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Article

Short-Term Abandonment versus Mowing in a Mediterranean-Temperate Meadow: Effects on Floristic Composition, Plant Functionality, and Soil Properties—A Case Study

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Abstract: Hay meadows are secondary grasslands maintained by mowing, and their ecological importance resides in the inherent biodiversity and carbon stocking. We investigated the plant community and soil properties of a sub humid acid grassland near the Fucecchio marshes (Italy), managed as a hay meadow, mowed once a year, and not fertilized. Part of the meadow had been abandoned for three years. We analysed the soil properties (i.e., organic carbon and total nitrogen content, available phosphorus, pH, cation-exchange capacity, texture, and conductibility) and the plant community structure (composition, functionality, and species richness) of the two sides of the meadow (mowed and abandoned). Our aim was to highlight the changes in soil properties and vegetation community, and to find out to what extent abandonment can affect those dynamics. Our results showed that after short-term abandonment, soil pH, C and N increased; litter biomass and perennial forbs increased; and annual forbs decreased. New species colonising after abandonment, thus enriching the flora, may keep spreading and eventually hinder the growth of the specialists if mowing is not resumed. Certain valuable meadow habitats need constant human intervention to maintain their peculiar vegetation, most especially if they are a buffer zone in the proximity of natural protected areas.

Keywords: *Anthoxanthum odoratum*; plant cover; species richness; soil nitrogen; soil pH; plant functional types; Fucecchio marshes

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1. Introduction

Semi-natural (secondary) grasslands are considered as species-rich plant communities [1] and agro-pastoral activities, such as mowing or grazing, have been reported as positive drivers for biodiversity in terms of the total number of species, but not for rare species [2]. Grassland management also has a positive impact in terms of agronomic and ecological functioning [3]. In addition to the botanical and ecological importance of the hay meadows, economic aspects also inform these communities, as plant composition and richness are some of the key factors that affect forage quality [4].

Grasslands are usually dominated by grasses, and due to their heterogeneity and microtopography, they often hold a notable biodiversity of flora and fauna, especially pollinators [5]. Many of the living organisms of grasslands around the world are potentially affected by extinction debt because of land use changes [6] as well as the policies that give priority to afforestation [7].

As a result of land use change and abandonment, grasslands are among the most threatened ecosystems and are being studied in order to find ways to conserve nature as well as to create economic opportunities [8]. Conservation projects on grasslands and meadows with high botanical value vegetation require constant investigation since changes in soil properties due to management and climate can modify plant composition [9].

From an environmental point of view, grasslands are of great importance because of their capacity to stock 34% of the whole amount of organic carbon, most of which is in the soil (87%). Prolonged droughts and increases in temperature due to climate change, could turn grasslands from a sink to a source of carbon [10]. There are indications however, that managed grasslands, in a warmer world scenario, could counteract the carbon source effect exerted by unmanaged grasslands [11].

The factors affecting plant composition in meadows, at the field (e.g., mowing frequency and time, soil nutrients) and landscape scales (e.g., landscape heterogeneity, habitat fragmentation), have been widely investigated [3,12]. Extensive mowing of meadows (low-intermediate mowing and fertilization intensity) is a form of disturbance that enhances plant diversity since it prevents competitive exclusion and enables the co-existence of several species with different competition strengths in relation to light and soil resources [3,13]. However, although changing the mowing time can be either positive or neutral in terms of plant biodiversity [14], the moderate disturbance creates gaps in the vegetation and allows seedling recruitment and the vegetative spread of weak competitive species [15]. On the other hand, removing hay prevents the accumulation of litter and thus the nutrients in the soil [15].

Stopping the mowing of hay meadows may negatively impact species diversity and composition, as the natural secondary succession resumes in a very site-specific way [16]. Over the course of a few years, shrubs, tall grasses, and woody plants, which are strong competitors, gradually increase, whereas grassland specialists that are very sensitive to environmental changes decrease, resulting in a serious loss of biodiversity [3]. When meadow cultivation is abandoned, coverage by some unpalatable perennial weeds increases along with the soil nitrogen and carbon content [15].

