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Improved field margins highly increase slug activity in Switzerland

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Abstract Most field margins on arable land in Switzerland are narrow and intensively managed. As a consequence, field margins generally harbour few plant and animal species. To enhance biodiversity in arable landscapes, sown species-rich field margins, so-called improved field margins, were introduced in 2008 as a part of the Swiss agri-environment scheme. Here, we tested whether improved field margins increase slug activity density. Slug activity density in and next to improved field margins was compared to slug activity in and next to conventional field margins. Over a period of 3 years, slugs were sampled in three regions in northern Switzerland in late spring using bait stations. Our results show that improved field margins have higher slug activity density, of +191 %, than conventional field margins, independently of the region. The predominant slugs were *Arion lusitanicus* and *Deroceras* spp. While *A. lusitanicus* was generally more abundant in field margins than in fields, with intermediate numbers in

the adjacent crop margins, *Deroceras* spp. showed a more even distribution.

Keywords *Arion lusitanicus* · *Deroceras* spp. · Pest slug · Agri-environment scheme · Crop protection · Semi-natural habitat · Ecological infrastructure

1 Introduction

Nowadays, field margins along crop borders in Switzerland are usually narrow, mown several times a year and often affected by fertiliser and pesticide drift. Consequently, these conventional field margins generally exhibit low plant and animal diversity (Théato 2002). Seed mixtures and management strategies for species-rich field margins—so-called improved field margins—were developed in order to enhance biodiversity and connect habitats in arable landscapes. Introduced in 2008 as the newest type of ecological compensation area, improved field margins are part of the Swiss agri-environment scheme, and are now subsidised with direct payments. Such field margins are semi-natural, permanent habitats a minimum of 3 m wide sown with indigenous forbs, grasses and legumes and adjacent to arable fields. They are not fertilised, and weeds are mainly controlled mechanically when necessary. Every second year, half of the field margin is mown lengthways. In contrast to improved field margins, wildflower strips, another type of ecological compensation area on arable land, are not permanent, do not contain sown grasses and are usually not mown during the vegetation period.

Previous studies carried out in experimental improved field margins have shown that they enhance the diversity of many groups of organisms such as plants, butterflies, grasshoppers, ground beetles and spiders (Jacot et al. 2007). Given, however, that alternative farming practices such as set-aside can lead to increased populations of crop pests such as slugs (Griffiths et al.

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1998), it stands to reason that improved field margins could also provide a suitable habitat for slugs.

Mechanical soil cultivation reduces slug populations directly by damaging slugs or egg batches, or indirectly by destroying the vegetation cover or soil macropores serving as refuge habitats for them (Voss et al. 1998). Since the soil of improved field margins is not cultivated after sowing, slugs may find conditions in such margins to be favourable.

Improved field margins usually have a various vegetation structure, which can protect slugs from desiccation. Moreover, such areas are likely to harbour various oviposition sites and different fodder plants. It is unclear whether the vegetation of improved field margins serves as a preferred food source, or whether slugs spread out into the crop to feed. Studies with freshly sown wildflower strips and narrow grassy strips adjacent to oilseed rape showed the highest slug damage to the crops at one metre's distance from the strips, declining with increasing distance from the latter (Frank 1998a, b). In contrast to this result, Hof and Bright (2010) found that the presence of grassy field margins decreased the abundance of gastropods in adjacent arable fields.

To date, no information has been published on the influence of improved field margins on slug activity density. As improved field margins are the newest type of ecological compensation area, for practice it is important to know how they influence slug populations in the margins and the adjacent crops. Improved field margins are wider and managed more extensively than conventional field margins, and may differ from the latter in various aspects such as type and structure of vegetation cover or microclimate (e.g. they usually contain more plant species and dead plant material). Consequently, slug activity density could be increased in improved field margins.

In this study, newly established improved field margins were compared to conventional field margins, the predominant type in Switzerland. The following questions were addressed: (1) Is slug activity density in improved field margins higher than those in conventional field margins? (2) How do the two types of field margins influence slug activity density in the crop? (3) To what extent do sampling year and region affect the abundance of slugs?

