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Changes in pasture vegetation in the Maritime Alps in a scenario of climate change
A 20-year monitoring (2003-2024)

by Vanessa Bianchi[1,2]

1. University of Turin – Master's Degree Program in Forest Systems and Territory Sciences and Technologies
2. CAI – Pinerolo Section

Premise

This article summarizes the findings of the Master's thesis entitled *"Twenty-year variations (2003-2024) in pasture vegetation in the Protected Areas of the Maritime Alps in a scenario of climate change"* (candidate: Vanessa Bianchi; supervisor: prof. Michele Lonati). The study was conducted by the research group "Ecology and Management of Agro-Pastoral Systems" at the University of Turin – DISAFA (Department of Agricultural, Forest and Food Sciences), with the contribution of the *Ente di Gestione delle Aree Protette delle Alpi Marittime* (Maritime Alps Protected Areas Management Authority). The research was carried out as part of the agreement on the *"Study of Pastoral Vegetation, Forage Availability and Wetlands in Natura 2000 Sites of the Maritime Alps Protected Areas in Relation to Climate Change"* (scientific coordinator: prof. Giampiero Lombardi), within the framework of the Interreg VI-A France-Italy ALCOTRA 2021-2027 project no. 20138 "ACLIMO" – Action 4.2.

Abstract:

Alpine semi-natural grasslands, shaped by centuries of extensive human management, represent key ecosystems for biodiversity and agricultural sustainability, but are currently threatened by climate change and land-use transformations. This study aims to contribute to the understanding of vegetation changes that occurred between 2003 and 2024 in the grasslands of the Protected Areas of the Maritime Alps (northwestern Italy, 1300-2400 m a.s.l.). The research is based on the resampling of 58 vegetation surveys conducted in the same locations in 2003, followed by an assessment of changes in floristic composition through statistical analyses. Climatic data show an increase in mean annual temperature and total annual precipitation, along with high interannual variability in rainfall and several summer drought events, which may have caused stress to the vegetation. The vegetation showed an overall increase in species diversity, particularly in thermophilous grasslands and in montane and subalpine *Nardus* grasslands (a priority habitat under the Habitats Directive). A general expansion of species typical of nutrient-rich grasslands was observed, as well as species characteristic of xeric grasslands and ruderal communities, accompanied by an increase in the nitrogen indicator value (N), indicating soil enrichment. It is hypothesized that unsustainable grazing practices – with intensification in more accessible areas and consequent abandonment in economically marginal ones – have led to an increasingly heterogeneous vegetation mosaic. These findings highlight the urgent need to deepen the understanding of management practices and to initiate long-term vegetation monitoring, in order to adopt management strategies that ensure the conservation of these fragile yet ecologically crucial alpine ecosystems.

Introduction: alpine semi-natural grasslands and the threats of global change

Semi-natural grasslands of the Alpine arc represent one of the most biodiversity-rich ecosystems, while also being among the most vulnerable.

Their existence is closely linked to centuries of extensive human management in high mountain environments (Hejcman *et al.*, 2013), primarily through traditional agricultural practices such as grazing and mowing. These practices have historically shaped the landscape and contributed to maintaining the balance among the various ecosystem components (Figure 1).

The importance of permanent pastures and meadows lies in their multifunctionality: grass swards provide forage for livestock, enhance soil fertility through their plasticity, and host high levels of floristic richness (Gusmeroli, 2012).

In the Piedmont Alps alone, there are 92 pasture types and 646 pasture facies (Cavallero *et al.*, 2007), ranging from xerophilous high-altitude grasslands to mesophilous valley-bottom meadows, each characterized by a distinct floristic composition and specific ecological dynamics.

The millennia-old balance between human activities and natural processes is now under threat from multiple fronts: on one hand, agricultural intensification tends to simplify plant communities and deplete soil quality; on the other, the abandonment of marginal areas promotes the recolonization by woody species (Giarrizzo *et al.*, 2016). Within this scenario, climate change represents an additional disturbance factor, capable of altering the phenology, composition, and structure of plant communities.

