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Impact of farm size and topography on plant and insect diversity of managed grasslands in the Alps

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ARTICLE INFO

Article history:
Received 20 June 2008
Received in revised form
16 October 2008
Accepted 26 October 2008
Available online 4 December 2008

Keywords:
Agricultural intensification
Butterfly
Eutrophication
Grassland management
Insect conservation
Orthoptera

ABSTRACT

Since the second half of the 20th century, the intensification of land-use practices and the associated decline in semi-natural habitats have been the major drivers of farmland biodiversity loss. In many marginal agricultural systems, a structural transformation of farms, from small and traditional to large and intensive, has also been observed. We unravelled the impact of farm size and slope on plant, orthopteran and butterfly diversity in 132 hay meadows in a region of the Italian Alps. We defined three farm size classes representing different levels of intensification and used mixed models to test the influence of farm size along with topographic slope. The diversity of plants, orthopterans and butterflies declined with management intensity at the field scale, which mainly depended on farm size and grassland topography. We found a positive effect of slope and a negative influence of farm size on species richness of the three taxonomic groups. Large farms were strongly associated with higher production of organic fertilizers and higher soil fertility than small traditional farms, irrespective of meadow slope. At the regional scale, we found that large farms managed flatter meadows (slope = 9.0) than small traditional farms (slope = 13.5), contributing to the abandonment of steep species-rich grassland areas. Regional stakeholders should consider targeted conservation schemes to prevent the ongoing substitution of small farms with large intensive farms. A complementary solution could be to target future conservation measures to support farms with low production of organic fertilizers and to reward the maintenance of the current management of steep meadows.

1. Introduction

Since the second half of the 20th century, the intensification of land-use practices and the associated decline in semi-natural habitats have been the major drivers of farmland biodiversity loss at local, regional and global scales (Norris, 2008). Over the same period, a structural transformation of farms has also been observed (MacDonald et al., 2000). In many European countries the number of small, traditional farms has been decreasing, replaced by more large, modern and specialized farms (EUROSTAT, http://www.europa.eu/). These changes are particularly evident in traditional extensive agricultural systems, such as those found in marginal boreal and mountain areas (Pykälä, 2000; Streifeneder and Ruffini, 2007). Although several studies have focused on the effects of agricultural intensification on farmland biodiversity at the field

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0006-3207/$ - see front matter
doi:10.1016/j.biocon.2008.10.034

scale (Benton et al., 2003; Pywell et al., 2004), detailed studies on the impact of factors related to farm structure such as size or degree of intensification are still lacking.

Among the different habitats, permanent meadows contribute significantly to the biodiversity of mountain agro-ecosystems, providing a wide range of ecosystem services that are of socio-economic value to human society (Sala and Peruelo, 1997). There is a relatively large consensus about the detrimental effect of intensive grassland management such as high cutting frequency or intensive grazing on plant and invertebrate diversity (Kruess and Tscharntke, 2002; Schwab et al., 2002; Myklestad and Sætersdal, 2004; Maurer et al., 2006; Marini et al., 2008). Against the background of drastic structural transformation of agriculture in mountain areas (Streifeneder and Ruffini, 2007) there is, however, a need to ascertain the impact of factors acting at the whole-farm level to shed light on the possible consequences of the current transformation of low intensity grassland systems into more intensive systems dominated by a few, large and intensive farms. Several studies have investigated the effects of farm structure on agricultural land-use change dynamics over time (e.g. Mottet et al., 2006). Nevertheless, as far as we are aware, only few studies have attempted to link farm-structure transformation directly to biodiversity losses (but see Belfrage et al., 2005; Schmitzberger et al., 2005).

Along with farm structure, topography is suggested to be a further key factor driving long-term agricultural transformation at the landscape scale (Mottet et al., 2006) and affecting management practices at the field scale in mountain areas (Kampmann et al., 2008). In montane agricultural landscapes with highly-varied topography, steep slopes are one of the main management constraints leading to low intensity management of grasslands (e.g. due to mechanization difficulties and low soil fertility). The increasing economic pressure to maintain farm incomes in mountain areas has resulted in intensification of the flatter and more productive soils, and in a partial abandonment of steep areas characterized by high labour requirements (MacDonald et al., 2000).

In this study, we contribute to filling the gap in the literature by quantifying the impact of farm structure and topography on grassland biodiversity in an Alpine region in a state of structural transformation of marginal agricultural systems. As important biotic components of grassland ecosystems, we considered vascular plants, orthopterans, and butterflies. Plants are the primary producers, while orthopterans and butterflies are two contrasting ecological groups of herbivores inhabiting grasslands. Orthopterans are sedentary organisms with low level of food specialization, while butterflies are more mobile and their larval stages exhibit higher food specialization. We defined three farm size classes representing different farming structures from small traditional to large and intensive farms, and tested the influence on biodiversity of this factor along with the topographic slope of meadow parcels. We further gathered and organized information on all farms and on their meadows in the region to determine relations between farm size, production of organic fertilizers, and meadow slope in order to derive effective conservation measures at the regional scale. Specifically, we addressed the following questions: (i) Do steeper meadows coincide with low intensity farming practices and thus with a greater level of biodiversity? (ii) Is the high intensification of large farms related to more intensive management practices and thus to lower biodiversity?, and (iii) Does the effect of farm intensification on biodiversity depend on slope? The results might assist policy-makers in understanding the impact on biodiversity of the current structural transformation from small traditional to large intensive farms and in evaluating the consequences of a further slope-driven abandonment of steep meadows in mountain agricultural systems.

