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The Biodiversity Promotion Areas: effectiveness of agricultural direct payments on plant diversity conservation in the semi-natural grasslands of the Southern Swiss Alps

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Abstract

An agro-environmental payment for the management of the so-called 'Biodiversity Promotion Areas' (BPA) has been used to accomplish biodiversity conservation goals in Switzerland. These areas have been managed according to specific limitations on mowing dates and fertilizers. We assessed the regional-scale effectiveness of BPA implementation within Ticino Canton by answering the following questions: (i) is plant species diversity higher in BPA than in conventionally managed grasslands (CMG)? (ii) which are the differences between BPA and CMG in terms of climatic, topographical, ecological, and vegetation variables? (iii) which vegetation types, functional groups, and plant species are specifically related to BPA? A total of 242 vegetation surveys (64 in BPA and 178 in CMG, respectively) was carried out in 55 farms and the main climatic and topographic features were assessed. Differences in terms of plant diversity, ecological indicator and pastoral values, species functional groups, vegetation types, and indicator species between BPA and CMG were assessed. The BPA harboured a higher plant diversity. They were located in steeper areas, at higher elevations, and characterised by lower soil nutrient content, mowing tolerance, and pastoral value than CMG. Dry meadow species number and cover were higher in BPA, while nutrient-rich meadow species number was higher in CMG. The species associated to BPA belonged to a wider range of functional groups and 38% of them belonged to the national list for biodiversity promotion in agriculture, whereas no species associated to CMG belonged to that list. Thus, our results confirmed the effectiveness of BPA for biodiversity conservation for the Southern Swiss Alps.

Keywords Agricultural policy · Extensive meadows · Low-intensive meadows · Extensive pastures · Species richness · Vegetation types

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Introduction

Semi-natural extensive grasslands of temperate regions are amongst the most species-rich terrestrial ecosystems on the Earth (Wilson et al. 2012). A remarkable number of grassland specialists, among which many endemic and threatened species, composes a significant proportion of this high biodiversity, for both flora and fauna (Nagy 2009; WallisDeVries and Van Swaay 2009; Tocco et al. 2013; Fournier et al. 2017; Kadereit 2017). These highly diverse open habitats are the result of long-term extensive mowing and grazing regimes and most of the extreme-richness sites are managed with no fertilisation and no more than one cut per year (Dengler et al. 2014). Indeed, regular and low-intensive biomass removal reduces the competitive advantage that fast-growing plant species have in highly disturbed habitats, allowing their coexistence with low-growing species and resulting in an overall increase in species richness (Roleček et al. 2014). Moreover, species diversity is generally promoted by the spatial heterogeneity of environmental conditions (e.g. variation in temperature, solar radiation, soil depth and type, and water and nutrient availability) occurring over short distances, a common situation in mountain areas (Körner 2003). Indeed, a general increase in the richness of vascular plants was recorded from the colline to the mountain belts in Switzerland, which is also the result of the decrease in management intensity occurring at increasing elevations as a consequence of lower grassland productivity (Koordinationsstelle Biodiversitäts-Monitoring Schweiz 2009).

However, during the last century, these species-rich ecosystems have experienced a dramatic loss in their area across the entire Palearctic region, due to both agricultural intensification and abandonment processes (Dengler et al. 2014). In the most accessible and productive sites, extensive semi-natural grasslands have been often converted to arable lands or their management has been intensified by means of synthetic fertilizers and pesticides, increased cutting frequency, higher animal stocking rates, and re-sowing with a limited array of forage species (Manning et al. 2015). Consequently, intensified management has modified their botanical composition, by shifting species-rich plant communities towards less-biodiverse grasslands dominated by a specific functional group of species, namely productive grasses (Hejcman et al. 2012). Indeed, these species are able to adapt to frequent and intense defoliation regimes due to their fast leaf turnover rates, in contrast to nutrient-poor low-growing species (Pittarello et al. 2018). Conversely, in the most marginal and less productive sites, semi-natural grasslands have often been abandoned, since traditional management has become economically unviable under current socio-economic conditions, with an exacerbated trend over European montane regions (Estel et al. 2015). Therefore, the agro-pastoral abandonment has also resulted in widespread vegetation cover and composition changes, with grassland loss because of tree and shrub encroachment (Orlandi et al. 2016).

In recent decades, there has been a growing attention throughout all Europe for the preservation of grassland biodiversity, since it is a non-renewable genetic source related to the provision of several ecosystem services irreplaceable for human society, such as food production, climate regulation, nutrient cycling, pollination, soil protection, water control, wild-fire risk mitigation, and tourism and recreation opportunities (Harrison et al. 2010). In addition, a higher biodiversity generally increases stress tolerance of communities, thus enhancing the protection of ecosystems against disturbances (Hooper et al. 2005). It is also worth mentioning that grasslands are one of the most important soil cover types across all Europe. Indeed, in 2016, the area covered by permanent grasslands at a continental scale amounted to 13.2% of the total surface or 34.3% of the utilized agricultural area of the 28

member states of the European Union plus Switzerland (UST 2018a; EUROSTAT 2019). For all the above-mentioned reasons, nowadays many European agricultural and environmental policies reflect the current societal need of preserving grassland biodiversity (Habitat Directive 1992/43/EEC, Bird Directive 2009/147/EC, EU Regulation 1307/2013).

