2008), therewith diminishing negative effects in terms of landscape simplification and a long-term decrease of grassland specialists species that are of high conservation concern (Giupponi et al., 2006). At the local scale, recent research found that traditional farming systems and the related agricultural practices are often associated with high biodiversity (Pykälä, 2000; Luoto et al., 2003; Myklestad and Sætersdal, 2004; Belfrage et al., 2005; Schmitzberger et al., 2005; Marini et al., 2009).

In Europe, agricultural change has been largely driven by policy (e.g. laws and regulations) (IEEP, 2007; Osterburg et al., 2010), social and cultural changes (Antrop, 2005; Mattison and Norris, 2005), economic instruments (e.g. subsidies and taxes) Q2 (Aviron et al., 2008; Stoate et al., 2009), and technological innovations (Schneeberger et al., 2007). In particular, the Common Agricultural Policy (CAP) has played a crucial role by generally stimulating increased productivity that led to agricultural intensification and farm specialization (Tappeiner et al., 2003; Acs et al., 2010; Stoate et al., 2009). However, through its contribution to supporting farm incomes, direct payments in the first pillar of the CAP have also contributed to maintaining the extensive management of some vulnerable landscapes and semi-natural habitats, especially in less-favoured or marginal areas (IEEP, 2007; Alliance Environment, 2008). In the last decades reforms to the CAP have put a greater emphasis on environmental concerns by introducing accompanying measures such as agri-environment schemes (AES) and by making direct payments to farmers conditional on meeting the cross compliance requirements (Aviron et al., 2008; Stoate et al., 2009).

Agricultural change and the associated transition from traditional to modern farming is further intrinsically tied to the process of structural transformation that involves a reallocation of resources, including employment, across the broad economic sectors. In Europe structural transformation has led to a falling share of employment in agriculture and a rising share of employment in sectors such a commerce and tourism (MacDonald et al., 2000; Schmitzberger et al., 2005). Against the background of structural transformation, it remains unclear whether future agri-environmental policies will be capable to maintain traditional farming systems and to guarantee their socio-ecological resilience in marginal areas (Milestad and Hadatsch, 2003). Hence, in order to assist policymakers in establishing policies that preserve and enhance biodiversity and related ecosystem services in marginal systems, it is crucial to integrate ecological and socio-economic research approaches at multiple spatial scales (Mattison and Norris, 2005; Kizos and Koulouri, 2006; Kizos et al., 2010).

Taking a marginal area in the Italian Alps as a case study, we aim at identifying trends in the dairy farming sector over time and to explore potential causes and consequences of these trends on land-use change, grassland farming systems and biodiversity. We focus on dairy farming which is the key sector for maintaining heterogeneous landscapes and biodiversity in the Alpine grasslands. The study pursues the following specific aims: (i) to identify major trends experienced by the dairy sector over the last decades in relation to structural transformation trends (socio-economic and demographic) across the broad economic sectors, and to explore potential causes and consequences of these trends on land-use change at the municipality scale; (ii) to identify the main causes of this transition and to compare the characteristics of small traditional vs. large modern farms; and (iii) to propose a regional agri-environment scheme to mitigate the impacts of the decline of traditional farming on biodiversity of hay meadows.

2. Materials and methods

2.1. Study area

The study was carried out in 2009 within the province of Trento (north-eastern Italy). The province extends over a total area of ca. 6200 km^2 and is composed of 223 municipalities

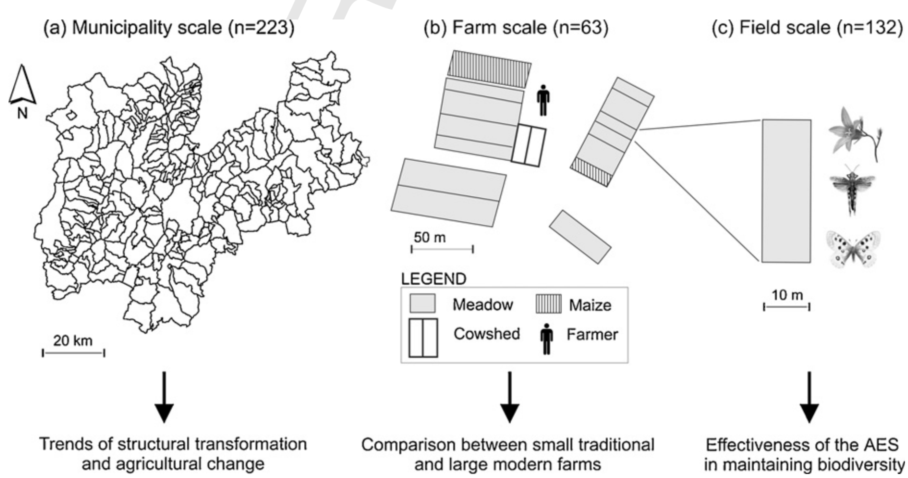

Fig. 1 – Scheme to visualize the three scales of analysis of the study: (a) in the Trento province, that is composed of 223 municipalities, we analysed trends of structural transformation across sectors and trends experienced by the dairy sector; (b) at the farm scale we interviewed 63 dairy farmers to compare small traditional vs. large modern farms; and (c) at the field scale we assessed plant, orthopteran and butterfly species diversity to evaluate the ecological effectiveness of a proposed regional agri-environment scheme (AES).

Please cite this article in press as: Marini, L. et al., Mitigating the impacts of the decline of traditional farming on mountain landscapes and biodiversity: a case study in the European Alps, Environ. Sci. Policy (2010), doi:10.1016/j.envsci.2010.12.003

(Fig. 1). Municipalities are small administrative units with an average size of 30 km^2. The province of Trento is an autonomous province with the right to fulfil administrative functions regarding the agricultural and forestry sector (including agri-environmental policy). Over recent decades, agriculture has reached as high level of specialization, therewith maintaining relatively high farm incomes in comparison to other Alpine regions (Streifeneder et al., 2007).