The physical, chemical, and biological properties of the soil affect the vegetation in semi-natural grasslands [17]. Plant functional groups play an important role in species coexistence. A soil feedback mechanism affects the soil stock of C and N [3] and the variations in species composition and diversity more than the direct effect of mowing abandonment [18]. In fact, periodical mowing and the following harvest of plant biomass reduce the nutrient intake to the soil [19,20]. The cessation of mowing can cause eutrophication, leading to a decline in plant diversity due to the spread of species with fast growth rates as the greater nutrient availability leads to a stress reduction [21].

The ecological study of grasslands has been carried out in Northern and Central Europe and North America, as well as in the Mediterranean region. In particular, the dry-Mediterranean grasslands are important hot spots of biodiversity. However, Mediterranean grasslands in wet areas also have an important ecological value, creating buffer zones between arable land and wetlands [22]. The effects of haying or grazing have been mainly studied on dry grasslands and they are compared in terms of plant diversity, herbage quality and legumes presence, concluding that the three aspects are not compatible with only one form of management [23] and that plant traits are affected by the intensity of grazing and mowing [24]. Moreover, in the Mediterranean region, grasslands are strongly dependent on water availability in terms of vegetation and energy fluxes (productivity and carbon exchanges) [25].

Besides its important ecological role, such vegetation is related to the economic, cultural, and social heritage of the local population [26]. This makes its conservation a priority in many small-scale economies. Grasslands and meadows are important buffers when close to protected areas, as they tend to be managed in accordance with sustainable agriculture practices that are acceptable in such protected areas, and this proximity means that they have an important conservation value [22]. However, as semi-natural grasslands are likely to disappear in many geographical areas where the economy related to their cultivation is no longer profitable, the importance of carrying out the characterization of their vegetation has grown significantly, especially in wet areas ranging from small to large-scale, as the effects are strongly affected by the regional context [27].

The aim of the study was to find out how and to what extent the abandonment of yearly mowing affects species composition, plant functionality and the related soil properties of a sub humid hay meadow in a Mediterranean climate. This entailed discovering how the disturbance created by mowing helps to maintain grassland biodiversity. We thus investigated the soil properties and plant community structure, vegetation composition, richness, and functionality of two portions of the same meadow: one cultivated and one that had been abandoned for three years.

2. Materials and Methods

2.1. Study Site Description

The study site is located in Tuscany, central Italy, not far from the Padule di Fucecchio wetland nature reserve (43°47′ N, 10°43′ E). The area surrounding the reserve is farmed and there are lowland hay meadows [28]. The area is close to the boundary between the transitional Mediterranean-Oceanic climate and the semi-Continental Oceanic climates [29]. Total annual precipitation during the study was 1341 mm, (max 204 mm in January, min 3.8 mm in March) whereas mean minimum–maximum annual daily air temperatures were 4.2–29.6 °C.

Our study focused on a 3.5 ha grassland mowed to produce hay for horses. The management regime included a once-a-year mowing (May or June) without fertilisation. Three years before the sampling, part of the meadow had been abandoned as the owner decided to stop cultivation (Figure 1). The survey was conducted on the managed part of the meadow (hereafter hay meadow—HM), which was mowed in late June during the study, and on the part that had been abandoned (hereafter abandoned meadow—AM).

2.2. Data Collection

Vegetation and soil data were collected in May 2015 from four blocks (two in HM and two in AM), composed of eight plots (2 × 2 m), for a total of 16 plots per management type, avoiding meadow borders. The distance between plots in the same block was 2.5 m. Each plot was divided into four subplots (1 × 1 m): one subplot was designated in terms of species and plant functionality composition as well as light availability measurements, and the others in terms of destructive sampling (aboveground biomass and soil sample collections). The distance between blocks in HM and AM was 5 m (Figure 2).

2.3. Soil Analysis

Three soil samples (soil corer 2.5 cm Ø and 10 cm depth) were collected in each plot, both in HM and AM. The analyses were carried out to determine pH, total nitrogen (N_{tot}), organic carbon (C_{org}), available phosphorus (AP), cation-exchange capacity (CEC), texture, and electrical conductibility (EC) [30]. C_{org} and N_{tot} contents were determined by dry combustion using a Leco CHN Analyzer.