In countries characterised by a higher percentage of grassland cover, such as Switzerland, this attention has become a real priority in agricultural and environmental policies. Indeed, in 2018, Swiss permanent grasslands (without considering alpine summer pastures) amounted to 607.539 ha, corresponding to 14.7% and 58.1% of total national surface and utilized agricultural area, respectively, with a remarkable proportion of montane meadows and pastures (Swiss National Agricultural Report 2019). Since the beginning of '90s, the Swiss government introduced an agro-environmental payment for the management of specific areas (formerly called 'Ecological Compensation Areas', nowadays 'Biodiversity Promotion Areas', BPA) to accomplish the environmental goals for agriculture in terms of biodiversity conservation (UFAG 2020a). The current legislation sets specific rules to farmers to receive agricultural direct payments, among which the obligation that at least 7% of their agricultural area must be managed as a BPA (Swiss Ordinance 910.13). For grasslands, this means that specific limitations on mowing dates and on the use of fertilizers have to be complied. Under this framework, three grassland BPA are envisaged: (i) extensive meadows, receiving no fertilizer nor manure inputs, (ii) low-intensive meadows, that can receive manure or compost input up to 30 kg N ha^{-1} year^{-1}, and (iii) extensive pastures, receiving only grazing animal excreta. Meadows and pastures must be mown or grazed at least once a year, respectively, with meadows that must not be mown before July 1st or 15th at lower and higher mountain zones, respectively.

In recent years, some studies have been conducted to assess the effectiveness of this agri-environmental policy (Herzog et al. 2005; Knop et al. 2006; Dietschi et al. 2007; Kampmann et al. 2008; Peter et al. 2009; Riedel et al. 2019). These authors have generally measured positive effects of BPA management on vascular plant diversity conservation, even if with some contrasting results, depending on particular vegetation types or functional groups of species. However, the abovementioned studies have been conducted in the Northern and Eastern-Central Alps, while no specific study focused on the Southern Alps (i.e. Ticino Canton). This region is characterised by different biogeographic and socio-economic conditions and by a peculiar flora, shaped by distinct climatic conditions, which are influenced by the presence of high mountain massifs and the southern Po Basin (Ozenda 1985; Welten and Sutter 1982; Gonseth et al. 2001). Over the last decades, the Ticino Canton has faced a stronger agricultural abandonment process compared to the average Swiss trend, due to a more pronounced decrease in the number of farms, agricultural employees, and livestock units, resulting in a higher reduction in the area covered by grasslands (UST 2018b).

To fill this gap, the current study aims to assess the regional-scale effectiveness of BPA implementation for plant diversity conservation in the Southern Swiss Alps by specifically answering the following questions: (i) is vascular plant species diversity higher in grasslands managed as BPA than in conventionally managed grasslands (CMG)? (ii) which are the differences between BPA and CMG in terms of climatic, topographical, ecological, and vegetation variables? (iii) which vegetation types, functional groups, and plant species are specifically related to the BPA?

Material and methods

Study area

The study was conducted in the Ticino Canton (Switzerland). The surveyed area was characterised by a warm-humid insubric climate, with average annual precipitation ranging from 1318 to 1897 mm and average annual temperature ranging from 5.2 to 12.4 °C, respectively. The vegetation of 55 farms was investigated, exploring a wide range of environmental and management conditions. The farms involved in the study were selected to cover a large area within the Ticino canton, encompassing all the main valleys and a wide range of different climatic, topographic and vegetation conditions, so as to be representative of the regional scale investigated (Fig. 1). For every farm, an average number of 4.6 surveys (standard error: 0.36) was conducted, i.e. one per each homogeneous vegetation type found within the farm. The studied grasslands were located between 197 and 1611 m a.s.l. on slopes ranging from 0.6° to 37.6° and were characterized by an aspect comprised between 6.7° and 338.5°. Grasslands were managed by direct grazing (by dairy cows, sheep, or goats) and/or by cutting for fresh foddering, haymaking, and silage production. Within each farm, grasslands were alternatively considered as BPA (if that management regime had been applied at least for the five previous years) or CMG (if grasslands were not subjected to management restrictions and generally cut and/or grazed two to six times per year, depending on pedo-climatic conditions and potential forage yield).

Vegetation surveys

Grassland vegetation of the studied farms was assessed by means of 242 vegetation surveys, conducted once between 2012 and 2016 in either May, June, or July, with a balanced proportion of surveys carried out between BPA and CMG within each year (Fig. 1 and Table 1). A total of 64 and 178 surveys were carried out within BPA and CMG, respectively. Concerning BPA, 43% of them was composed by extensive meadows, 33% by low-intensive meadows, and 24% by extensive pastures, respectively. For each survey, elevation, slope, and aspect were calculated from the Swiss digital height model (Federal Office of Topography 2018) using QGIS 3.10 software (QGIS Development team 2019). Southness, an index of south-facing aspect, was computed as a linear transformation of aspect ($180° − |aspect − 180°|$; Chang et al. 2004). Average annual precipitation was calculated according to the available data from the nearest meteorological station.