In the present study, we focus on grassland-based dairy farming systems. Within the study area, managed grasslands can be grouped into two main categories: only-cut hay meadows and only-grazed pastures, while mixed management is rare. Hay meadows are typically located in the valley bottoms normally between 250 and 1300 m a.s.l., while pastures are located at higher altitudes and are grazed only for ca. 3 months in summer. For the purpose of this study, we focus only on meadows managed for hay production for at least 20 years (permanent meadows). This habitat type is widely distributed in the Alps, and is a key ecosystem for many plant and invertebrate species. The management of hay meadows is part of the dairy farming system in the Alps. A typical dairy farm keeps the cattle in stables for ca. 9 months, while in summer livestock is often moved to high-altitude pastures for 2–3 months, which normally do not belong to the farms. The dairy farms within the study area are mainly composed of hay meadows and secondarily of apple orchards and annual crops due to the cold mountain climate. The meadows belonging to one farm are relatively small (usually less than 1 ha), spatially scattered and interspersed with other management units belonging to other farms. As cattle stay in stables for long periods of time (ca. 9 months) most of the nutrients produced within the farm are distributed by the farmers on the land as organic fertilizers.

2.2. *Structural transformation and agricultural change at the municipality scale*

To describe trends associated with the process of structural transformation across broad economic sectors and to identify trends that are driving change within the agricultural sector (Fig. 1a) we gathered information from different sources at the municipality scale over the last decades. Socio-economic and demographic variables associated with the process of structural transformation were derived from the 10th, 11th, 12th, 13th and 14th general censuses of population and housing (1961, 1971, 1981, 1991, 2001; source: ISTAT), while agricultural variables related to change within the dairy sector were derived from the 3rd, 4th and 5th agriculture general census (1982, 1990, 2001; source: ISTAT). More recent data (from 2001 onwards) were obtained by integrating the above-mentioned data with official data gathered by the Veterinary department of the Trento province. The variables considered at the municipality scale comprised human population size, the number of workers employed in agriculture, industry, commerce and tertiary sector, and the number of dairy farms and livestock units classified into four size classes (1–4, 5–9, 10–50, and >50 livestock units). At the same spatial scale, we also gathered land-use data (percentage cover of grasslands, apple, vineyard, and forest within each municipality) at three time steps (1982, 1990, and 2001).

First, we used General Linear Mixed Models to test the effect farm size, time, and topography (slope and elevation) on the trend in the number of dairy farms and livestock units at the municipality scale (n = 223). We included municipality as a random factor to account for the fact that the number of farms in each size class were counted in the same municipality. Analyses were performed using the 'nlme' package in R (R Development Core Team, 2008). Second, we used linear regression to test if the change in cover of agricultural land (apple and vineyard), grassland, and forest was related to the change in number of farms and livestock units (%) over the same period (1982–2001).

2.3. *Comparison between traditional and modern farms*

To compare the characteristics of traditional, small vs. modern, large dairy farms and to identify potential drivers of the ongoing transition between the two farming systems, we performed structured interviews with the farmers. We randomly selected a subset of 132 dairy farms that were stratified according to their size into three classes. At the provincial scale, the total number of farms was ca. 1300. 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 is more suitable for indicating the degree of specialization in dairy farming. Then, we defined three classes of farm size: (i) small farms (2 < number of LU < 10); (ii) farms with characteristics intermediate between those of the previous and the next class (15 < number of LU < 35); (iii) large farms (number of LU > 50). The structured interview was based on a questionnaire and most questions focused on socio-economic and structural farm characteristics.

We additionally asked closed-ended questions to ascertain the farmers' perception towards farm abandonment. Specifically, we asked whether and why the farmers will abandon their farming activity within the next 15–20 years. Amongst the selected 132 farmers only 63 farmers agreed to participate in the surveys and were interviewed in a face-to-face situation (15 small farms, 25 intermediate farms, and 23 large farms).

To test for differences in socio-economic and structural variables between the three farm size classes, we used one-way ANOVA for continuous variables and a χ^2 test for frequency data.

2.4. *Effectiveness of the proposed agri-environment scheme in maintaining biodiversity*

Within the study area, AESs are considered the most important policy instruments to preserve and enhance farmland biodiversity. As part of the Rural Development Programme (2003–2006) of the Trento province, two voluntary AESs have been designed and implemented aimed at compensating dairy farmers for income foregone associated with adopting environmentally friendly farming practices. The first AES compensates farmers for grazing high altitude pastures during the summer ('Pasture AES'), while the second AES provides compensation payments to farmers for mowing hay meadows ('Meadow AES'). Both schemes are also part of the present Rural Development programming period (2007–2013). Within the Trento province the uptake of both schemes

Table 1 – Requirements of the different payment levels for (a) the current elevation-based 'Meadow AES' and (b) the proposed slope-based 'Meadow AES'. The term 'conventional' refers to those hay meadows that were not under agri-environmental agreements and that were managed according to common agricultural practices.

Payment level	€ ha^{-1}	Ratio between LU and farm area (ha)	(a) Elevation (m)	(b) Slope (°)
Level 1	200	2.0–2.5	<900	<15
Level 2	260	<2.0	<900	<15
Level 3	340	<2.5	>900	>15
Conventional	0	N/A	N/A	N/A

is high with an average annual amount of money spent of 4.3 M € for the 'Meadow AES' and 2.7 M € for the 'Pasture AES'. Approximately 10% of the farmers' income is attributable to the participation in these two AESs (period 2003–2006; FADN database for the Trento province, source: INEA).

