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Combining fertilisation and mowing as an effective practice to control *Brachypodium rupestre* encroachment in an abandoned grassland of the Alps

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ABSTRACT

In the Alps, grasslands have been the basis for European mountain farming systems for centuries, but nowadays agro-pastoral abandonment is among the major threats to their conservation. Grazing and mowing interruption favours the spread of coarse plants, such as the tall grass *Brachypodium rupestre*, which negatively impacts grassland agroecosystem functions and ultimately leads to grassland degradation. Practices such as nutrient addition (i.e. fertilisation) and biomass removal (i.e. mowing) have been successfully applied in several mountain environments to reverse the degradation process and restore the original species composition. However, in the Alps, experiments combining both practices have been scarce so far. We hypothesised that the benefits of fertilisation and mowing on the species composition of a *B. rupestre* encroached grassland could be maximised by coupling fertilisation (120 kg ha^{-1} N – 80 kg ha^{-1} P_2O_5 – 80 kg ha^{-1} K_2O) and mowing. Treatments were carried out yearly over ten years and data were collected throughout the entire period to study the changes in agronomic performances (i.e. pastoral value and abundance of meso-eutrophic grassland species cover), plant diversity (i.e. species richness and effective number of species), and botanical composition. Fertiliser addition effectively enhanced meso-eutrophic grassland species after five years but did not affect either *B. rupestre* cover or the sward pastoral value. Instead, it slightly reduced the dry grassland species cover, which is considered of conservation interest, and the plant diversity. Mowing successfully reduced *B. rupestre* presence after five years while maintaining the initial dry grassland species cover and overall species diversity as well. However, it did not improve either meso-eutrophic grassland species cover or the pastoral value. The combination of fertilisation and mowing showed the most promising results. It was able to decrease *B. rupestre* cover (- 80 %) in the short term while increasing meso-eutrophic grassland species cover (+ 300 %) and the pastoral value (+ 6.5), without negatively impacting dry grassland species cover and plant diversity. According to our long-term study, combining biomass removal by mowing and nutrient addition by fertilisation can be a suitable strategy to achieve agronomic performances and habitat conservation targets, and successfully restore degraded mountain grasslands in the Alps.

1. Introduction

In the Alps, mountain grasslands are agroecosystems generally composed of secondary semi-natural vegetation shaped by a long history of human use (Hejcman et al., 2013; Poschlod and WallisDeVries, 2002). They have been maintained through centuries mainly to support mountain farming systems (Jäger et al., 2020), but they also provide several other services to society (Bengtsson et al., 2019). For instance, they can host a huge variety of plant and animal species (Nagy et al., 2012) and, for this reason, many grassland vegetation communities are considered priority habitats for biodiversity conservation by the European Union (Habitat Directive 92/43/EEC). Mountain grasslands as well as their multiple services largely depend upon the continuation of long-term agricultural practices such as mowing, grazing, fertilization, and/or their combination, which have been historically applied to provide high-quality forage for farming and prevent the natural

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succession towards scrublands and woodlands (Ignatavičius et al., 2013). However, since the 1950s, they have been increasingly threatened by progressive management reduction and cessation that have occurred in all mountainous regions because of rural population decline and land abandonment (Estel et al., 2015).

The interruption of practices such as mowing and grazing following abandonment is a known driver of vegetation changes and biomass accumulation at early stages of succession, with coarse tall grasses replacing less competitive and stress-tolerant species (Catorci et al., 2011b). After establishment, coarse species tend to dominate the plant community through tall canopies, extensive lateral spread, and abundant litter deposition (Grime, 2006), and by limiting the availability of resources such as light, water, and nutrients, for the other species (Catorci et al., 2011a). This determines changes in community structure and species composition (Bonanomi et al., 2006; Catorci et al., 2014b) that lead to grassland degradation (Tardella et al., 2018) and loss of biodiversity (Bonanomi et al., 2009; Catorci et al., 2011a; Kılıç et al., 2018). Moreover, the spread of coarse species dramatically reduces grassland forage yield and quality (Vitasović Kosić et al., 2014), eventually fostering mountain farming abandonment (Prishchepov, 2020) for the negative effects on both shepherding (Catorci et al., 2014a) and wild herbivore habitat suitability (Corazza et al., 2016).

Brachypodium rupestre (Host) Roem. & Schult. is a very common perennial coarse grass in the Italian peninsula (Bonanomi et al., 2013) that frequently encroaches on species-rich, nutrient-poor, low-managed grasslands in succession towards fringe communities (Gianguzzi et al. 2018). It is a tall (40−70 cm), competitive, stress-tolerant species with a late spring-early summer flowering peak, that predominantly grows on clayey and calcareous soils at a broad range of elevations (0–2000 m a.s.l., thus up to the alpine belt; Pignatti, 1982). The competitive success of *B. rupestre* is mainly due to peculiar plant traits such as plant height, high tiller density and branching frequency (Grime, 2006; Pottier and Evette, 2010), and high clonal growth and integration strategy (De Kroon and Bobbink, 1997). Consequently, at advanced encroached stages, the coalescence of different *Brachypodium* patches often forms nearly mono-dominant tall and dense stands (De Kroon and Bobbink, 1997).

Fertilisation is a management strategy frequently applied to hinder undesired coarse plant encroachment in abandoned grasslands (see for instance, Pecháčková et al., 2010) and prevent soil nutrient depletion where degradation is due to low rather than high management intensities (Schils et al., 2020). Direct application of mineral fertiliser is not a common practice in mountain grasslands due to the harsh topography, which reduces the possibility of mechanisation and determines highly heterogeneous soil features. However, several studies with restoration purposes demonstrated that the increase in soil nutrient content through mineral fertilisation can benefit the non-dominant grasses and forbs, by increasing their competitive ability (Samuil et al., 2018). Also, it may increase eutrophic species cover and, therefore, boost forage yield and quality (Boch et al., 2021). However, to prevent habitat eutrophication, the amount of fertiliser to be used in mountain grasslands should be carefully quantified before application. While intermediate levels of nutrients are known to support both agronomic performances and habitat diversity (Boch et al., 2021; Pittarello et al., 2018), an excess of nitrogen can determine a decrease in forage quality and a loss of diversity and variability over time (Humbert et al., 2016; Samuil et al., 2013). On the other hand, when grassland biomass is removed (especially when mowing), fertiliser inputs are generally required to maintain soil nutrient status (Chapin et al., 1986).

To limit *B. rupestre* and coarse plant encroachment and improve or restore grassland ecosystem services, targeted disturbance regimes of biomass removal can also be applied. Specifically, mowing is considered one of the most appropriate management practices for species-rich grassland conservation and restoration (Tälle et al., 2018), able to decrease the competitive ability, resource acquisition, resource storage, and sexual reproduction of coarse plants (Bricca et al., 2020). Despite it is a non-selective disturbance (Köhler et al., 2005), some species are less tolerant than others due to their reproductive strategy, life form, and life cycle. For instance, Landolt et al. (2010) consider *B. rupestre* as a species with little tolerance to mowing that generally occurs in grasslands mown (or grazed) no more than twice a year and only in the late vegetative season. Also targeted grazing can be adopted for the restoration of *Brachypodium* encroached grassland (Catorci et al., 2014a, 2014b), especially where mowing is difficult due to the harsh mountain environment (heavy slopes, terrain roughness, limited access, etc.). However, many authors advise against livestock feeding on *Brachypodium* species (e.g. Scocco et al., 2013), as they have silica-rich, tough, and hairy leaves, which make the plant poorly palatable to domestic herbivores (Canals et al., 2017).

Fertilisation and mowing positive effects on grassland restoration have been proved also by combining both management practices. Mowing can reduce the dominance of the encroaching species while fertilization can balance that effect by supporting the shoot frequency of other grasses in the upper vegetation layer (Pecháčková et al., 2010). Besides, mowing encourages seed germination by preventing canopy closure and litter accumulation, while fertilisation prevents system impoverishment and supports the growth of valuable forage species (i.e. grasses belonging to meso-eutrophic environments). However, experiments specifically combining mowing and fertilisation to address *B. rupestre* encroachment have been scarce so far in the Alps. In the Apennines (mountain area of Central Italy) instead, Tardella et al. (2020) and Bonanomi et al. (2006) tested respectively the medium-long-term (six years) effects of mowing and the short-term (three years) effects of mowing coupled with nitrogen addition on *B. rupestre* grasslands. Both studies agreed in considering cutting as an option to increase specie richness by encouraging annual species while reducing *B. rupestre* cover. But when considering nitrogen addition, Bonanomi et al. (2006) observed a negative effect of fertilisation on species richness despite a general increase in biomass mainly due to the dominant plants. Fertilisation proved to be effective in enhancing species diversity (mostly annuals) only when coupled with mowing. The combined effect of mowing and fertilisation on *B. rupestre* grasslands was also explored by Susan and Ziliotto (2005) in a two-year trial, the only one carried out in the Alps so far. The authors highlighted the value of nutrient addition (specifically, phosphorus) when aiming to contrast the spread of *B. rupestre*, but they confirmed the importance of mowing to accomplish the restoration objective. This study provided noteworthy information about the use of mowing and fertilisation for the restoration of abandoned *B. rupestre* encroached grasslands, but it showed some limitations. Firstly, the authors did not assess the medium-long-term effects of their experiment, which should be instead pursued in mountain environments to disentangle the variations caused by interannual fluctuations (Skálová et al., 2022). Secondly, they mainly focused on the species diversity of grasslands, paying little attention to their agronomic performances, while semi-natural grasslands can preserve or increase their ecological value only if their agronomic performances meet the farm needs in terms of both forage quality and quantity.

In this context, our study aimed at assessing both single and combined effects of mowing and fertilisation on a dry grassland encroached by *B. rupestre* in the North Western Italian Alps. We carried out a long-term experiment, hypothesising that the coupled effect of fertilisation and mowing would be the most effective and balanced treatment to achieve grassland restoration in terms of both agronomic performances and plant diversity. Target variables were measured to evaluate the changes in (i) the cover of the dominant coarse grass *B. rupestre* and of the phytosociological pools of species; (ii) the grassland agronomic performances; (iii) the plant diversity; and (iv) the plant species composition.

2. Materials and methods

2.1. Study area

The study area was located in the North Western Italian Alps, within the 'Gran Bosco di Salbertrand' Natural Park (Ente di Gestione dei Parchi delle Alpi Cozie; WGS84: 45.0567 N, 6.8891 E), at 1360 m a.s.l. with homogeneous slope (25°) and aspect (101°N). The area was characterised by an endalpic continental climate (Ozenda, 1985), with an average annual precipitation of 765 mm, mainly concentrated in spring and autumn, and an average annual temperature of 6.6 °C (1991–2021 average annual values from the nearby 'Salbertrand' and 'Le Selle' weather stations; ARPA, 2022). Soil originated from a calcareous bedrock and could be identified as Inceptisols (Regione Piemonte, 2020). The main soil chemical features of the study area are reported in Table 1 (Italian Ministry of University, Research Program 2005, prot. 2005072127). Major vegetation communities in the surroundings were woodlands dominated by *Abies alba* Mill., *Fagus sylvatica* L., *Larix decidua* Mill., and *Picea abies* (L.) H. Karst. The experiment was carried out on an abandoned secondary grassland that had been extensively grazed by transhumant grazing sheep twice a year until the '60 s on their way to the upper summer pastures (in late spring) and to the lower winter barns (in late summer). Hence, animal dung and urine depositions were then the only soil nutrient source besides atmospheric inputs. The cessation of grazing in the '60 s, i.e. about four decades before the start of the experiment, was part of the widespread abandonment that started in the Alps after the Second World War (e.g. Chauchard et al., 2010). At the time of this study, the grassland was characterised by a species-rich, less nutrient-demanding vegetation belonging to *Festuco-Brometea* phytosociological class (6210 Nat-2000 Habitat, 92/46/EEC Directive) and was dominated by the coarse tall grass *B. rupestre*.

2.2. Experimental design and vegetation transects

The experiment consisted of four treatments: (i) mineral fertilisation (F), i.e. addition of a manufactured commercial fertiliser providing 120 kg ha^{-1} N – 80 kg ha^{-1} P_2O_5 – 80 kg ha^{-1} K_2O by surface broadcasting; (ii) mowing (M), i.e. sward cutting with a brush cutter equipped with a three-teeth iron blade at a height of 5 cm from the soil surface and biomass removal (to simulate the use of a mower for haymaking); (iii) mineral fertilisation coupled with mowing (FM), to assess their combined effect; and (iv) control (C), i.e., no treatments. Our fertilization treatment aimed to replicate the N provision under typical local conditions, supplying the same amount of N as ordinarily managed meadows in the NW Italian Alps receive through fertilization, i.e. 20–25 t ha^{-1} of farm manure (with 5 kg_N t^{-1}). Even if the soil analyses did not evidence shortage of P and K availability, we decided to supply extra amounts of this nutrients to prevent any interaction with N fertilisation, provided as urea. Instead of farm manure, we opted for a mineral fertilizer to maximise control over the supplementation of each element. In a long-term experiment, the use of manure would have hindered the regular provision of elements through years and survey plots due to its wide variability in chemical composition. This variability can be influenced by several factors such as livestock type, age, and diet, amount of bedding or water added to the manure, and manure storage type and duration.

Table 1
Main chemical and physical soil features (average value ± standard error, n=16) of the study area.

Parameter	Unit	Mean ± SE
Sand	%	68.1 ± 1.71
Silt	%	25.3 ± 1.47
Clay	%	6.6 ± 0.53
pH		6.7 ± 0.06
N	g/kg	0.4 ± 0.01
P	mg/kg	19.9 ± 1.33
K	mg/kg	80.3 ± 4.18

The experimental area was divided into 16 survey plots of 2 × 5 m each. Eight fertilised plots were arranged downward in the experimental area to avoid possible leaching and/or runoff toward the non-fertilised plots, which were arranged upward. Four mown and four non-mown plots were randomly distributed among fertilised and not-fertilised treatments, respectively, for a total of four replicates per each of the four treatments (Fig. 1). The treatments were applied yearly, from 2006 to 2015 (i.e. for ten years), in mid-summer after *B. rupestre* flowering.

In 2006, 2007, 2008, 2011, 2013, and 2015, the botanical composition within each plot was assessed before treatment application by applying the vertical point-quadrat method (Daget and Poissonet, 1971) on 25 points along a permanent transect following the vertical axis of symmetry of the plots. At each point (i.e. every 20 cm), the plant species touching a steel needle were identified and recorded. Since occasional species are often missed by this method, a complete list of all other plant species included within each 2 × 5-m plot was also recorded (Mainetti et al., 2023; Pittarello et al., 2019). Nomenclature followed Aeschimann et al. (2004).

2.3. Data analysis

2.3.1. Vegetation variables

Species relative abundance (SRA) of each plant species recorded along the transects was computed by dividing its frequency of occurrence by the sum of the frequencies of occurrence of all species in the transect and by multiplying it by 100 (Pittarello et al., 2019; Ravetto Enri et al., 2021). The SRA can be used to quantify in percentage the proportion of different species occurring along the transect.

The SRA was used to calculate the pastoral value (PV) of the plots, a synthetic value of forage yield and quality based on species composition and abundance (Daget and Poissonet, 1971). To compute the PV of each plot, an index of specific quality (ISQ) was preliminarily attributed to each plant species found along the transect (Cavallero et al., 2007; see Appendix A). The ISQ depends on the productivity, morphology, structure, and palatability of plants, and ranges from 0 (low) to 5 (high). The PV was calculated as follows:

$$PV = \sum_{i=1}^{n} (SRA_i \bullet ISQ_i) \bullet 0.2$$

where SRA_i and ISQ_i are the SRA and the ISQ values for the species *i*, respectively (Cavallero et al., 2007; Pittarello et al., 2020).

To assess the treatment effects on plant diversity, the alpha-diversity (i.e. species richness) and the effective number of species (ENS) were computed per each plot. The ENS is the exponential of the Shannon-Weiner index computed according to Jost (2006) using the SRA as the

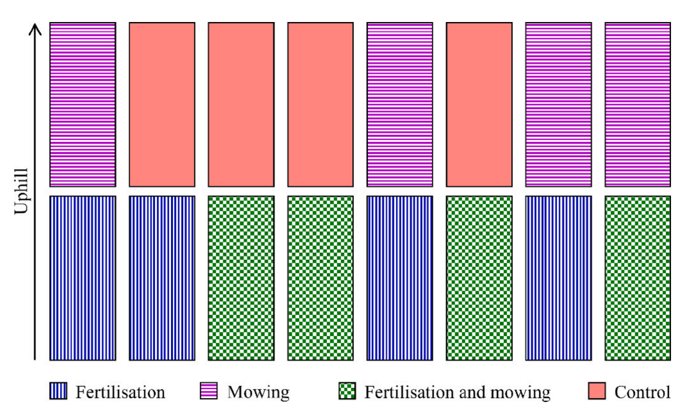

Fig. 1. Experimental design with the treatments applied in the 16 plots of the study area.

abundance term.