2.4. Vegetation Analysis

Each species was recorded in each plot and assigned to one of the following plant functional types (PFTs): annual forbs (AF), perennial forbs (PF), legumes (L), graminoids (G), and shrubs (S) [31]. The PFT composition was calculated by dividing the percentage canopy cover of each PFT by the total canopy cover of all the PFTs recorded [32]. Plant richness was evaluated by counting the number of species in each subplot. The above-ground biomass of plants rooted within a 0.2 m^2 (two 10 × 100 cm) strips was collected in a subplot, and the biomass was separated into litter, graminoids, legumes, forbs and shrubs. The biomass was then dried at 60 °C until a constant weight [33].

Figure 1. Map of the site from 2012 to 2015, to highlight the cultivation before the abandonment of one portion.

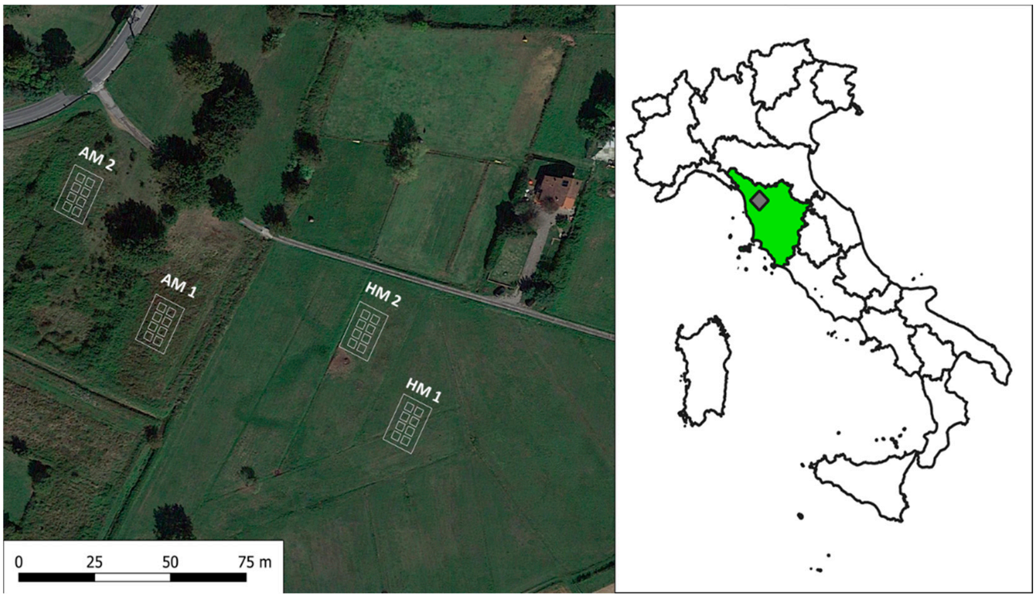

Figure 2. Map of the site with the position of the four blocks and the subplots, on the right HM (=hay meadow) on the left AM (=abandoned meadow).

Photosynthetically active radiation (PAR, µmol m^{-2} s^{-1}) was measured using a light meter (1-m length Decagon Ceptometer) on a cloudless day at solar noon (11 a.m. to 2 p.m.). For each subplot, PAR measurements were collected at ground level and above the vegetation. The light availability was calculated as the ratio of PAR below and above the vegetation.

2.5. Statistical Analysis

In order to evaluate the variance of plant biomass (Table 2) and soil properties (Table 3) in mowed and unmoved soil, we adopted ANOVA with nested factors to manage the random effect due to its division into four blocks.

In order to analyse the impact of soil and management factors on species composition we used redundancy analysis (RDA). RDA is a commonly used analysis method in the field of ecological environment and is very effective in the analysis of the impact of explanatory variables on response variables. The percentage cover of plant species was transformed using the Hellinger method [34]. In addition, species with a frequency of less than 5% (rare species) in the whole data set were excluded from the ordination analysis [18]. Data were reported as mean ± standard error. Statistical analyses were performed using R v. 4.1.1 (R Foundation for Statistical Computing, Vienna, Austria). In particular, the packages "nortest", "stats", "vegan" and "ggplot2" were used.