In this study, we focus exclusively on the 'Meadow AES', as for the 'Pasture AES' no biological and management data (e.g. stocking rate, pasture area, etc.) were available for high altitude pastures. The 'Meadow AES' comprises three different payment levels that are defined according to the ratio between LU units and farmland area and the elevation of the meadow. As meadows are rarely grazed, this ratio should not be considered as a measure of stocking rate but should rather be understood as a proxy for the mean annual fertilizer output per area. Further requirements for farmer participation in the scheme are: (i) 5-year commitment, (ii) minimum of two cuts below 900 m and one cut above 900 m, (iii) minimum total area of 1 ha, (iv) limited use of mineral fertilizers (maximum N: 40 kg ha^{-1}, P: 20 kg ha^{-1} and K: 20 kg ha^{-1}). Using previous research data gathered within the study area, we propose a modification of the current AES which introduces a slope instead of the elevation criterion for each payment level (Table 1). All other statutory requirements remain the same. This new criterion is suggested as steep slope has been demonstrated to be a better indicator of low-input management and species-rich meadows than elevation (Marini et al., 2008). The proposed AES was also discussed with the local stakeholders in order to provide a tool that could be easily implemented in the regional agri-environment policy. From this discussion it emerged that the only criterion that could be modified in the short-term was the elevation.

To evaluate whether the current AES prevents farmers from abandoning their activity, and to ascertain the farmers' attitude towards changing from an elevation to a slope-based criterion to qualify for the payment, we used closed-ended questions. As we were further interested in assessing the performance of both criteria in supporting plant and insect diversity, we used published data regarding the number of plant, orthopteran, and butterfly species in 132 hay meadows (Marini et al., 2009). The meadows were managed by the same farmers who were contacted for the socio-economic surveys. The 132 meadows included both conventional and AES hay meadows under different levels of payment. All selected AES hay meadows had been under the agri-environment scheme agreements for between 4 and 7 years. We used one-way ANOVA to test difference in species richness between the different levels of payment within the two schemes. We are not interested in testing the effects of farm size or farm characteristics on biodiversity as this has already been investigated in previous studies (Marini et al., 2008, 2009).

3. Results

3.1. *Structural transformation and agricultural change at the municipality scale*

At the municipality scale, human population has steadily increased since 1940 onwards. Trends in the employment in the different sectors of the economy reveal contrasting results. The number of workers employed in agriculture has sharply decreased since 1960s from ca. 35% to less than 10%. This decrease corresponds to an increased proportion of people employed in the tertiary sector which is the only one steadily increasing. Both industry and commerce, after an increase between 1960s and 1980s, are more or less constant or slightly decreasing.

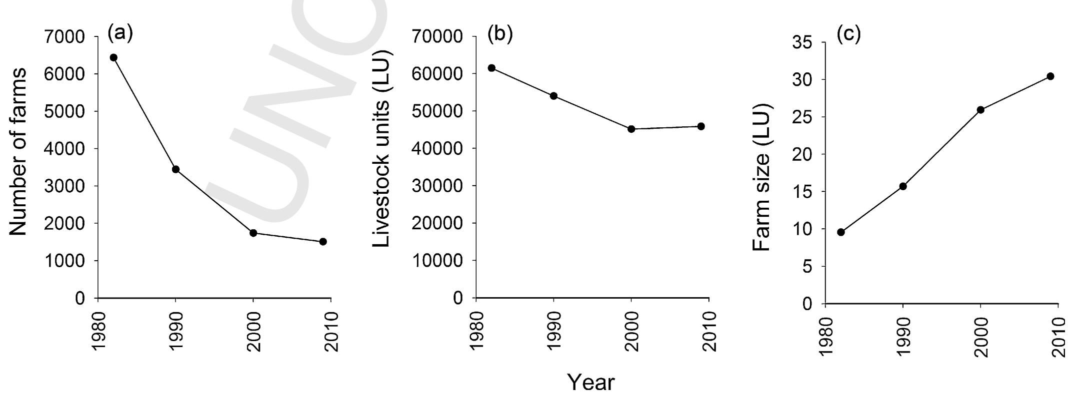

Fig. 2 – Trends in (a) the total number of conventional dairy farms, (b) bovine livestock units (LU) aggregated across 223 municipalities, and (c) in average farm size.

Please cite this article in press as: Marini, L. et al., Mitigating the impacts of the decline of traditional farming on mountain landscapes and biodiversity: a case study in the European Alps, Environ. Sci. Policy (2010), doi:10.1016/j.envsci.2010.12.003

Table 2 – Socio-economic, structural, and management variables gathered at the farm scale using semi-structured interviews with the holders of small (2 < LU < 10), medium (10 < LU < 35), and large farms (>50 LU).

Variables	Description	Unit	Small (n = 15)	Medium (n = 25)	Large (n = 23)
Milk production*	Average milk production per cow	l year^{-1}	4501	6250	7512
Agricultural area*	Total agricultural fertilized area	ha	6.3	14.1	40.8
Permanent grassland*	Proportion of permanent hay meadows		97%	85%	89%
Other cultures*	Proportion of other crops (e.g. apple, potatoes, vine)		3%	15%	11%
Hay yield*	Average hay production	t ha^{-1}	5.3	5.8	7.4
Mowing§					
(a) Traditional	Light walk-behind tractors		77%	0	0
(b) Specialized	Bar or rotary mower powered by a 4-wheel tractor		23%	100%	100%
Produced/total concentrate	Ratio between home-grown concentrate produced within the farm and the total (produced + purchased)		5%	5%	7%
Produced/total hay	Ratio between home-grown hay produced within the farm and the total (produced + purchased)		95%	95%	93%
Mineral fertilizer	Proportion of farms using mineral fertilizers		7%	28%	12%
Type of fertilizer§					
(a) Farmyard manure	Solid manure obtained using straw bedding		100.0%	80.0%	84.0%
(b) Liquid manure	Liquid manure obtained using concrete slat floors		0%	20.0%	16.0%
Livestock units*	Average number of livestock units	LU	5	24	90
Organic N per area*	Ratio between organic N production and the fertilized area	kg ha^{-1}	99	175	215
Summer transhumance	Use of high altitude pastures during the summer months		70%	76%	87%
Age*	Average age of farm holder	year	65.1	45.4	46.4
Abandonment§	Proportion of farms that will be abandoned within the next 15–20 years		71%	56%	40%
Reason for abandonment§					
(a) Low farm income	The farm income is too low to maintain the activity		30%	64%	73%
(b) No successor	The holder is old and no one within the family will take over the farm		70%	36%	27%

* Indicate significant differences ($P < 0.05$) from a one-way ANOVA.
§ Indicate significant differences ($P < 0.05$) from a χ^2 test.

