicates (Zuur et al., 2009). Response variable was the log transformed orthopteran densities after baling, the fixed effect was the treatments (zones 1, 2, 3 or 4; Fig. 1), and the replicates were designated as a random effect. To know how the treatments differ, three planned orthogonal comparisons were done by removing zero, one or two treatments from the data set. Mixed effects models were run using the *lmer*() function from the lme4 package for R (Bates et al., 2011). *P*-values and confidence intervals were computed with the *pvals.fnc*() function from the languageR package using 10,000 Markov chain Monte Carlo iterations (Baayen, 2011). Further nonparametric statistics were performed to test if the density of orthopterans within zones significantly changed (increased or decreased) over the harvesting process. Interest was on the relative changes and not on the absolute changes in population densities, because an increase from four to eight should be seen as similar as an increase from 20 to 40 and not as 20–24. First the relative changes were calculated for each replicate (e.g. density after mowing/density before mowing), then 10,000 bootstraps (random sampling with replacement) were used to calculate 95% Confidence Intervals (CIs) (Manly, 1997). Species of the suborders Ensifera are usually bigger than the species of the suborder Caelifera, their mobility and ecology often differs too and thus they may respond differently to the harvesting regime (Reinhardt et al., 2005). To see if responses differ between both suborders, the same statistics were rerun on each suborder and compared. All statistics were performed using R version 2.14.1 (R Development Core Team, 2011).

3. Results

3.1. Refuge experiment

Orthopteran densities before mowing varied across meadows and ranged between 3.5 and 39.5 individuals per m^2. Densities were, on average, 15.2 (Standard Error SE = 5.6) for treatment plots and 16.9 (SE = 5.1) for control plots (Fig. 2; Appendix A). The dominant species were *Chorthippus parallelus*, *Chorthippus biguttulus*, *Mecosthetus parapleurus* (all from the Acrididae family) and *Metrioptera roeselii* (Tettigoniidae family). For more details on the species found, see Appendix B. After baling, density in the refuge was 28.7 (SE = 8.7) individual per m^2, two times higher than before mowing and was significantly higher than the density around the refuge (zone 2) 2.0 (SE = 0.8), and in the centre (zone 3) 2.9 (SE = 1.1) and periphery of the control plot (zone 4) 3.0 (SE = 1.1) (within refuge vs around the refuge: estimate = 2.78, 95% CI = 1.56–4.05, $P < 0.001$; within refuge vs central zone of the control plot: estimate = 2.36, 95% CI = 1.46–3.21, $P < 0.001$; within refuge vs periphery zone of the control plot: estimate = 2.39, 95% CI = 1.37–3.49, $P < 0.001$). Densities around the refuge, in the control plot central and periphery zones were not significantly different from each other (around the refuge vs central zone of the control plot: estimate = −0.42, 95% CI = −1.30 to 0.45, $P = 0.316$; around the refuge vs periphery zone of the control plot:: estimate = −0.39, 95% CI = −1.50 to 0.65, $P = 0.456$; central zone of the control plot vs periphery zone of the control plot: estimate = 0.03, 95% CI = 0.90 to −0.84, $P = 0.956$). Note that estimates are on the log scale.

Within refuges (zone 1), the relative density of orthopterans increased during the mowing process 2.72-fold (95% CI = 2.03–3.58). After baling, orthopteran density was 0.76 times lower (95% CI = 0.62–0.87) than after mowing, though it was higher than before mowing; 2.00 times higher (95% CI = 1.50–2.73). In the three other zones, relative densities after baling were always lower than the initial density (around the refuge: 0.18, 95% CI = 0.07–0.34; central zone of the control plot: 0.20, 95% CI = 0.10–0.36; periphery zone of the control plot: 0.24, 95% CI = 0.09–0.47). Finally, the proportion of orthopterans that survived in the entire treatment plot equalled in average 0.365 ($0.1 \times 2.00 + 0.9 \times 0.18$) and in the entire control plot equalled in average 0.24 ($0.1 \times 0.20 + 0.9 \times 0.24$). This gives a with: without refuge ratio of 1.53. Regarding the suborder analyses, density of Ensifera within refuge was on average 3.29 (95% CI = 2.14–4.93) times higher after baling than before mowing and density of Caelifera 1.78 (95% CI = 1.17–2.62) times higher (see Appendix A for more details).