2 Materials and methods

2.1 Study region and experimental fields

Sampling was carried out in three regions in the northern part of Switzerland: Aesch (Basel-Land canton), Oberwil-Lieli (Aargau canton) and the Klettgau (Schaffhausen canton). Although arable farming is common in all three regions, they differ from one another in terms of altitude, climate and soil properties. In Aesch (300–500 m a.s.l.), mean annual

precipitation is 849 mm, mean annual temperature 10.7 °C (mean values for 2002, 2004 and 2005 in Binningen, 7-km distance; MeteoSchweiz (2011)) and most abundant soil types are brown earth and pseudogley. In Klettgau (420–470 m a.s.l.), mean annual precipitation is 1,023 mm, mean annual temperature 9.6 °C (mean values for 2002, 2004 and 2005 in Hallau, 5-km distance; MeteoSchweiz (2011)) and most abundant soil type is brown earth with high clay and stone content. In Oberwil-Lieli (530–620 m a.s.l.), mean annual precipitation is 1,042 mm, mean annual temperature 9.8 °C (mean values for 2002, 2004 and 2005 in Zurich-Reckenholz, 13-km distance; MeteoSchweiz (2011)) and most abundant soil types are sandy loam, gleysol (buntogley) and pseudogley-brown earth.

Slugs were sampled in newly sown improved field margins and conventional field margins. The improved field margins, strips of 3 or 5 m width along the crop borders, were sown in 2001 for the experiment. Depending on the prevailing site conditions (dry, fresh or moist), the seed mixtures sown contained 26 to 35 indigenous forb, legume and grass species, and during the study period, an average of 19 plant species per 20 m² were found in the improved field margins. Estimated average moist mass of forbs in the improved field margins was 32 %. Once every second year in August, half the area of the improved field margins was mown lengthwise. The conventional field margins were permanent, grass-dominated strips of around 0.5 to 1 m in width alongside arable crops. Mown twice or three times a year, they harboured few grass, forb and legume species (personal observation; five to ten plant species per 20 m²; 5–20 % of moist mass were forbs).

In each study region, three conventional and three improved field margins were examined. In Oberwil-Lieli, one of the improved field margins was ploughed at the beginning of the final study year owing to weed problems, and crop rotation was resumed. As a replacement, a comparable improved field margin which had been sown in 2003 was included in the experiment. Slugs were collected within the field margin, in the adjacent crop at one metre's distance ('crop margin'), and at 15-m distance from the field margin ('crop'). The fields were approximately 1 ha in size, and the crops were cereal (in 26 cases), grass-clover ley (14), maize (3), wildflower strip (3), sunflower (2), sugar beet (2), pasture (2), potato (1), soybean (1) and broad bean (1). Pasture and wildflower strips were included and used for the analyses because slug activity density here was not substantially different from those found in the arable crops, for which not enough numbers were available.

2.2 Slug sampling

Slug activity density was measured once at the beginning of May and once at the end of May/beginning of June in 2002,

2004 and 2005, respectively. Samplings were done in May and June because these are the months when the fields are usually covered with crops and slug populations are quite large (Grimm 2001). At each time period, the three regions were sampled on three subsequent days using bait stations ('slug trap 007', B. Egger, Abtwil, Switzerland; Fig. 1). Each trap consisted of a plastic pot saucer with a diameter of 15 cm, baited with five slices of cucumber and covered with a plastic lid. A gap was left to allow the slugs to enter the trap. Eight traps were positioned in each habitat, i.e. field margin, crop margin or crop, in a transect 10 m apart from each other. The traps were placed on the soil surface before dusk and left exposed overnight. Between 6 and 9 a.m. the following morning, the slugs in or on the traps were counted, identified in the field and released again. Since *Arion hortensis* s.s. and *Arion distinctus* can only be distinguished on the basis of the internal anatomy of their reproductive systems (Iglesias and Speiser 2001), these slugs were not identified to species level.

2.3 Statistical analyses

The slug numbers of the eight traps per transect were summed for the analyses and referred to as slug activity density. Slug data of the two sampling periods per year were pooled because we were interested in the annual effect rather than in individual dates. Slug numbers were log-transformed to meet the assumptions of the performed regressions (normal distribution and homogeneity of residual variance). Data were analysed with linear mixed regression, and inferences on the variables were obtained using likelihood ratio tests. Region, field margin type, habitat and year were fixed factors, while crop type was a random factor. Tukey's post hoc test was used to analyse differences between groups. All statistical tests were performed using



Fig. 1 Slug trap with slugs and cucumber slices (photo: Stephan Bosshart, ART)

the statistics software R, version 2.12.1 (R-Development-Core-Team 2010).