Considering the dairy sector, the mixed model indicates that the number of farms has sharply declined between 1980 and 2009 (time, $P < 0.01$). We find a significant interaction between farm size and time (size × time, $P < 0.01$), i.e. the number of small farms declines more sharply than the number of large farms. Relating to the farms with more than 50 LU, their number increases over the same period. Considering the total number of LU, the decline is less pronounced but still significant (time, $P < 0.01$). Again the decline is steeper for small compared to large farms (size × time, $P < 0.01$). Trends in the number of LUs and farms clearly demonstrate that farms become larger over time, from a mean number of 10–30 LU per farm (Fig. 2). We find no significant effect of topography (slope and elevation) of the municipality on the decline of number of both farms and LUs.

We find no relationship between changes in the number of farms (or LU) and changes in land-use area (percentage cover of grasslands, apple orchards and vineyards and forest) occurring over the same period (1982–2000) at the municipality scale. Hence, the concentration of livestock on fewer and larger farms does not cause a significant change in land-use patterns at the municipality scale.

3.2. Comparison between traditional and modern farms

The farmers' interviews yield several significant differences between the three farm size classes (Table 2). Compared to intermediate and large sized farms, traditional small farms are less specialized and are characterized by a lower milk production per cow, lower hay productivity, and lower mean annual organic N production. All small farms produce only farmyard manure, while ca. 20% of intermediate and large sized farms produce liquid manure as organic fertilizer. The machines used for mowing are lighter and smaller than those employed by large farms. We find no differences between the farm size classes concerning the proportion of home-grown feedstuff and hay produced. All the farms are self-supporting for hay production, while more than 90% of the concentrate

Please cite this article in press as: Marini, L. et al., Mitigating the impacts of the decline of traditional farming on mountain landscapes and biodiversity: a case study in the European Alps, Environ. Sci. Policy (2010), doi:10.1016/j.envsci.2010.12.003

feedstuff is purchased on the market, i.e. the whole dairy sector depends on concentrate feedstuff produced outside the province. A large majority of farms uses high altitude pastures during the summer, irrespective of farm size.

Holders of traditional small farms are, on average, older than those running intermediate or large farms. The probability of farm abandonment within the next 15–20 years is higher for traditional small (71%) than for intermediate (56%) and large farms (40%). The reason stated for farm abandonment also differs, i.e. small farms indicate that the primary reason is the lack of successors within the family to take over the farm (70%), while only 30% of the farmers state the low farm income as a reason. For both intermediate and large farms the only reason is insufficient farm income (100%).

3.3. *Effectiveness of the proposed agri-environment scheme in maintaining biodiversity*

The farmers perceive the current 'Meadow AES' as a key policy instrument to support their farming activity, although none declares that the scheme will prevent them from abandoning the farming activity in the future. In general, farmers find that the current requirements to receive the payments are too demanding, mainly due to the commitment for a minimum period of at least 5 years. However, this assessment differs between small traditional (47%) and medium (64%) and large (56%) farms (χ^2, $P < 0.01$). The proposal to change the current criterion based on elevation with one based on slope is positively evaluated by 80% of small farms, and 70% of both intermediate and large farms.

The performance of the elevation- and slope-based 'Meadow AES' differs in supporting biodiversity of the three investigated taxa (Fig. 3). The highest payment levels of the current elevation-based 'Meadow AES' are associated with a higher number of species only for plants and orthopterans, while for butterflies the payment level is not related to the number of species. The slope-based 'Meadow AES' clearly separates the meadows hosting the greatest number of both plant and insect species in the highest payment level, while there is no difference between the meadows without any agri-environmental payment (conventional) and the first two payment levels.

4. Discussion

4.1. *Structural transformation and agriculture change at the municipality scale*

Within the study area, both population size and employment have profoundly changed in the last 50 years. In contrast to several other marginal mountain areas (MacDonald et al., 2000; Streifeneder et al., 2007; Rescia et al., 2009), human population has steadily increased since the Second World War. This is mainly attributable to the rising share of economic activity in tertiary sector within the study area. Tourism is considered the mainstay of the provincial economy as these alpine landscapes are renowned tourist destinations. Tourism has a strong link with the environment and in particular with the natural and semi-natural landscapes maintained by agricultural management. Moreover, agriculture is still profitable due to a high degree of specialization in apple and vine production. However, the proportion of workers employed in agriculture is presently less than 10%,