4. Discussion

Haying has a severe direct negative impact on orthopterans and other field invertebrates (e.g. Humbert et al., 2009). In view of this, leaving uncut grass areas as refuge has often been recommended (see also Braschler et al., 2009; Cizek et al., 2012; Gardiner and Hassall, 2009; Humbert et al., 2010a; Marini et al., 2009), yet no studies have demonstrated its direct benefits. Our results demonstrate that providing uncut grass refuges is a simple and effective measure to mitigate the direct negative impact of the harvesting process on orthopterans. For species that are particularly sensitive to mechanized mowing, including orthopterans but potentially also other invertebrate groups such as lepidopteran caterpillars (Humbert et al., 2010b), a refuge might have major conservation benefits.

This finding is important for many grassland agri-environmental schemes, such as extensively managed meadows and field margins, that seek to enhance both flora and fauna diversity (e.g. Albrecht et al., 2010; Kleijn et al., 2006). Leaving uncut grass refuges within extensively managed meadows when harvesting, or leaving some parts of the field margins uncut, does not require extra work and can be easily added to the management guidelines of AES. Currently, in Switzerland, leaving uncut refuges within extensively managed meadows under agri-environmental contracts is an optional compensated measure that is widely implemented in many parts of the country (e.g. Canton Argovia, 2009). This finding is also important for the management of nature reserves such as wetlands, where rotational mowing will not only mitigate the negative impact of harvesting, but also provide overwintering habitat for many arthropod species (Cattin et al., 2003; Schmidt et al., 2008). Road verge management guidelines also often include biodiversity aspects, and leaving uncut grass strips is expected to similarly benefit road verge invertebrates, especially when flail mowers are used, a technique that inflicts high fauna mortality (Hemmann et al., 1987; Humbert et al., 2009; Noordijk et al., 2009).

4.1. Benefits of refuge for Orthoptera

Our results show that when mowing, leaving an uncut grass refuge benefits orthopterans by reducing their exposure to harvesting machineries. Individuals already present within the refuge avoided the impacts of mowing, and additional orthopterans were able to move away from the harvesting activity into the refuge during the mowing process. This protected them from post-mowing harvesting stages. During the post-mowing harvesting stages, orthopteran density slightly decreased within the refuge (Fig. 2). This pattern might be explained by the inability of the refuge to support the higher orthopteran densities that occur after mowing. It is also possible that this could reflect disturbance during the sampling procedure which encouraged movement out of the relatively small refuge area (16 m diameter).

After baling, the density in the refuge was twice higher than before mowing (Fig. 2), meaning that at least 20% of the orthopteran initial population survived within refuges following the meadow harvesting process. On the other hand, after baling, around the refuge as well as in the central and periphery zones of the control plots, orthopteran densities were 76–82% lower than the initial population size (before mowing). Specifically in the control plot; orthopteran population was reduced to 24% of the initial population size. This is lower, but close to the orthopteran surviving rates of 32% found in Humbert et al. (2010a) when meadows were mown without conditioner (as in our experiment). Retaining a 10% uncut grass refuge area results in a final population size that is 53% higher than without a refuge.

While orthopteran initial densities strongly varied across sites and dates of the experiment, every replicate displayed the same pattern (Appendix A), indicating some reliability for the broader relevance of our results to other temperate mown grasslands. Responses of Caelifera and Ensifera were similar to the overall orthopteran response, with a significant increase in density within refuges and significant decreases in the other zones (Appendix A), though, it should be recognised that the Ensifera populations were represented mainly by a single species, *M. roeselii* (>90% abundance). For this reason we do not elaborate differences between suborders.

4.2. Implications for other taxa

While we focused our study on Orthoptera, similar patterns have been observed in other invertebrates of similar size and mobility. For example, a net movement of volant arthropods, as well as epigeal beetles and spiders, from cut to uncut plots was also detected after the harvesting process by Hossain et al. (2002). Similarly, immediate migration of spiders and staphylinid beetles (but not carabid beetles) following grass cutting has been noted by Thorbek and Bilde (2004). Some lepidopteran caterpillars have also shown surprising short-term dispersal capacities; in a similar pilot experiment (three replicates), 22 out of 300 marked caterpillars released in the centre of a 50 m × 50 m plot were recaptured after tedding in adjacent uncut margins, meaning that they moved about 25 m in less than 8 h (Humbert, unpublished data).