3. Results

3.1. Plant Community Composition

The species identified in the grassland are reported in Table 1. Twenty-seven species were common, 18 species were exclusive to the abandoned meadow (total = 45), and nine were found just in the hay meadow (tot $n = 36$). The average number of species per plot in HM was 15 ± 0.5, and 10 ± 0.9 in AM ($p < 0.01$), thus the plots in HM overall had fewer species, which were more uniformly distributed. In contrast, AM showed an overall higher number of plant species that were unevenly distributed among plots, and a lower number of species per plot. In terms of plant functionality (PFT), perennial forbs showed statistically significant differences, and were higher in AM compared to HM ($p = 0.004$), while annual forbs were higher in HM ($p = 0.046$). The most species rich PFT were graminoids and perennial forbs with 27 and 18 species, respectively, while annual forbs, legumes and shrubs accounted only for five, three and one species, respectively (Table 1; Figure 3).

Table 1. Species present in the meadow, family, and functional groups [35]. AM = exclusive after the abandonment; HM = exclusive to the hay meadow; C = common.

Species	Family	Functional Group	Site
Agrimonia eupatoria L.	Rosaceae	Perennial forb	AM
Agrostis stolonifera L.	Poaceae	Graminoid	AM
Anthoxanthum odoratum L.	Poaceae	Graminoid	C
Avena sterilis L. subsp. *sterilis*	Poaceae	Graminoid	C
Briza maxima L.	Poaceae	Graminoid	HM
Briza minor L.	Poaceae	Graminoid	C
Carex divulsa Stokes	Cyperaceae	Graminoid	C
Carex flacca Schreb.	Cyperaceae	Graminoid	HM
Carex hirta L.	Cyperaceae	Graminoid	C
Carex spicata Huds.	Cyperaceae	Graminoid	AM
Carex tomentosa L.	Cyperaceae	Graminoid	AM
Centaurea nigrescens Willd.	Asteraceae	Perennial forb	HM
Cichorium intybus L.	Asteraceae	Perennial forb	AM
Clinopodium nepeta (L.) Kuntze	Lamiaceae	Perennial forb	AM
Coleostephus myconis (L.) Cass. ex Rchb. f.	Asteraceae	Annual forb	C
Convolvolus arvensis L.	Convolvulaceae	Perennial forb	C
Convolvulus sepium L.	Convolvulaceae	Perennial forb	AM
Cynodon dactylon (L.) Pers	Poaceae	Graminoid	AM
Cyperus spp.	Cyperaceae	Graminoid	C
Dactylis glomerata L.	Poaceae	Graminoid	C
Danthonia decumbes (L.) DC.	Poaceae	Graminoid	HM
Daucus carota L. subsp. *carota*	Apiaceae	Annual forb	C
Dianthus armeria L.	Caryophyllaceae	Perennial forb	AM
Filipendula vulgaris Moench.	Rosaceae	Perennial forb	AM
Galium verum L.	Rubiaceae	Perennial forb	C
Gaudinia fragilis (L.) P. Beauv.	Poaceae	Graminoid	HM
Geranium dissectum L.	Geraniaceae	Annual forb	C
Holcus lanatus L.	Poaceae	Graminoid	C
Hypericum perforatum L.	Hypericaceae	Perennial forb	AM
Hypochoeris radicata L.	Asteraceae	Perennial forb	C
Kickxia spuria (L.) Dumort.	Plantaginaceae	Annual forb	C
Leontodon tuberosus L.	Asteraceae	Perennial forb	HM
Leucanthemum ircutianum DC.	Asteraceae	Perennial forb	HM
Linaria vulgaris Mill.	Plantaginaceae	Perennial forb	AM
Linum bienne Mill.	Linaceae	Perennial forb	C
Lolium arundinaceum (Schreb.) Darbysh.	Poaceae	Graminoid	C
Lotus conrniculatus L.	Fabaceae	Legumes	AM
Luzula multiflora (Ehrh.) Lej.	Juncaceae	Graminoid	C
Lythrum salicaria L.	Lythraceae	Perennial forb	AM
Oenanthe pimpinelloides L.	Apiaceae	Perennial forb	AM
Plantago lanceolata L.	Plantaginaceae	Perennial forb	C
Potentilla reptans L.	Rosaceae	Perennial forb	C
Prunella laciniata L. (L.)	Lamiaceae	Perennial forb	C
Prunella vulgaris L.	Lamiaceae	Perennial forb	C
Prunella x intermedia Link	Lamiaceae	Perennial forb	C
Ranunculus bulbosus L.	Ranunculacea	Perennial forb	C
Rubus spp.	Rosaceae	Shrub	C
Sanguisorba minor Scop.	Rosaceae	Perennial forb	C
Silene flos-cuculi (L.) Clairv.	Caryophyllaceae	Perennial forb	C
Sonchus oleraceus L.	Asteraceae	Annual forb	AM
Trifolium campestre Schreb.	Fabaceae	Legumes	HM
Urospermum delachampii (L.) F.W. Schmidt	Asteraceae	Perennial forb	AM
Vicia sativa L.	Fabaceae	Legumes	HM