Figure 1 – Herd of cattle grazing in the Stura Valley (Piedmont, NW Italy) - Photo by Vanessa Bianchi

Several studies, including recent ones, have examined the potential impacts of climate change on alpine grasslands (Bellocchi & Cochard, 2021; Matteodo *et al.*, 2016; Vittoz *et al*., 2009; Pauli *et al.*, 2003).

For instance, various authors have reported increases in species richness in alpine and subnival vegetation (Pauli *et al.*, 2007; Vittoz *et al.*, 2006; Walther *et al.*, 2005).

According to the latest report from the Intergovernmental Panel on Climate Change (IPCC, 2023), global mean temperatures are projected to rise by an additional 1.5 °C to 2 °C above pre-industrial levels over the coming decades, with potentially significant consequences for mountain ecosystems. Future scenarios suggest an accelerated loss of habitat for many alpine species and increasing competition among species adapted to different climatic conditions. In this context, monitoring vegetation changes over time is crucial for understanding the ongoing dynamics and developing effective conservation strategies.

This study addresses that need by documenting and interpreting the changes in floristic composition that have occurred over the past twenty years in the semi-natural grasslands of the Maritime Alps (northwestern Italy).

The ecological context of the Maritime Alps

The territory safeguarded by the Management Authority of the Maritime Alps Protected Areas includes two parks, eight nature reserves, and twenty sites within the European Natura 2000 Network, covering nearly 100,000 hectares in the Province of Cuneo. This area forms a mosaic of natural and semi-natural environments situated at the ecological interface between the Alps and the Mediterranean. This ecological transition results in high floristic heterogeneity, characterized by the presence of numerous endemic species and an extraordinary variety of habitats. According to Casazza *et al.* (2005), the Italian Maritime Alps alone host over 3,000 taxa, more than one hundred of which are local endemics. This makes the region one of the ten biodiversity hotspots of the Mediterranean Basin (Médail & Quézel, 1997), and one of the most important biogeographical areas in Europe.

The landscape is dominated by high-altitude grasslands, heathlands, subalpine forests, and rocky environments (Figures 2 and 3).

The climate is characterized by a western sublittoral rainfall regime, with precipitation peaks in spring and autumn, and relatively dry, but not arid, summers. The complex topography and diverse lithological substrates (calcareous, siliceous, and serpentine) further contribute to vegetation heterogeneity.

This research was carried out within this complex ecological context, supported by the European Union through the Interreg-ALCOTRA project no. 20138 "ACLIMO," aimed at supporting the territory – particularly pastoral activities – in addressing the challenges of climate change, with specific attention to water availability and the conservation of natural habitats.

Figure 2 – View of one of the valleys in the study area (Lake Visaisa, Val Maira, Piedmont) – Photo by Vanessa Bianchi

Figure 3 – The Colle della Maddalena pass (Piedmont, NW Italy) – Photo by Vanessa Bianchi

Figure 4 – Survey of a Festuca paniculata grassland at 1,930 m a.s.l. in the Stura Valley (municipality of Vinadio) – Photo by V. Bianchi

Figure 5 – Survey of a Festuca rubra grassland at 2,086 m a.s.l. in the Maira Valley (municipality of Canosio) – Photo by V. Bianchi

Figure 6 – Survey of a Trifolium meadow at 2.065 m a.s.l. in the Ellero Valley (municipality of Roccaforte Mondovì) – Photo by V. Bianchi

Methods: vegetation resampling and statistical analyses

The study is based on the resampling of vegetation at known sites, originally surveyed in 2003 as part of a project to characterize pastures in the Piedmont region (Cavallero *et al*., 2007). The method used is the phytopastoral technique developed by Daget & Poissonet (1969), which involves recording plant species at 50 observation points along a 25-meter linear transect (Figures 4, 5, and 6). Nomenclature follows the most recent Italian flora (Bartolucci *et al*., 2024; Galasso *et al*., 2024).