2. Materials and methods

2.1. *Study area and structural change of agriculture*

The study was carried out in 2007 in the 11 administrative districts of the Province of Trento, in north-eastern Italy. In 2007, the area covered by hay meadows was c. 16,000 ha and the number of dairy farms for which we had complete information was 1325. The province extends over an area of c. 6200 km^2. Official data from two national censuses of dairy farming (Provincia Autonoma di Trento, Servizio Statistica, 2004) revealed that from 1990 to 2000 the number of farms in the study region decreased by c. 50%, while the total number of cattle livestock units (LU) decreased only by c. 16%. In the same period, the mean number of LU per farm increased from 16 to 26 (it was 10 LU per farm in 1982). All of these processes have continued in the first decade of the 21st century. Indeed, these structural and land-use changes apply to many European marginal mountain regions (e.g. MacDonald et al., 2000; Gellrich and Zimmermann, 2007; Streifeneder and Ruffini, 2007).

Within our study area, managed grasslands can be grouped into two main categories: only-cut hay meadows and only-grazed pastures; mixed management is rare. Hay meadows were located in the valley bottoms around the dwellings and along the valley slopes normally between 250 and 1300 m a.s.l, while pastures were located at higher altitudes and were grazed only for c. 3 months in summer. In this study, we included only montane meadows managed for hay production for at least twenty years (permanent meadows). The plant communities considered in this study belonged mainly to the *Arrhenatherion elatioris* phytosociological alliance. This habitat type is widely distributed in the Alps, and is a key ecosystem for many plant and invertebrate species (Knop et al., 2006). The management of the hay meadows is part of the dairy farming Alpine system. A typical dairy farm keeps the cattle in stables most of the time, while in summer livestock is often moved to high-altitude pastures, which normally do not belong to the farms, for two to three months. The farms are mainly composed of hay meadows, and secondarily of apple orchards and annual crops (e.g. maize or potato). The management units belonging to one farm are normally small (less than 1 ha), scattered and mixed with other parcels belonging to different farms. Farmland is very seldom consolidated. The large proportion of the annual amount of fertilizers distributed on the hay meadows came from the organic fertilizers produced within the farm, while mineral fertilizers were applied rarely and in small quantities.

2.2. Sampling design

In order to test both the main effects of farm size and slope and their interaction on grassland biodiversity, we applied a balanced and orthogonal sampling design. Based on official data of the Agriculture Department of the Province of Trento, we brought together information on farm structure and meadow topography in a GIS environment. We considered all of the conventional dairy farms in the province ($n = 1325$) for which information was available. Organic dairy farms comprised only 2.5% of the total number (Provincia Autonoma di Trento, Servizio Statistica, 2004), and thus it was not possible to include this farming type in this study. As a measure of farm size we used the total number of livestock units (LU) per farm instead of total farm area (ha). Contrary to the latter, the former variable gives an estimate of the annual production of organic fertilizers per farm and is suitable for indicating the degree of farm intensification (Schmitzberger et al., 2005). Then, we defined three classes of farm size: (i) small farms corresponded to the traditional farm type characterized by a low degree of intensification and often run by older farmers (2 < number of LU < 10); (ii) farms with characteristics intermediate between those of the previous and the next class (15 < number of LU < 35); and (iii) large farms corresponded to highly-intensive farms run by yield optimizer farmers (number of LU > 50). The three farm size classes had a mean number of livestock units of 5.4, 26.1, and 97.6 LU, respectively. Among the 1325 farms, 1091 fell at least in one of the three size classes. Then, we defined four classes of slope (mean topographic slope of the meadow): (i) 0–5°; (ii) 5–10°; (iii) 10–15°; and (iv) 15–25° (due to the low number of steep meadows, we extended the fourth class over a 10° interval).

In total, we sampled 44 meadow triplets across the whole study region in a GIS environment by applying a stratified random design. Each triplet consisted of three meadows belonging to one of the four slope classes and was managed by a large, an intermediate or a small farm, respectively (Fig. 1). Although there was a certain degree of variability within our slope and farm classes the correlation between the two factors was not significant ($r_s = -0.10$, $n = 132$, $p = 0.23$). Hence, the two factors were independent as the sampling design was balanced and orthogonal (each combination of farm size and slope class was replicated in equal number). Meadows in each triplet were solely cut for hay, were close to one another, and had similar abiotic conditions (e.g. soil type, exposition). Considering the surrounding landscape, there was no significant difference in landscape composition (proportion of grasslands and forest in a 500 m radius) between the three classes of farm size. Moreover, no difference in mean altitude was found between the three classes of farm size (ANOVA *F*-test, $p = 0.93$) and slope ($p = 0.11$). The grouping of meadows in triplets therefore facilitated the comparison between the three farm size classes. Overall, we sampled 132 meadows belonging to 132 different farms. We chose this partially-nested sampling design with one factor within site (farm size) and one among sites (slope class), as it was not possible to find all the combinations of our factors within each site.