The species percentage cover (% SC) was computed for the plant species recorded along each transect by converting the frequency of occurrence to 100 measurements (i.e. by multiplying its value by four; Perotti et al., 2018). A % SC = 0.3 was attributed to all occasional plant species not recorded along the transects (Pittarello et al., 2019; Ravetto Enri et al., 2021). The % SC was preferred to SRA to assess the effects of treatments on species composition because it allows consideration of species overlapping and gives a good representation of the density of the vegetation cover (Gallet and Rozé, 2001). Since the sum of % SC per plot can be greater than 100, it was not possible to use this metric for the calculation of PV and ENS.

The main phytosociological pools of plant species (*viz* social behaviour types, SBT, *sensu* Troiani et al., 2016, and Tardella et al., 2018) were identified with a two-step procedure. Firstly, each plant species was classified according to its phytosociological optimum at the class level, as identified by Aeschimann et al. (2004). Secondly, species belonging to different phytosociological classes with physiognomic, ecological, and floristic similarities were pooled in SBT according to Theurillat et al. (1995). Ten SBT were found (Table 2), but only dry grassland and meso-eutrophic grassland SBT were retained for further analyses, being the most abundant in the study area and the most interesting for the research. The sum of the % SC of the species belonging to these two vegetation units was calculated for each transect to assess changes in the plant diversity over time. Being *B. rupestre* a species belonging to the dry grassland SBT, its % SC was not considered in the calculation of this SBT to avoid a redundant effect.

To visualise the treatment effects compared to control while considering inter-annual variability, all vegetation variables within each treatment and year were transformed into percentage relative variation (RV %) according to the following formula (Bayfield, 1979):

$$RV\,\% = \frac{\overline{X}_{Ty}}{\overline{X}_{Cy}} \bullet cf \bullet 100$$

where $\overline{X}_{Ty}$ is the average value of the variable *X* obtained from the four plots of the treatment *T* at the year *y*; $\overline{X}_{Cy}$ is the average value of the same variable *X* obtained from the four plots of the control at the year *y; cf* is a correction factor computed as follows:

$$cf = \frac{\overline{X}_{Cy0}}{\overline{X}_{Ty0}}$$

where $\overline{X}_{Cy0}$ is the average value of the variable *X* obtained from the four plots of the control at the year 0, i.e. 2006; $\overline{X}_{Ty0}$ is the average value of the variable *X* obtained from the four plots of the treatment *T* at the year 0, i.e. 2006. The RV % helps to illustrate the temporal variability considering the heterogeneity amongst treatments at the year 0 (Bayfield, 1979; Gallet and Rozé, 2001; Cole and Monz, 2003) and for this reason, it was used to graphically present the data collected during the experiment. Subsequent statistical analyses were run using original data.

Table 2
Social behaviour types (SBT) and corresponding phytosociological optimum at the class level (Aeschimann et al., 2004; Theurillat et al., 1995) of the plant species recorded on the vegetation transects. See Appendix B for the correspondence species-phytosociological optimum-SBT.

Social behaviour type (SBT)	Phytosociological optimum
Annual ruderal	*Stellarietea mediae*
Dry grassland	*Festuco-Brometea*
Fringe	*Epilobietea angustifolii*
	Mulgedio-Aconitetea
	Trifolio-Geranietea sanguinei
Meso-eutrophic grassland	*Molinio-Arrhenatheretea*
Montane-alpine sward	*Elyno-Seslerietea variae*
	Juncetea trifidi
	Nardetea strictae
Perennial ruderal	*Artemisietea vulgaris*
Scree	*Asplenietea trichomanis*
	Thlaspietea rotundifolii
Therophitic	*Koelerio-Corynephoretea*
Woodland	*Carpino-Fagetea sylvaticae*
	Quercetea robori-sessiliflorae
	Vaccinio-Piceetea excelsae
Xerophile scrub	*Rosmarinetea*

2.3.2. Statistical analyses

Prior to conducting the main analyses, we assessed disparities among treatments in 2006 to highlight potential relevant differences testing the following vegetation variables: species richness, ENS, *B. rupestre* % SC, dry grassland % SC, meso-eutrophic grassland % SC, and PV. After checking for normality and homoscedasticity of residuals, we opted for non-parametric Kruskal-Wallis tests for all variables. Then, linear mixed effect models (LMM) were run with the *lme* function included in the *nlme* package (Pinheiro et al., 2007) and used to assess the effects of treatment, year, and their interaction (set as fixed factors) on the above mentioned vegetation variables (set as dependent factors). The plot was considered as random factor to account for repeated measure structure and spatial autocorrelation. Significance of fixed and interacting factors in each model was assessed through *join_tests* function in *emmeans* package (Lenth et al., 2021) and then differences of each treatment versus control, within each year in case of significant interacting effect, were assessed from LMM results. The assumptions of homogeneity of variances, normality, and independence of the residuals were graphically checked. As model residuals were often affected by heteroscedasticity, a weighting function was used to correct the variances in each model, and assumptions were checked again. This variance correction was carried out through the argument *varIdent* in the *lme* function by setting the factor for which heterogeneity of variance of residuals was detected as grouping variable. Spatial autocorrelation of model residuals was also considered using the coordinates of the plot centroids based on a fictive reference system in metres to take into account the actual distance among plots. Both Moran's I and Mantel tests were performed on model residuals and no spatial autocorrelation was ever found. Moran's I tests were carried out with the *Moran.I* function in *ape* package (Paradis and Schliep, 2019) and Mantel tests with *mantel* function in *vegan* package (Oksanen et al., 2020).

Differences in single-plant species composition among treatments and through time were evaluated by performing multivariate analyses on % SC. Data were preliminarily Hellinger-transformed to express species abundances as square-root transformed proportions in each plot. This transformation allows to overcome the double-zeros problem and make species abundances suitable for linear ordination methods, such as principal component analysis (PCA) and principal response curve (PRC) (Legendre and Gallagher, 2001). The transformation was carried out with the *decostand* function in *vegan* package. A constrained method, i.e. PRC, was used to analyse the treatment effects against the control (i.e. control was set as the reference level) conditioned by the effect of time. For this purpose, the PRC treats the year as a covariate and the treatment × year interaction as the explanatory variable. The analysis was carried out with the *prc* function in *vegan* package. PRC axis significance was assessed through 999 restricted permutations. Such permutations were set to preserve the temporal order of years, while plots within years were freely randomised. The permutation scheme was set according to the *how* function in *permute* package (Simpson et al., 2022). Six permutational multivariate analyses of variance (PERMANOVA), one for every year of data, were carried out to assess the differences among treatments and control in terms of species composition. The Hellinger distance (i.e. Euclidean distance on Hellinger-transformed data) was used to calculate the distance matrix. PERMANOVA were performed with the *adonis2* function in *vegan* package and the significance was assessed with 999 free-exchangeable permutations. Differences between each treatment and control were assessed through pairwise comparisons using the *pairwise.adonis* function in *pairwiseAdonis* package (Arbizu, 2017). A transform-based PCA (tb-PCA), an unconstrained ordination method based on pre-transformed species composition data to avoid double-zero problem (Legendre and Gallagher, 2001), was used to analyse the variations in single-plant species composition over the years without a treatment direct effect, as in the case of constrained ordination methods. Therefore, tb-PCA allowed the effects of treatments to be observed indirectly and was used to check whether the results were comparable with the PRC. The tb-PCA was carried out on Hellinger-transformed data with the *rda* function of *vegan* package for each single year dataset. Dry grassland % SC, meso-eutrophic grassland % SC, PV, species richness, and ENS were fitted afterwards onto the tb-PCA ordination plot as passive variables (*envfit* function of *vegan* package; Oksanen et al., 2020) to assess how strongly they were related to the ordination axes. Significance of such relationships was tested through 999 permutations.

Statistical analyses were carried out in R, version 4.1.2 (R Core Team, 2021). For all analyses, the level of significance was set at 0.05.

3. Results

A total of 104 plant species was found in the experimental area during the ten-year study (see Appendix B for the complete list of species). Among them, 30 species belonged to the dry grassland SBT and 23 to the meso-eutrophic one. The treatments differently impacted *B. rupestre* abundance and grassland vegetation, affecting both grassland agronomic performances (PV and meso-eutrophic grassland % SC) and plant diversity (species richness, ENS, SBT, and single-plant species composition). The preliminary non-parametric Kruskal-Wallis tests conducted on 2006 data revealed no significant differences among treatments for the studied vegetation variables.

The % SC of *B. rupestre* significantly changed among treatments and years (Fig. 2a and Table 3), as shown by the significant interaction between these two fixed factors of the LMM. Specifically, M and FM treatments determined a reduction of *B. rupestre* cover since the sixth year after the beginning of the experiment, compared to the control treatment. Differences increased in the last years of the experiment, with the final % SC of *B. rupestre* limited to 50 % and 20 % of the initial values in the M and FM treatments, respectively. Contrarily, the decrease in cover observed in F treatment was not significantly different from the control values.

The dry grassland % SC increased over time in all monitored plots (Table 3) but the differences with initial values were statistically non-significant. When compared to control, the treatments had weak effects on this SBT across the years (Fig. 2b). Nevertheless, a significant difference was observed in F plots at the end of the monitoring period (i.e. in 2015), showing the lowest relative variation determined by this treatment.

Since the sixth year from the beginning of treatment application (i.e. in 2011), the % SC of meso-eutrophic grasslands was significantly higher in F and FM plots, compared to the control ones (Fig. 2c and Table 2). This difference partially decreased in the following years, being non-significant for F treatment in 2013. However, at the end of the experiment (i.e. in 2015), the cover of meso-eutrophic grassland species was more than two-fold of both the initial values recorded in F and FM plots and the final values recorded in the control ones. Oppositely, the % SC of this SBT in M treatment did not significantly differ from control over time.

Concerning PV, both time and treatments, as well as their interaction, determined significant variations in the recorded values (Fig. 3). However, when considering their interaction, the only treatment significantly different from the control was FM, which displayed a

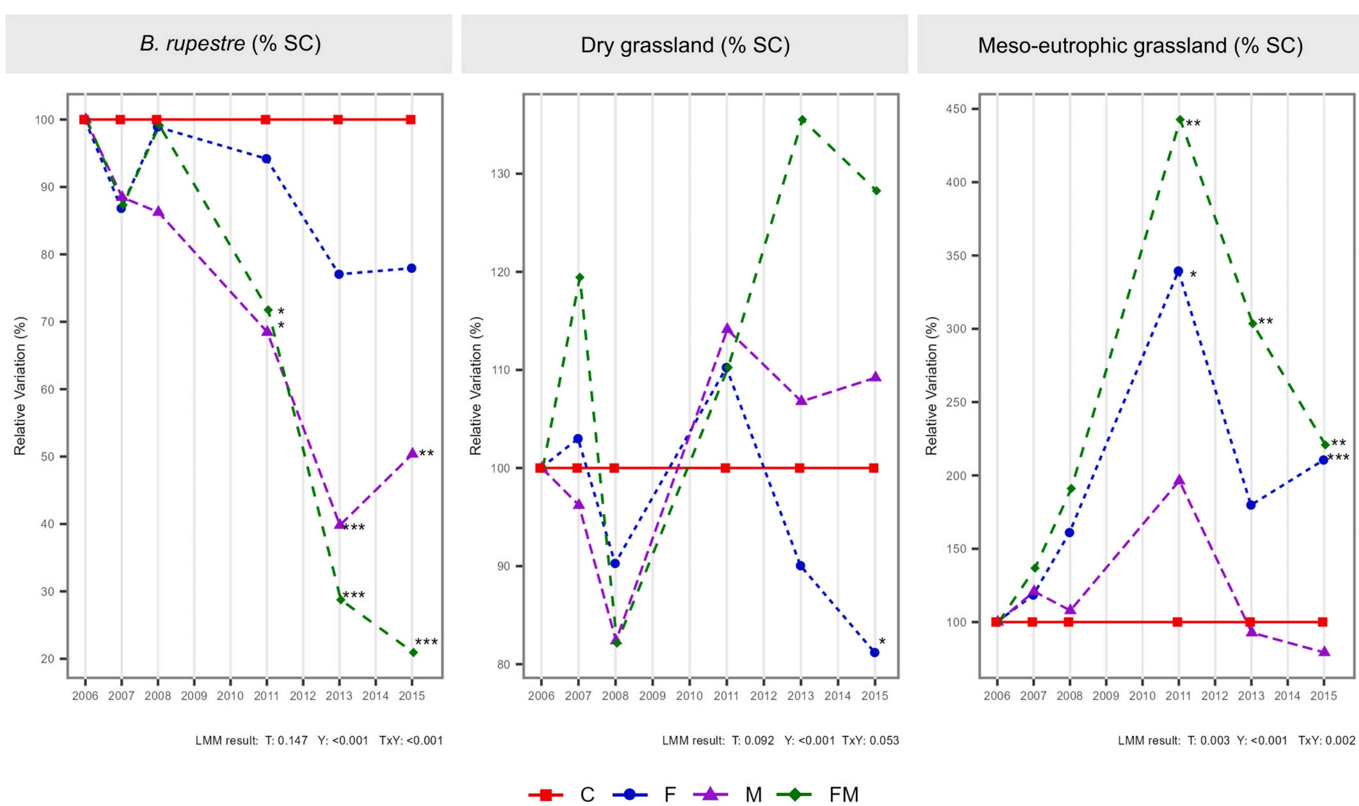

Fig. 2. Percentage relative variation over time of the species percentage cover (% SC) of (a) *Brachypodium rupestre* and (b) dry grassland and (c) meso-eutrophic grassland social behaviour types by treatment (F, fertilised; M, mowed; FM, fertilised and mowed) compared to control (C). Linear mixed models (LMM) results show the main effect of treatment (T), year (Y), and their interaction (T×Y); since significant interactions were found, each significant difference between each treatment and control, within every year, is reported in the figure: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$.

Table 3
Mean values (± standard error) of the variables assessed during the study per year and per each of the four treatments: C, control; F, fertilised; M, mowed; FM, fertilised and mowed. When significant treatment × year interactions were found, significant differences between each treatment and control, within every year, are reported: ***, p < 0.001; **, p < 0.01; *, p < 0.05; ns, p ≥ 0.05. % SC, species percentage cover; PV, pastoral value; ENS, effective number of species.

Variable	Year	Treatment						
		C	F		M		FM	
Brachypodium rupestre % SC								
	2006	69.0 ± 9.85	75.0 ± 6.61		78.0 ± 6.22		87.0 ± 11.70	
	2007	89.0 ± 4.73	84.0 ± 5.66		89.0 ± 4.43		98.0 ± 2.00	
	2008	80.0 ± 4.90	86.0 ± 2.58		78.0 ± 5.29		100.0 ± 0.00	
	2011	84.0 ± 6.73	86.0 ± 3.46	ns	65.0 ± 7.19	*	76.0 ± 7.12	*
	2013	80.0 ± 4.32	67.0 ± 13.70	ns	36.0 ± 12.11	***	29.0 ± 1.00	***
	2015	72.0 ± 4.90	61.0 ± 11.00	ns	41.0 ± 10.50	**	19.0 ± 2.52	***
Dry grassland % SC								
	2006	107.2 ± 15.90	84.9 ± 8.23		124.2 ± 10.94		74.3 ± 16.58	
	2007	155.7 ± 13.41	127.0 ± 24.88		173.6 ± 14.37		128.9 ± 25.10	
	2008	154.1 ± 8.24	110.2 ± 17.87		147.1 ± 17.77		87.7 ± 23.59	
	2011	129.6 ± 8.33	113.2 ± 31.44		171.4 ± 17.65		99.0 ± 14.49	
	2013	120.9 ± 13.56	86.2 ± 27.08		149.6 ± 10.84		113.5 ± 22.36	
	2015	196.0 ± 17.64	126.1 ± 41.47	*	248.0 ± 19.29	ns	174.2 ± 31.44	ns
Meso-eutrophic grassland % SC								
	2006	43.1 ± 4.68	48.8 ± 11.67		32.7 ± 3.15		43.6 ± 4.43	
	2007	53.1 ± 5.74	71.1 ± 26.45		48.6 ± 8.25		73.4 ± 7.06	
	2008	47.2 ± 7.64	86.1 ± 14.79		38.6 ± 9.25		91.2 ± 7.54	
	2011	20.7 ± 6.71	79.4 ± 20.42	*	30.7 ± 6.02	ns	92.4 ± 17.55	**
	2013	31.5 ± 6.26	64.1 ± 9.66	ns	22.1 ± 6.46	ns	96.7 ± 15.79	**
	2015	62.4 ± 9.96	148.6 ± 32.42	***	37.4 ± 19.78	ns	139.2 ± 21.48	**
PV								
	2006	28.4 ± 0.81	29.7 ± 0.73		25.4 ± 1.61		24.7 ± 1.21	
	2007	24.3 ± 1.62	28.3 ± 1.64		24.8 ± 1.74		24.9 ± 0.95	
	2008	21.5 ± 1.83	28.2 ± 1.03	ns	23.5 ± 0.87	ns	26.4 ± 1.39	**
	2011	22.2 ± 1.52	26.6 ± 2.15	ns	22.9 ± 0.97	ns	36.0 ± 1.55	***
	2013	22.7 ± 0.48	23.8 ± 3.48	ns	21.4 ± 1.38	ns	28.7 ± 2.24	**
	2015	25.4 ± 1.20	29.4 ± 1.61	ns	20.9 ± 1.19	ns	31.2 ± 2.79	**
Species richness								
	2006	29.8 ± 2.29	25.0 ± 0.58		30.0 ± 4.02		26.8 ± 1.03	
	2007	41.3 ± 1.93	38.5 ± 1.19		43.8 ± 3.71		43.3 ± 2.29	
	2008	44.8 ± 0.95	41.5 ± 2.18		44.5 ± 1.32		43.5 ± 1.89	
	2011	42.8 ± 1.03	42.5 ± 2.25		47.5 ± 2.18		40.0 ± 1.63	
	2013	45.3 ± 1.75	37.0 ± 2.12		44.8 ± 3.01		43.5 ± 2.22	
	2015	44.5 ± 1.94	34.0 ± 1.58		45.0 ± 3.54		41.3 ± 2.29	
ENS								
	2006	10.9 ± 0.52	8.4 ± 1.03		11.3 ± 1.78		8.8 ± 0.64	
	2007	15.6 ± 0.33	12.5 ± 0.74		16.4 ± 1.84		15.0 ± 0.45	
	2008	17.0 ± 0.86	13.1 ± 0.63		14.4 ± 1.61		15.2 ± 1.53	
	2011	10.4 ± 0.62	12.6 ± 1.24		13.8 ± 0.84		10.4 ± 1.10	
	2013	13.4 ± 1.01	12.6 ± 0.87		14.9 ± 0.73		16.3 ± 1.57	
	2015	14.7 ± 0.61	13.1 ± 0.90		15.8 ± 2.10		14.5 ± 0.59	

greater PV from the third year of treatment application (i.e. 2008). The PV increased within FM from 24.7 in 2006 to 36.0 in 2011 and to 31.2 after ten years of treatment application (Table 2). In contrast, F and M did not determine any significant variation of PV compared to the control plots.