A total of 58 surveys were selected for the present study, located between 1,300 and 2,400 m a.s.l. across several valleys (Figure 7), and representative of the most widespread pasture types in the region (Cavallero *et al*., 2007), listed below according to ecological group:

- Xerophilous grasslands on poorly developed soils: type 13 – *Sesleria varia* (= *S. caerulea*), type 19 – *Festuca ovina* aggr.
- Thermophilous grasslands on developed soils: type 25 – *Brachypodium rupestre*, type 26 – *Festuca paniculata* (= *Patzkea paniculata*).
- Oligotrophic grasslands on acidic soils: type 30 – *Nardus stricta* (30a: montane and subalpine, 30b: alpine), type 33 – *Trifolium alpinum* and *Carex sempervirens.*
- Mesotrophic grasslands on acidic soils: type 52 – *Festuca rubra* aggr. and *Agrostis tenuis* (= *A. capillaris*).

These pasture types were also matched to habitats protected under the EU Habitats Directive, following the correspondences proposed by Biondi *et al*. (2010); for example, montane and subalpine Nardus grasslands fall under the priority habitat 6230*.

For each survey, the cover and relative abundance of each plant species were calculated, along with biodiversity indices (species richness, Effective Number of Species, Simpson's index), ecological indicator values (temperature, nutrients, moisture, and soil pH, per Landolt *et al.*, 2010), and composition in "Social Behaviour Types" (as defined by Borhidi, 1995), which helps in interpreting ecological balances among species groups.

To compare the historical (2003) and current (2024) data, statistical analyses were performed (tb-PCA on all recorded species, and paired t-tests on 26 vegetation variables), pairing surveys from both years.

Additionally, climatic data for the 2003-2024 period were extracted and analysed from the NWIOI dataset (ARPA Piemonte), specifically annual mean temperatures and total precipitation (annual and summer), corresponding to the territorial sections in which the 58 survey points are located (9 grid cells, 12x12 km resolution).

Statistical analyses included linear correlations between climate variables and years, aimed at assessing the significance of temporal trends.