Therefore, it appears that mechanical disturbance triggers the movement of many invertebrates, and it is likely that these organisms will move until they reach an uncut sward that provides similar habitat to that of the pre-disturbance conditions. Typically, five to 24 h separate the different harvesting stages, and this will allow some invertebrates to find a refuge before the start of the next harvesting stage, given the availability of such refuges in the vicinity. Although larger organisms are more vulnerable to the direct impact of mechanized harvesting (Humbert et al., 2010b), they are usually more mobile and therefore may benefit more substantially from the availability of refuges.

Uncut refuges will also provide continuity of shelter and food sources when most other parts of the landscape have been mown. In this context, partial or rotational mowing has long been recommended for orthopterans (e.g. Gardiner and Hassall, 2009; Marini et al., 2009; Van Wingerden et al., 1991), lepidopterans (e.g. Cizek et al., 2012; Dover et al., 2010; Feber et al., 1996; Valtonen et al., 2006), spiders (e.g. Baines et al., 1998; Cattin et al., 2003; Nyffeler and Breene, 1990; Schmidt et al., 2008), plant- and leafhoppers (Auchenorrhyncha) (Nickel and Achtziger, 2005), and many other groups (see Fenner and Palmer, 1998; Hoste-Danylow et al., 2010; Morris, 2000). Sward architecture is also higher in uncut areas, a factor known to promote invertebrate species richness in general (Woodcock et al., 2009).

Looking beyond invertebrates, ground nesting bird mortality due to mowing can be substantial (e.g. Tyler et al., 1998), and leaving unmown areas has also proved beneficial for several bird species (Broyer, 2003; Grüebler et al., 2012). However, conservation actions should not only focus on reducing nest losses by leaving refuges or postponing mowing, but should also promote grassland management systems that support a rich and abundant invertebrate community (as well as seed sources) upon which many birds depend (Britschgi et al., 2006; Smith and Jones, 1991; Vickery et al., 2001).

Information on the susceptibility of different field invertebrates to meadow harvesting process, including the use of different types of machinery and adoption of refuges, will facilitate more effective land use decision making. Such information will also contribute a better understanding of whether managed meadows represent source or sink populations for field invertebrates, and thus the long-term persistence of populations across the landscape. Long-term experiments are, however, necessary to evaluate if increasing survivorship actually improves long-term population persistence and expansion of field invertebrates across the landscape. Such landscape scale experiments require coordinated trials that encompass several landowners in different agricultural settings.

4.3. Management recommendations

Mechanized meadow harvesting processes have strong negative impacts on orthopterans and other less mobile invertebrates, with direct mortality as high as 82% (Humbert et al., 2010a). Therefore, when mowing, we recommend leaving uncut grass refuges of at least 10% of the field area. These refuges should be retained until the next haying event. If the meadow is suggested to aftermath grazing, patches of tall grass (also termed islets) will be naturally left by the grazers, which functions are similar to uncut refuges (Helden et al., 2010). In addition to refuges, low-impact mowing techniques, such as bar mowers, are often advocated to mitigate against impacts on field invertebrates during haying (see Humbert et al., 2009 and citations within). This recommendation, however, neglects post-mowing harvesting impacts (Humbert et al., 2010a), and the harvesting regime characterised by least impact on field invertebrates remains uncertain, though preliminary data suggest that a combination of rotary mower and 10% refuge is less damaging on orthopteran populations than mowing with a bar mower without a refuge (Humbert et al., 2010c).

Only one harvesting regime with 10% of the surface left uncut was investigated. We do not know whether this is an optimal area, though this is accepted in practice by farmers in Switzerland (Canton Argovia, 2009). Note that the only cost to farmers linked to this measure, is a correspondingly 10% reduction in hay production. Although not tested in this study, it is suggested that mowing should be in the direction of the refuge to encourage movement of invertebrates towards it, and that the location of the refuge should change from time to time to avoid vegetation succession (Grime, 2001). Given the low dispersal ability of many field invertebrates, as Hossain et al. (2002) we recommend a maximum of 30 m distance between two refuges. In European low input grasslands, a late cut (after September 1st) is also a safe measure regarding the conservation of orthopteran species that lay their eggs in or near the soil (Gardiner and Hassall, 2009; Humbert et al., 2010c). Similarly, for butterflies (Valtonen et al., 2006), a late cut is suggested, and if earlier, then uncut refuges should be left.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2012.03.015.

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