Both diversity indices (i.e. species richness and ENS) were significantly affected by time and treatment but not by their interaction (Fig. 4). Among treatments, F was the only one that significantly differed from the control (Table 2), showing lower values of both species richness (36.4 species in F compared to 41.4 in C) and ENS (12.1 in F compared to 13.7 in C).

The effects of treatments on single-plant species composition evaluated through PRC and PERMANOVA are shown in Fig. 5. The first PRC axis explained 37.1 % of the total variability in species composition (F=13.025; P=0.003), highlighting the significant role of time and treatments in affecting plot species composition. According to PERMANOVA, the species composition of the plots did not differ from each other at the beginning of the experiment (i.e. in 2006). However, significant differences were observed from the second year (i.e. 2007) in the FM treatment and from the third (i.e. 2008) in the F treatment, until the end of the monitoring period. Specifically, an increase in the cover of species with a medium-high forage value and related to meso-eutrophic conditions (e.g. *Dactylis glomerata* L., *Trisetum flavescens* (L.) P Beauv., *Festuca pratensis* Huds.) was observed in FM and F plots over time. On the other hand, no significant differences over time were observed in the M treatment, which only slightly differed from the control because associated with species typical of dry grasslands, with medium to low forage value (e.g. *Festuca ovina* aggr., *Carex caryophyllea* Latourri, *Bromus erectus* Huds.).

The tb-PCA biplots allowed visualising the variability among the four treatments in terms of single-plant species composition across years (Fig. 6, Appendix C). The overlaps of the convex hulls in the 2006 biplot (which accounted for 27.5 % of explained variance) confirmed the similarity of the plots at the beginning of the experiment. Nonetheless, some species showed relationships with one treatment, such as *B. rupestre*, which was more related to FM. During the ten years of treatment application, the four treatments showed an increasing separation among each other along the first principal component, resulting in a clear segregation of FM and F, on one side, from M and C, on the opposite side, in the 2015 biplot. The variance explained by the analysis increased across years as well, up to a total of 28.9 % at the end of the study. The 2015 biplot confirmed the output of PRC and PERMANOVA: FM and F treatments were more related to the already-mentioned meso-eutrophic species and to lower species richness, while M and C were associated to dry grassland species with lower forage quality (e.g. *Briza media* L., *Sanguisorba minor* L., and *Salvia pratensis* L.). However, F plots

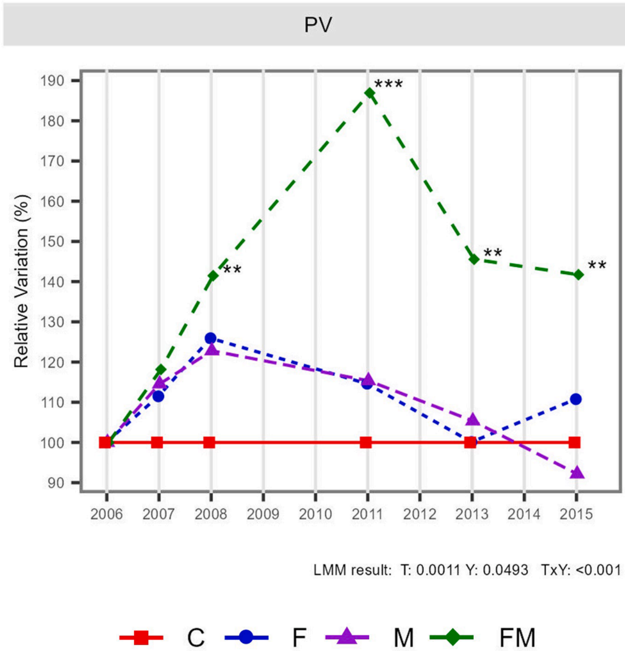

Fig. 3. Percentage relative variation over time of the pastoral value (PV) by treatment (F, fertilised; M, mowed; FM, fertilised and mowed) compared to control (C). Linear mixed models (LMM) results show the main effect of treatment (T), year (Y), and their interaction (T×Y); since a significant interaction was found, each significant difference between each treatment and control, within every year, is reported in the figure: ***, $p < 0.001$; **, $p < 0.01$.

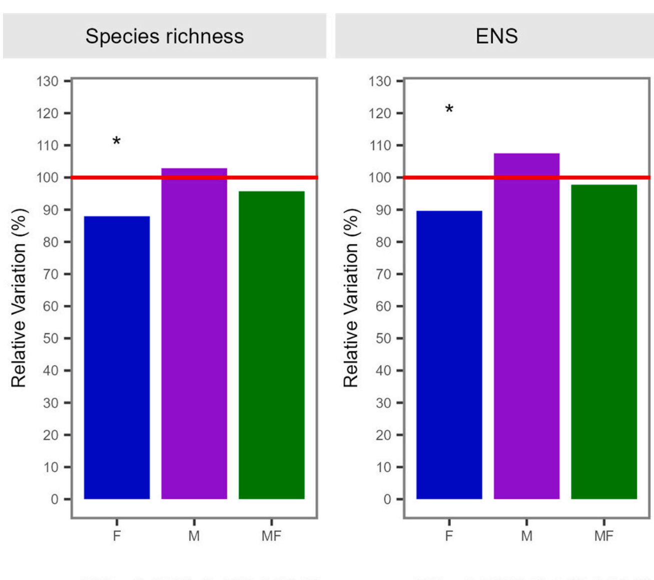

Fig. 4. Percentage relative variation of the overall (a) species richness and (b) effective number of species (ENS) by treatment (F, fertilised; M, mowed; FM, fertilised and mowed) compared to control (red line). Linear mixed models (LMM) results show the main effect of treatment (T), year (Y), and their interaction (T×Y); since a non-significant interaction was found, only the significant differences between each treatment and control (ten-year average values) are reported in the figure: *, $p < 0.05$.

were also characterised by large amounts of nitrophilous and ruderal coarse plants (e.g. *Urtica dioica* L., *Lamium album* L.).

4. Discussion

Our ten-year experiment provides unique information to address *B. rupestre* encroachment in mountain grasslands, showing the differing effectiveness of mowing, fertilisation, and their combination in controlling *B. rupestre* in the Alps. We also demonstrated that the outcomes (i.e. changes in agronomic performances and plant diversity) may differ depending on the practice applied and the duration of application.

As expected (e.g. Samuil et al., 2013), fertiliser addition (F treatment) increased the abundance of meso-eutrophic species in our grassland, but surprisingly, it did not reduce *B. rupestre* cover. This suggests that intermediate fertility levels do not limit the presence of this coarse grass and that further management practices should be implemented to achieve grassland restoration goals. For instance, when studying a Dutch chalk grassland encroached by another *Brachypodium* species (*B. pinnatum*), Smits et al. (2008) suggested that fertilisation had to be associated with biomass removal to balance nutrient inputs and reduce *Brachypodium* abundance. Instead, in the Eastern Italian Alps, Susan and Ziliotto (2005) observed that *B. rupestre* was favoured by the combination of N and K fertilisation with three cuts per year but limited by even small additions of P (54 kg P_2O_5 ha^{-1}). In their study, however, *B. rupestre* cover was particularly low at the beginning of the experiment (less than 10 % compared to 69–87 % in our study) and this may explain the different response of the species to fertilisation. In our experiment, the lack of a significant decrease in *B. rupestre* cover in the fertilised treatment likely hampered also the improvement of forage yield and quality, in terms of PV. Indeed, *B. rupestre* is a dry grassland species that can negatively affect PV because of its low forage quality (IQS = 1; see Appendix A) due to the abundant fibre fractions and poor protein content (Bovolenta et al., 2008; Ravetto Enri et al., 2017). Lastly, nutrient addition partially reduced plant diversity (− 5 species, − 1.5 ENS compared to control plots, on average) while enhancing a few fast-growing grasses shading out the smallest species (Hautier et al., 2009), as often occurs in mountain and dry grassland environments (Boch et al., 2021; Marini et al., 2007; Pavlů et al., 2012). This confirms that fertilisation cannot be proposed for plant diversity conservation in species-rich dry grasslands. Indeed, European environmental policies already discourage high levels of fertiliser or manure distribution in dry grasslands, aiming to protect these habitats from species loss (EUROMONTANA, 2021; Ravetto Enri et al., 2020).

Previous research demonstrated that other management options, particularly biomass removal (i.e. mowing), may successfully limit *Brachypodium* sp. encroachment in mountain dry grasslands. For instance, in Southern Switzerland, Stampfli and Zeiter (1999) proved in a ten-year study that midsummer cutting can reduce *B. pinnatum* competition abilities towards the other species and limit the formation of new shoots from rhizomes. In Central Italy, Tardella et al. (2020, 2018) confirmed the effectiveness of late mowing and litter removal for the control of *B. rupestre* over a six-year time span. Bricca et al. (2020), in similar environments, demonstrated that *B. rupestre* can counterbalance mowing by producing an increased number of seeds, shifting its reproduction from typically agamic (through stolons and rhyzomes) to gamic, but this strategy becomes weaker when the number of cuts increases. In our study, one mowing event per year proved to be successful in reducing *B. rupestre* cover after five years of application, but overall, it weakly affected species composition and quality. Specifically, the abundance of the two SBT (*viz* dry and meso-eutrophic grasslands) did

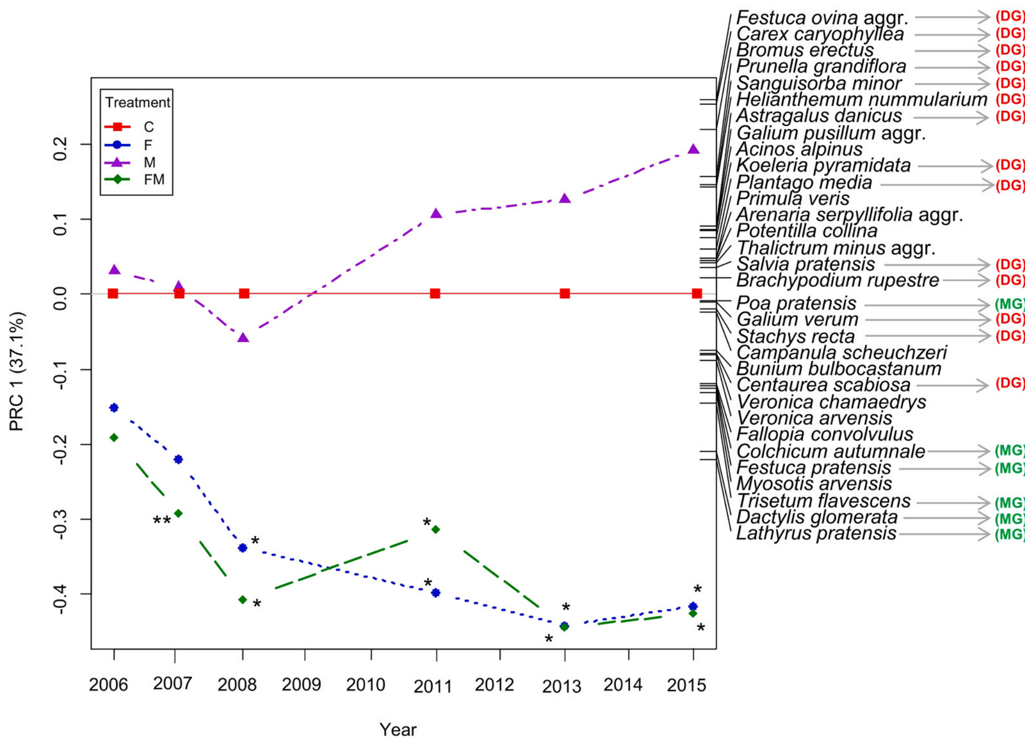

Fig. 5. Principal response curve (PRC) diagram showing the differences over time of single-plant species composition by treatment (F, fertilised; M, mowed; FM, fertilised and mowed) compared to control (C). The most abundant species (average species percentage cover > 2 %) are shown on the right side of the figure: DG, species belonging to dry grassland social behaviour type; MG, species belonging to meso-eutrophic grassland social behaviour type. The variance explained by the first axis of the PRC is reported in brackets. Each significant difference according to PERMANOVA between each treatment and control, within each year, is reported in the figure: **, $p < 0.01$; *, $p < 0.05$.

not differ between treated and untreated plots over time, and no changes were also observed in terms of PV. The ineffectiveness of mowing in increasing high-quality forage species (i.e. meso-eutrophic grassland species) abundance (and therefore, PV), confirmed that these species need other factors, such as a higher soil nutrient content, to increase in cover (see e.g. Berauer et al., 2020). However, a little (even if not significant) increase in dry grassland SBT was observed after five years, as well as in plant diversity (i.e. higher average species richness and ENS), suggesting a weak positive effect on species richness. Also, the species composition of M plots was mostly similar to the control, as highlighted by the multivariate analyses where the two treatments were strongly associated with each other even after ten years of mowing. It is noteworthy to point out that, unlike other studies, our control plots already hosted a remarkable species richness (i.e. more than 30 species) at the beginning of the experiment. For instance, in a *B. rupestre* encroached grassland in the Apennines and on wider plots (25 m^2), Bricca et al. (2021) found less than 20 up to 25 species respectively at the beginning of their study and after ten years of mowing. Thus, even the weak increase in species number observed in our study could be regarded as a positive outcome. Moreover, most of the species enhanced by mowing belonged to the dry grassland SBT (e.g. *Festuca ovina* aggr., *Bromus erectus*, and *Helianthemum nummularium* (L.) Mill). Therefore, even if mowing did not improve the agronomic performances (PV and meso-eutrophic grassland % SC), this treatment can be considered the management practice to apply to restore dry grassland vegetation while contrasting both coarse grasses and shrub and tree species encroachment. Such results confirm the outcomes of previous studies (Canella et al., 2020; Carboni et al., 2015) as well as the need of maintaining traditional mowing for the conservation of species-rich dry grasslands also including 6210$^{(*)}$ habitat (Olmeda et al., 2020).

In our study, the combined application of both fertilisation and mowing showed the most promising results in terms of species composition changes. Firstly, it decreased *B. rupestre* cover over time (as in the fertilised-mown treatment applied by Smits et al. 2008 on *B. pinnatum*), driving it to values below 20 % at the end of the trial. Additionally, it increased the abundance of nutrient-demanding plant species, also characterized by a higher forage quality. Meso-eutrophic grassland species showed the highest values at the end of the experiment, being 3.5-fold more than the initial cover, while the PV significantly increased above 30 only in this treatment. Therefore, we could consider the combination of fertilisation with mowing as an effective practice to achieve the aim of improving grassland agronomic performances, which is a pivotal condition to encourage the permanence and return of farming activities in the Alps (e.g. Sturaro et al., 2013). Concerning plant diversity, our study demonstrated that the combination of nutrient addition with biomass removal can be also effective in preserving the diversity of abandoned grasslands while reaching the goal of enhancing good-quality forage plants. Furthermore, the effectiveness in enhancing grassland agronomic performances became evident in the long term (i.e. from the sixth year of treatment application), highlighting the importance of carrying out long-term experiments in agro-environmental trials (Melts et al., 2018). The effect of fertilisation associated with mowing can be beneficial to species diversity only when complying with the principles of the 'Dynamic Equilibrium Model' (Huston, 1979, 1994), which merges the 'Intermediate Disturbance Hypothesis' (Connell, 1978; Grime, 1973) and the 'Intermediate Stress Hypothesis' (Grime, 1979, 1973). According to this theory, the highest species richness is expected in conditions of low to intermediate frequencies of population reductions (disturbance) and growth rates (negatively related to environmental stress) (Gao and Carmel, 2020; Kammer and Möhl, 2002). In our case, dry grassland species SBT, the most valuable for the conservation purposes of 6210$^{(*)}$ Nat-2000 Habitat, was not negatively affected by fertilisation when coupled with mowing, highlighting the ability of this combined treatment in meeting both goals of enhancing agronomic performances and habitat conservation. This was likely due to a balance in resource inputs-outputs that determined an optimal (i.e.