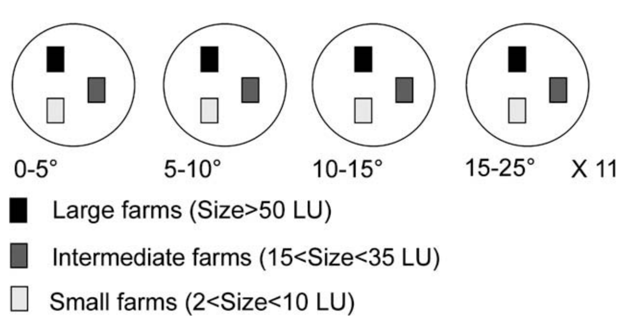

Fig. 1 – The partially-nested sampling design used to select the 132 meadows, in which we recorded plant, orthopteran, and butterfly (only 120 meadows) species richness. The circles indicate the 44 farm triplets, in which we sampled three meadows, one belonging to a small, one to an intermediate, and one to a large farm. The grouped meadows within each farm triplet belonged to the same slope class. Overall, we had 11 replicates for each combination of farm size and slope class.

We further gathered and organized information on 1325 dairy farms and their managed meadows at the regional scale in order to find relations between production of organic fertilizers, total farm area, and meadow slope. The results of this regionally scaled analysis refer to the whole study region and not only to the farms and hay meadows in which we sampled biodiversity.

2.3. Vascular plant, orthopteran, and butterfly surveys

We estimated vascular plant species richness once before the first grassland cut. We randomly established two vegetation sampling plots of 4×4 m in each meadow, with a separation of 10 m. Within each meadow we avoided sampling zones containing anomalous areas (e.g. organic fertilizer deposits, small rock outcrops, paths, trees). Edge effects were reduced by the exclusion from sampling of a 10 m buffer zone from the meadow boundaries. Within each sampling plot, we recorded vascular plants to species level.

We sampled Orthoptera (*Ensifera* and *Caelifera*) by visiting the 132 meadows twice, during the periods of maximum activity and density of the species. The first period was at the end of July (from 18th to 28th), and the second at the end of August (from 15th to 29th) to ensure detection of species with different phenological patterns. Surveys took place between 10.00 and 17.00 h on warm sunny days that did not follow a day of high rainfall. In each meadow we determined orthopteran species richness and abundance by using a 'box quadrate' with high sides (Gardiner et al., 2005). We used a white quadrate sampler, a box with open top and bottom, and with a side length of 1.0 m and a height of 0.75 m. Within each meadow, we carried out 12 samplings per visit by laying the sampler down rapidly in a vertical position, and therewith capturing all the individuals within the sampler. We assessed the number of samples required by analyzing species accumulation curves with a preliminary sampling in 12 meadows with very high species diversity. This method also enabled recording of those species that spend most of the time in the lowest vegetation layer or on the ground (e.g. bush-crickets and crickets).

We sampled diurnal Lepidoptera (*Hesperioidea* and *Papilionidea*), hereafter labelled as butterflies, by using an area transect survey (Balmer and Erhardt, 2000); i.e. within each meadow, a fixed rectangular area of 1000 m^2 (25 × 40 m) was patrolled in a serpentine way for 15 min. We identified and counted all of the butterflies within reach of the net. This method was more suitable than a linear transect survey (Pollard and Yates, 1993) due to the small size of our meadows (Balmer and Erhardt, 2000). Surveys took place between 10.30 and 17.00 in sunny (cloud cover <25%) and warm conditions (air temperature >8°C). We repeated the sampling five times from the first half of May to the end of August. In each meadow, the sequence of surveys was alternated to avoid any systematic effect of time of day. Due to the relatively cold and rainy Alpine weather and the high number of multi-species surveys, it was impossible to carry out five surveys in optimal weather conditions in more than 120 meadows.

2.4. Explanatory variables

Information on farm structure and topography was available from the Agricultural Informative Systems of the Province of Trento (Table 1). We recorded information on the sampled farms ($n = 132$) and on all the farms within the province, which were included in one of the three classes of farm size considered ($n = 1091$). We computed the number of livestock units (LU) per farm according to annex V of the European Commission regulation (EC) 1974/2006 (http://www.eur-lex.europa.eu). Then we converted the number of LUs in production of organic fertilizers, expressed in kg of nitrogen (N), according to Walther et al. (1994). At the whole-farm level, we standardized the amount of organic fertilizers per area by calculating the ratio between the total amount of N and the total farm area (all cultures, which were normally fertilized with organic fertilizers excluding extensive high-altitude summer pastures). If a farmer moved cattle to summer pastures for a period, we multiplied its amount of N by the number of days in stables and divided by 365, and then we calculated an adjusted ratio. At the field level, we selected exchangeable Olsen P_2O_5 (P) as a surrogate measure for soil fertility, following studies in which phosphorus has been shown to be the most important soil variable for determining plant species richness and composition in hay meadows (Marini et al., 2007). We took eight samples at a depth of 0–20 cm, after removing the organic layer, and bulked prior to analyses. For each meadow, we also quantified vegetation height using a drop-disc method (Stewart et al., 2001). We directly determined the number of cuts per year by interviewing the farmers.