Botanical composition was determined using the vertical point-quadrat method (Daget and Poissonet 1971) along 25-m transects placed within vegetation patches representative of the overall grassland botanical composition. Within each transect, at every 50-cm interval, plant species touching a steel needle were identified and recorded (i.e. 50 points of vegetation measurements per transect). To account for occasional species, likely missing with the point-quadrat method, a complete list of all other species included within a 1-m buffer area surrounding the transect was also recorded. The frequency of occurrence of each plant species recorded (fi = number of occurrences/50 points of vegetation measurement), which is an estimate of species canopy cover, was calculated for each transect and converted to percentage cover (Perotti et al. 2018). To all occasional plant species, not recorded along the vegetation transect but only within the 1-m buffer area around it, a percentage cover of 0.3% was attributed (Pittarello et al. 2017). Species relative abundance
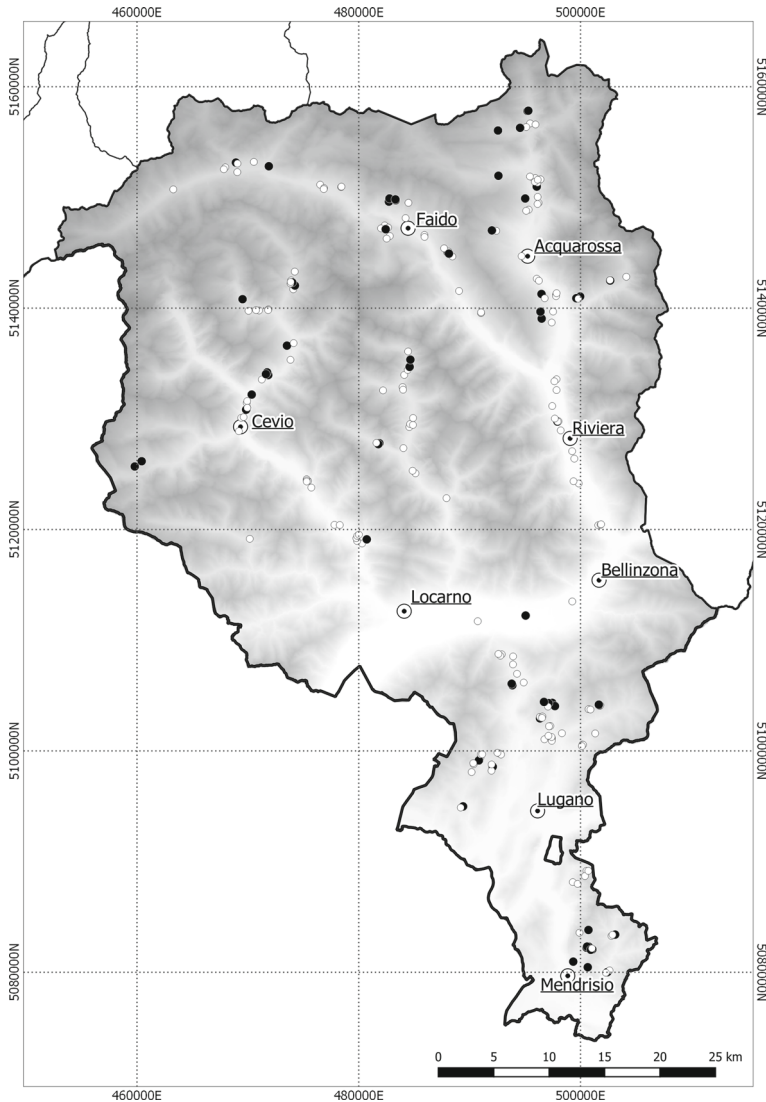
Fig. 1 Location of the 242 vegetation surveys carried out in the Ticino Canton, Switzerland (UTM zone 32°N, WGS84 datum). Black dots identify surveys carried out in Biodiversity Promotion Areas (BPA) while white dots those in conventionally managed grasslands (CMG). Darker shadows of grey correspond to higher elevations

(*SRAi*) was determined in each transect and used to detect the proportion of different species according to Daget and Poissonet (1971):

$$SRAi = \frac{fi}{\sum_{i=1}^{n} fi} \times \ 100 \ (\%),$$

where *SRAi* and *fi* are species relative abundance and frequency of occurrence of species *i*. Plant species nomenclature followed Aeschimann et al. (2004).

Table 1 Number of studied farms and vegetation surveys according to livestock species	Livestock species	Number of farms	Number of surveys
	Dairy cows	19	105
	Goats	7	51
	Sheep	7	9
	Dairy cows and goats	10	38
	Dairy cows and sheep	6	12
	Goats and sheep	6	27
	Total	55	242

Plant diversity was assessed for every vegetation survey by computing species richness, Shannon diversity index (Magurran 1988), and species evenness (Magurran 2004). Moreover, each plant species was classified according to the indicator values for soil moisture, soil nutrient content (mainly nitrogen), and mowing tolerance identified by Landolt et al. (2010). Each indicator value ranges from 1 (low requirement or tolerance) to 5 (high requirement or tolerance). The mean Landolt's indicator values for soil moisture, soil nutrient content, and mowing tolerance were computed per each transect by averaging species values weighted on their relative abundance. Additionally, forage pastoral value, a synthetic index based on forage yield and quality ranging from 0 to 100, was calculated following the equation proposed by Daget and Poissonet (1971):

$$Pastoral\,value = \sum_{i=1}^{n}(SRA_i \times ISQ_i) \times 0.2,$$

where SRA_i and ISQ_i are the species relative abundance and the index of specific quality (ranging from 1 to 5, and according to Cavallero et al. 2007) of the species i, respectively.