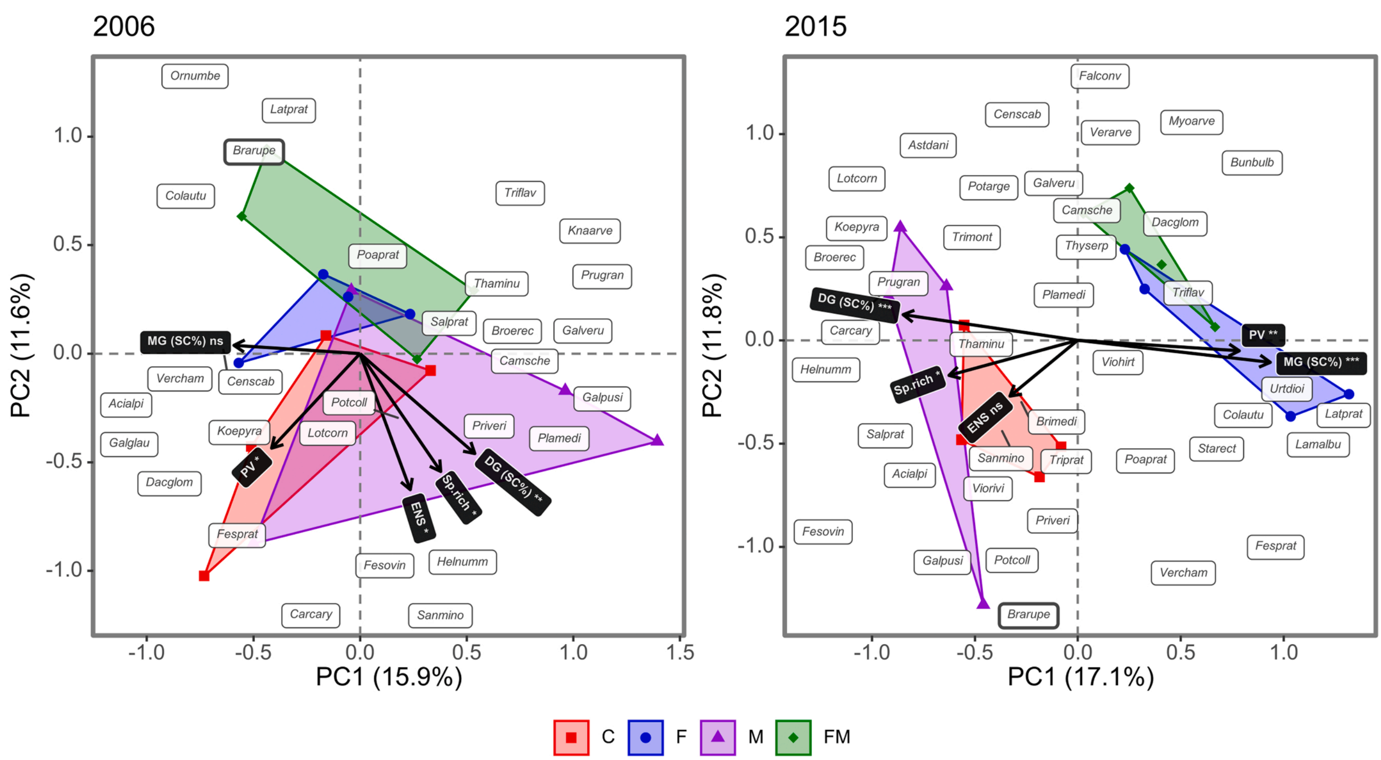

Fig. 6. Transform-based principal component analysis (tb-PCA) biplots highlighting single-plant species distribution at the beginning (2006) and at the end (2015) of the experiment. Only most abundant species (average species percentage cover > 2 %) are highlighted with abbreviations; the complete species names are listed in Appendix B. The variance explained by each axis is reported in brackets. Convex hulls encompass plot coordinates of the four treatments: C, control; F, fertilised; M, mowed; FM, fertilised and mowed. Black arrows indicate the relationships with passive variables: dry grassland (DG), and meso-eutrophic grassland (MG) species cover (% SC), pastoral value (PV), species richness, and effective number of species (ENS). The significance of the relationship of each passive variable with PC 1 and 2 is reported in the figure: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; ns, $p \geq 0.05$.

slight) increase in nutrient availability in the FM treatment compared to the others. Indeed, in F treatment, the input of fertiliser without biomass (and thus nutrient) removal resulted in a high nutrient availability that threatened dry grassland species, while in M treatment the output caused by biomass removal without fertiliser addition resulted in a low nutrient availability that was detrimental for meso-eutrophic grassland species. It is anyway important to point out that different results were achieved by Kotas et al. (2017) in Central Europe when coupling mowing and fertilisation (78 kg ha^{-1} N – 123 kg ha^{-1} P_2O_5 – 123 kg ha^{-1} K_2O) in a meadow dominated by the coarse grass *Molinia caerulea* (L.) Moench. These authors observed that the combination of treatments was not effective in enhancing aboveground biomass production, even after 16 years of treatment implementation. This could be due to the different vegetation community they examined (apparently less sensitive to nutrient addition than our grassland), to different amounts of nutrients supplied (with less N and more P and K than our fertiliser) and/or to different soil nutrient deficiencies. Also, it is known that N is one of the main limiting factors for the development of highly-productive vegetation (Oyarzabal and Oesterheld, 2022). Nonetheless, Kotas et al. (2017) also observed that the combined treatment effectively maintained a high plant species richness, but only in the short term (i.e. four years), and concluded that mowing could only partially prevent the decline of plant species richness caused by fertilization, as previously shown by Lepš (2014).

In our experiment, some slight variations in species composition and the derived variables were also observed in the control plots, where no treatments were applied. This may occur in such long-term studies, where the presence and abundance of some species are not significantly different from those expected by chance, likely driven by stochastic events (i.e. random assemblage) rather than by deterministic processes (see for instance Bricca et al., 2021). Additionally, as observed by Isbell et al. (2015) and Gaisler et al. (2019), grasslands with large amounts of occasional species with SRA < 1 % are more prone to species fluctuation. However, our experiment based on treatments applied for ten consecutive years confirmed the importance of long-term studies for the restoration of abandoned grassland vegetation. Significant changes in vegetation indexes were observed approximately after five years of management simulation, but the effects progressively increased with time. Nevertheless, we expect that the interruption of the treatments and the encroaching ability of *B. rupestre* would likely lead to the pre-experiment condition and we suggest that further and thorough investigations are needed to assess the potential effectiveness of the treatments after their cessation.

Further studies on this research purposes appear still advisable to address thoroughly the investigated topic. Specifically, future trials should consider replicating the experimental approach in additional sites, potentially featuring ecological conditions contrasting those of the present experiment. Additional research should also explore the interaction between restoration treatments and the reproduction strategies of *B. rupestre*, considering its ability to spread through both gamic and agamic strategies. Moreover, evaluating the effectiveness of achieving the restoration purposes here reported could involve the implementation of complementary experimental treatments, such as targeted grazing with hardy livestock species or breeds, eventually combined with those we proposed.

5. Conclusions

Our ten-year experiment provided novel and encouraging results on the long-term application of mowing and fertilisation for the restoration of degraded grasslands in the Alps. Specifically, we demonstrated that the effectiveness of these management practices may significantly change depending on both treatments (i.e. applied solely or combined) and time (i.e. duration of application), thus determining different outcomes in terms of agronomic performance and plant diversity variation. Fertilisation enhanced meso-eutrophic grassland species but did not limit the spread of *B. rupestre*, while did not positively affect pastoral value, plant diversity, and dry grassland species abundance. Therefore, this practice might threaten habitat conservation, with possible degradation of the 6210(*) "Semi-natural dry grasslands and scrubland facies on calcareous substrates" towards the 6520 habitat ("Mountain hay meadows"), characterised by high nutrient-demanding plants. On the other hand, mowing reduced *B. rupestre* without altering the overall species composition and diversity but with weak effects on grassland agronomic performances with a consequent decrease in the interest for implementing this practice when the aim is to improve attractiveness for pastoral management. Definitely, our research showed instead the positive impacts of combining fertilisation and mowing: *B. rupestre* presence was remarkably reduced and the pastoral value was enhanced while habitat conservation was not threatened by the modification of species composition. Dry grassland mowing is generally recommended by European and national policies for the protection of open habitats, while the use of fertilisers (especially if manufactured) is frequently restricted as it can cause eutrophication and decrease species richness. Our research demonstrated that land managers should attentively balance the agroecosystem inputs and outputs to achieve intermediate nutrient levels and maximise grassland forage quality (to meet mountain farm needs) and plant diversity (to preserve grassland natural value).

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CRediT authorship contribution statement

Giampiero Lombardi: Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Michele Lonati:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Simone Ravetto Enri:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Alessandra Gorlier:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Marco Pittarello:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendices A. –C. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agee.2024.109048.

References

Aeschimann, D., Lauber, K., Moser, D.M., Theurillat, J.P., 2004. Flora Alpina: Atlante Delle 4500 Piante Vascolari Delle Alpi. Zanichelli, Bologna, Italy.

Arbizu, P.M., 2017. Pairwiseadonis Pairwise Multilevel Comparison Using Adonis. R package version 0.4.1.

Bayfield, N.G., 1979. Recovery of four montane heath communities on Cairngorm, Scotland, from disturbance by trampling. Biol. Conserv 15, 165–179. https://doi.org/10.1016/0006-3207(79)90038-7.

Bengtsson, J., Bullock, J.M., Egoh, B., Everson, C., Everson, T., O'Connor, T., O'Farrell, P.J., Smith, H.G., Lindborg, R., 2019. Grasslands—more important for ecosystem services than you might think. Ecosphere 10, e02582. https://doi.org/10.1002/ecs2.2582.

Berauer, B.J., Wilfahrt, P.A., Reu, B., Schuchardt, M.A., Garcia-Franco, N., Zistl-Schlingmann, M., Dannenmann, M., Kiese, R., Kühnel, A., Jentsch, A., 2020. Predicting forage quality of species-rich pasture grasslands using vis-NIRS to reveal effects of management intensity and climate change. Agric. Ecosyst. Environ. 296, 106929 https://doi.org/10.1016/j.agee.2020.106929.

Boch, S., Kurtogullari, Y., Allan, E., Lessard-Therrien, M., Rieder, N.S., Fischer, M., Martínez De León, G., Arlettaz, R., Humbert, J.-Y., 2021. Effects of fertilization and irrigation on vascular plant species richness, functional composition and yield in mountain grasslands. J. Environ. Manag. 279, 111629 https://doi.org/10.1016/j.jenvman.2020.111629.

Bonanomi, G., Caporaso, S., Allegrezza, M., 2006. Short-term effects of nitrogen enrichment, litter removal and cutting on a Mediterranean grassland. Acta Oecologica 30, 419–425.

Bonanomi, G., Caporaso, S., Allegrezza, M., 2009. Effects of nitrogen enrichment, plant litter removal and cutting on a species-rich Mediterranean calcareous grassland. Plant Biosyst. 143, 443–455.

Bonanomi, G., Incerti, G., Allegrezza, M., 2013. Assessing the impact of land abandonment, nitrogen enrichment and fairy-ring fungi on plant diversity of Mediterranean grasslands. Biodivers. Conserv. 22, 2285–2304.

Bovolenta, S., Spanghero, M., Dovier, S., Orlandi, D., Clementel, F., 2008. Chemical composition and net energy content of alpine pasture species during the grazing season. Anim. Feed Sci. Technol. 146, 178–191. https://doi.org/10.1016/j.anifeedsci.2008.06.003.

Bricca, A., Tardella, F.M., Ferrara, A., Panichella, T., Catorci, A., 2021. Exploring assembly trajectories of abandoned grasslands in response to 10 years of mowing in sub-mediterranean context. Land 10, 1158.

Bricca, A., Tardella, F.M., Tolu, F., Goia, I., Ferrara, A., Catorci, A., 2020. Disentangling the effects of disturbance from those of dominant tall grass features in driving the functional variation of restored grassland in a sub-mediterranean context. Diversity 12, 11.

Canals, R.M., Emeterio, L.S., Durán, M., Múgica, L., 2017. Plant-herbivory feedbacks and selective allocation of a toxic metal are behind the stability of degraded covers dominated by *Brachypodium pinnatum* in acidic soils. Plant Soil 415, 373–386.

Canella, M., Poloniato, G., Lasen, C., Orsenigo, S., Rossi, G., Müller, J.V., Abeli, T., 2020. Benefits of conservation-driven mowing for the EU policy species Gladiolus palustris Gaudin in mountain fen meadows: a case-study in the European Alps. J. Mt. Sci. 17, 2097–2107. https://doi.org/10.1007/s11629-019-5781-4.

Carboni, M., DengLer, J., MantiLLa-Contreras, J., Venn, S., Török, P., 2015. Conservation value, management and restoration of Europe's semi-natural open landscapes. Hacquetia 14.

Catorci, A., Antolini, E., Tardella, F.M., Scocco, P., 2014a. Assessment of interaction between sheep and poorly palatable grass: a key tool for grassland management and restoration. J. Plant Interact. 9, 112–121.

Catorci, A., Cesaretti, S., Tardella, F.M., 2014b. Effect of tall-grass invasion on the flowering-related functional pattern of submediterranean hay-meadows. Plant Biosyst. Int. J. Deal. Asp. Plant Biol. 148, 1127–1137.

Catorci, A., Cesaretti, S., Gatti, R., Ottaviani, G., 2011a. Abiotic and biotic changes due to spread of Brachypodium genuense (DC.) Roem. & Schult. in sub-Mediterranean meadows. Community Ecol. 12, 117–125.

Catorci, A., Ottaviani, G., Cesaretti, S., 2011b. Functional and coenological changes under different long-term management conditions in Apennine meadows (central Italy). Phytocoenologia 41, 45.

Cavallero, A., Aceto, P., Gorlier, A., Lombardi, G., Lonati, M., Martinasso, B., Tagliatori, C., 2007. I tipi pastorali delle Alpi piemontesi: vegetazione e gestione dei pascoli delle Alpi occidentali. Alberto Perdisa Editore, Bologna, Italy.

Chapin, F.S., Vitousek, P.M., Van Cleve, K., 1986. The nature of nutrient limitation in plant communities. Am. Nat. 127, 48–58. https://doi.org/10.1086/284466.

Chauchard, S., Beilhe, F., Denis, N., Carcaillet, C., 2010. An increase in the upper tree-limit of silver fir (Abies alba Mill.) in the Alps since the mid-20th century: A land-use change phenomenon. For. Ecol. Manag. 259, 1406–1415.

Cole, D.N., Monz, C.A., 2003. Impacts of camping on vegetation: response and recovery following acute and chronic disturbance. Environ. Manag. 32, 693–705.