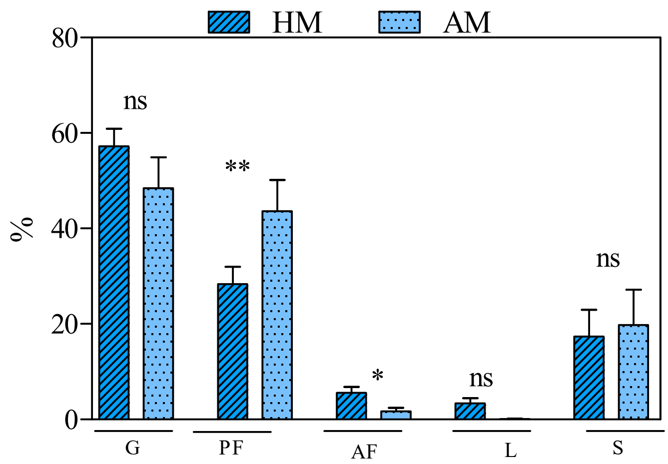

Figure 3. Plant functional type composition (% PTF) in hay (HM) and abandoned (AM) meadow, as the ratio of the percentage canopy cover of each PFT to the total canopy cover of all the PFTs recorded. G = graminoid; PF = perennial forbs; L = legumes; AF = annual forbs; S = shrubs. Data are means of 16 samples ± SE. Asterisks represent significance of $p < 0.05$; * = $p < 0.05$; ** = $p < 0.01$; ns = not significant.

Significant differences were detected in litter biomass, which was higher in AM ($p < 0.001$), while graminoids, legumes, forbs (both perennial and annual), and shrub biomasses did not differ significantly between the treatment and control plots (Table 2).

Table 2. Plant biomass of functional types and litter in hay (HM) and abandoned (AM) meadow. Data are means of 16 samples ± SE. Asterisks represent significance of $p < 0.05$; *** = $p < 0.001$; ns = not significant, calculated by ANOVA with nested factor (blocks have been considered as random effect).

	Biomass DW (g)		
	HM	**AM**	***p* Values**
Litter	3.9 ± 0.83	26.2 ± 2.83	***
Graminoid	46.0 ± 6.89	33.8 ± 5.50	ns
Legumes	0.4 ± 0.09	0.5 ± 0.49	ns
Forbs	11.8 ± 1.47	17.3 ± 3.80	ns
Shrubs	3.9 ± 1.91	5.6 ± 3.55	ns

In HM, light availability was significantly higher, reaching 320, compared to AM, which reached 143 ($p < 0.01$).

3.2. Soil Properties and Plant Community

The soil was characterized by a sub-acid reaction and loam-sandy texture; CEC and EC were similar in the two sampled areas (Table 3); pH, N_{tot} and C_{org} were lower in HM than in AM ($p = 0.001$, $p = 0.01$, $p = 0.01$, respectively). The correlation reported in Table 4 shows a significant positive effect of soil carbon and nitrogen on the biomass of legumes, but a negative effect on species richness. Soil pH positively affected the biomass of the litter and negatively affected the biomass of graminoids and species richness. Litter biomass was negatively correlated to species richness.

Table 3. Soil properties of hay (HM) and abandoned (AM) meadow. Data are means of 16 samples ± SE. Asterisks represent significance of $p < 0.05$ (*); $p < 0.01$ (**); $p < 0.001$(***), calculated by ANOVA with nested factor (blocks have been considered as random effect). ns = not significant.