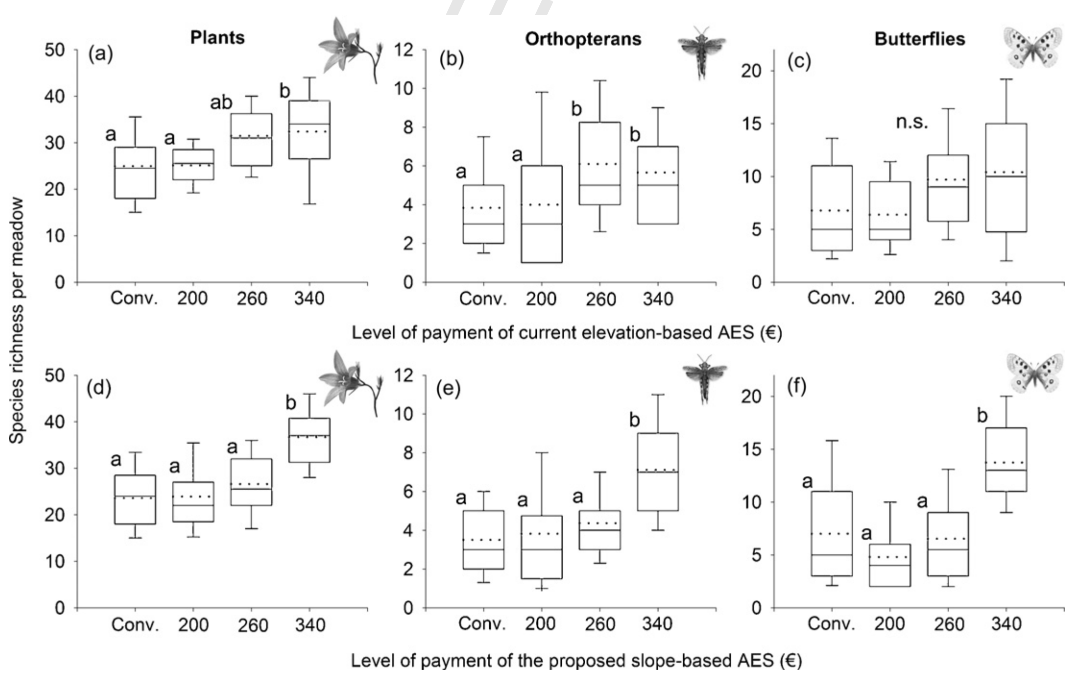

Fig. 3 – Mean species richness in the three payment levels for the current elevation-based 'Meadow AES' (a–c) and for the proposed slope-based 'Meadow AES' (d–f). Payment levels are described in Table 1. Dotted line indicates the mean while solid line indicates the median. Different letters indicate significant difference according to a Tukey–Kramer test (P < 0.01). Conv. indicates conventionally managed hay meadows that do not participate in the 'Meadow AES'.

Please cite this article in press as: Marini, L. et al., Mitigating the impacts of the decline of traditional farming on mountain landscapes and biodiversity: a case study in the European Alps, Environ. Sci. Policy (2010), doi:10.1016/j.envsci.2010.12.003

indicating that other sectors of economy such as commerce and tertiary now draw the young generations more heavily than agriculture. This downward trend in agricultural employment largely corresponds to those trends observed in other marginal systems across Europe (MacDonald, 2000; Schmitzberger et al., 2005; Dallimer et al., 2009).

Within the dairy sector, we observe a transition from a large number of small traditional to fewer and larger farms. In the last 30 years there has been almost an 80% drop in the number of dairy farms, while the number of livestock units has declined only by 25%. On the one hand, these values correspond well to the national trend and to those trends reported from other countries in southern Europe (e.g. Spain). On the other hand, these values are higher than those from other alpine regions such as Austria or Switzerland (Streifeneder et al., 2007) and from more agriculture intensive countries such as Belgium or Germany (Alliance Environment, 2008). These trends indicate both a concentration of livestock on larger farms and a decrease of employees within the dairy sector (see also Rescia et al., 2009). Although the EU and national agricultural policies have generally promoted more competitive and industrial farming systems at the expense of smaller family holdings (CEAS et al., 2000), both the CAP direct payments for income support and the targeted agri-environmental payments could have also contributed to slow down this process in marginal areas by supporting small farm holdings with rather poor economic performance (IEEP, 2007). However, with decreasing public support most farmers need to have larger numbers of livestock in order to stay in business and to generate a reasonable level of farm income. The concentration of livestock on fewer and larger farms is common for the whole Alpine area (Streifeneder et al., 2007) and poses the question how these large farms will manage grassland and the associated biodiversity in the future.

Our results indicate that there is no relationship between the trends in both number of livestock units and dairy farms and land-use change. Although the abandonment of farms is high over the last decades, large areas of agricultural land have not been abandoned in the studied period. As small farms abandon the activity, large farms progressively acquire the land formerly managed by traditional farms, either by buying or by leasing, therewith enlarging their operational farm size. This confirms the results obtained by Streifeneder et al. (2007) who indicates that our studied area is amongst those with the lowest level of land abandonment in the European Alps. There are various possible explanations for the remarkably low level of agricultural land abandonment in our studied area, such as the autonomous statute of the province, strong political influence of the stakeholders on the agricultural sector and high levels of EU subsidies. In contrast, in neighbouring Alpine regions several authors (Bebi and Baur, 2002; Sturaro et al., 2005; Giupponi et al., 2006; Gellrich et al., 2008; Tappeiner et al., 2008; Tappeiner et al., 2007) report a close relationship between the transition from traditional to modern dairy farming systems and land-use change from grassland to forest.

4.2. *Comparison between traditional and modern farms*

Although there is no significant impact of the current transition from traditional to modern dairy farming systems on land-use area change, we find significant differences in socio-economic and structural farm characteristics between the size classes. This indicates that the transition between the two farming systems might strongly affect the ecological quality of the meadows rather than their extension. Although the number of LU slightly decline and the meadow area remain more or less constant over the last decades, the transition from small to large farms leads to higher farm specialization and higher levels of milk production per LU. High production cows require large amount of concentrate feedstuff that needs to be imported from outside the study area where more favourable conditions permit the cultivation of cereals. In the study area, almost all the concentrate feedstuff is bought on the market by the 63 interviewed dairy farmers. This contributes to an increased production of organic fertilizers per LU by large farms, which have twice as high N ha^{-1} rates as small farms. Considering the body of research regarding the impact of meadow management on biodiversity (e.g. Zechmeister et al., 2003; Maurer et al., 2006; Marini et al., 2008, 2009; Humbert et al., 2009), it is evident that the farming practices adopted by small farms generally support higher species diversity than those associated with large farms. For instance, small farms have a lower production of organic fertilizer per area, which is likely to maintain lower soil fertility, and thus higher plant and insect biodiversity (e.g. Knop et al., 2006; Kampmann et al., 2008; Marini et al., 2009). There is further evidence that smaller and lighter mowing machines employed by small farms could reduce mortality of invertebrates with low mobility (Humbert et al., 2009). These results confirm the conclusions drawn by other authors that small traditional farm holdings might preferentially be supported by agri-environmental payments as they often employ less intensive management practices than large and specialized farms (Schmitzberger et al., 2005; Belfrage et al., 2005; Marini et al., 2009).