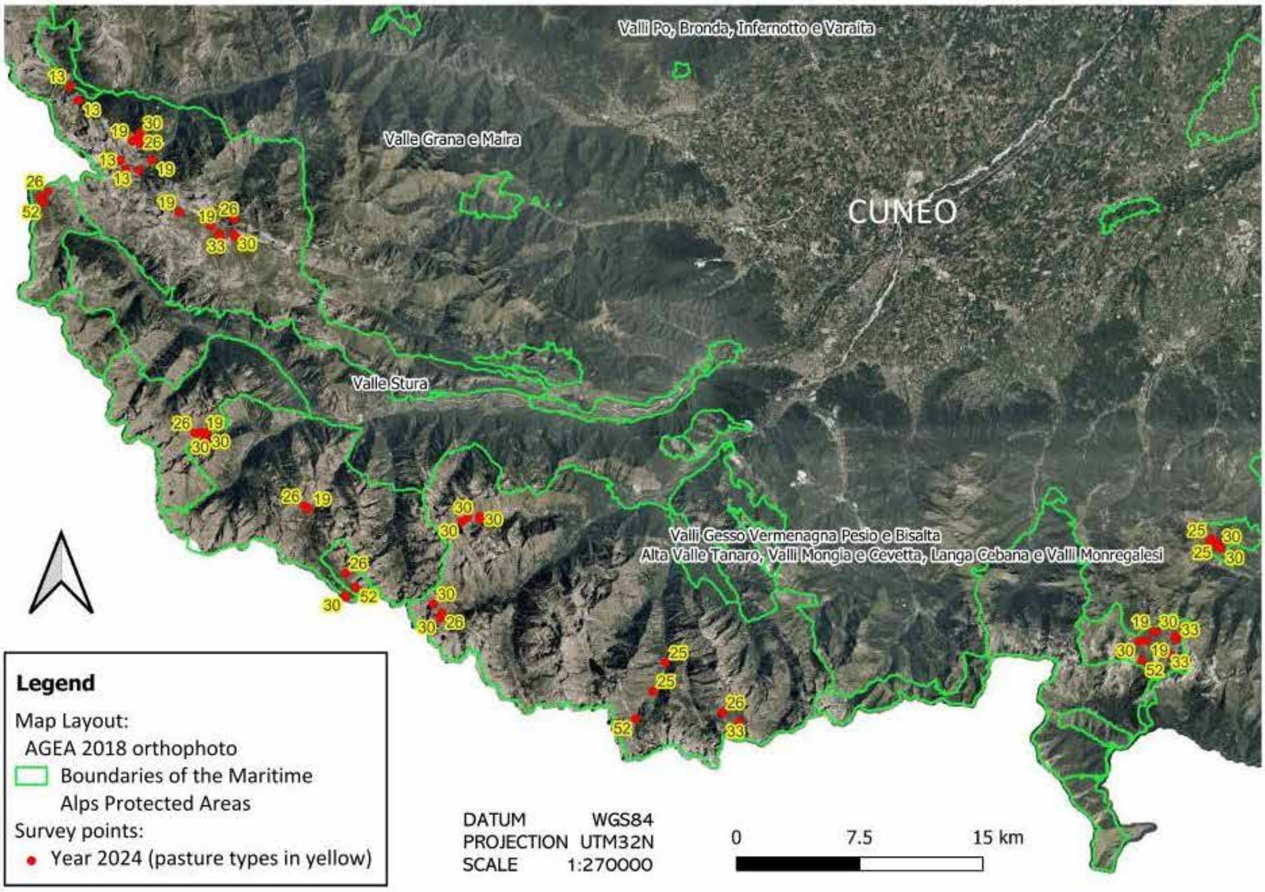

Figure 7 – Boundaries of the Protected Areas of the Maritime Alps and location of the 58 survey points recorded in 2024 across five valleys (from East to West: Ellero Valley, Gesso Valley, Stura di Demonte Valley, Grana Valley, and Maira Valley)