Soil Properties	HM	AM	*p* Values
pH	5.6 ± 0.03	6.0 ± 0.05	***
C_{org}%	1.7 ± 0.09	2.2 ± 0.16	**
N_{tot}%	0.20 ± 0.02	0.26 ± 0.01	*
AP	0.66 ± 0.23	0.71 ± 0.21	ns
CEC (cmol kg^{-1})	14.1 ± 1.29	15.5 ± 0.68	ns
EC (dS/m)	0.20 ± 0.01	0.20 ± 0.01	ns

Table 4. Pearson correlation between the soil properties and vegetation data (PFTs biomass and species richness). Coefficients of correlation in bold are significant for $p \leq 0.05$ (*), $p < 0.01$ (**) and $p < 0.001$ (***). SR = species richness. Number of samples = 32.

	pH	EC	CEC	Corg	N	Litter	Graminoid	Legumes	Forbs	Shrub
pH										
EC	0.46									
CEC	0.36	0.36								
Corg	0.39	0.11	0.15							
N	0.39	0.14	0.25	0.67 ***						
Litter	0.54 **	0.04	−0.001	0.31 *	0.28					
Graminoid	−0.36 **	−0.31 *	−0.18	−0.10	−0.01	−0.17				
legumes	0.11	0.08	0.22	0.58 *	0.42 *	0.08	−0.07			
Forbs	0.43	0.23	0.11	0.12	0.30	0.11	−0.001	0.26		
Shrub	0.01	0.06	0.05	0.22	0.03	−0.06	−0.24	−0.09	−0.29 *	
SR	−0.32 *	0.11	−0.03	−0.44 **	−0.21 *	−0.66 ***	0.21	−0.08	0.14	−0.27

3.3. RDA

Figure 4 reports the redundancy analysis which highlights the shared effects of the two explanatory variables, soil properties (pH, C_{org}, N_{tot}) and mowing, on the species composition of HM and AM. First, the AM and HM plots were well separated by the RDA, and AM plots showed a positive relationship with a higher pH. The RDA analysis revealed that the variation in species composition was significantly explained by pH ($p = 0.01$) and not by N_{tot} ($p = 0.32$) or C_{org} ($p = 0.99$). The RDA analysis also revealed that the variance cumulatively explained by the three constrained axes was 53%, of which 37% could be attributed to pH. The adjusted R-squared of the total RDA was 24%, while the R-squared value relating to pH was 28%. Species such as *A. odoratum*, *D. carota* subsp. *carota*, *G. fragilis*, *L. ircutianum*, *P. lanceolata*, *S. flos-cuculi*, *T. campestre* were found to be much more related to the HM plot. On the other hand, *A. stolonifera*, *D. glomerata*, *H. perforatum*, *P. reptans* and *S. minor* subsp. *balearica* were more related to the AM plots. Other species such as *C. arvensis*, *H. lanatus* and *L. multiflora*, were common to both plots, without being predominant in either.