Since topography has been recognized to be a highly significant factor in land-use decision making of farmers in mountain regions (e.g. Mottet et al., 2006), we considered topographic slope as surrogate of farming mechanisability and labour requirements. We calculated the mean slope of each meadow in SAGA GIS Version 1.2 (available at http://www.saga-gis.org/) using a digital elevation model with a cell size of 10 × 10 m (SIAT, Servizio Urbanistica e Tutela del Paesaggio, Trento, Italy).

2.5. Data analysis

For the statistical analyses, we pooled together the samples for each taxonomic group within each meadow. The species richness of vascular plants was the pooled number of species

Table 1 – Characteristics (mean values) of the three classes of farm size within the study region (Province of Trento). The data are presented for sampled farms (n = 132), and for all the farms in the study region, which belonged to one of our three size classes (n = 1091).

	Large farms (LU > 50)	Intermediate farms (15 < LU < 35)	Small farms (2 < LU < 10)	p[a]
Sampled farms	$n = 44$	$n = 44$	$n = 44$	
Farm size (LU)	97.9	27.0	5.4	<0.01
Farm total area (ha)[b]	43.5	16.3	5.9	<0.01
Production of organic fertilizers per area (kg N ha^{-1})	215	146	84	<0.01
Soil Olsen P (mg kg^{-1})	63.0	55.0	47.6	<0.01
Vegetation height (cm)	29.4	30.5	26.2	<0.01
Number of cuts per year	2.2	2.2	2.0	0.33
All farms in the province	$n = 204$	$n = 279$	$n = 608$	
Farm size (LU)	95.3	24.5	4.5	<0.01
Farm total area (ha)[b]	33.0	14.6	5.8	<0.01
Production of organic fertilizers per area (kg N ha^{-1})	243	175	87	<0.01
Mean slope of grasslands (deg)[c]	9.04	11.85	13.47	<0.01
Proportion of livestock units on the total number (whole province)	55.0%	19.3%	7.7%	–
Proportion of managed meadows on the total area (whole province)	37.3%	23.3%	19.1%	–

a *p*-Value from one-way ANOVA.
b We included only cultures which could potentially be fertilized with organic fertilizers: meadows, farm pastures (summer extensive pastures were excluded), orchards, vineyard, and intensive cultures (e.g. maize or potato).
c We calculated the mean topographic slope of all the meadows managed by farms belonging to our size classes, weighted by parcel area.

found in the two plots. The species richness of orthopterans and butterflies was the cumulative number of species found during the two and the five visits, respectively. To test the effects of farm size and topography on the species richness of vascular plants, orthopterans, and butterflies, we used a multi-factorial mixed ANOVA (Zar, 1999). As neighbouring meadows managed by large, intermediate, and small farms within each triplet were not spatially independent, we added the site identification number as a random block factor (site). Slope class (slope) was an among-site fixed factor, while farm size (farm) was a within-site fixed factor. According to traditional multi-factorial ANOVA assumptions, each possible combination of the two fixed factors was present and had the same number of replicates. Prior to analyses, we square-root transformed butterfly and orthopteran species richness to achieve normal distribution and homogeneity of variance of the residuals. Then, we tested the two main fixed effects (farm and slope) and their interaction (farm × slope) for significance, following the hypothesis testing procedure suggested in Zar (1999).

3. Results

3.1. Farm and meadow characteristics related to farm size and slope

Considering the 132 farms in which we sampled biodiversity, the three classes of farm size differed significantly in terms of annual production of organic fertilizers, with 215, 146, and 84 kg N ha^{-1} for large, intermediate and small farms, respectively (Table 1). The number of cuts per year did not differ between the three farm classes. The mean soil fertility in the investigated meadows, expressed as soil Olsen P (mg kg^{-1}), and the vegetation height were higher in the meadows managed by large and intermediate farms than in those managed by small farms, irrespective of slope. Soil fertility, vegetation height, and cutting frequency were significantly higher in the lowest slope classes than in the steeper classes, irrespective of farm size (Table 2).

At the regional scale, considering all of the farms belonging to our three size classes ($n = 1091$) in which we did not sample biodiversity, the three farm classes showed similar trends to the 132 sampled farms with regard to farm size, total area, and production of organic fertilizers (Table 1). The production of organic fertilizers per unit area increased with farm size. This is a result of a significant positive non-linear relation between farm size (LU) and farm area (ha) (Farm area = 3.787 + 0.4771 * (Farm size)−0.0011 * (Farm size)^2, $p < 0.001$, $R^2 = 0.81$). Calculating the mean slope for each size class, we found that large farms mainly managed meadows located on flatter areas (slope = 9.0°) compared to those managed by small farms (slope = 13.5°).