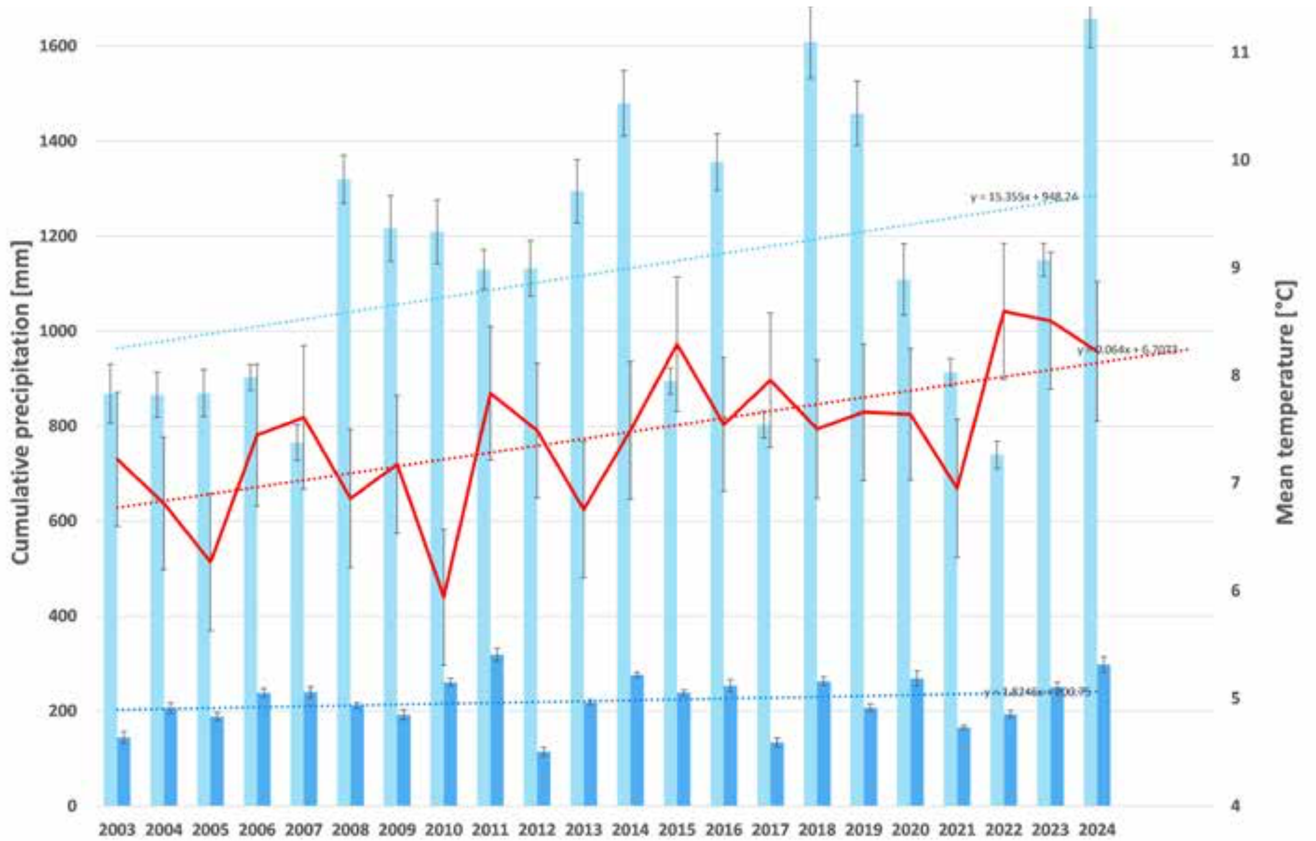

Figure 8 – Thermo-pluviometric diagram (2003–2024) showing mean values of the 9 raster cells (12 × 12 km resolution) containing the 58 survey points, with corresponding trend lines and standard error bars

Results: signals of climate and vegetation change

Analysis of temperature and precipitation data (Figure 8) showed a steady increase in annual mean temperatures between 2003 and 2024, with an average variation of +0.064 °C/year (+1.34 °C over 20 years). Annual cumulative precipitation also increased (+15.24 mm/year, +322.5 mm in twenty years), though with marked seasonal variability: very wet years (2024, 2018, 2014) alternated with drought years (2022, 2017, 2007). Summer droughts (June-August) occurred in 2021, 2017, 2012, and 2003, likely causing water stress for pasture vegetation. These trends align with both IPCC data and national data from ISTAT, highlighting the urgent need to assess the impacts of climate change on alpine ecosystems, where plant distribution and abundance are primarily influenced by low temperatures and short growing seasons (Körner, 2003).

Analysis of the 2024 vegetation data revealed significant shifts in community composition. A total of 409 species were recorded, including 36 alpine endemics, compared to 356 species in 2003. Increases were observed in eutrophic/good forage species (e.g., *Lolium pratense*, *Poa pratensis*, *Dactylis glomerata*) and the nitrophilous species *Rumex alpinus*, all associated with high management intensity. Concurrently, shrub species (e.g., *Juniperus communis*, *Vaccinium* spp.) increased, typically linked to the abandonment of traditional agricultural practices. The greatest declines were observed in oligotrophic species such as *Carex sempervirens*, *Nardus stricta*, and *Festuca ovina* aggr.

Multivariate analysis (Figure 9) enabled the projection of floristic composition data onto a cartesian plane and the study of correlations among points based on their spatial distance. Figure 9c shows the top 50 species defining the axis extremes; their distribution reveals two ecological gradients: increasing temperature along the x-axis (left –