3 Results and discussion

3.1 Slug activity density and trapping methods

A total of 9,076 slugs were sampled over the entire study period, comprising 4,740 specimens of *Arion lusitanicus*, 4,193 *Deroceras* spp. and 143 *A. distinctus/A. hortensis* s.s. No other slug species were sampled. On the whole, most *A. lusitanicus* individuals were found in the improved field margins ($n=1,926$), and to a lesser extent in the adjacent crop margins ($n=1,127$), whilst in the conventional field margins, 476 individuals were sampled and in the adjacent crop margins 553. Overall, and irrespective of the adjacent field margin type, the lowest total numbers of *A. lusitanicus*, i.e. 306 (adjacent to improved field margins) and 352 (adjacent to conventional field margins) individuals, respectively, were counted in the crops. High numbers of *Deroceras* spp. individuals were recorded in improved field margins ($n=948$), the adjacent crop margins ($n=825$) and crops ($n=780$), but differences between habitats were less pronounced than for *A. lusitanicus*. Fewer individuals were counted in the conventional field margins ($n=592$) and adjacent crop margins ($n=493$) and crops ($n=555$). The majority of *A. distinctus/A. hortensis* s.s. individuals ($n=109$) were found in the crops. Because of their low numbers, this group was not further analysed.

Baiting methods are commonly used to trap slugs in different crop and habitat types, but they are biased in favour of certain species. *Deroceras reticulatum*, a surface-dwelling slug, and *A. lusitanicus* that is also often found on or near the soil surface, are more likely to be trapped than *A. hortensis* s.s., a species active underground (Hunter 1968). The abundance of *A. hortensis* slugs may therefore have been underestimated. Given that the dominant slug species of our study, *D. reticulatum* and *A. lusitanicus*, are now the major pest slugs across wide regions of Europe (South 1992; Grimm and Paill 2001) as well as in Switzerland (Speiser et al. 2001), the trapping method clearly covered the most important species of pest slugs.

3.2 Effect of field margin type on slug activity density

Field margin type significantly influenced slug activity density (Table 1). Often, activity density of both *A. lusitanicus* and *Deroceras* spp. was significantly higher in the improved field margins than in the conventional margins (Figs. 2 and 3, Table 1). The main reason for this result is probably the less intensive management of improved field margins. A high abundance and variety of forbs may also have

Table 1 Effects of region, field margin type (improved, conventional), habitat (field margin, crop margin, crop), and year on the total number of slug individuals and on the number of *A. lusitanicus* and *Deroceras* spp. slug individuals recorded separately (activity density)

	Df effect	Both slugs		<i>Arion lusitanicus</i>		<i>Deroceras</i> spp.	
		Chi ²	P (≥Chi ²)	Chi ²	P (≥Chi ²)	Chi ²	P (≥Chi ²)
Region	2	17.55	<0.001	14.60	<0.001	11.73	0.003
Field margin type	1	13.25	<0.001	5.06	0.024	12.66	<0.001
Habitat	2	13.89	<0.001	13.46	0.001	6.89	0.032
Year	2	60.47	<0.001	23.93	<0.001	43.52	<0.001
Region×field margin type	2	0.15	0.941	3.55	0.169	0.76	0.683
Region×habitat	4	6.82	0.146	11.16	0.025	7.90	0.095
Region×year	4	54.56	<0.001	36.81	<0.001	64.47	<0.001
Field margin type×habitat	2	2.55	0.280	5.54	0.063	0.27	0.875
Field margin type×year	2	13.62	0.001	4.57	0.102	11.24	0.004
Habitat×year	4	5.64	0.228	3.16	0.531	5.09	0.278

Data were log-transformed and analysed with linear mixed regression, and inference on variables is based on likelihood ratio tests

contributed to the creation of a more favourable slug habitat (Cook et al. 1996; Briner and Frank 1998).

Slugs have many natural enemies, for example several species of nematodes, carabids, staphylinids, glow worms, protozoa, birds and mammals (e.g. hedgehogs) (Barker 2004). Improved field margins and wildflower strips promote slug predators such as carabids and staphylinids (Pfiffner and Luka 2000), but these two Coleoptera families also benefit from simple grassy strips (beetle banks) (MacLeod et al. 2004). However, it is still unclear for many slug predators to

which extent their populations are influenced by the habitat type and if the predation pressure on slugs is different in improved field margins compared to conventional ones.