3.2. Effect of farm size and slope on biodiversity

Overall 212 plant species were recorded in the 132 meadows. Plant species richness averaged 30 per 32 m^2, with a minimum of 14 and a maximum of 56. In the ANOVA model for

Table 2 – Comparing mean values of our three indicators of management intensity between the four topographic slope classes using one-way ANOVA.

	Slope class				*p*
	0–5°	5–10°	10–15°	15–25°	
Sampled farms ($n = 132$)	$n = 33$	$n = 33$	$n = 33$	$n = 33$	
Number of cuts per year	2.5	2.3	2.0	1.8	<0.01
Soil Olsen P (mg kg^{-1})	68.5	67.0	51.1	41.2	<0.01
Vegetation height (cm)	33.0	33.3	25.9	22.7	<0.01

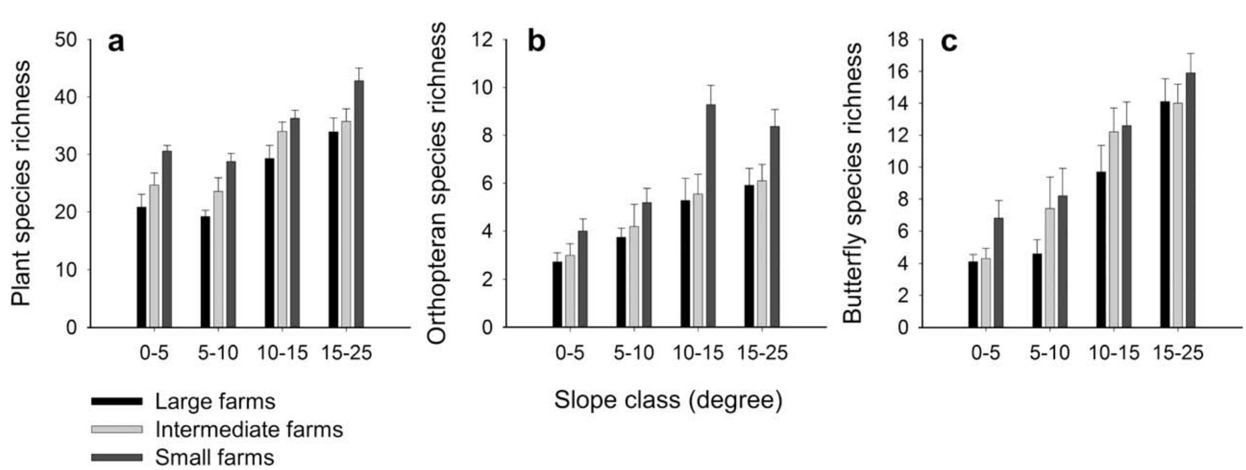

Fig. 2 – Mean species richness of (a) plants, (b) orthopterans, and (c) butterflies in relation to the four slope classes and the three farm size classes. Standard errors are also reported.

plants the interaction term was not significant, while we found a pronounced positive effect of slope on plant species richness and a negative effect of farm size. Small traditional farms supported greater species richness, irrespective of slope, while the large and highly-intensive farms were those with the lowest number of species (Fig. 2a). Overall, 58 orthopteran species were recorded and 6129 individuals were captured and counted during the two visits. The overall mean orthopteran species richness was five per 24 m^2, with a minimum of zero and a maximum of 14. The mean density was 46 individuals per meadow, with a minimum of zero and a maximum of 292 per 24 m^2. The interaction term was not significant, while all of the main effects were significant (Table 3). As for plants, we found a pronounced positive effect of slope and a negative effect of farm size on orthopteran species richness (Fig. 2b). In the 120 meadows, 83 butterfly species were identified and 5942 individuals were recorded during the five visits. Butterfly species richness averaged nine per 1000 m^2, with a minimum of one and a maximum of 22 species. The mean density was 41 individuals per meadow, with a minimum of four and a maximum of 169 per 1000 m^2. Again, the interaction term was not significant, while all of the main effects were (Table 3). We found a positive effect of slope and a negative effect of farm size on butterfly species richness (Fig. 2c).

Considering the meadow management at the field scale, we found negative relationships between the species richness of the three taxonomic groups and cutting frequency (Fig. 3a–c), P content in soil (Fig. 3d–f), and vegetation height (Fig. 3g–i). However, plant species richness decreased in non-linear manner with P. Species numbers of the three taxonomic groups were significantly correlated with each other (plants vs. orthopterans: $r = 0.62$, $p < 0.01$; plants vs. butterflies: $r = 0.68$, $p < 0.01$; orthopterans vs. butterflies: $r = 0.67$, $p < 0.01$).

4. Discussion

Our results clearly showed a strong positive effect of slope and a negative influence of farm size on the species richness of plants, orthopterans and butterflies of hay meadows in the Italian Alps. Our study stressed the negative effect of intensive management (high cutting frequency and soil fertility, and tall swards) on plant and insect diversity and demonstrated that the management intensity was mainly driven by topography and by the degree of intensification of the farms (Fig. 4). To our knowledge this is the first study that reveals the negative impact of the current structural transformation of farms on diversity of plants and insects in managed grasslands.