In order to identify different functional groups of species, which are characterised by similar ecological needs, each plant species was classified according to its phytosociological optimum at the class level, as identified by Aeschimann et al. (2004). Then, species in phytosociological classes having physiognomic, ecological and floristic similarity were grouped according to Theurillat et al. (1995). Nine functional groups of species were identified: rocky, terophytic-pioneer, wetland, shrubland–woodland, heathland, edge (including dry and mesophilous edge), ruderal (including annual and perennial ruderal), pasture (including basophilous and acidophilous pasture), and meadow (including dry and nutrient-rich meadow) species. The complete species list and the corresponding phytosociological optima and functional groups are available in Online Resource 1. The total species number and cover accounting for each functional group were calculated for each vegetation survey.

Statistical analyses

Generalized linear mixed models (GLMMs) were performed in order to test for differences between BPA and CMG in terms of plant diversity indexes, climatic, topographic, and ecological features (i.e. elevation, slope, southness, precipitation, soil moisture, soil nutrient content, mowing tolerance, and pastoral value), and number and cover of species belonging to different functional groups. Management regime (i.e. BPA vs CMG) was considered as fixed factor, farm as random factor, and the vegetation survey was the statistical unit. Sequential Bonferroni correction was applied to adjust for multiple

comparisons. Shannon diversity index, species evenness, climatic, topographic, and ecological features, and species covers of functional groups, being continuous variables, were modelled with both Gaussian and gamma functions, while species richness, species numbers of functional groups, being count variables, were modelled with both Poisson and negative-binomial functions. Then, the model resulting in the lowest Akaike's Information Criterion (AIC) value for each analysis was considered as the best fitting one and retained (Zuur et al. 2009). The analyses were carried out with SPSS 25 (IBM Corp. 2017).

Botanical data were classified by hierarchical cluster analysis, in order to assign each vegetation survey to a specific vegetation type. The cluster analysis was performed using Past 4.01 software (Hammer et al. 2001), by setting Pearson's correlation coefficient to calculate the similarity matrix and the paired group UPGMA as agglomeration method for the between-group linkage. A χ^2 test with Yate's correction for small samples was carried out to assess if each vegetation type was significantly associated to BPA or to CMG using SPSS 25.

An indicator species analysis was carried out to identify the indicator species significantly associated to BPA and CMG (Dufrêne and Legendre 1997). The analysis was carried out with R software (R Core Team 2019) using 'multipatt' function in 'indicspecies' package (De Cáceres and Legendre 2009; De Cáceres et al. 2010).

Results

A total of 389 plant species, belonging to 28 different phytosociological classes, was found during the vegetation surveys (Online Resource 1). Among them, 59 and 81 species were found exclusively within BPA and CMG (corresponding to 60.3 and 80.4 species as estimated true species richness calculated with Chao 2 estimator; Chao 1987), respectively. Average plant diversity (per 50 m^2) was higher in BPA than in CMG, in terms of both species richness and Shannon index, while no difference in species evenness was detected (Table 2).

The BPA were steeper and located at higher elevations and were characterised by significantly lower soil nutrient content, mowing tolerance, and pastoral value than CMG (Table 3). Contrarily, no differences in southness, precipitation, and soil moisture were detected between management regimes.

The BPA were characterised by a higher number of shrubland–woodland, edge, and pasture species (Table 4). In most of the cases, the cover of the species belonging to these groups was also significantly higher in BPA than in CMG. Ruderal species number and cover, instead, were higher in CMG. Dry meadow species number and cover were higher in BPA, while nutrient-rich meadow species were higher in CMG, but only in terms of

Table 2 Differences between conventionally managed grasslands (CMG) and Biodiversity Promotion Areas (BPA) in terms of plant diversity indexes (mean ± standard error of the mean)

	CMG	BPA	
Species richness	36.6 ± 0.73	**44.8 ± 1.30**	***
Shannon index	4.2 ± 0.03	**4.5 ± 0.05**	***
Species evenness	0.8 ± 0.00	0.8 ± 0.01	ns

When significant differences are present, highest values are highlighted in bold

***$p < 0.001$; ns, $p \geq 0.05$

Table 3 Differences between conventionally managed grasslands (CMG) and Biodiversity Promotion Areas (BPA) in terms of topographic, climatic, ecological, and vegetation characteristics (mean ± standard error of the mean)

	CMG	BPA	
Elevation (m a.s.l.)	784.2 ± 25.45	**1053.8 ± 41.96**	***
Slope (°)	11.4 ± 0.68	**19.8 ± 1.11**	***
Southness (°)	110.3 ± 3.39	113.5 ± 5.73	ns
Precipitation (mm)	1712.2 ± 12.86	1718.9 ± 20.92	ns
Soil moisture	2.7 ± 0.01	2.8 ± 0.02	ns
Soil nutrient content	**3.2 ± 0.03**	2.9 ± 0.04	***
Mowing tolerance	**3.5 ± 0.02**	3.1 ± 0.04	***
Pastoral value	**37.0 ± 0.66**	29.3 ± 0.87	***