Connell, J.H., 1978. Diversity in tropical rain forests and coral reefs. Science 199, 1302–1310. https://doi.org/10.1126/science.199.4335.1302.
Corazza, M., Tardella, F.M., Ferrari, C., Catorci, A., 2016. Tall grass invasion after grassland abandonment influences the availability of palatable plants for wild herbivores: insight into the conservation of the Apennine Chamois Rupicapra pyrenaica ornata. Environ. Manag. 57, 1247–1261. https://doi.org/10.1007/s00267-016-0679-1.
Daget, P., Poissonet, J., 1971. Une méthode d'analyse phytosociologique des prairies. Ann. Agron. 22, 5–41.
De Kroon, H., Bobbink, R., 1997. Clonal Plant Dominance under Elevated Nitrogen Deposition, with Special Reference to Brachypodium Pinnatum in Chalk Grassland. in: The Ecology and Evolution of Clonal Plants. Backhuys Publishers, pp. 359–379.
Estel, S., Kuemmerle, T., Alcántara, C., Levers, C., Prishchepov, A., Hostert, P., 2015. Mapping farmland abandonment and recultivation across Europe using MODIS NDVI time series. Remote Sens. Environ. 163, 312–325. https://doi.org/10.1016/j.rse.2015.03.028.
EUROMONTANA, 2021. Overview of Sustainable Practices for the Management of Mountain Grasslands in Europe (Report). European Union, Oreka Mendian.
Gaisler, J., Pavlů, L., Nwaogu, C., Pavlů, K., Hejcman, M., Pavlů, V.V., 2019. Long-term effects of mulching, traditional cutting and no management on plant species composition of improved upland grassland in the Czech Republic. Grass Forage Sci. 74, 463–475. https://doi.org/10.1111/gfs.12408.
Gallet, S., Rozé, F., 2001. Resistance of Atlantic Heathlands to trampling in Brittany (France): influence of vegetation type, season and weather conditions. Biol. Conserv. 97, 189–198.
Gao, J., Carmel, Y., 2020. Can the intermediate disturbance hypothesis explain grazing–diversity relations at a global scale? Oikos 129, 493–502. https://doi.org/10.1111/oik.06338.
Gianguzzi, L., Caldarella, O., Di Pietro, R., 2018. A phytosociological analysis of the Brachypodium rupestre (Host) Roem. & Schult. communities of Sicily. Plant Sociol. 55, 65–88.
Grime, J.P., 1973. Competitive exclusion in herbaceous vegetation. Nature 242, 344–347. https://doi.org/10.1038/242344a0.
Grime, J.P., 1979. Plant Strategies and Vegetation Processes. Wiley, Chichester, UK.
Grime, J.P., 2006. Plant Strategies, Vegetation Processes, and Ecosystem Properties. John Wiley & Sons.
Hautier, Y., Niklaus, P.A., Hector, A., 2009. Competition for light causes plant biodiversity loss after eutrophication. Science 324, 636–638. https://doi.org/10.1126/science.1169640.
Hejcman, M., Hejcmanova, P., Pavl\uu, V., Beneš, J., 2013. Origin and history of grasslands in C entral E urope–a review. Grass forage Sci. 68, 345–363.
Humbert, J.-Y., Dwyer, J.M., Andrey, A., Arlettaz, R., 2016. Impacts of nitrogen addition on plant biodiversity in mountain grasslands depend on dose, application duration and climate: a systematic review. Glob. Change Biol. 22, 110–120.
Huston, M., 1979. A general hypothesis of species diversity. Am. Nat. 113, 81–101.
Huston, M.A., 1994. Biological Diversity: the Coexistence of Species. Cambridge University Press.
Ignatavičius, G., Sinkevičius, S., Ložytė, A., 2013. Effects of grassland management on plant communities. Ekologija 59.
Isbell, F., Craven, D., Connolly, J., Loreau, M., Schmid, B., Beierkuhnlein, C., Bezemer, T. M., Bonin, C., Bruelheide, H., de Luca, E., Ebeling, A., Griffin, J.N., Guo, Q., Hautier, Y., Hector, A., Jentsch, A., Kreyling, J., Lanta, V., Manning, P., Meyer, S.T., Mori, A.S., Naeem, S., Niklaus, P.A., Polley, H.W., Reich, P.B., Roscher, C., Seabloom, E.W., Smith, M.D., Thakur, M.P., Tilman, D., Tracy, B.F., van der Putten, W.H., van Ruijven, J., Weigelt, A., Weisser, W.W., Wilsey, B., Eisenhauer, N., 2015. Biodiversity increases the resistance of ecosystem productivity to climate extremes. Nature 526, 574–577. https://doi.org/10.1038/nature15374.
Jäger, H., Peratoner, G., Tappeiner, U., Tasser, E., 2020. Grassland biomass balance in the European Alps: current and future ecosystem service perspectives. Ecosyst. Serv. 45, 101163 https://doi.org/10.1016/j.ecoser.2020.101163.
Jost, L., 2006. Entropy and diversity. Oikos 113 (2), 363–375.
Kammer, P.M., Möhl, A., 2002. Factors controlling species richness in alpine plant communities: an assessment of the importance of stress and disturbance. Arct., Antarct. Alp. Res. 34, 398–407.
Kılıç, D.D., Kutbay, H.G., Sürmen, B., Hüseyinoğlu, R., 2018. The classification of some plants subjected to disturbance factors (grazing and cutting) based on ecological strategies in Turkey. Rend. Lince. Sci. Fis. e Nat. 29, 87–102.
Köhler, B., Gigon, A., Edwards, P.J., Krüsi, B., Langenauer, R., Lüscher, A., Ryser, P., 2005. Changes in the species composition and conservation value of limestone grasslands in Northern Switzerland after 22 years of contrasting managements. Perspect. Plant Ecol. Evol. Syst. 7, 51–67.
Kotas, P., Choma, M., Šantr\uucková, H., Lepš, J., Tříska, J., Kaštovská, E., 2017. Linking above-and belowground responses to 16 years of fertilization, mowing, and removal of the dominant species in a temperate grassland. Ecosystems 20, 354–367.
Landolt, E., Bäumler, B., Erhardt, A., Hegg, O., Klotzli, F., Lammler, W., Nobis, M., Rudmann-Maurer, K., Schweingruber, F.H., Theurillat, J.-P., Urmi, E., Vust, M., Wohllgemuth, T., 2010. Flora indicativa: ökologische Zeigerwerte und biologische Kennzeichen zur Flora der Schweiz und der Alpen = ecological indicator values and biological attributes of the flora of Switzerland and the Alps. Editions des Conservatoire et Jardin botaniques de la Ville de Genève & HauptVerlag, Bern, Stuttgart, Vienna:
Legendre, P., Gallagher, E.D., 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129, 271–280. https://doi.org/10.1007/s004420100716.
Lenth, R.V., Buerkner, P., Giné-Vázquez, I., Herve, M., Jung, M., Love, J., Miguez, F., Riebl, H., Singmann, H., 2021. emmeans: Estimated Marginal Means, aka Least-Squares Means.
Lepš, J., 2014. Scale-and time-dependent effects of fertilization, mowing and dominant removal on a grassland community during a 15-year experiment. J. Appl. Ecol. 51, 978–987.
Mainetti, A., Ravetto Enri, S., Pittarello, M., Lombardi, G., Lonati, M., 2023. Main Ecological and Environmental Factors Affecting Forage Yield and Quality in Alpine Summer Pastures (NW-Italy, Gran Paradiso National Park). Grass and Forage Science.
Marini, L., Scotton, M., Klimek, S., Isselstein, J., Pecile, A., 2007. Effects of local factors on plant species richness and composition of Alpine meadows. Agric. Ecosyst. Environ. 119, 281–288. https://doi.org/10.1016/j.agee.2006.07.015.
Melts, I., Lanno, K., Sammul, M., Uchida, K., Heinsoo, K., Kull, T., Laanisto, L., 2018. Fertilising semi-natural grasslands may cause long-term negative effects on both biodiversity and ecosystem stability. J. Appl. Ecol. 55, 1951–1955.
Nagy, L., Grabherr, G., Körner, C., Thompson, D.B., 2012. Alpine Biodiversity in Europe. Springer Science & Business Media.
Oksanen, J., Simpson, G.L., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Solymos, P., Stevens, M.H.H., Szoecs, E., Wagner, H., Barbour, M., Bedward, M., Bolker, B., Borcard, D., Carvalho, G., Chirico, M., Caceres, M.D., Durand, S., Evangelista, H.B.A., FitzJohn, R., Friendly, M., Furneaux, B., Hannigan, G., Hill, M.O., Lahti, L., McGlinn, D., Ouellette, M.-H., Cunha, E.R., Smith, T., Stier, A., Braak, C.J.F.T., Weedon, J., 2020. Vegan: Community Ecology Package.
Olmeda, C., Šefferová, V., Underwood, E., Millan, L., Naumann, S., 2020. Action Plan to Maintain and Restore to Favourable Conservation Status the Habitat Type 4030 European Dry Heaths | Ecologic Institute: Science and Policy for a Sustainable World. European Commission, Directorate-General Environment.
Oyarzabal, M., Oesterheld, M., 2022. Assessing multiple limiting factors of seasonal biomass production and N content in a grassland with a year-round production. Oecologia 201 (3), 841–852.
Ozenda, P., 1985. La végétation de la chaîne alpine dans l'espace montagnard européen. Masson, Paris, New York, Barcelona, Milan, Mexico, Sao Paulo.
Paradis, E., Schliep, K., 2019. ape 5.0: an environment for modern phylogenetics and evolutionary analyses in R. Bioinformatics 35, 526–528.
Pavlů, V., Gaisler, J., Pavlů, L., Hejcman, M., Ludvíková, V., 2012. Effect of fertiliser application and abandonment on plant species composition of Festuca rubra grassland. Acta Oecologica 45, 42–49.
Pecháčková, S., Hadincová, V., Münzbergová, Z., Herben, T., Krahulec, F., 2010. Restoration of species-rich, nutrient-limited mountain grassland by mowing and fertilization. Restor. Ecol. 18, 166–174.
Perotti, E., Probo, M., Pittarello, M., Lonati, M., Lombardi, G., 2018. A 5-year rotational grazing changes the botanical composition of sub-alpine and alpine grasslands. Appl. Veg. Sci. 21, 647–657. https://doi.org/10.1111/avsc.12389.
Pignatti, S., 1982. Flora d'Italia. Edagricole, Bologna, Italy.
Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., EISPACK authors, Heisterkamp, S., Van Willigen, B., Johannes, R., R Core Team, 2007. nlme: Linear and Nonlinear Mixed Effects Models.
Pittarello, M., Lonati, M., Ravetto Enri, S., Lombardi, G., 2020. Environmental factors and management intensity affect in different ways plant diversity and pastoral value of alpine pastures. Ecological Indicators 115, 106429.
Pittarello, M., Lonati, M., Gorlier, A., Perotti, E., Probo, M., Lombardi, G., 2018. Plant diversity and pastoral value in alpine pastures are maximized at different nutrient indicator values. Ecol. Indic. 85, 518–524.
Pittarello, M., Probo, M., Perotti, E., Lonati, M., Lombardi, G., Ravetto Enri, S., 2019. Grazing Management Plans improve pasture selection by cattle and forage quality in sub-alpine and alpine grasslands. J. Mt. Sci. 16, 2126–2135. https://doi.org/10.1007/s11629-019-5522-8.
Poschlod, P., WallisDeVries, M.F., 2002. The historical and socioeconomic perspective of calcareous grasslands—lessons from the distant and recent past. Biol. Conserv. 104, 361–376.
Pottier, J., Evette, A., 2010. On the relationship between clonal traits and small-scale spatial patterns of three dominant grasses and its consequences on community diversity. Folia Geobot. 45, 59–75.
Prishchepov, A.V., 2020. Agricultural Land Abandonment. Oxford Bibliographies. Environmental Science.
R Core Team, 2021. R: A Language and environment for statistical computing. R Foundation for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
Ravetto Enri, S., Petrella, F., Ungaro, F., Zavattaro, L., Mainetti, A., Lombardi, G., Lonati, M., 2021. Relative importance of plant species composition and environmental factors in affecting soil carbon stocks of Alpine pastures (NW Italy). Agriculture 11, 1047.
Ravetto Enri, S., Probo, M., Renna, M., Caro, E., Lussiana, C., Battaglini, L.M., Lombardi, G., Lonati, M., 2020. Temporal variations in leaf traits, chemical composition and in vitro true digestibility of four temperate fodder tree species. Anim. Prod. Sci. 60, 643–658.
Regione Piemonte, 2020. Soil Map of the Piedmont Region 1:250.000 [WWW Document]. URL ⟨https://www.geoportale.piemonte.it/geonetwork/srv/ita/catalog.search#/metadata/r_piemon:42ebc0a1-6fc5-433b-9162-fa60322ffa8c⟩ (accessed 7.14.23).
Ravetto Enri, S., Renna, M., Probo, M., Lussiana, C., Battaglini, L.M., Lonati, M., Lombardi, G., 2017. Relationships between botanical and chemical composition of forages: a multivariate approach to grasslands in the Western Italian Alps. J. Sci. Food Agric. 97, 1252–1259. https://doi.org/10.1002/jsfa.7858.

Samuil, C., Stavarache, M., Sirbu, C., Vintu, V., 2018. Influence of sustainable fertilization on yield and quality food of mountain grassland. Not. Bot. Hortic. Agrobot. Cluj. Napoca 46, 410–417. https://doi.org/10.15835/nbha46210660.
Samuil, C., Vintu, V., Sirbu, C., Stavarache, M., 2013. Influence of fertilizers on the biodiversity of semi-natural grassland in the Eastern Carpathians. Not. Bot. Hortic. Agrobot. Cluj. Napoca 41, 195–200. https://doi.org/10.15835/nbha4118363.
Schils, R.L., Newell Price, P., Klaus, V., Tonn, B., Hejduk, S., Stypinski, P., Hiron, M., Fernández, P., Ravetto Enri, S., Lellei-Kovács, E., 2020. European permanent grasslands mainly threatened by abandonment, heat and drought, and conversion to temporary grassland. in: Proceedings of the 28th General Meeting of the European Grassland Federation. Wageningen Academic Publishers, pp. 553–555.
Scocco, P., Mercati, F., Brusaferro, A., Ceccarelli, P., Belardinelli, C., Malfatti, A., 2013. Keratinisation degree of rumen epithelium and body condition score in sheep grazing on Brachypodium rupestre. Vet. Ital. 49, 211–217.
Simpson, G.L., R. Core Team, Bates, D.M., Oksanen, J., 2022. Permute: Functions for Generating Restricted Permutations of Data.
Skálová, H., Hadincová, V., Krahulec, F., Pecháčková, S., Herben, T., 2022. Dynamics of a mountain grassland: environment predicts long-term trends, while species' traits predict short-term fluctuations. J. Veg. Sci. 33, e13138 https://doi.org/10.1111/jvs.13138.
Smits, N. a c, Willems, J. h, Bobbink, R., 2008. Long-term after-effects of fertilisation on the restoration of calcareous grasslands. Appl. Veg. Sci. 11, 279–286. https://doi.org/10.3170/2008-7-18417.
Stampfli, A., Zeiter, M., 1999. Plant species decline due to abandonment of meadows cannot easily be reversed by mowing. A case study from the southern Alps. J. Veg. Sci. 10, 151–164.
Sturaro, E., Thiene, M., Cocca, G., Mrad, M., Tempesta, T., Ramanzin, M., 2013. Factors influencing summer farms management in the Alps. Ital. J. Anim. Sci. 12, e25 https://doi.org/10.4081/ijas.2013.e25.
Susan, F., Ziliotto, U., 2005. Effects of N, P and K fertilisation on *Brachypodium rupestre* ssp. *caespitosum* in a mountain meadow. Integr. Effic. Grassl. Farming Biodivers. 260.
Tälle, M., Deák, B., Poschlod, P., Valkó, O., Westerberg, L., Milberg, P., 2018. Similar effects of different mowing frequencies on the conservation value of semi-natural grasslands in Europe. Biodivers. Conserv. 27, 2451–2475. https://doi.org/10.1007/s10531-018-1562-6.
Tardella, F.M., Bricca, A., Goia, I.G., Catorci, A., 2020. How mowing restores montane Mediterranean grasslands following cessation of traditional livestock grazing. Agric. Ecosyst. Environ. 295, 106880.
Tardella, F.M., Malatesta, L., Goia, I.G., Catorci, A., 2018. Effects of long-term mowing on coenological composition and recovery routes of a Brachypodium rupestre-invaded community: insight into the restoration of sub-Mediterranean productive grasslands. Rend. Lince. Sci. Fis. e Nat. 29, 329–341.
Theurillat, J.P., Aeschimann, D., Küpfer, P., Spichiger, R., 1995. The higher vegetation units of the Alps. Colloq. Phytosociol. 23, 190–239.
Troiani, N., Tardella, F.M., Malatesta, L., Corazza, M., Ferrari, C., Catorci, A., 2016. Long-term cropland abandonment does not lead per se to the recovery of semi-natural herb communities deemed habitats of community interest. Acta Bot. Croat. 75 (2), 226–235.
Vitasović Kosić, I., Tardella, F.M., Grbeša, D., Škvorc, Ž., Catorci, A., 2014. Effects of abandonment on the functional composition and forage nutritive value of a North Adriatic dry grassland community (Ćićarija, Croatia). Appl. Ecol. Environ Res. 12, 285–299.

Appendix A. List of plant species and respective index of specific quality (ISQ) used for the calculation of the pastoral value (PV; Daget and Poissonet, 1971) as reported in Cavallero et al. (2007), updated according to the Executive Decree 01/06/2018 n.638 of Piedmont Region – Bureau of Agricultural and Livestock Productions. Nomenclature follows Pignatti (1982).

Cavallero, A., Aceto, P., Gorlier, A., Lombardi, G., Lonati, M., Martinasso, B., Tagliatori, C., 2007. I tipi pastorali delle Alpi piemontesi: vegetazione e gestione dei pascoli delle Alpi occidentali. Alberto Perdisa Editore, Bologna, Italy.

Daget, P., Poissonet, J., 1971. Une méthode d’analyse phytosociologique des prairies. Annales Agronomiques 22, 5–41.

Pignatti, S., 1982. Flora d’Italia. Edagricole, Bologna, Italy.