3.3 Effect of habitat on slug numbers

Irrespective of the field margin type, activity density of *A. lusitanicus* was different in the three habitats (field margins, crop margins, crops; Table 1), in particular being higher in the field margins than in the crops (Table 2, Fig. 2). A study

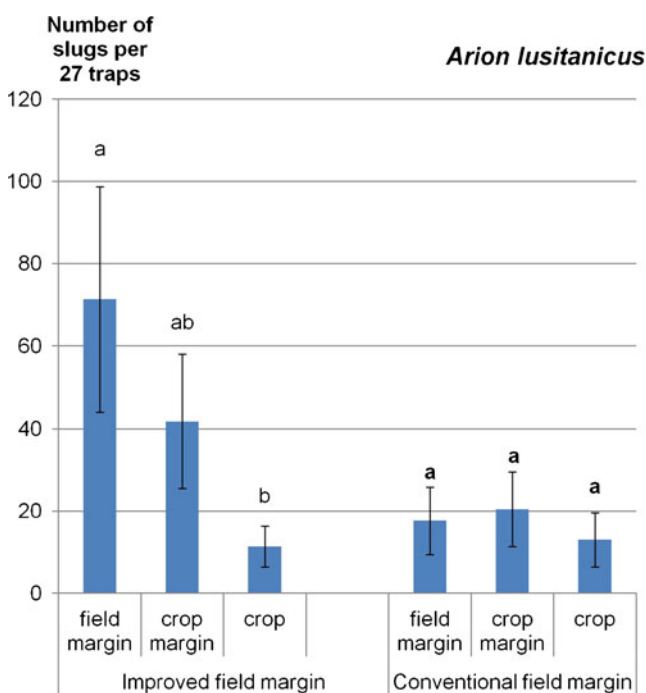


Fig. 2 Numbers (activity density) of *A. lusitanicus* in the three habitat types of the two field-margin-type treatments (means±SE, $n=3$; data summarised for all years and regions). Slugs were counted in the field margins, adjacent crop margins and crops. Different letters above bars indicate significant differences between habitats within the same field margin type

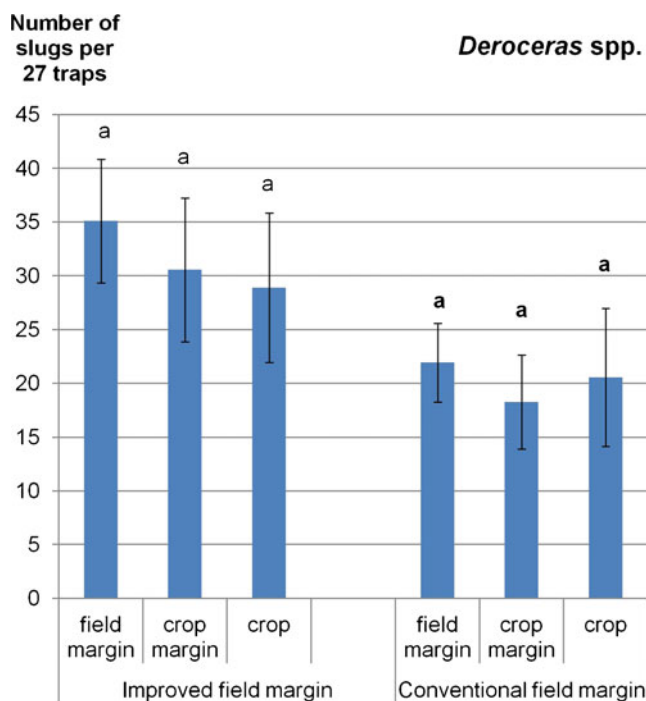


Fig. 3 Numbers (activity density) of *Deroceras* spp. in the three habitat types of the two field-margin-type treatments (means±SE, $n=3$; data summarised for all years and regions). Slugs were counted in the field margins, adjacent crop margins and crops. Different letters above bars indicate significant differences between habitats within the same field margin type

Table 2 Multiple comparisons of means of main effects using Tukey's post hoc test