When significant differences are present, highest values are highlighted in bold

***$p < 0.001$; ns, $p \geq 0.05$

Table 4 Differences between conventionally managed grasslands (CMG) and Biodiversity Promotion Areas (BPA) in terms of species belonging to different functional groups (mean ± standard error of the mean)

Functional groups	Species number			Species cover (%)		
	CMG	BPA		CMG	BPA	
Rocky species	0.1 ± 0.02	0.2 ± 0.06	ns	0.1 ± 0.05	**0.8 ± 0.32**	**
Terophytic-pioneer species	1.4 ± 0.06	1.4 ± 0.11	ns	10.4 ± 0.74	9.4 ± 1.19	ns
Wetland species	0.0 ± 0.02	0.1 ± 0.06	ns	0.1 ± 0.12	0.3 ± 0.16	ns
Shrubland–woodland species	0.7 ± 0.11	**1.8 ± 0.24**	***	3.9 ± 0.82	8.7 ± 2.06	ns
Heathland species	0.1 ± 0.03	0.2 ± 0.06	ns	0.4 ± 0.23	1.4 ± 0.62	ns
Total edge species	3.5 ± 0.16	**5.1 ± 0.30**	***	23.7 ± 1.67	**34.8 ± 3.36**	**
Dry edge species	2.3 ± 0.11	**3.0 ± 0.19**	**	15.2 ± 1.24	17.9 ± 1.91	ns
Mesophilous edge species	1.3 ± 0.10	**2.1 ± 0.23**	**	8.5 ± 1.02	**16.9 ± 2.82**	**
Total ruderal species	**2.6 ± 0.14**	1.8 ± 0.20	***	**17.1 ± 1.55**	8.5 ± 1.45	**
Annual ruderal species	**1.2 ± 0.08**	0.8 ± 0.11	***	7.0 ± 0.79	4.4 ± 0.98	ns
Perennial ruderal species	**1.4 ± 0.10**	0.9 ± 0.12	**	**10.0 ± 1.22**	4.1 ± 0.89	**
Total pasture species	1.9 ± 0.16	**4.5 ± 0.42**	***	13.3 ± 1.56	**32.2 ± 3.46**	***
Basiphilous pasture species	0.3 ± 0.05	**1.0 ± 0.17**	***	1.0 ± 0.19	**4.1 ± 0.79**	**
Acidophilous pasture species	1.6 ± 0.13	**3.5 ± 0.30**	***	12.3 ± 1.52	**28.1 ± 3.29**	***
Total meadow species	26.0 ± 0.48	**29.2 ± 0.89**	**	**358.2 ± 7.04**	327.2 ± 12.81	**
Dry meadow species	3.8 ± 0.22	**7.0 ± 0.56**	***	28.6 ± 2.22	**58.1 ± 6.17**	***
Nutrient-rich meadow species	22.2 ± 0.39	22.1 ± 0.64	ns	**329.6 ± 7.19**	269.1 ± 13.21	***

When significant differences are present, highest values are highlighted in bold

***$p < 0.001$; **$p < 0.01$; ns, $p \geq 0.05$

species cover. When considering total meadow species, the species number was higher in BPA, whereas the species cover was higher in CMG.

The hierarchical cluster analysis individuated six vegetation types (the complete dendrogram with the classification of the vegetation surveys is reported in Online Resource 2). These vegetation types were identified and named by the respective dominant plant

species: (i) *Dactylis glomerata—Poa trivialis*, (ii) *Festuca rubra* aggr.—*Brachypodium rupestre*, (iii) *Agrostis capillaris*, (iv) *Festuca rubra* aggr., (v) *Arrhenatherum elatius*, and (vi) *Anthoxanthum odoratum*. The χ^2 test reported significant differences among vegetation types (Pearson $\chi^2 = 38.375$; $p < 0.001$), highlighting that only the *F. rubra—B. rupestre* type was more represented in BPA than in CMG, whereas all the other five vegetation types were more frequently found in CMG than in BPA (Table 5).

The number of significant indicator species associated to BPA was higher than that of species associated to CMG (Table 6). Among the species associated to BPA, three of them were exclusively found within these grasslands, namely *Anthyllis vulneraria*, *Potentilla rupestris*, and *Polygonum viviparum*. Moreover, the species significantly related to BPA belonged to a wider range of different functional groups than those of CMG and 28 of them were species belonging to the national list of species of priority interest for biodiversity promotion in agriculture, whereas no species associated to CMG belonged to that list.

Discussion

Vascular plant species diversity

Although previous literature already reported positive effects related to the implementation of BPA for Swiss biodiversity conservation, the present research proved for the first time the effectiveness of this policy measure for the Southern Swiss Alps, a region characterised by different vegetation and socio-economic conditions. Indeed, grasslands managed under the extensive BPA system harboured a higher plant diversity than CMG, both in terms of species richness and Shannon diversity index. In particular, the higher plant species richness within BPA was consistent with previous findings reported for the Northern and Central Eastern Alps by Knop et al. (2006), Dietschi et al. (2007), Kampmann et al. (2008), and Peter et al. (2009). The species richness was comparable among all these studies, even if the extent of vegetation plots and the methodologies used for botanical surveys differed. In addition, the proportion of species with different percentage cover was comparable between BPA and CMG, as highlighted by the not significant evenness index of these