Species	ISQ
Abies alba	0
Acer campestre	0
Acer opulifolium	0
Acer platanoides	0
Acer pseudoplatanus	0
Aceras anthropophorum	0
Achillea erba-rotta	0
Achillea macrophylla	1
Achillea millefolium gr.	1
Achillea moschata	0
Achillea nana	0
Achillea stricta	1
Achillea tomentosa	0
Achnatherum calamagrostis	0
Acinos alpinus	0
Acinos arvensis	0
Aconitum anthora	0
Aconitum napellus	0
Aconitum vulparia	0
Adenostyles alliariae	0
Adenostyles glabra	0
Adenostyles leucophylla	0
Adonis annua	0
Adoxa moschatellina	0
Aegopodium podagraria	0
Aetheorrhiza bulbosa	0
Agrimonia eupatoria	0
Agropyron caninum	0
Agropyron intermedium	0
Agropyron repens	0
Agrostis alpina	1
Agrostis canina	2
Agrostis rupestris	1
Agrostis schraderana	2
Agrostis stolonifera	2
Agrostis tenuis	2
Ajuga genevensis	0
Ajuga pyramidalis	0
Ajuga reptans	0
Alchemilla alpina gr.	0
Alchemilla coriacea	1
Alchemilla glabra	1
Alchemilla glaucescens	1
Alchemilla pentaphyllea	1
Alchemilla saxatilis	0
Alchemilla splendens	1
Alchemilla straminea	1

Alchemilla vaccariana	0
Alchemilla vulgaris	2
Alchemilla vulgaris gr.	2
Alchemilla xanthochlora	2
Allium carinatum	0
Allium cirrhosum	0
Allium insubricum	0
Allium lusitanicum	0
Allium narcissiflorum	0
Allium oleraceum	0
Allium schoenoprasum	0
Allium scorodoprasum	0
Allium sp.	0
Allium sphaerocephalon	0
Allium ursinum	0
Allium victorialis	0
Alnus viridis	0
Alopecurus gerardi	1
Alopecurus pratensis	2
Alyssum alpestre	0
Alyssum alyssoides	0
Alyssum montanum	0
Amelanchier ovalis	0
Anacamptis pyramidalis	0
Anagallis arvensis	0
Anagallis foemina	0
Anchusa arvensis	0
Anchusa barellieri	0
Anchusa officinalis	0
Androsace carnea	0
Androsace obtusifolia	0
Androsace villosa	0
Anemone baldensis	0
Anemone narcissiflora	0
Anemone nemorosa	0
Anemone ranunculoides	0
Anemone trifolia	0
Angelica sylvestris	0
Antennaria carpathica	0
Antennaria dioica	0
Anthemis montana	0
Anthericum liliago	0
Anthoxanthum aggr.	1
Anthoxanthum alpinum	1
Anthoxanthum odoratum	1
Anthriscus sylvestris	1
Anthyllis montana	2
Anthyllis vulneraria	2

Antirrhinum latifolium	0
Aphanes arvensis	0
Aquilegia atrata	0
Aquilegia vulgaris	0
Arabidopsis thaliana	0
Arabis allionii	0
Arabis alpina	0
Arabis auriculata	0
Arabis brassica	0
Arabis ciliata	0
Arabis collina	0
Arabis glabra	0
Arabis hirsuta	0
Arabis nova	0
Arabis soyeri	0
Arabis sp.	0
Arctium lappa	0
Arctium minus	0
Arctium nemorosum	0
Arctostaphylos alpinus	0
Arctostaphylos uva-ursi	0
Arenaria biflora	0
Arenaria ciliata	0
Arenaria serpyllifolia gr.	0
Arenaria marschlinsii	0
Arenaria moehringioides	0
Arenaria serpyllifolia	0
Arenaria sp.	0
Aristida gracilis	0
Aristolochia pallida	0
Armeria alpina	0
Armeria plantaginea	0
Arnica montana	0
Arrhenatherum elatius	4
Artemisia absinthium	0
Artemisia campestris	0
Artemisia genipi	0
Artemisia glacialis	0
Artemisia umbelliformis	0
Artemisia vulgaris	0
Asperula aristata	0
Asperula cynanchica	0
Asperula purpurea	0
Asperula rupicola	0
Asphodelus albus	0
Asphodelus microcarpus	0
Asplenium trichomanes	0
Asplenium viride	0

Aster alpinus	0
Aster bellidiastrum	0
Astragalus alpinus	1
Astragalus australis	1
Astragalus cicer	1
Astragalus danicus	1
Astragalus glycyphyllos	0
Astragalus monspessulanus	1
Astragalus onobrychis	1
Astragalus penduliflorus	0
Astragalus purpureus	1
Astragalus sempervirens	0
Astrantia major	0
Astrantia minor	0
Athamanta cretensis	0
Athyrium distentifolium	0
Athyrium filix-foemina	0
Avena fatua	2
Avenella flexuosa	1
Avenula praeusta	1
Avenula pratensis	1
Avenula pubescens	1
Avenula versicolor	1
Ballota nigra	0
Barbarea bracteosa	0
Barbarea intermedia	0
Barbarea vulgaris	0
Bartsia alpina	0
Bellis perennis	1
Berberis vulgaris	0
Betula pendula	0
Bidens tripartita	0
Biscutella gr.	0
Biscutella laevigata	0
Blackstonia perfoliata	0
Blechnum spicant	0
Blysmus compressus	0
Bothriochloa ischaemon	0
Botrychium lunaria	0
Brachypodium aggr.	1
Brachypodium caespitosum	1
Brachypodium rupestre	1
Brachypodium sylvaticum	1
Brassica repanda	0
Briza media	1
Bromus erectus	1.5
Bromus hordeaceus	0
Bromus inermis	3

Bromus rigidus	1
Bromus sterilis	0
Bromus tectorum	1
Buglossoides arvensis	0
Buglossoides purpurocaerulea	0
Bunium bulbocastanum	0
Buphthalmum salicifolium	0
Bupleurum baldense	0
Bupleurum falcatum	0
Bupleurum petraeum	0
Bupleurum ranunculoides	0
Bupleurum stellatum	0
Calamagrostis arundinacea	0
Calamagrostis varia	0
Calamagrostis villosa	0
Calamintha grandiflora	0
Calamintha nepeta	0
Callianthemum coriandrifolium	0
Calluna vulgaris	0
Caltha palustris	0
Camelina microcarpa	0
Camelina sativa	0
Campanula aggr.	0
Campanula alpestris	0
Campanula barbata	0
Campanula cenisia	0
Campanula cochlearifolia	0
Campanula excisa	0
Campanula glomerata	1
Campanula patula	0
Campanula persicifolia	0
Campanula rapunculoides	0
Campanula rhomboidalis	0
Campanula rotundifolia	0
Campanula scheuchzeri	0
Campanula spicata	0
Campanula stenocodon	0
Campanula thyrsoides	0
Campanula trachelium	0
Capsella bursa-pastoris	0
Cardamine amara	0
Cardamine bellidifolia	0
Cardamine impatiens	0
Cardamine resedifolia	0
Cardaminopsis halleri	0
Carduus carlinaefolius	0
Carduus defloratus	0
Carduus defloratus gr.	0

Carduus nutans	0
Carduus sp.	0
Carex alba	0
Carex aterrima	0
Carex atrata	1
Carex bicolor	0
Carex brizoides	0
Carex caespitosa	0
Carex canescens	0
Carex capillaris	0
Carex caryophyllea	0
Carex contigua	1
Carex curvula	0
Carex davalliana	0
Carex digitata	0
Carex dioica	0
Carex divulsa	0
Carex elata	0
Carex elongata	0
Carex ericetorum	0
Carex ferruginea	1
Carex fimbriata	0
Carex firma	0
Carex flacca	1
Carex flava	0
Carex foetida	2
Carex frigida	0
Carex fusca	0
Carex contigua gr.	0.5
Carex ferruginea gr.	1
Carex flava gr.	0
Carex gracilis	0
Carex hirta	1
Carex hostiana	0
Carex humilis	0
Carex irrigua	0
Carex lachenalii	0
Carex lepidocarpa	0
Carex leporina	1
Carex limosa	0
Carex microglochin	0
Carex montana	1
Carex mucronata	0
Carex ornithopoda	0
Carex ornithopodioides	0
Carex pairaei	0
Carex pallescens	1
Carex panicea	0

Carex paniculata	0
Carex parviflora	0
Carex pauciflora	0
Carex pendula	0
Carex pilulifera	0
Carex rosae	0
Carex rostrata	0
Carex rupestris	0
Carex sempervirens	1
Carex stellulata	0
Carex tendae	1
Carex tomentosa	0
Carex tumidicarpa	0
Carex umbrosa	0
Carex vaginata	0
Carlina acaulis	0
Carlina sp.	0
Carlina utzka	0
Carlina vulgaris	0
Carum carvi	1
Castanea sativa	0
Centaurea bracteata	0
Centaurea cyanus	0
Centaurea jacea gr.	0
Centaurea nervosa gr.	0
Centaurea nigra gr.	0
Centaurea triumfetti gr.	0
Centaurea maculosa	0
Centaurea montana	0
Centaurea nervosa	0
Centaurea nigra	0
Centaurea nigrescens	0
Centaurea phrygia	0
Centaurea scabiosa	0
Centaurea triumfetti	0
Centaurea uniflora	0
Centaurium erythraea	0
Cephalanthera longifolia	0
Cephalaria alpina	0
Cerastium alpinum	0
Cerastium arvense gr.	0
Cerastium brachypetalum	0
Cerastium cerastioides	0
Cerastium glomeratum	0
Cerastium holosteoides	0
Cerastium latifolium	0
Cerastium lineare	0
Cerastium pedunculatum	0

Cerastium uniflorum	0
Cerinthe glabra	0
Cerinthe minor	0
Chaerophyllum aureum	0
Chaerophyllum hirsutum	1
Chamaecytisus hirsutus	1
Chamaeorchis alpina	0
Chenopodium bonus-henricus	0
Chondrilla juncea	2
Chrysanthemum coronarium	0
Chrysopogon gryllus	1.5
Cichorium intybus	2
Cirsium acaule	0
Cirsium arvense	0
Cirsium eriophorum	0
Cirsium erisithales	0
Cirsium helenioides	0
Cirsium oleraceum	1
Cirsium palustre	0
Cirsium spinosissimum	0
Cirsium vulgare	0
Clematis vitalba	0
Clinopodium vulgare	0
Coeloglossum viride	0
Colchicum alpinum	0
Colchicum autumnale	0
Conopodium majus	0
Convallaria majalis	0
Convolvulus arvensis	1
Conyza canadensis	0
Coronilla emerus	0
Coronilla minima	0
Coronilla vaginalis	0
Coronilla varia	0
Cortusa matthioli	0
Corydalis solida	0
Corylus avellana	0
Cotoneaster integerrimus	0
Cotoneaster nebrodensis	0
Crataegus monogyna	0
Crataegus oxyacantha	0
Crepis albida	1
Crepis alpestris	1
Crepis aurea	1
Crepis biennis	1
Crepis capillaris	0
Crepis conyzifolia	1
Crepis mollis	0

Crepis paludosa	1
Crepis pontana	0
Crepis pyrenaica	0
Crepis sancta	0
Crepis setosa	0
Crepis sp.	0
Crepis vesicaria	0
Crocus albiflorus	0
Cruciata glabra	0
Cruciata laevipes	0
Cruciata pedemontana	0
Crupina vulgaris	0
Cryptogramma crispa	0
Cuscuta epithymum	0
Cynodon dactylon	0
Cynoglossum officinale	0
Cynosurus cristatus	1
Cynosurus echinatus	1
Cystopteris fragilis	0
Cytisus scoparius	0
Cytisus sessilifolius	0
Dactylis glomerata	5
Danthonia alpina	0
Danthonia decumbens	0
Daphne alpina	0
Daphne cneorum	0
Daphne mezereum	0
Dasypyrum villosum	1
Daucus carota	1
Delphinium dubium	0
Deschampsia caespitosa	1
Dianthus carthusianorum	1
Dianthus deltoides	1
Dianthus furcatus	1
Dianthus neglectus	1
Dianthus seguieri	1
Dianthus sp.	1
Dianthus superbus	1
Dianthus sylvestris	1
Digitalis grandiflora	0
Digitalis lutea	0
Diplotaxis tenuifolia	0
Dipsacus fullonum	0
Doronicum austriacum	0
Doronicum grandiflorum	0
Dorycnium pentaphyllum	1
Draba aizoides	0
Draba hoppeana	0

Draba muralis	0
Draba siliquosa	0
Dryas octopetala	0
Dryopteris affinis	0
Dryopteris dilatata	0
Dryopteris filix-mas	0
Echinops ritro	0
Echinops sphaerocephalus	0
Echium italicum	1
Echium plantagineum	1
Echium vulgare	1
Eleocharis carniolica	0
Eleocharis quinqueflora	0
Elyna myosuroides	0
Empetrum hermaphroditum	0
Epilobium alpestre	0
Epilobium anagallifolium	0
Epilobium angustifolium	0
Epilobium fleischeri	0
Epilobium hirsutum	0
Epilobium montanum	0
Epilobium palustre	0
Epipactis atropurpurea	0
Epipactis helleborine	0
Equisetum arvense	0
Equisetum palustre	0
Equisetum sylvaticum	0
Equisetum variegatum	0
Erica arborea	0
Erica carnea	0
Erigeron acer	0
Erigeron alpinus	0
Erigeron annuus	0
Erigeron atticus	0
Erigeron polymorphus	0
Erigeron uniflorus	0
Eriophorum angustifolium	0
Eriophorum latifolium	0
Eriophorum scheuchzeri	0
Eriophorum vaginatum	0
Eritrichium nanum	0
Erodium cicutarium	0
Erophila verna	0
Erucastrum nasturtiifolium	0
Eryngium campestre	0
Erysimum jugicola	0
Erysimum sp.	0
Erysimum virgatum	0

Erythronium dens-canis	0
Eupatorium cannabinum	0
Euphorbia carniolica	0
Euphorbia cyparissias	0
Euphorbia dulcis	0
Euphorbia flavicoma	0
Euphorbia hyberna	0
Euphrasia alpina	0
Euphrasia hirtella	0
Euphrasia minima	0
Euphrasia picta	0
Euphrasia rostkoviana	0
Euphrasia salisburgensis	0
Euphrasia sp.	0
Euphrasia stricta	0
Fagus sylvatica	0
Festuca alpestris	0
Festuca arundinacea	4
Festuca circummediterranea	1
Festuca curvula	2
Festuca diffusa	2
Festuca dimorpha	1
Festuca flavescens	0
Festuca gigantea	2
Festuca varia gr.	0
Festuca rubra gr.	2.5
Festuca halleri gr.	0
Festuca violacea gr.	1
Festuca halleri	0
Festuca heterophylla	1
Festuca nigrescens	3
Festuca ovina	2
Festuca ovina gr.	1.5
Festuca paniculata	1
Festuca pratensis	4
Festuca puccinellii	1
Festuca quadriflora	0
Festuca rubra	3
Festuca scabriculmis	0
Festuca tenuifolia	2
Festuca trachyphylla	1
Festuca varia	0
Festuca violacea	1
Filipendula ulmaria	0
Filipendula vulgaris	0
Foeniculum vulgare	0
Fragaria vesca	0
Fragaria viridis	0

Frangula alnus	0
Fraxinus excelsior	0
Fraxinus ornus	0
Fritillaria tubaeformis	0
Fumana procumbens	0
Gagea fistulosa	0
Galeopsis ladanum	0
Galeopsis pubescens	0
Galeopsis speciosa	0
Galeopsis tetrahit	0
Galium album	0
Galium anisophyllum	0
Galium aparine	0
Galium baldense	0
Galium boreale	0
Galium corrudifolium	0
Galium divaricatum	0
Galium glaucum	0
Galium baldense gr.	0
Galium lucidum gr.	0
Galium mollugo gr.	0
Galium rubrum gr.	0
Galium laevigatum	0
Galium lucidum	0
Galium megalospermum	0
Galium mollugo	0
Galium obliquum	0
Galium odoratum	0
Galium palustre	0
Galium pseudohelveticum	0
Galium pumilum	0
Galium pusillum	0
Galium pusillum gr.	0
Galium rubrum	0
Galium saxatile	0
Galium sp.	0
Galium tendae	0
Galium verum	0
Genista cinerea	0
Genista germanica	0
Genista pilosa	0
Genista radiata	0
Genista tinctoria	0
Gentiana asclepiadea	0
Gentiana bavarica	0
Gentiana brachyphylla	0
Gentiana clusii	0
Gentiana cruciata	0