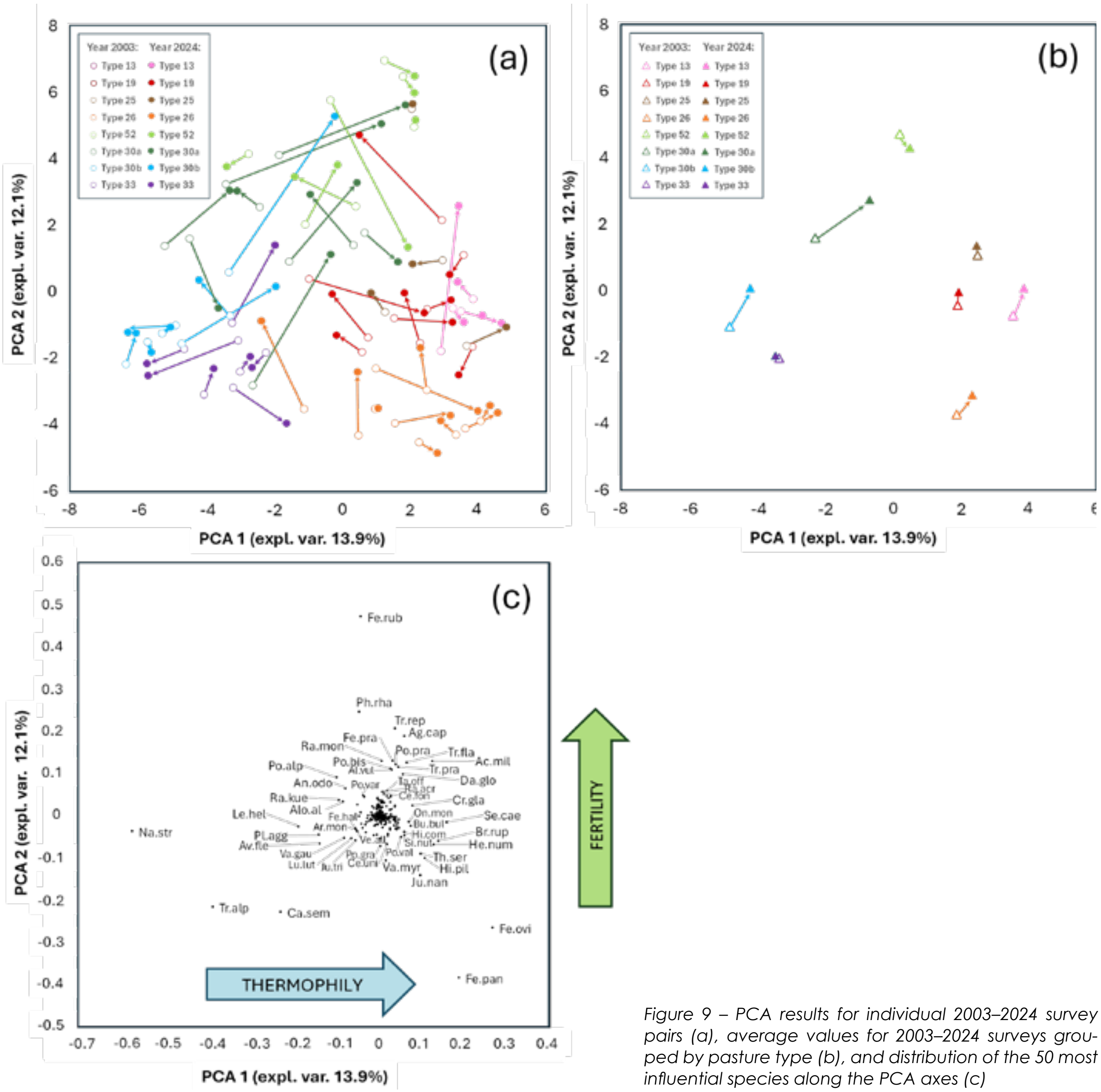

Figure 9 – PCA results for individual 2003–2024 survey pairs (a), average values for 2003–2024 surveys grouped by pasture type (b), and distribution of the 50 most influential species along the PCA axes (c)

high-altitude species; right – lower-elevation, thermophilous species) and increasing soil fertility along the y-axis (bottom – oligotrophic species; top – species typical of more fertile environments). Based on these gradients, figures 9a and 9b visualize vegetation changes as arrows connecting the 2003 and 2024 surveys.