Table 3 – Results of the multi-factorial mixed ANOVA for vascular plants, orthopterans, and butterflies in the 132 meadows (only 120 for butterflies), considering farm size (farm) and slope of the meadow (slope) as fixed factors and triplet identification number (site) as a random, block factor.

Source of variation[a]	df	SS	MS	F[b]	p
Plants					
Among-blocks					
Slope	3	35.45	11.82	19.31	<0.001
Site (slope)	40	24.48	0.61		
Within-blocks					
Farm	2	15.78	7.89	25.70	<0.001
Slope × farm	6	0.95	0.16	0.52	0.792
Farm × site (slope)	80	24.54	0.31		
Orthopterans[c]					
Among-blocks					
Slope	3	15.40	5.13	10.37	<0.001
Site (slope)	40	19.02	0.47		
Within-blocks					
Farm	2	6.80	3.40	17.72	<0.001
Slope × farm	6	0.98	0.16	0.83	0.550
Farm × site (slope)	80	15.36	0.19		
Butterflies[c]					
Among-blocks					
Slope	3	50.80	16.93	20.25	<0.001
Site (slope)	37	30.92	0.84		
Within-blocks					
Farm	2	4.72	2.36	6.68	0.002
Slope × farm	6	1.27	0.21	0.60	0.729
Farm × site (slope)	71	25.07	0.35		

a As we had no repeated measures within the 132 meadows, the terms site (slope) and farm × site (slope) could not be tested for significance.
b For further details on the hypothesis testing procedure see Zar (1999).
c Response variable was square-root transformed.