However, our results pose some questions on the effectiveness of targeting agri-environmental payments predominantly at small farms by diverting a greater share of the agri-environment budget from large, specialized to small, traditional farming systems. Importantly, our study gains insight into the drivers that determine the abandonment of small traditional farms. Small farms are run exclusively by old farmers that are very likely to abandon their activity in the next decades (Schmitzberger et al., 2005). Old farmers respond that they will abandon their activity within the next 15–20 years not because of economic reasons but due to the lack of successors within the family to take over the farm (cf. Kizos and Koulouri, 2006; Kizos et al., 2010). The current levels of income are sufficient for an old farmer but do not make dairy farming attractive to young people. This result is relevant to policymakers in case they may consider farm size as a criterion for reallocating financial resources. As suggested by Mattison and Norris (2005), conservation measures in agriculture should always take into account the effect of the political, social, economic, and technological background. In our specific case study, it seems reasonable to assume that even a higher share of the current agri-environment budget spent on maintaining traditional low-intensity farming may not prevent small farms from abandoning their activity.

Please cite this article in press as: Marini, L. et al., Mitigating the impacts of the decline of traditional farming on mountain landscapes and biodiversity: a case study in the European Alps, Environ. Sci. Policy (2010), doi:10.1016/j.envsci.2010.12.003

4.3. *Effectiveness of the proposed agri-environment scheme in maintaining biodiversity*

Although our proposed slope-based 'Meadow AES' is not specifically aimed at plant or insect diversity conservation and does not include any strict management prescriptions, the results indicate that the levels of payments are positively related to the number of plant, orthopteran and butterfly species. Our proposed slope-based 'Meadow AES' could easily be implemented in the future as it performs slightly better than the current elevation-based 'Meadow AES' in supporting the conservation of the most species-rich meadows. On the one hand, the AES compensates the farmers for keeping lower production of organic fertilizers at the farm scale, which is the main cause of meadow eutrophication and consequent biodiversity loss. To comply with the AES large farms with high ratios between LU and farm area need to enlarge their meadow area to reduce their average level of fertilization. On the other hand, slope can be considered a good proxy for management intensity (Bennie et al., 2006; Klimek et al., 2007; Marini et al., 2009) and it is one of the most important factors causing the abandonment of semi-natural meadows and long-term landscape simplification (Bebi and Baur, 2002; Tasser et al., 2007). Given the fact that in the study area the animal diet is mostly based on the use of concentrates and that hay is used only for providing the quantity of fibre necessary for digestion, it seems unlikely that the proposed scheme would give farmers any incentive to intensify management of steep meadows. Thus, incorporating the slope-based criterion into the scheme design would probably contribute to maintaining the already existing low-input management of the steep meadows in the future. Similarly to the Ecological Compensation Areas (ECA) scheme applied in the Swiss Alps (Knop et al., 2006), our 'Meadow AES' with the slope-based criterion would mostly compensate farmers for maintaining existing species-rich hay meadows located in unfavourable conditions but it would not stimulate any change in current high-input management practices of flat meadows (Marini et al., 2009).

5. Conclusions

Advances in biodiversity research have already identified most of the threats to grassland diversity at both local and landscape scale. There is further evidence that traditional farming and related farming practices are often associated with high biodiversity (Pykälä, 2000; Luoto et al., 2003; Belfrage et al., 2005; Schmitzberger et al., 2005; Marini et al., 2009; Dallimer et al., 2009). However, our study indicates that the ongoing transition from traditional to modern dairy farming is likely to be largely irreversible because it is part of a broader process of social and structural transformation that involves a reallocation of employment across broad economic sectors (cf. Milestad and Hadatsch, 2003). If the current socio-economic background and agri-environmental policies remain unchanged, the traditional dairy farming dominated by small farms is likely to disappear in the next decades (IEEP, 2007).

Our results demonstrate that the proposed slope-based 'Meadow AES' is positively related to biodiversity across multiple taxa. Hence, compensating farmers for keeping a low production of organic fertilizers at the farm scale and for maintaining the extensive management of steep meadows at the field scale could provide a simple but effective tool to mitigate the impacts on biodiversity of the decline of traditional farming. However, dairy farmers that participate within the AES would probably still depend on additional payments for income support. Against this background, it is, therefore, crucial to find an appropriate balance between targeted agri-environmental payments and direct payments to guarantee the viability of the farms and reduce farm abandonment in marginal areas (Osterburg et al., 2010). In order to halt the ongoing decline of farmland biodiversity, our study indicates that large and specialized farms probably need to get more involved in biodiversity conservation as they will be the main actors in the future of Alpine farming (see also Streifeneder et al., 2007; IEEP, 2007). Apart from an adaptation of existing economic instruments such as AESs (Wrbka et al., 2008), this will probably require the design and implementation of new instruments and landscape programmes developed in a transdisciplinary framework such as payment schemes that compensate farmers for the provision of environmental services (Stöcklin et al., 2007; Fischer et al., 2008; Klimek et al., 2009; Fonderflick et al., 2010; Lindemann-Matthies et al., 2010). Our results should stimulate discussion Q5 and further research around this topic in order to develop new instruments to mitigate the ecological consequences of the observed agricultural change in the Alpine regions.

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.). The funding source had no part in planning or performing the study, providing only the funds to the project. We are grateful to L. Rizzi (Cavizzana, TN) for support during the field surveys and interviews. Riccardo Bommarco provided insightful comments on earlier versions of the manuscript. Comments from one anonymous reviewer improved the quality of the study. We thank M. Fezzi, E. Arnoldi, and L. Pedron at the Agriculture Department of the Province of Trento for providing general data about farms and hay meadows. We wish to thank Sonia Marongiu (INEA) for providing economic data from the RICA database (FADN).