Gentiana acaulis gr.	0
Gentiana bavarica gr.	0
Gentiana punctata gr.	0
Gentiana kochiana	0
Gentiana ligustica	0
Gentiana lutea	0
Gentiana nivalis	0
Gentiana pneumonanthe	0
Gentiana punctata	0
Gentiana purpurea	0
Gentiana rostanii	0
Gentiana verna	0
Gentiana villarsii	0
Gentianella aggr.	0
Gentianella campestris	0
Gentianella germanica	0
Gentianella ramosa	0
Gentianella tenella	0
Geranium columbinum	0
Geranium dissectum	0
Geranium molle	1
Geranium nodosum	1
Geranium phaeum	0
Geranium pratense	0
Geranium purpureum	0
Geranium pusillum	0
Geranium pyrenaicum	0
Geranium reflexum	0
Geranium robertianum	0
Geranium rotundifolium	1
Geranium sanguineum	0
Geranium sylvaticum	0
Geum montanum	0
Geum reptans	0
Geum rivale	0
Geum urbanum	0
Gladiolus palustris	0
Glechoma hederacea	0
Globularia cordifolia	0
Globularia punctata	0
Gnaphalium hoppeanum	0
Gnaphalium norvegicum	0
Gnaphalium supinum	0
Gnaphalium sylvaticum	0
Gratiola officinalis	0
Gymnadenia conopsea	0
Gymnocarpium dryopteris	0
Gypsophila repens	0

Hedypnois cretica	0
Hedysarum brigantiacum	1
Hedysarum hedysaroides	1
Helianthemum apenninum	0
Helianthemum nummularium	0
Helianthemum oelandicum	0
Helictotrichon parlatorei	0
Helictotrichon sedenense	0
Helictotrichon sempervirens	0
Helleborus foetidus	0
Helleborus viridis	0
Hepatica nobilis	0
Heracleum sphondylium	1
Herniaria alpina	0
Heteropogon contortus	0
Hieracium alpinum	0
Hieracium aurantiacum	0
Hieracium auricula	1
Hieracium auricula/glaciale	0
Hieracium bifidum	0
Hieracium bupleuroides	0
Hieracium cymosum	0
Hieracium glaciale	0
Hieracium glanduliferum	0
Hieracium intybaceum	0
Hieracium lanatum	0
Hieracium lawsonii	0
Hieracium morisianum	0
Hieracium murorum	0
Hieracium murorum gr.	0
Hieracium pallidum	0
Hieracium panphilii	0
Hieracium peletieranum	0
Hieracium pilosella	0
Hieracium piloselloides	0
Hieracium prenanthoides	0
Hieracium pseudopilosella	0
Hieracium sabaudum	0
Hieracium saussureoides	0
Hieracium sp.	0
Hieracium staticifolium	0
Hieracium sylvaticum	0
Hieracium tenuiflorum	0
Hieracium tomentosum	0
Hieracium umbellatum	0
Hieracium villosum	0
Hieracium x auriculiforme	0
Hippocrepis comosa	1

Hirschfeldia incana	0
Holcus lanatus	1
Holcus mollis	1
Homogyne alpina	0
Hordeum murinum	1
Horminum pyrenaicum	0
Hugueninia tanacetifolia	0
Huperzia selago	0
Hutchinsia alpina	0
Hypericum coris	0
Hypericum humifusum	0
Hypericum maculatum	0
Hypericum montanum	0
Hypericum perforatum	0
Hypericum richeri	0
Hypochoeris maculata	1
Hypochoeris radicata	0
Hypochoeris uniflora	1
Iberis sempervirens	0
Inula hirta	0
Inula salicina	0
Jasione montana	0
Juglans regia	0
Juncus arcticus	0
Juncus articulatus	0
Juncus bulbosus	0
Juncus compressus	0
Juncus conglomeratus	0
Juncus effusus	0
Juncus filiformis	0
Juncus jacquinii	0
Juncus monanthos	0
Juncus sp.	0
Juncus tenuis	0
Juncus trifidus	0
Juncus triglumis	0
Juniperus communis	0
Juniperus nana	0
Knautia arvensis	1
Knautia dipsacifolia	1
Knautia mollis	0
Koeleria cenisia	0
Koeleria hirsuta	1
Koeleria macrantha	1
Koeleria pyramidata	1
Koeleria vallesiana	1
Laburnum alpinum	0
Laburnum anagyroides	0

Lactuca perennis	1
Lactuca serriola	1
Lagurus ovatus	0
Lamiastrum galeobdolon	0
Lamium album	0
Lamium garganicum	0
Lamium maculatum	0
Lamium purpureum	0
Lamium sp.	0
Lapsana communis	0
Larix decidua	0
Laserpitium gallicum	0
Laserpitium halleri	0
Laserpitium krapfii	0
Laserpitium latifolium	0
Laserpitium siler	0
Lathyrus angulatus	1
Lathyrus cicera	1
Lathyrus heterophyllus	1
Lathyrus hirsutus	0
Lathyrus latifolius	1
Lathyrus montanus	1
Lathyrus niger	1
Lathyrus occidentalis	1
Lathyrus pratensis	1
Lathyrus sphaericus	1
Lathyrus sylvestris	1
Lathyrus vernus	1
Lavandula angustifolia	0
Lembotropis nigricans	0
Leontodon autumnalis	1
Leontodon crispus	1
Leontodon helveticus	1
Leontodon hispidus	1
Leontodon montanus	1
Leontodon villarsii	0
Leontopodium alpinum	0
Leopoldia comosa	0
Leucanthemopsis alpina	0
Leucanthemum adustum	0
Leucanthemum ceratophylloides	0
Leucanthemum coronopifolium	0
Leucanthemum atratum gr.	0
Leucanthemum heterophyllum	0
Leucanthemum praecox	0
Leucanthemum vulgare	0
Leucanthemum vulgare gr.	0
Leucojum vernum	0

Leucorchis albida	0
Ligusticum ferulaceum	0
Ligusticum mutellina	1
Ligusticum mutellinoides	0
Lilium bulbiferum	0
Lilium martagon	0
Linaria alpina	0
Linaria angustissima	0
Linaria genistifolia	0
Linaria repens	0
Linaria supina	0
Linum alpinum	0
Linum bienne	0
Linum catharticum	0
Linum suffruticosum	0
Linum tenuifolium	0
Listera ovata	0
Lloydia serotina	0
Loiseleuria procumbens	0
Lolium multiflorum	5
Lolium perenne	5
Lonicera coerulea	0
Lotus alpinus	2
Lotus corniculatus	2
Lotus corniculatus gr.	2
Lotus uliginosus	2
Luzula albida	0
Luzula alpino-pilosa	1
Luzula campestris	0
Luzula campestris gr.	0
Luzula spicata gr.	0
Luzula lutea	0
Luzula luzulina	0
Luzula multiflora	0
Luzula nivea	0
Luzula nutans	0
Luzula pedemontana	0
Luzula sieberi	0
Luzula spicata	0
Luzula sudetica	0
Luzula sylvatica	0
Lychnis flos-cuculi	0
Lychnis flos-jovis	0
Lychnis viscaria	0
Lycopodium annotinum	0
Lycopodium clavatum	0
Lysimachia nummularia	0
Lysimachia vulgaris	0

Lythrum salicaria	0
Maianthemum bifolium	0
Malus domestica	0
Malva moschata	0
Matricaria inodora	0
Medicago lupulina	2
Medicago minima	1
Medicago sativa	5
Melampyrum arvense	0
Melampyrum pratense	0
Melampyrum sylvaticum	0
Melica ciliata	1
Melica nutans	0
Melica uniflora	0
Melilotus alba	0
Melilotus officinalis	0
Mentha arvensis	0
Mentha longifolia	0
Mentha spicata	0
Mercurialis perennis	0
Meum athamanticum	1
Milium effusum	0
Minuartia austriaca	0
Minuartia capillacea	0
Minuartia lanceolata	0
Minuartia laricifolia	0
Minuartia mutabilis	0
Minuartia recurva	0
Minuartia rupestris	0
Minuartia sedoides	0
Minuartia verna	0
Moehringia ciliata	0
Molinia arundinacea	0.5
Molinia coerulea	0
Muscari atlanticum	0
Muscari botryoides	0
Myosotis alpestris	0
Myosotis arvensis	0
Myosotis decumbens	0
Myosotis ramosissima	0
Myosotis scorpioides	0
Myosotis sylvatica	0
Myosoton aquaticum	0
Myrrhis odorata	0
Narcissus poeticus	0
Narcissus radiiflorus	0
Nardus stricta	0
Nasturtium officinale	0

Nepeta nepetella	0
Nigritella corneliana	0
Nigritella nigra	0
Odontites lutea	0
Odontites rubra	0
Onobrychis arenaria	2
Onobrychis montana	3
Onobrychis viciifolia	3
Ononis arvensis	0
Ononis cristata	0
Ononis natrix	0
Ononis repens	0
Ononis rotundifolia	0
Ononis spinosa	0
Onopodium acanthium	0
Onosma fastigiatum	0
Ophrys fuciflora	0
Orchis latifolia	0
Orchis maculata	0
Orchis mascula	0
Orchis militaris	0
Orchis morio	0
Orchis purpurea	0
Orchis sambucina	0
Orchis sp.	0
Orchis tridentata	0
Orchis ustulata	0
Oreochloa disticha	0
Oreochloa seslerioides	0
Origanum vulgare	0
Ornithogalum gussonei	0
Ornithogalum umbellatum	0
Ornithopus compressus	0
Ornithopus pinnatus	0
Orobanche caryophyllacea	0
Orobanche sp.	0
Orthilia secunda	0
Oxalis acetosella	0
Oxalis corniculata	0
Oxyria digyna	0
Oxytropis campestris	1
Oxytropis halleri	1
Oxytropis helvetica	1
Oxytropis jacquinii	1
Oxytropis lapponica	1
Oxytropis pyrenaica	1
Oxytropis sp.	1
Paeonia officinalis	0

Panicum acuminatum	0
Papaver dubium	0
Papaver rhoeas	0
Paradisea liliastrum	0
Paris quadrifolia	0
Parnassia palustris	0
Paronychia polygonifolia	0
Pastinaca sativa	1
Pedicularis adscendens	0
Pedicularis cenisia	0
Pedicularis comosa	0
Pedicularis foliosa	0
Pedicularis gyroflexa	0
Pedicularis kerneri	0
Pedicularis oederi	0
Pedicularis rosea	0
Pedicularis rostrato-spicata	0
Pedicularis sp.	0
Pedicularis tuberosa	0
Pedicularis verticillata	0
Petasites albus	0
Petasites hybridus	1
Petasites paradoxus	0
Petrocallis pyrenaica	0
Petrorhagia saxifraga	0
Petroselinum sativum	0
Peucedanum cervaria	0
Peucedanum officinale	0
Peucedanum oreoselinum	0
Peucedanum ostruthium	0
Phalaris coerulescens	0
Phegopteris polypodioides	0
Phleum alpinum	3
Phleum bertolonii	3
Phleum hirsutum	3
Phleum phleoides	3
Phleum pratense	5
Phyteuma betonicifolium	1
Phyteuma charmelii	0
Phyteuma globularifolium	0
Phyteuma hemisphaericum	0
Phyteuma michelii	1
Phyteuma orbiculare	1
Phyteuma ovatum	1
Phyteuma scheuchzeri	0
Phyteuma scorzonerifolium	1
Phyteuma sieberi	0
Phyteuma spicatum	1

Picea excelsa	0
Picris hieracioides	0
Pimpinella major	1
Pimpinella saxifraga	1
Pinguicula alpina	0
Pinguicula leptoceras	0
Pinguicula vulgaris	0
Pinus cembra	0
Pinus mugo	0
Pinus nigra	0
Pinus sylvestris	0
Pinus uncinata	0
Plantago aggr.	1
Plantago alpina	1
Plantago atrata	1
Plantago coronopus	1
Plantago cynops	0
Plantago fuscescens	2
Plantago lanceolata	2
Plantago major	1
Plantago media	1
Plantago serpentina	1
Platanthera bifolia	0
Platanthera chlorantha	0
Poa alpina	2
Poa annua	0
Poa bulbosa	1
Poa cenisia	0
Poa chaixii	1
Poa compressa	0
Poa glauca	0
Poa laxa	0
Poa minor	0
Poa nemoralis	2
Poa pratensis	3
Poa supina	0
Poa trivialis	2
Poa violacea	0
Polygala alpestris	0
Polygala alpina	0
Polygala amara	0
Polygala amarella	0
Polygala chamaebuxus	0
Polygala comosa	0
Polygala sp.	0
Polygala vulgaris	0
Polygonatum multiflorum	0
Polygonatum odoratum	0

Polygonatum verticillatum	0
Polygonum alpinum	0
Polygonum aviculare	0
Polygonum bistorta	2
Polygonum persicaria	0
Polygonum viviparum	0
Polypodium vulgare	0
Polystichum lonchitis	0
Populus alba	0
Populus tremula	0
Potamogeton pectinatus	0
Potentilla alba	0
Potentilla argentea	0
Potentilla aurea	0
Potentilla brauneana	0
Potentilla caulescens	0
Potentilla collina	0
Potentilla crantzii	0
Potentilla erecta	0
Potentilla frigida	0
Potentilla fruticosa	0
Potentilla grandiflora	0
Potentilla intermedia	0
Potentilla nivea	0
Potentilla pusilla	0
Potentilla recta	0
Potentilla reptans	0
Potentilla rupestris	0
Potentilla tabernaemontani	0
Potentilla thuringiaca	0
Potentilla valderia	0
Prenanthes purpurea	0
Primula auricula	0
Primula elatior	0
Primula farinosa	0
Primula halleri	0
Primula hirsuta	0
Primula latifolia	0
Primula marginata	0
Primula pedemontana	0
Primula veris	1
Primula vulgaris	0
Prunella grandiflora	1
Prunella laciniata	1
Prunella vulgaris	1
Prunus avium	0
Prunus brigantina	0
Prunus domestica	0

Prunus spinosa	0
Psoralea bituminosa	0
Pteridium aquilinum	0
Pulmonaria angustifolia	0
Pulmonaria australis	0
Pulmonaria officinalis	0
Pulsatilla alpina	0
Pulsatilla halleri	0
Pulsatilla vernalis	0
Pyrola minor	0
Pyrola rotundifolia	0
Quercus petraea	0
Quercus pubescens	0
Quercus robur	0
Quercus rubra	0
Ranunculus aconitifolius	0
Ranunculus acris	0
Ranunculus aduncus	0
Ranunculus alpestris	0
Ranunculus bulbosus	0
Ranunculus ficaria	0
Ranunculus friesianus	0
Ranunculus glacialis	0
Ranunculus lanuginosus	0
Ranunculus montanus	0
Ranunculus montanus gr.	0
Ranunculus platanifolius	0
Ranunculus pyrenaeus	0
Ranunculus repens	0
Ranunculus seguieri	0
Ranunculus serpens	0
Ranunculus sp.	0
Ranunculus thora	0
Reichardia picroides	0
Reseda lutea	0
Rhamnus alpinus	0
Rhamnus pumilus	0
Rhinanthus alectorolophus	0
Rhinanthus aristatus	0
Rhinanthus mediterraneus	0
Rhinanthus minor	0
Rhinanthus ovifugus	0
Rhinanthus serotinus	0
Rhodiola rosea	0
Rhododendron ferrugineum	0
Rhynchosinapis richeri	0
Ribes uva-crispa	0
Robinia pseudoacacia	0

Rorippa islandica	0
Rorippa sylvestris	0
Rosa aggr.	0
Rosa canina	0
Rosa gallica	0
Rosa pendulina	0
Rosa pimpinellifolia	0
Rubus aggr.	0
Rubus caesius	0
Rubus idaeus	0
Rubus saxatilis	0
Rubus sp.	0
Rubus ulmifolius	0
Rumex acetosa	0
Rumex acetosella	0
Rumex alpestris	0
Rumex alpinus	0
Rumex crispus	0
Rumex nivalis	0
Rumex obtusifolius	0
Rumex scutatus	0
Rumex tenuifolius	0
Sagina glabra	0
Sagina nodosa	0
Sagina procumbens	0
Sagina saginoides	0
Sagina sp.	0
Salix alba	0
Salix appendiculata	0
Salix breviserrata	0
Salix caesia	0
Salix caprea	0
Salix foetida	0
Salix glaucosericea	0
Salix hastata	0
Salix helvetica	0
Salix herbacea	1
Salix myrsinifolia	0
Salix purpurea	0
Salix reticulata	0
Salix retusa	0
Salix rosmarinifolia	0
Salix serpyllifolia	0
Salvia glutinosa	0
Salvia pratensis	1
Sambucus ebulus	0
Sambucus nigra	0
Sambucus racemosa	0