Table 5 Differences between conventionally managed grasslands (CMG) and Biodiversity Promotion Areas (BPA) in the frequencies of occurrence of the six vegetation types resulting from the cluster analysis, in terms of vegetation surveys conducted within each of the two management regimes

Vegetation type	CMG	BPA	χ^2	Sig.
Dactylis glomerata—Poa trivialis	**32**	4	20.3	***
Festuca rubra aggr.—*Brachypodium rupestre*	4	**17**	6.9	**
Agrostis capillaris	**34**	9	13.4	***
Festuca rubra aggr.	**81**	28	24.8	***
Arrhenatherum elatius	**11**	2	4.9	*
Anthoxanthum odoratum	**16**	4	6.1	*
Total	178	64		

The reported species names indicate the most abundant plant species and identifies the related vegetation type. When significant differences are present, highest values are highlighted in bold

***p < 0.001; **p < 0.01; *p < 0.05

Table 6 Significant indicator species for conventionally managed grasslands (CMG) and Biodiversity Promotion Areas (BPA)

Conventionally managed grasslands (CMG)			Dry edge species			*Carlina acaulis*	0.249	**
Terophytic-pioneer species			*Cruciata glabra*	0.476	**	*Centaurea scabiosa*	0.361	**
Rumex acetosa	0.725	*	*Lilium bulbiferum*	0.248	*	*Dianthus carthusianorum*	0.441	***
Annual ruderal species			*Polygonatum odoratum*	0.245	**	*Euphorbia cyparissias*	0.425	**
Stellaria media	0.419	*	*Potentilla rupestris*	0.250	**	*Festuca ovina* aggr.	0.467	***
Perennial ruderal species			*Silene nutans*	0.458	**	*Galium pumilum*	0.357	**
Poa angustifolia	0.481	*	Mesophilous edge species			*Helianthemum nummularium*	0.482	***
Rumex obtusifolius	0.487	**	*Fragaria vesca*	0.362	*	*Hieracium pilosella*	0.413	**
Nutrient-rich meadow species			*Hypericum maculatum*	0.333	***	*Hippocrepis comosa*	0.231	*
Achillea millefolium	0.753	***	*Poa chaixii*	0.522	***	*Orchis ustulata*	0.230	*
Arrhenatherum elatius	0.667	**	*Silene dioica*	0.385	*	*Polygala pedemontana*	0.213	*
Cerastium fontanum	0.617	*	*Veratrum album*	0.356	**	*Polygala vulgaris*	0.337	**
Dactylis glomerata	0.736	*	Basiphilous grassland species			*Sanguisorba minor*	0.469	***
Lolium multiflorum	0.384	*	*Acinos alpinus*	0.272	*	*Scabiosa columbaria*	0.513	***
Lolium perenne	0.747	***	*Arabis ciliata*	0.211	*	*Thymus serpyllum* aggr.	0.659	***
Phleum pratense	0.527	*	*Biscutella laevigata*	0.368	***	*Trifolium montanum*	0.463	**
Poa pratensis	0.637	*	*Galium anisophyllon*	0.207	*	Nutrient-rich meadow species		
Poa trivialis	0.693	***	*Helictotrichon parlatorei*	0.282	**	*Agrostis capillaris*	0.682	*
Ranunculus acris	0.688	*	*Myosotis alpestris*	0.229	*	*Alchemilla xanthochlora*	0.607	***
Taraxacum officinale aggr.	0.759	***	*Polygonum viviparum*	0.217	*	*Anthriscus sylvestris*	0.494	***
Trifolium repens	0.790	***	Acidophilous grassland species			*Crocus albiflorus*	0.492	*
			Arnica montana	0.239	*	*Euphrasia rostkoviana*	0.324	**

Table 6 continued

Biodiversity Promotion Areas (BPA)			*Campanula scheuchzeri*	0.333	**	*Festuca rubra* aggr.	0.728	**
Rocky species			*Carex pallescens*	0.464	***	*Gymnadenia conopsea*	0.230	*
Vincetoxicum hirundinaria	0.241	*	*Crepis conyzifolia*	0.210	*	*Helictotrichon pubescens*	0.572	*
Wetland species			*Geum montanum*	0.244	*	*Lathyrus pratensis*	0.477	**
Dactylorhiza maculata aggr.	0.214	*	*Luzula multiflora*	0.223	*	*Lotus corniculatus*	0.705	***
Shrubland–woodland species			*Nardus stricta*	0.522	***	*Narcissus verbanensis*	0.332	*
Avenella flexuosa aggr.	0.303	***	*Paradisea liliastrum*	0.346	***	*Phleum rhaeticum*	0.461	***
Festuca filiformis	0.351	**	*Phyteuma betonicifolium*	0.564	**	*Rhinanthus alectorolophus*	0.464	*
Fraxinus excelsior	0.210	*	*Poa variegata*	0.425	***	*Stachys officinalis*	0.369	*
Galium rubrum	0.363	**	*Potentilla aurea*	0.282	*	*Tragopogon pratensis*	0.407	*
Lathyrus linifolius	0.390	***	*Potentilla erecta* aggr.	0.604	***	*Trollius europaeus*	0.394	*
Oxalis acetosella	0.214	*	Dry meadow species			*Vicia cracca*	0.586	*
Solidago virgaurea aggr.	0.276	*	*Anthyllis vulneraria*	0.250	**	*Viola tricolor*	0.557	**
Veronica officinalis	0.268	**	*Brachypodium rupestre*	0.626	***			
Heathland species			*Briza media*	0.601	***			
Carex pilulifera	0.300	**	*Bromus erectus*	0.393	*			

For each species, the indicator value and the significance level according to indicator species analysis are reported

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

vegetation communities, whose values were extremely comparable to the ones measured by Peter et al. (2009).