REFERENCES

Acs, S., Hanley, N., Dallimer, M., Robertson, P., Wilson, P., Gaston, K.J., Armsworth, P.R., 2010. The effect of decoupling on marginal agricultural systems: implications for farm incomes, land use and upland ecology. Land Use Policy 27, 550–563.

Alliance Environment, 2008. Evaluation of the environmental impacts of milk quotas. Report for DG Environment, European Commission, 187 pp.

Antrop, M., 2005. Why landscapes of the past are important for the future. Landscape Urban Plan. 70, 21–34.

Aviron, S., Nitsch, N., Jeanneret, J., Buholzer, S., Luka, H., Pfiffner, L., Pozzi, S., Schüpbach, B., Walter, T., Herzog, F., 2008. Ecological cross compliance promotes farmland biodiversity in Switzerland. Front. Ecol. Environ. 7, 247–252.

Bebi, P., Baur, P., 2002. Forest expansion in the Swiss Alps: a quantitative analysis of bio-physical and socio-economic causes. Austrian J. Forest Sci. 119, 217–230.

Belfrage, K., Björklund, J., Salomonsson, L., 2005. The effects of farm size and organic farming on diversity of birds, pollinators, and plants in a Swedish landscape. AMBIO 34, 582–588.

Bennie, J., Hill, M.O., Baxter, R., Huntley, B., 2006. Influence of slope and aspect on long-term vegetation change in British chalk grasslands. J. Ecol. 94, 355–368.

CEAS Consultants (Wye) Ltd. and European Forum on Nature Conservation and Pastoralism, 2000. The environmental impact of dairy production in the EU: practical options for the improvement of the environmental impact. Report for DG Environment, European Commission, 176 pp.

Dallimer, M., Tinch, D., Acs, S., Hanley, N., Southall, H.R., Gaston, K.J., Armsworth, P.R., 2009. 100 years of change: examining agricultural trends, habitat change and stakeholder perceptions through the 20th century. J. Appl. Ecol. 46, 334–343.

Fischer, M., Rudmann-Maurer, K., Weyand, A., Stöcklin, J., 2008. Agricultural land use and biodiversity in the Alps: how cultural tradition and socio-economically motivated changes are shaping grassland biodiversity in the Swiss Alps. Mt. Res. Dev. 28, 148–155.

Fonderflick, J., Lepart, J., Caplat, P., Debussche, M., Marty, P., 2010. Managing agricultural change for biodiversity conservation in a Mediterranean upland. Biol. Conserv. 143, 737–746.

Gellrich, M., Baur, P., Robinson, B.H., Bebi, P., 2008. Combining classification tree analyses with interviews to study why sub-alpine grasslands sometimes revert to forest: a case study from the Swiss Alps. Agr. Syst. 96, 124–138.

Giupponi, C., Ramanzin, M., Sturaro, E., Fuser, S., 2006. Land use change, biodiversity and agricultural policy in the Belluno province, Italy. Environ. Sci. Policy 9, 163–173.

Humbert, J.-Y., Ghazoul, J., Walter, T., 2009. Meadow harvesting techniques and their impacts on field fauna. Agr. Ecosyst. Environ. 130, 1–8.

IEEP (Institute of European Environmental Policy), 2007. Evaluation of the environmental impacts of CAP (Common Agricultural Policy) measures related to the beef and veal sector and the milk sector. Report prepared for DG Agriculture, European Commission, 290 pp.

Kampmann, D., Herzog, F., Jeanneret, P., Konold, W., Peter, M., Walter, T., Wildi, O., Lüscher, A., 2008. Mountain grassland biodiversity: impact of site conditions versus management type. J. Nat. Conserv. 16, 12–25.

Kizos, T., Dalaka, A., Petanidou, T., 2010. Farmers' attitudes and landscape change: evidence from the abandonment of terraced cultivations on Lesvos, Greece. Agr. Hum. Values 27, 199–212.

Kizos, T., Koulouri, M., 2006. Agricultural landscape dynamics in the Mediterranean: Lesvos (Greece) case study using evidence from the last three centuries. Environ. Sci. Policy 9, 330–342.

Klimek, S., Richter, gen., Kemmermann, A., Hofmann, M., Isselstein, J., 2007. Plant species richness and composition in managed grasslands: the relative importance of field management and environmental factors. Biol. Conserv. 134, 559–570.

Klimek, S., Richter, gen., Kemmermann, A., Steinmann, H.H., Freese, J., Isselstein, J., 2009. Rewarding farmers for delivering vascular plant diversity in managed grasslands: a transdisciplinary case-study approach. Biol. Conserv. 141, 2888–2897.

Knop, E., Kleijn, D., Herzog, F., Schmid, B., 2006. Effectiveness of the Swiss agri-environment scheme in promoting biodiversity. J. Appl. Ecol. 43, 120–127.

Lindborg, R., Bengtsson, J., Berg, Å., Cousins, S.A.O., Eriksson, O., Gustafsson, T., Hasund, K.P., Lenoir, L., Pihlgren, A., Sjödin, E., 2008. A landscape perspective on conservation of semi-natural grasslands. Agr. Ecosyst. Environ. 125, 213–222.

Lindemann-Matthies, P., Briegel, R., Schüpbach, B., Junge, X., 2010. Aesthetic preference for a Swiss alpine landscape: the impact of different agricultural land-use with different biodiversity. Landscape Urban Plan. 98, 99–109.

Luoto, M., Rekolainen, S., Aakkula, J., Pykälä, J., 2003. Loss of plant species richness and habitat connectivity in grasslands associated with agricultural change in Finland. AMBIO 32, 447–452.

MacDonald, D., Crabtree, J.R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Gutierrez Lazpita, J., Gibon, A., 2000. Agricultural abandonment in mountain areas in Europe: environmental consequences and policy response. J. Environ. Manage. 59, 47–69.