	All slugs	<i>Arion lusitanicus</i>	<i>Deroceras</i> spp.
2002–2004	<0.001	<0.001	<0.001
2002–2005	0.028	0.564	0.173
2004–2005	<0.001	<0.001	<0.001
Aesch–Klettgau	<0.001	<0.001	0.003
Aesch–Oberwil	0.627	0.809	0.999
Klettgau–Oberwil	<0.001	0.002	0.002
Field margin–crop margin	0.028	0.352	0.096
Field margin–crop	<0.001	<0.001	0.042
Crop margin–crop	0.504	0.048	0.936

Shown are adjusted *p* values using the single-step method for all slug individuals and for *A. lusitanicus* and *Deroceras* spp. separately

by Zweifel (1998) showed *A. lusitanicus* to be more numerous in crops adjacent to wildflower strips; sometimes this species was abundant up to 12 m into the crop. Zweifel (1998) concluded that *A. lusitanicus* numbers were encouraged by wildflower strips. Friedli and Frank (1998) and Calame (2000) found *A. lusitanicus* in higher numbers in wildflower strips than in the crops, and Speiser and Niederhauser (1997) counted more *A. lusitanicus* individuals in extensively managed grassland than in crops, which accords with our findings. In the adult stage, *A. lusitanicus* is a very large slug which can hardly penetrate into the soil, and is therefore reliant on dense vegetation for shelter. This favours the establishment of populations in field margins rather than in crop fields.

In this study, the distribution of *Deroceras* spp. was relatively even, with only a slightly significant difference between field margins and crops (Table 2, Fig. 3). Similarly to our results, in experiments by Frank (1998b) and Friedli and Frank (1998), *D. reticulatum* was evenly distributed over arable fields adjacent to sown wildflower strips. Zweifel (1998) never found higher numbers of *D. reticulatum* in sown wildflower strips than in the adjacent wheat plots. Nevertheless, it was observed that numbers of this species increased with distance from the edge of the wildflower strips when the crop was well developed and thus afforded cover (Zweifel 1998). *D. reticulatum* can penetrate well into the soil in the daytime, where it is protected from drying out, and where it also survives soil cultivation. This favours the establishment of permanent populations in crop fields.

Crop type as random factor had a significant effect on slug activity density (data not shown). This means that it is important which crop type is situated adjacent to the field margins. Reasons for this might be that crops differ regarding their attractiveness as food and as habitat for slugs.

3.4 Effect of year and region on slug activity density

Slug activity density differed considerably between years both for *A. lusitanicus* and *Deroceras* spp. (Table 1). The year 2004 was significantly different from the other 2 years (Table 2), with remarkably low slug activity density (data not shown). Whereas climate data were quite similar and not exceptional in 2004 and 2005, the summer of 2003 was characterised by heat and drought in Europe (Ciais et al. 2005). In Switzerland, it was the warmest and driest summer since the beginning of systematic climate measurements in 1864 (Bader 2004). The low slug activity density in 2004 may have been the result of this climatic phenomenon—the longer the period of dry weather, the greater the reduction in subsequent slug population numbers (Willis et al. 2003).

Slug activity density did not increase with the age of the field margins. The significant field margin type \times year interaction (Table 1) also indicates that slug activity density in improved field margins (particularly those of *Deroceras* spp.) was not higher in all years. Independently of the year, habitat type had the same effect on the slugs (Table 1). Region as well as year had a highly significant effect on slug activity density (Table 1), with the Klettgau region differing significantly from the other two regions (Table 2). It was not possible to investigate the reasons for these differences in this project, but it is worthwhile to note that Klettgau differs from the other two regions in terms of climate and soil properties. Furthermore, during one of the two samplings in Klettgau in 2005, a very cold wind was blowing (personal observation).

Further, there was an interaction of year and region (Table 1): in the Klettgau region in particular, few slugs were found in both 2004 and 2005 (data not shown). Depending on the region, *A. lusitanicus* showed a slightly different distribution within the three habitats (Table 1); despite this, no region \times field-margin-type interaction was found (Table 1). It therefore appears that improved field margins served to increase slug activity density independently of the region.

4 Conclusions

Slug activity density was increased by the establishment of improved field margins in our study. This means that crops grown near improved field margins suffer a higher risk of slug damage. Where possible, farmers should refrain from growing susceptible crops such as oilseed rape or sugar beet adjacent to an improved field margin. If necessary, a strip treatment with molluscicide pellets may reduce slug damage (Friedli and Frank 1998).

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