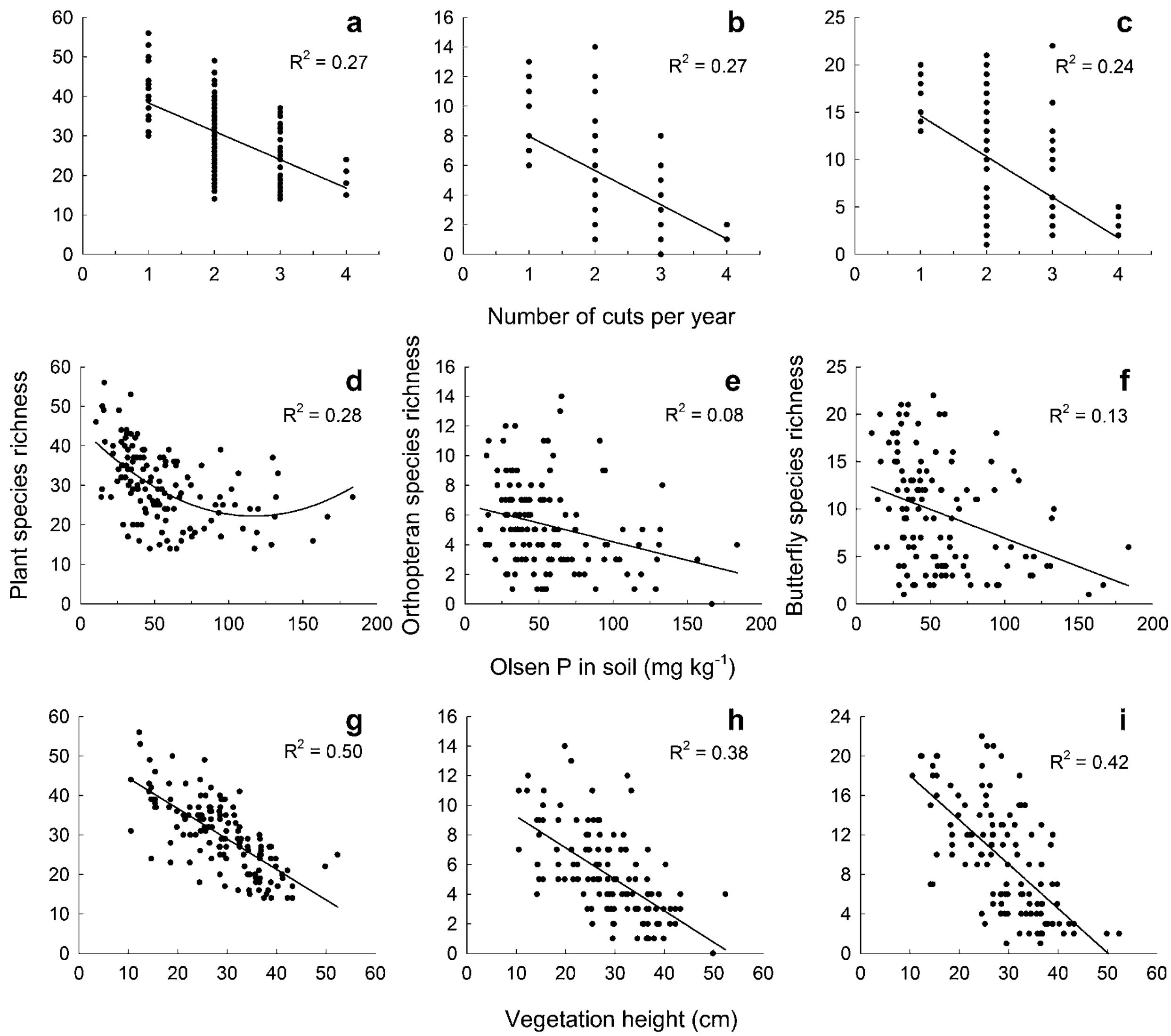

Fig. 3 – Simple regression models of the number of plant, orthopteran, and butterfly species vs. cutting frequency (a, b, and c), Olsen P soil content (d, e, and f) and vegetation height (g, h, and i). Trends are shown by fitting linear, quadratic, and cubic functions when significant (*F*-test, $p < 0.01$).

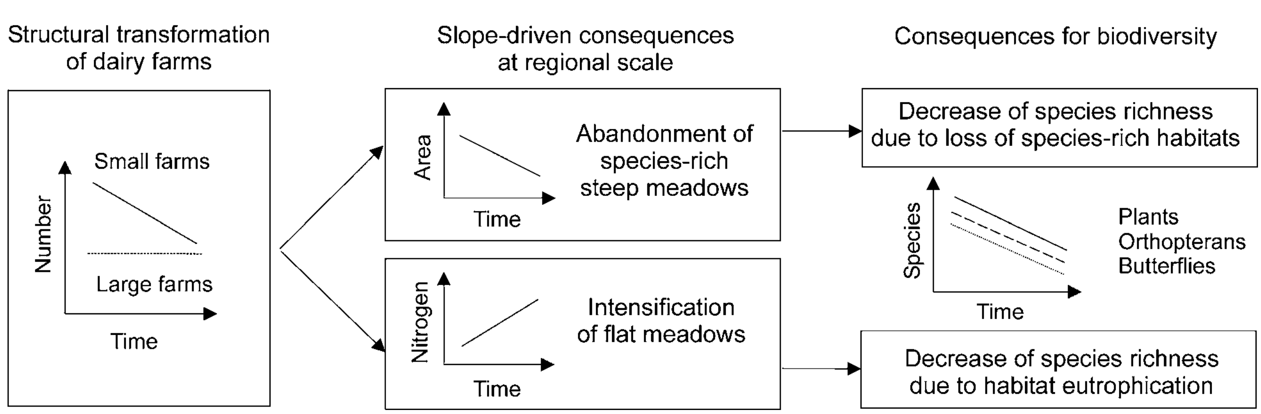

Fig. 4 – Schematic representation of the consequences of the current structural transformation of dairy farms in our marginal mountain system at the regional scale as indicated by the results of this study.

4.1. Topographic slope

Our sampling design allowed testing four different topographic slope classes taking into account the farm size effect. We found strong evidence that above 10°, irrespective of the farm size, the biodiversity of the three taxonomic groups drastically increased. The results indicated that the abandonment and further reforestation of steep meadows will result in the loss of the areas with the highest plant and insect diversity. The influence of slope on biodiversity has seldom been tested with a targeted sampling design (but see Guretzky et al., 2007), and never along with farm structure, although the positive relationship between slope and plant diversity has indirectly been reported in several studies (Maurer et al., 2006; Klimek et al., 2007). In flat meadows, we found greater soil fertility (P), taller vegetation height and higher cutting frequency, all indicators of intensively managed meadows. Thus, the high positive influence of slope on species richness was probably an indirect effect related to the behaviour of the farmers, who managed steep meadows less intensively than flat ones (Kampmann et al., 2008). However, no interaction was found between farm type and slope. The plant communities observed on flat areas were dominated by productive species (mainly grasses), whilst steeper meadows were characterized by a greater diversity due to the presence of small stress-tolerant species. Moreover, steep slopes with poor soils are characterized by more extreme microclimatological conditions, irrespective of the level of fertilization (Pykälä et al., 2005), and thus are supposed to be more resistant to eutrophication processes (Cousins and Eriksson, 2001; Bennie et al., 2006).

Grassland management is supposed to affect insect diversity through both direct (mainly disturbance) and indirect effects via vegetation modification altering food-resource availability and sward structure (Wettstein and Schmid, 1999). Orthopteran diversity may have benefited from low soil fertility as the less dense and tall structure created by stress-tolerant plant species provided more suitable microhabitats (Kampmann et al., 2008; Marini et al., 2008). Furthermore, steep slopes may contribute to warmer microclimatic conditions within the sward due to higher solar radiation. In fact, most of the temperate orthopteran species require open, thin and relatively dry and warm meadows (Knop et al., 2006; Steck et al., 2007), which were mainly located on steep slopes in our study region. Modification in vegetation structure due to intensive grasslands management is considered one of the main threats to species-rich orthopteran communities (Marini et al., 2008). Moreover, the high disturbance caused by the high cutting frequency (three or four cuts a year) on flat areas, is considered one of the most important factors limiting orthopteran populations due to mortality caused by the physical process of mowing (Gardiner and Hill, 2006; Marini et al., 2008) and possible high sward temperatures created by removal of the standing biomass (Gardiner and Hassall, 2008).