Sanguisorba minor	1
Sanguisorba officinalis	1
Saponaria lutea	0
Saponaria ocymoides	0
Saponaria officinalis	0
Satureja montana	0
Saussurea alpina	0
Saussurea depressa	0
Saussurea discolor	0
Saxifraga aizoides	0
Saxifraga androsacea	0
Saxifraga aspera	0
Saxifraga biflora	0
Saxifraga bryoides	0
Saxifraga bulbifera	0
Saxifraga caesia	0
Saxifraga cuneifolia	0
Saxifraga exarata	0
Saxifraga moschata gr.	0
Saxifraga lingulata	0
Saxifraga moschata	0
Saxifraga oppositifolia	0
Saxifraga paniculata	0
Saxifraga purpurea	0
Saxifraga rotundifolia	0
Saxifraga seguieri	0
Saxifraga stellaris	0
Saxifraga valdensis	0
Scabiosa columbaria	0
Scabiosa columbaria gr.	1
Scabiosa gramuntia	0
Scabiosa lucida	0
Scabiosa vestita	0
Schoenoplectus mucronatus	0
Scilla bifolia	0
Scirpus sylvaticus	0
Scleranthus annuus	0
Scleranthus perennis	0
Scleranthus polycarpos	0
Scorpiurus muricatus	0
Scorzonera aristata	1
Scorzonera austriaca	1
Scorzonera humilis	1
Scrophularia canina	0
Scrophularia nodosa	0
Scutellaria alpina	0
Sedum acre	0
Sedum album	0

Sedum alpestre	0
Sedum anacampseros	0
Sedum anopetalum	0
Sedum atratum	0
Sedum reflexum gr.	0
Sedum maximum	0
Sedum montanum	0
Sedum rubens	0
Sedum rupestre	0
Sedum sediforme	0
Sedum sexangulare	0
Selaginella helvetica	0
Selaginella selaginoides	0
Sempervivum arachnoideum	0
Sempervivum grandiflorum	0
Sempervivum montanum	0
Sempervivum tectorum	0
Sempervivum wulfenii	0
Senecio capitatus	0
Senecio doronicum	0
Senecio fuchsii	0
Senecio halleri	0
Senecio incanus	0
Senecio jacobaea	0
Senecio viscosus	0
Serratula nudicaulis	0
Serratula tinctoria	0
Seseli annuum	0
Seseli libanotis	0
Sesleria autumnalis	0
Sesleria cylindrica	1
Sesleria tenuifolia	0
Sesleria varia	1
Sibbaldia procumbens	0
Sideritis romana	0
Silene acaulis	0
Silene alba	0
Silene dioica	0
Silene nutans	0
Silene otites	0
Silene rupestris	0
Silene saxifraga	0
Silene vallesia	0
Silene vulgaris	1
Sisymbrium austriacum	0
Soldanella alpina	0
Soldanella pusilla	0
Solidago canadensis	0

Solidago gigantea	0
Solidago virgaurea	0
Sonchus arvensis	2
Sonchus oleraceus	0
Sorbus aria	0
Sorbus aucuparia	0
Sorbus chamaemespilus	0
Spergula arvensis	0
Sphagnum sp.	0
Stachys officinalis	1
Stachys pradica	1
Stachys recta	1
Stachys sylvatica	1
Stellaria graminea	0
Stellaria holostea	0
Stellaria media	0
Stellaria nemorum	0
Stipa johannis	0
Stipa pennata	0
Succisa pratensis	1
Swertia perennis	0
Symphytum officinale	0
Tamus communis	0
Tanacetum vulgare	0
Taraxacum aggr.	1
Taraxacum alpestre	1
Taraxacum alpinum	1
Taraxacum fontanum	1
Taraxacum laevigatum	1
Taraxacum megalorrhizon	1
Taraxacum officinale	2
Taraxacum palustre	1
Taraxacum schroeteranum	1
Tetragonolobus maritimus	1
Teucrium chamaedrys	0
Teucrium lucidum	0
Teucrium montanum	0
Teucrium scorodonia	0
Thalictrum aquilegifolium	0
Thalictrum foetidum	0
Thalictrum gr.	0
Thalictrum minus	0
Thalictrum saxatile	0
Thelypteris limbosperma	0
Thesium alpinum gr.	0
Thesium alpinum gr.	0
Thesium linophyllon	0
Thesium pyrenaicum	0

Thlaspi alpestre	0
Thlaspi brachypetalum	0
Thlaspi montanum	0
Thlaspi perfoliatum	0
Thlaspi praecox	0
Thlaspi rotundifolium	0
Thlaspi sp.	0
Thlaspi sylvium	0
Thymus alpestris	0
Thymus alpigenus	0
Thymus froelichianus	0
Thymus glabrescens	0
Thymus serpyllum gr.	0
Thymus humifusus	0
Thymus polytrichus	0
Thymus praecox	0
Thymus pulegioides	0
Thymus serpyllum	0
Tilia cordata	0
Tofieldia calyculata	0
Torilis nodosa	0
Tragopogon dubius	1
Tragopogon pratensis	1
Traunsteinera globosa	0
Trichophorum caespitosum	0
Trifolium alpestre	2
Trifolium alpinum	2
Trifolium angustifolium	1
Trifolium arvense	1
Trifolium aureum	1
Trifolium badium	2
Trifolium campestre	1
Trifolium fragiferum	2
Trifolium glomeratum	1
Trifolium hirtum	1
Trifolium hybridum	4
Trifolium incarnatum	3
Trifolium medium	2
Trifolium montanum	3
Trifolium nigrescens	2
Trifolium pallescens	1
Trifolium pannonicum	2
Trifolium pratense	4
Trifolium pratense s sp. *nivale*	4
Trifolium pratense s sp. *pratense*	4
Trifolium repens	3
Trifolium rubens	2
Trifolium thalii	1

Triglochin palustre	0
Trinia glauca	0
Trisetum distichophillum	0
Trisetum flavescens	2
Trollius europaeus	0
Tulipa australis	0
Tussilago farfara	0
Typhoides arundinacea	0
Urospermum dalechampii	2
Urtica dioica	0
Vaccinium gaultherioides	0
Vaccinium myrtillus	0
Vaccinium uliginosum	0
Vaccinium vitis-idaea	0
Valeriana celtica	0
Valeriana collina	0
Valeriana officinalis gr.	0
Valeriana montana	0
Valeriana officinalis	0
Valeriana saxatilis	0
Valeriana tripteris	0
Valeriana versifolia	0
Valerianella locusta	0
Valerianella rimosa	0
Veratrum album	0
Verbascum densiflorum	0
Verbascum lychnitis	0
Verbascum nigrum	0
Verbascum thapsus	0
Veronica allionii	0
Veronica alpina	0
Veronica aphylla	0
Veronica arvensis	0
Veronica bellidioides	0
Veronica chamaedrys	0
Veronica fruticans	0
Veronica fruticulosa	0
Veronica fruticans gr.	0
Veronica montana	0
Veronica officinalis	0
Veronica persica	0
Veronica praecox	0
Veronica prostrata	0
Veronica serpyllifolia	0
Veronica teucrium	0
Veronica urticifolia	0
Veronica verna	0
Viburnum lantana	0

Viburnum opulus	0
Vicia atropurpurea	1
Vicia cracca	1
Vicia cracca gr.	1
Vicia hirsuta	1
Vicia hybrida	1
Vicia incana	1
Vicia onobrychioides	1
Vicia sativa	2
Vicia sepium	1
Vicia sp.	1
Vicia tenuifolia	1
Vicia tetrasperma	0
Vicia villosa	2
Vincetoxicum hirundinaria	0
Viola arvensis	0
Viola biflora	0
Viola calcarata	0
Viola canina	0
Viola hirta	0
Viola odorata	0
Viola palustris	0
Viola pinnata	0
Viola pyrenaica	0
Viola reichenbachiana	0
Viola riviniana	0
Viola rupestris	0
Viola sp.	0
Viola suavis	0
Viola thomasiana	0
Viola tricolor	0
Vitaliana primulaeflora	0
Vulpia bromoides	0
Vulpia ciliata	1

Appendix B. List of all plant species found during the ten-year study and relative phytosociological optimum (class level; Aeschimann et al., 2004), social behaviour type (SBT; Theurillat et al., 1995), and abbreviation used in Figure 6 (if relevant). Nomenclature follows Aeschimann et al. (2004).

Plant species	Phytosociological optimum class	Social behaviour type	Abbreviation
Bunium bulbocastanum	Stellarietea mediae	Annual Ruderal	Bunbulb
Fallopia convolvulus	Stellarietea mediae	Annual Ruderal	Falconv
Myosotis arvensis	Stellarietea mediae	Annual Ruderal	Myoarve
Stellaria media	Stellarietea mediae	Annual Ruderal	
Veronica arvensis	Stellarietea mediae	Annual Ruderal	Verarve
Vicia sativa	Stellarietea mediae	Annual Ruderal	
Anthyllis vulneraria	Festuco-Brometea	Dry grasslands	
Artemisia campestris	Festuco-Brometea	Dry grasslands	
Astragalus danicus	Festuco-Brometea	Dry grasslands	Astdani
Brachypodium rupestre	Festuco-Brometea	Dry grasslands	Brarupe
Briza media	Festuco-Brometea	Dry grasslands	Brimedi
Bromus erectus	Festuco-Brometea	Dry grasslands	Broerec
Campanula glomerata	Festuco-Brometea	Dry grasslands	
Carex caryophyllea	Festuco-Brometea	Dry grasslands	Carcary
Centaurea nigrescens	Festuco-Brometea	Dry grasslands	
Centaurea scabiosa	Festuco-Brometea	Dry grasslands	Censcab
Dianthus carthusianorum	Festuco-Brometea	Dry grasslands	
Festuca ovina aggr.	Festuco-Brometea	Dry grasslands	Fesovin
Festuca valesiaca	Festuco-Brometea	Dry grasslands	
Galium verum	Festuco-Brometea	Dry grasslands	Galveru
Helianthemum nummularium	Festuco-Brometea	Dry grasslands	Helnumm
Hieracium cymosum	Festuco-Brometea	Dry grasslands	
Hieracium pilosella	Festuco-Brometea	Dry grasslands	
Koeleria pyramidata	Festuco-Brometea	Dry grasslands	Koepyra
Medicago lupulina	Festuco-Brometea	Dry grasslands	
Onobrychis viciifolia	Festuco-Brometea	Dry grasslands	
Plantago media	Festuco-Brometea	Dry grasslands	Plamedi
Polygala nicaeensis	Festuco-Brometea	Dry grasslands	
Potentilla neumanniana	Festuco-Brometea	Dry grasslands	
Prunella grandiflora	Festuco-Brometea	Dry grasslands	Prugran
Ranunculus bulbosus	Festuco-Brometea	Dry grasslands	
Salvia pratensis	Festuco-Brometea	Dry grasslands	Salprat
Sanguisorba minor	Festuco-Brometea	Dry grasslands	Sanmino
Silene vulgaris	Festuco-Brometea	Dry grasslands	
Stachys recta	Festuco-Brometea	Dry grasslands	Starect
Teucrium chamaedrys	Festuco-Brometea	Dry grasslands	
Thymus serpyllum aggr.	Festuco-Brometea	Dry grasslands	Thyserp

Plant species	Phytosociological optimum class	Social behaviour type	Abbreviation
Trifolium montanum	Festuco-Brometea	Dry grasslands	Trimont
Astragalus cicer	Trifolio-Geranietea sanguinei	Fringe	
Centaurea triumfettii	Trifolio-Geranietea sanguinei	Fringe	
Clinopodium vulgare	Trifolio-Geranietea sanguinei	Fringe	
Cruciata glabra	Trifolio-Geranietea sanguinei	Fringe	
Fragaria vesca	Epilobietea angustifolii	Fringe	
Galium glaucum aggr.	Trifolio-Geranietea sanguinei	Fringe	Galglau
Galium mollugo aggr.	Trifolio-Geranietea sanguinei	Fringe	
Geranium sylvaticum	Mulgedio-Aconitetea	Fringe	
Hypericum perforatum	Trifolio-Geranietea sanguinei	Fringe	
Silene nutans	Trifolio-Geranietea sanguinei	Fringe	
Thalictrum minus aggr.	Trifolio-Geranietea sanguinei	Fringe	Thaminu
Trifolium aureum	Trifolio-Geranietea sanguinei	Fringe	
Veronica chamaedrys	Trifolio-Geranietea sanguinei	Fringe	Vercham
Viola hirta	Trifolio-Geranietea sanguinei	Fringe	Viohirt
Achillea millefolium aggr.	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Alchemilla xanthochlora	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Astrantia major	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Cerastium fontanum	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Colchicum autumnale	Molinio-Arrhenatheretea	Meso-eutrophic meadows	Colautu
Crocus albiflorus	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Dactylis glomerata	Molinio-Arrhenatheretea	Meso-eutrophic meadows	Dacglom
Festuca pratensis	Molinio-Arrhenatheretea	Meso-eutrophic meadows	Fesprat
Festuca rubra aggr.	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Helictotrichon pubescens	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Hypochaeris radicata	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Knautia arvensis	Molinio-Arrhenatheretea	Meso-eutrophic meadows	Knaarve
Lathyrus pratensis	Molinio-Arrhenatheretea	Meso-eutrophic meadows	Latprat
Leontodon hispidus	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Leucanthemum vulgare aggr.	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Lotus corniculatus	Molinio-Arrhenatheretea	Meso-eutrophic meadows	Lotcorn
Narcissus radiiflorus	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Ornithogalum umbellatum	Molinio-Arrhenatheretea	Meso-eutrophic meadows	Ornumbe
Plantago lanceolata	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Poa pratensis	Molinio-Arrhenatheretea	Meso-eutrophic meadows	Poaprat
Polygonum bistorta	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Taraxacum officinale s. l.	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Tragopogon pratensis	Molinio-Arrhenatheretea	Meso-eutrophic meadows	
Trifolium pratense	Molinio-Arrhenatheretea	Meso-eutrophic meadows	Triprat
Trifolium repens	Molinio-Arrhenatheretea	Meso-eutrophic meadows	

Plant species	Phytosociological optimum class	Social behaviour type	Abbreviation
Trisetum flavescens	Molinio-Arrhenatheretea	Meso-eutrophic meadows	Triflav
Acinos alpinus	Elyno-Seslerietea variae	Montane-Alpine Swards	Acialpi
Campanula scheuchzeri	Juncetea trifidi	Montane-Alpine Swards	Camsche
Crepis conyzifolia	Juncetea trifidi	Montane-Alpine Swards	
Luzula campestris aggr.	Nardetea strictae	Montane-Alpine Swards	
Phyteuma betonicifolium	Juncetea trifidi	Montane-Alpine Swards	
Ranunculus montanus aggr.	Elyno-Seslerietea variae	Montane-Alpine Swards	
Aegopodium podagraria	Artemisietea vulgaris	Perennial Ruderal	
Cerinthe minor	Artemisietea vulgaris	Perennial Ruderal	
Cirsium eriophorum	Artemisietea vulgaris	Perennial Ruderal	
Cynoglossum officinale	Artemisietea vulgaris	Perennial Ruderal	
Galium aparine	Artemisietea vulgaris	Perennial Ruderal	
Geum urbanum	Artemisietea vulgaris	Perennial Ruderal	
Lamium album	Artemisietea vulgaris	Perennial Ruderal	Lamalbu
Picris hieracioides	Artemisietea vulgaris	Perennial Ruderal	
Urtica dioica	Artemisietea vulgaris	Perennial Ruderal	Urtdioi
Galium pusillum aggr.	Asplenietea trichomanis	Screes	Galpusi
Vincetoxicum hirundinaria	Thlaspietea rotundifolii	Screes	
Arabidopsis thaliana	Koelerio-Corynephoretea	Therophitic	
Arenaria serpyllifolia aggr.	Koelerio-Corynephoretea	Therophitic	
Potentilla argentea	Koelerio-Corynephoretea	Therophitic	Potarge
Potentilla collina	Koelerio-Corynephoretea	Therophitic	Potcoll
Rumex acetosa	Koelerio-Corynephoretea	Therophitic	
Abies alba	Vaccinio-Piceetea excelsae	Woodlands	
Betula pendula	Quercetea robori-sessiliflorae	Woodlands	
Calamintha grandiflora	Carpino-Fagetea sylvaticae	Woodlands	
Euphorbia dulcis	Carpino-Fagetea sylvaticae	Woodlands	
Fraxinus excelsior	Carpino-Fagetea sylvaticae	Woodlands	
Oxalis acetosella	Carpino-Fagetea sylvaticae	Woodlands	
Primula veris	Carpino-Fagetea sylvaticae	Woodlands	Priveri
Prunus avium	Carpino-Fagetea sylvaticae	Woodlands	
Viola riviniana	Quercetea robori-sessiliflorae	Woodlands	Viorivi
Euphorbia flavicoma	Rosmarinetea	Xerophile scrub	
Rosa spp.	-	-	
Rubus spp.	-	-	

Aeschimann, D., Lauber, K., Moser, D.M., Theurillat, J.P., 2004. Flora alpina: atlante delle 4500 piante vascolari delle Alpi. Zanichelli, Bologna, Italy.

Theurillat, J.P., Aeschimann, D., Küpfer, P., Spichiger, R., 1995. The higher vegetation units of the Alps. Colloques Phytosociolog. 23, 190–239.

Appendix C. Transform-based principal component analysis (tb-PCA) plots highlighting treatment dynamics per each monitored year of the experiment (i.e. 2006, 2007, 2008, 2011, 2013, and 2015). The variance explained by each axis is reported in brackets. Convex hulls encompass plot coordinates of the four treatments: C, control; F, fertilised; M, mowed; FM, fertilised and mowed.