Figure 9b groups surveys by pasture type and suggests a general increase in species thermophily, possibly linked to "thermophilization" (Gottfried *et al.*, 2012), which refers to the upward shift of species distributions due to warming.

The same figure shows a general increase in fertility, influenced by complex interactions between climate, soil, grazing management, and species dynamics. However, figure 9a (individual surveys) reveals notable variability within each pasture type; for instance, type 33 (*Trifolium* grasslands, shown in purple) exhibits both positive and negative shifts along the two gradients. This variability likely reflects differences in site-specific environmental conditions due to the locations of survey points across different valleys.

Vegetation variable analysis revealed an overall increase in biodiversity (Figure 10), particularly in thermophilous grasslands and montane/subalpine *Nardus* grasslands.

This trend was less evident in high-altitude grasslands (types 30b and 33) and xerophilous grasslands (type 19), possibly due to the decline of cold-adapted, less competitive species (Gottfried *et al.*, 2012) and the stress resilience of xerophilous species under warming conditions (Dibari *et al.*, 2020).

Specifically, increases were observed in species typical of fertile grasslands (*Molinio-Arrhenatheretea* class) and in the nitrogen indicator value (N), denoting a general enrichment of soils.

This may result from intensified management, which typically occurs in more accessible and fertile areas, or from climate change-related processes, such as the increased atmospheric deposition of nitrogen compounds produced by human activities (Boutin *et al.*, 2016).

Simultaneously, a slight expansion was observed in species typical of heathlands (classes *Calluno-Ulicetea* and *Loiseleurio-Vaccinietea*) and herbaceous fringe communities (classes *Epilobietea angustifolii*, *Mulgedio-Aconitetea* and *Trifolio-Geranietea sanguinei*), indicative of a reduction or abandonment of traditional agricultural practices.

Among pasture types, xerophilous grasslands appeared relatively stable, likely due to the greater adaptability of dominant species to environmental stress. The most pronounced changes occurred in montane and subalpine *Nardus* grasslands (type 30a – a priority habitat), with increases in biodiversity, the nitrogen indicator value, and the cover of species typical of fertile grasslands, at the expense of *Nardus stricta* and other oligotrophic species.

Discussion: interpreting the changes

An increase in plant biodiversity driven by climate change has been reported in various studies on high-altitude grasslands (Pauli *et al*., 2012), attributed to altitudinal species migration (Gottfried *et al.*, 2012; Lenoir *et al.*, 2008) or expansion of pre-existing species (Cannone & Pignatti, 2014). In the Maritime Alps grasslands, this increase involved various Social Behaviour Types depending on pasture type, with gains in species from both fertile and oligotrophic grasslands, as well as shrubs and ruderal communities.

A plausible explanation lies in the over- and underutilization of vegetation caused by unsustainable grazing management. This results in reduced grazing pressure in economically marginal areas (e.g., distant from alpine pastures), and increased intensity in more accessible and fertile zones, altering the abundance of species either favored or suppressed by grazing.

The threat of abandonment is well known and leads to the loss of key ecosystems. Between the 1990s and 2013, Europe lost over 5 million hectares of meadow and pastureland (FAOSTAT, 2025).