Marini, L., Scotton, M., Klimek, S., Pecile, A., 2008. Patterns of plant species richness in Alpine hay meadows: local vs. landscape controls. Basic Appl. Ecol. 9, 365–372.

Marini, L., Fontana, P., Klimek, S., Battisti, A., Gaston, K.J., 2009. Impact of farm size and topography on plant and insect diversity of managed grasslands in the Alps. Biol. Conserv. 142, 394–403.

Mattison, E.H.A., Norris, K., 2005. Bridging the gaps between agricultural policy, land-use and biodiversity. Trends Ecol. Evol. 20, 611–616.

Maurer, K., Weyand, A., Fischer, M., Stöcklin, J., 2006. Old cultural traditions, in addition to land use and topography, are shaping plant diversity of grasslands in the Alps. Biol. Conserv. 130, 438–446.

Milestad, R., Hadatsch, S., 2003. Organic farming and social-ecological resilience: the Alpine valleys of Sölktäler, Austria. Conserv. Ecol. 8, 3.

Myklestad, Å., Sætersdal, M., 2004. The importance of traditional meadow management techniques for conservation of vascular plant species richness in Norway. Biol. Conserv. 118, 133–139.

O'Rourke, E., 2006. Changes in agriculture and the environment in an upland region of the Massif Central, France. Environ. Sci. Policy 9, 370–375.

Osterburg, B., Isermeyer, F., Lassen, B., Röder, N., 2010. Impact of economic and political drivers on grassland use in the EU. Grassl. Sci. Europe 15, 14–28.

Plieninger, T., Höchtl, F., Spek, T., 2006. Traditional land-use and nature conservation in European rural landscapes. Environ. Sci. Policy 9, 317–321.

Pykälä, J., 2000. Mitigating human effects on European biodiversity through traditional animal husbandry. Conserv. Biol. 14, 705–712.

R Development Core Team, 2008. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Rescia, A.J., Pons, A., Lomba, I., Esteban, C., Dover, J.W., 2009. Reformulating the social–ecological system in a cultural rural mountain landscape in the Picos de Europa region (northern Spain). Landscape Urban Plan. 88, 23–33.

Rounsevell, M.D.A., Berry, P.M., Harrison, P.A., 2006. Future environmental change impacts on rural land use and biodiversity: a synthesis of the ACCELERATES project. Environ. Sci. Policy 9, 93–100.

Schmitzberger, I., Wrbka, T., Steurer, B., Aschenbrenner, G., Peterseil, J., Zechmeister, H., 2005. How farming styles

influence biodiversity maintenance in Austrian agricultural landscapes. Agr. Ecosyst. Environ. 108, 274–290.
Schneeberger, N., Bürgi, M., Hersperger, A.M., Ewald, K.C., 2007. Driving forces and rates of landscape change as a promising combination for landscape change research—an application on the northern fringe of the Swiss Alps. Land Use Policy 24, 349–361.
Stoate, C., Báldi, A., Beja, P., Boatman, N.D., Herzon, I., van Doorn, A., de Snoo, G.R., Rakosy, L., Ramwell, C., 2009. Ecological impacts of early 21st century agricultural change in Europe—a review. J. Environ. Manage. 91, 22–46.
Stöcklin, J., Bosshard, A., Klaus, G., Rudmann-Maurer, K., Fischer, M., 2007. Landnutzung und biologische Vielfalt in den Alpen: Fakten, Perspektiven, Empfehlungen. vdf, Zurich, Switzerland.
Streifeneder, T., Tappeiner, U., Ruffini, F.V., Tappeiner, G., Hoffmann, C., 2007. Selected aspects of the agricultural structure change within the Alps—a comparison of harmonised agri-structural indicators on a municipal level within the Alpine Convention Area. Revue de Géographie Alpine 95, 41–52.
Sturaro, E., Cocca, G., Fuser, S., Ramanzin, M., 2005. Relationships between livestock production systems and landscape changes in the Belluno province, Italy. Ital. J. Anim. Sci. 4, 184–186.
Tappeiner, U., Tappeiner, G., Hilbert, A., Mattanovich, E., 2003. The EU Agricultural Policy and the Environment: Evaluation of the Alpine Region. Blackwell, Berlin.
Tappeiner, U., Tasser, E., Leitinger, G., Cernusca, A., Tappeiner, G., 2008. Effects of historical and likely future scenarios of land use on above- and belowground vegetation carbon stocks of an Alpine Valley. Ecosystems 11, 1383–1400.
Tasser, E., Walde, J., Tappeiner, U., Teutsch, A., Noggler, W., 2007. Land-use changes and natural reforestation in the Eastern Central Alps. Agr. Ecosyst. Environ. 118, 115–129.
Wrbka, T., Schindler, S., Pollheimer, M., Schmitzberger, I., Peterseil, J., 2008. Impact of the Austrian Agri-Environmental Scheme on diversity of landscapes, plants and birds. Commun. Ecol. 9, 217–227.
Zechmeister, H.G., Schmitzberger, I., Steurer, B., Peterseil, J., Wrbka, T., 2003. The influence of land-use practices and economics on plant species richness in meadows. Biol. Conserv. 114, 165–177.

Lorenzo Marini is a post-doc fellow at the University of Padova with a strong focus on conservation biology of plants and insects. His research interests in environmental sciences focus on the analysis of the impact of agricultural change on landscapes and biodiversity to derive effective policy guidelines for biodiversity conservation.

Sebastian Klimekis a research associate at the Johann Heinrich von Thünen-Institute in Germany. His research focuses on agricultural ecosystems and aims to derive practical policy recommendations that could be used for both refining existing agri-environment schemes and formulating new options that are aimed at conserving biodiversity.

Andrea Battisti is professor of entomology at the University of Padova and has 20 years experience in ecology and management of insects. He has coordinated several EU and national projects, including monitoring and early detection of introduced species. He is a member of IUFRO working parties and of IOBC.