The observed changes in plant communities from species-rich meadows to more productive species-poor meadows with decreasing slope might also have caused cascade effects on butterfly species (Pywell et al., 2004). On the one hand, mono- or oligophagous herbivores such as larval stages of most of the species recorded are strongly dependent on the presence and abundance of host plants (Dennis et al., 2004), and thus species-rich meadows on steep slopes are more likely to host a larger number of butterfly species. Moreover, the low cutting frequency of the steepest meadows (only once or twice a year) is likely to reduce egg destruction and larval mortality on the plants, thereby promoting higher population size and a reduced local extinction risk (Johst et al., 2006). On the other hand, adult butterflies, being nectar-feeding insects, should occur at higher densities in meadows with greater availability of nectar-rich flowers (Öckinger et al., 2006).

4.2. Farm size

As far as we know, this is the first time that a significant negative impact of farm size was found on grassland biodiversity. Even though not fully comparable, our results are similar to those of Belfrage et al. (2005) and Schmitzberger et al. (2005) who generally found a negative relation between farm size and plant and insect diversity in agricultural landscapes. In our study, large, intensive farms were strongly associated with higher production of organic fertilizers per unit area and higher soil fertility than small traditional farms, irrespective of farmland topography (Table 1). The relation between dairy farm size and production of organic fertilizers was confirmed also by the analysis of all the farms at the regional scale. The farm production of organic fertilizers is a very important indicator directly related to management intensity, as it quantifies the mean level of organic fertilization, which could potentially be applied at the whole-farm level. Thus, the significant negative effect of large farm management on biodiversity should be related to the higher degree of intensification. The strongest effect was found for orthopteran communities on the steep slopes. This finding may be explained by the traditional hay-making practices of small farms that are characterized by the use of small and light machines, which might have a less detrimental impact on orthopteran populations with low mobility (Guido and Gianelle, 2001; Gardiner and Hill, 2006). Considering our results at a regional scale, the small traditional farms are still managing most of the steep and low-productivity meadows. Thus, the role of small farms in grassland biodiversity conservation at a regional scale is twofold: (i) as they are generally characterized by a lower production of organic fertilizers per unit area than larger farms, they produced lower nutrient outputs, irrespective of farmland topography and (ii) as they tend to manage steep slopes which are normally disregarded by large and intensive farms, they actively contribute to preventing the abandonment of species-rich meadows.

5. Conclusions

We demonstrated that the diversity of plants, orthopterans and butterflies declined with management intensity at the field scale and that management intensity depends mainly on farm size and grassland topography. At the regional scale, the substitution of small farms with large and intensive farms is causing eutrophication of flat areas and abandonment of steep extensively-managed areas, with negative consequences on plant and insect diversity (Fig. 4). Our findings confirmed that traditional animal husbandry should be maintained (Pykälä, 2000; Myklestad and Sætersdal, 2004), as grassland management related to these systems demonstrated to support greater biodiversity than modern and intensive systems. Thus, regional stakeholders should consider measures to prevent or at least to reduce the ongoing structural transformation of farms. However, as this process is related to many socio-economic variables, interdisciplinary studies are urgently needed to evaluate different future scenarios prior to implementing any policy-making (Norris, 2008). A complementary solution might be to target future conservation measures to support farms with low production of organic fertilizers per unit area and to prevent the abandonment of extensively-managed steep meadows. Steep slope has been demonstrated to be a key factor in supporting species-rich meadows, although they are more prone to abandonment due to the current transformation of agriculture. Moreover, this environmental policy would promote also land-use diversity at the landscape scale by favouring the maintenance of high landscape heterogeneity provided by many small farms (Fischer et al., 2008). These regional schemes, aiming at preventing the impact of the current structural transformation of agriculture, should eventually be associated with other measures providing specific management practices at the field scale (Zechmeister et al., 2003; Steck et al., 2007; Marini et al., 2008), such as the ECA (Ecological Compensation Areas) hay meadow agri-environment scheme, already implemented in Switzerland (Knop et al., 2006; Kampmann et al., 2008), which has been demonstrated effectively to conserve plant and invertebrate diversity in managed grasslands in the European Alps. However, due to the high heterogeneity of environmental, social and economic conditions in the European Alps our results should be interpreted with caution and further research is needed to generalise our findings to larger geographical areas.

Acknowledgements

This work is part of the project 'Management Tools for Biodiversity Conservation in Alpine Agro-ecosystems' fully funded by 'Fondazione Cassa di Risparmio di Trento e Rovereto' (to L.M.). We are grateful to the farmers who allowed us to work on their land. We thank M. Fezzi, E. Arnoldi, and L. Pedron at the Agriculture Department of the Province of Trento for providing and organizing data about farms and meadows at the regional scale, and L. Rizzi for support during the field surveys and soil analyses.

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