Climatic, topographic, ecological, and vegetation characteristics

Compared to CMG, the BPA were characterised by steeper slopes and higher elevations. These topographical characteristics are consistent with the ones assessed by Kampmann et al. (2008) for 12 different municipalities in Northern and Central-Eastern Alps, who also found BPA to be placed in more remote sites, located on average 300 m above CMG and on more severe slopes as well. Conversely, Dietschi et al. (2007) did not find significant differences on slope, elevation, and accessibility from farmyard sites between BPA and CMG in the valleys of Albula and Surses, in the Eastern part of Switzerland. These results highlighted the remarkable local and regional differences, likely determined by different

farm distributions and holding structures, linked to socio-economic conditions and cultural heritages (Bätzing and Bartaletti 2005; Zabel 2019). However, slope and elevation are generally considered as driving forces of management intensity in mountain landscapes, since both factors are strongly related to the pedo-climatic conditions determining forage yield potential and thus the labour necessary for grassland management (Mottet et al. 2006). Kleijn and van Zuijlen (2004) pointed out the preference by farmers for the enrolment of more extensive areas in agri-environmental schemes. In that perspective, the institution of BPA proved to be an effective policy measure, since it encouraged the extensive management of the most marginal sites, which are those more subjected to agro-pastoral abandonment, above all in regions facing a stronger reduction in the number of farms, agricultural employees, and livestock units (Orlandi et al. 2016). This is particularly the case of the Ticino Canton, in which grassland cover decreased by 18% in the period 1979–2018 (against a slight increase of + 1% at a national level in the same period), due to the dramatic reduction in the number of cattle (− 44%), sheep (− 50%), and goats (− 38%) reared (data referred to 1996–2018 period; UST 2018b).

Conversely to slope and elevation, the BPA did not differ from CMG in terms of soil moisture indicator, precipitation, and southness, with the latter variable being consistent with the results of Kampmann et al. (2008). Altogether, these three variables highlighted that dryer ecological conditions were not associated to any specific management regime in the studied region. Therefore, we can exclude that the higher plant diversity measured within BPA was related to ecological conditions favouring the development of dry grasslands, since it is well known that dry grasslands generally harbour the highest plant diversity, as measured also by Dietschi et al. (2007). Contrarily, the lower intensity at which BPA were managed (i.e. the combined effects of low to null fertilization and low cutting/grazing frequency) may have been the main factor determining the higher plant diversity within those areas. Indeed, the lower soil nutrient content and mowing tolerance of BPA likely resulted from the long-term implementation of these extensive management practices, as well as their lower pastoral value, which is a good proxy of management intensity, as indicated by Pittarello et al. (2018). In this paper, based on a high number of vegetation surveys on alpine grasslands across large environmental and management gradients, the authors identified the values for the Landolt's indicator for soil nutrient content at which plant diversity and pastoral value peak. In the current study, the mean value for this variable within CMG (3.2) was very close to the value identified as peak for pastoral value in the montane and subalpine belts (3.1), while the mean value within BPA (2.9) was in between the values identified as peaks for plant diversity (2.5–2.6) and pastoral value (3.1), respectively. Therefore, in the Southern Swiss Alps, the BPA had a soil nutrient content ideal to provide both good forage quality and plant diversity levels, not so far from to the maximum values that can be found for alpine grasslands. A further prolongation of the implementation the BPA scheme in the future years within these grasslands would probably allow to reduce soil nutrient content levels and increasing vascular plant diversity as a consequence.

Vegetation types, functional groups, and plant species

The BPA were characterised by a larger proportion of species belonging to nutrient-poor (i.e. pasture species) and pre-forest (i.e. shrubland–woodland and edge species) vegetation communities than CMG, highlighting that these grasslands were characterised by a less productive vegetation, with several species typical of ecotones and forest-transition zones.

At the opposite, CMG hosted a greater proportion of fast-growing and productive species, including nutrient-rich meadow species and ruderal species, an expected result for grasslands characterised by intensive cut/grazing and fertilisation regimes (Hejcman et al. 2012). Considering vegetation types, *F. rubra—B. rupestre* type was the only one significantly associated to BPA. It is worth mentioning that *B. rupestre* is a summer drought stress tolerant tall-grass encroaching mountain grasslands when agro-pastoral management is strongly reduced and/or totally abandoned, causing a sharp decline of biodiversity and forage quality when it becomes dominant within the vegetation community (Cavallero et al. 2007; Bricca et al. 2020; Tardella et al. 2020). However, a regular and extensive disturbance management, such as the cutting/grazing regimes implemented within BPA, is recommended to reduce its dominance and maintain good level of vascular plant diversity (Tardella et al. 2020). Moreover, the regular and extensive BPA disturbance management proved to be efficient in avoiding the risk of natural succession towards communities dominated by tree and shrub species, as indicated by the low number and cover of typical shrubland–woodland and heathland species (Table 4).