Analysis group	all surveys					type 13 - *Sesleria varia*					type 19 - *Festuca ovina* aggr.				
Year	2003		2024		p-value	2003		2024		p-value	2003		2024		p-value
Biodiversity indices	mean ± SE		mean ± SE			mean ± SE		mean ± SE			mean ± SE		mean ± SE		
Species richness	**42.9**	**1.74**	**51.9**	**2.51**	***	**47.0**	**4.64**	**64.0**	**7.73**	*	54.9	5.26	59.3	6.80	ns
Effective Number of Species	**14.5**	**0.83**	**17.8**	**1.05**	***	**15.2**	**3.22**	**21.0**	**4.04**	*	20.6	2.44	20.6	2.49	ns
Simpson's index	**0.87**	**0.01**	**0.89**	**0.01**	*	0.86	0.03	0.91	0.01	ns	0.91	0.02	0.92	0.01	ns
Analysis group	type 25 - *Brachypodium rupestre*					type 26 - *Festuca paniculata*					type 30a - montane/subalpine Nardus grasslands				
Year	2003		2024		p-value	2003		2024		p-value	2003		2024		p-value
Biodiversity indices	mean ± SE		mean ± SE			mean ± SE		mean ± SE			mean ± SE		mean ± SE		
Species richness	**55.8**	**5.12**	**81.5**	**8.05**	*	***45.9***	***2.37***	***52.6***	***2.87***	†	**36.6**	**3.62**	**50.4**	**5.16**	*
Effective Number of Species	**20.8**	**2.13**	**26.7**	**2.60**	*	***13.3***	***0.74***	***15.7***	***1.61***	†	**12.8**	**2.48**	**20.4**	**2.92**	*
Simpson's index	0.91	0.01	0.94	0.00	ns	0.87	0.01	0.87	0.01	ns	**0.83**	**0.03**	**0.91**	**0.02**	*
Analysis group	type 30b - alpine Nardus grasslands					type 33 - *Trifolium alp.* & *Carex semp.*					type 52 - *Festuca rubra* aggr. & *Agrostis t.*				
Year	2003		2024		p-value	2003		2024		p-value	2003		2024		p-value
Biodiversity indices	mean ± SE		mean ± SE			mean ± SE		mean ± SE			mean ± SE		mean ± SE		
Species richness	32.9	2.46	39.6	4.48	ns	37.6	4.39	36.9	6.12	ns	**36.9**	**3.47**	**45.9**	**4.93**	*
Effective Number of Species	9.8	1.23	11.4	2.13	ns	11.8	0.93	13.7	2.89	ns	14.4	1.98	17.7	2.36	ns
Simpson's index	0.83	0.02	0.82	0.03	ns	0.87	0.01	0.87	0.02	ns	0.88	0.02	0.91	0.01	ns

*Figure 10 – Analysis of changes in biodiversity indices, showing means, standard errors (SE), and statistical significance (p-values) for all surveys and for each pasture type [*** = p < 0.001; ** = 0.01 > p > 0.001; * = 0.05 > p > 0.01; † = marginally significant 0.10 > p > 0.05; ns = not significant]*

Moreover, from an ecological perspective, increased biodiversity does not always equate to improvement. Examples include the spread of nitrophilous or ruderal species, often linked to sward degradation or grazing disturbance, and the expansion of pioneer shrubs or herbaceous fringe species, which indicate a successional process that, if not contained, can lead to the closure of grassland areas. This would result in substantial habitat loss and fragmentation for many animal species, including the sensitive butterfly communities.

Conclusions

Given their ecological importance and vulnerability to climate change, understanding vegetation dynamics in semi-natural grasslands is crucial for their conservation (Giarrizzo *et al.*, 2016).

The study's results suggest that both climate change and land-use changes are driving a progressive reorganization of herbaceous communities in the Protected Areas of the Maritime Alps.

Notably, the increasing heterogeneity of the vegetation mosaic indicates that over- and underutilization dynamics may have occurred over the past two decades. A more in-depth analysis of pastoral practices in the study area would be essential to fully understand this process.

These findings highlight the urgent need to investigate grazing impacts by collecting information on livestock densities or, on a smaller scale, monitoring animal behavior via GPS collars. Furthermore, establishing long-term vegetation monitoring – ideally through a network of well-stratified permanent plots (Chytrý *et al.*, 2013) – is necessary to understand how climate change will shape alpine plant communities.

The goal is to ensure the conservation of the Maritime Alps grasslands – fragile yet ecologically fundamental ecosystems.

These considerations highlight the need to reassess future management strategies for permanent grasslands, which should include regular vegetation monitoring, the promotion of actively grazed pastures, and particular attention to the prevention of land abandonment.

Figure 11 – Trollius europaeus (Globeflower), Frabosa Soprana – Photo by Vanessa Bianchi

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Figure 12 – View from the Maddalena Hill (CN) - Photo by Vanessa Bianchi

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