In their recent study conducted on 942 grasslands across Switzerland, Riedel et al. (2019) concluded that less than a half of the extensive and low-intensive BPA meadows belonged to the vegetation types that have been indicated as conservation targets by the Federal Office for Agriculture (UFAG 2020b), such as *Bromus erectus*-, *Arrhenaterum elatius*-, and *Trisetum flavescens*-dominated communities. Our results confirmed this conclusion, since only very few BPA belonged to these vegetation communities (e.g. those belonging to *Arrhenaterum elatius* type). The main reason lies in the fact that farmers are free to choose which grassland has to be indicated as BPA to have access to direct payments, regardless of site conditions, botanical composition, and thus the potential that a particular grassland has to achieve a specific vegetation community target. This consideration is particularly meaningful for nutrient-rich grasslands characterised by a low species richness, which could be difficulty shifted towards these vegetation targets, above all if a target seed bank is not present (Riedel et al. 2019). At the opposite, when considering the species significantly associated to BPA, 38% of them were species belonging to the national list of species of priority interest for biodiversity promotion in agriculture, whereas no species associated to CMG belonged to that list (Swiss Ordinance 910.13; UFAG 2020b). Moreover, the larger number of functional groups of species related to BPA confirmed the wider environmental heterogeneity of these grasslands, which was noticeable not only at species level, but also in terms of phytosociological syntaxa. Conversely, the species associated to CMG were all typical of more intensive management situations and included a large set of high-palatable grass-legume forage species (e.g. *Lolium perenne*, *L. multiflorum*, *D. glomerata*, *Phleum pratense*, *Poa pratensis*, *Trifolium repens*) or species favoured by very high fertilisation rates (e.g. *Rumex acetosa*, *R. obtusifolius*, *P. trivialis*) and/or disturbance regimes (e.g. *Stellaria media*, *Taraxacum officinale*).

Policy implications and future scenarios

According to the Swiss policy, farmers must manage at least 7% of their agricultural area as BPA to get access to agricultural direct payments. This system resulted to be effective to produce widespread benefits for the conservation of plant diversity at regional scale, as highlighted by our findings. Moreover, the beneficial results produced do not limit exclusively to flora, but they extend to a large number of animal taxa as well, such as

butterflies, grasshoppers and ground-nesting birds, which are favoured by late mowing regimes (Herzog et al. 2005; Knop et al. 2006; Zingg 2018). For this reason, the same principle of identifying a mandatory minimum percentage threshold of agricultural surface that must be managed according to extensive rules by farmers, in order to receive agricultural direct payments, should be encouraged and implemented in other countries as well. However, one of the major limitations of BPA implementation is the lack of precise obligations to farmers for the identification of surfaces eligible for the direct payments. Consequently, grasslands characterised by low plant diversity and/or a botanical composition unfavourable to achieve specific vegetation target goals have been often indicated as BPA. To improve this situation, the agricultural advice services can be an important support, providing both ecological and economic benefits to farmers (Chevillat et al. 2017).

Another possible limitation, in the context of future climate change scenarios, can be a too inflexible obligation on the mowing dates that are indicated for the different altitudinal belts. Indeed, the higher temperatures are determining a shift in grassland plant phenology all over the Alps, resulting in a marked advancement of the mean phenological stages for many species, accounting to 2–3 days every 10 years (Vuffray et al. 2016), and this process is foreseen to accelerate in the next decades, together with an increase of summer droughts, above all in the Southern Swiss Alps (Croci-Maspoli et al. 2018). Consequently, keeping inflexible mowing dates in the next future would probably determine a decrease in the quality of forage deriving from BPA as a result of too advanced phenological stages and a dominance of summer drought stress tolerant grasses of low forage quality, such as *B. rupestre* and typically associated late-flowering tall herbs (Tardella et al. 2020). For this reason, it could also have potential impacts on species community composition, resulting in a lower acceptance of this biodiversity-based scheme by farmers. As a consequence, it appears advisable to provide a more flexible range of mowing dates for the different altitudinal belts, whose indication could be based on the mean phenological stage of a set of key plant or animal species that could be communicated yearly to farmers, in order to take into account climatic interannual variations.

Conclusion

The present study highlighted the beneficial effects produced by Swiss agricultural direct payments in preserving vascular plant diversity at a landscape scale, since they encouraged extensive grassland management regime in the more marginal mountain sites, thus avoiding both agro-pastoral abandonment and intensification. These findings confirmed for the first time within the Southern Swiss Alps the results of previous research conducted over other alpine regions. According to the results of the present study, grasslands managed as 'Biodiversity Promotion Areas' harbour a higher plant diversity, as well as many species of priority interest for biodiversity promotion in agriculture, belonging to a wider range of different vegetation units than conventional managed grasslands. Future adaptations of this effective policy measure appear advisable to better adapt the legislation obligations to the environmental variations determined by forthcoming climatic scenarios.

Author contributions All authors contributed equally to this work.

Data availability The datasets generated and analysed during the current study are available in the Zenodo repository, https://zenodo.org/record/3755786#.XpnUEcgzbIU.

Code availability Not applicable.

Compliance with ethical standards

Conflict of interest Authors disclose all relationships or interests that could have direct or potential influence or impart bias on the work.

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