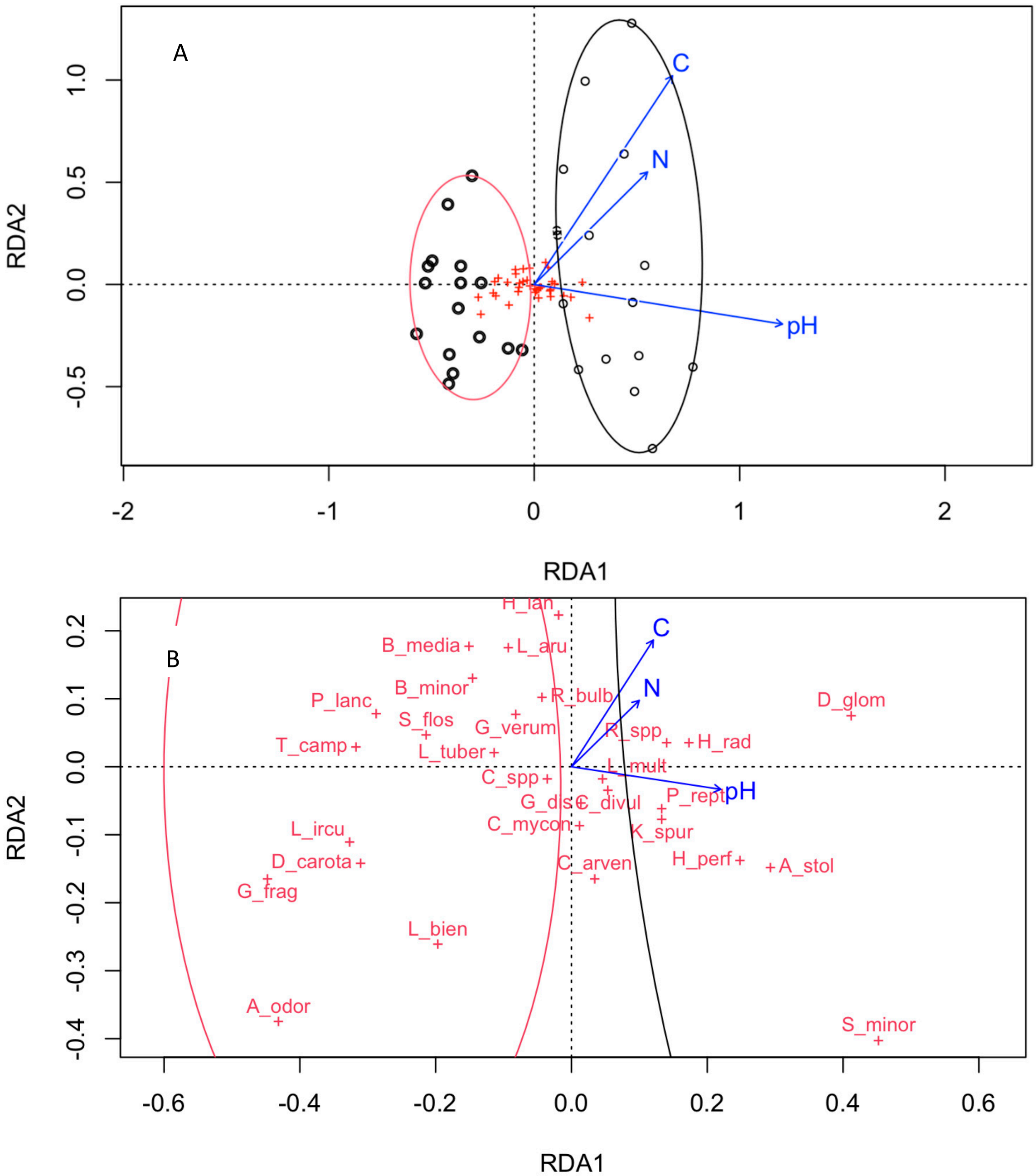

Figure 4. Ordination biplot of redundancy analysis (RDA) representing shared effects of two sets of explanatory variables (soil properties and management). C = total organic carbon; N = total nitrogen. (**A**) Circles in bold represent the HM plots, circles not in bold represent the AM plots, crosses represent the species. (**B**) the species reported are: A_odor = *A. odoratum*, A_stol = *A. stolonifera*, B_media, B_minor, C_divul = *C. divulsa*, C_mycon = *C. myconis*, C_arven = *C. arvensis*, C_spp = *Cyperus* sp., D_glom = *D. glomerata*, D_carota, L_aru = *L. arundinaceum*, G_verum, G_frag = *G. fragilis*, G_dis = *G. dissectum*, H_lan = *H. lanatus*, H_perf = *H. perforatum*, H_rad = *H. radicata*, K_spur = *K. spuria*, L_tuber = *L. tuberosus*, L_ircu = *L. ircutianum*, L_bien = *L. bienne*, L_mult = *L. multiflora*, P_lanc = *P. lanceolata*, P_rept = *P. reptans*, R_bulb = *R. bulbosus*, R_spp = *Rubus* sp., S_minor, S_flos = *S. flos-cuculi*, T_camp = *T. campestris*.

4. Discussion

The short-term abandonment of the grassland mowing changed the soil properties, i.e., pH, total nitrogen, and organic carbon content, as well as the plant community in terms of species composition, richness, and functionality. The results of our study showed that mowing allows the conservation of a specific vegetation composition, rich in graminoids and annual forbs, while after three years of abandonment, new species started to colonise the grassland, especially perennial forbs, and the abundance of this already present functional type was increased. This led to differences in species composition, showing up species common and exclusive in relation to their management and a shift in functional groups from annual to perennial forbs, as well as changes in soil properties, with increases in pH, organic carbon, and nitrogen. Although the pH belongs to the moderately acidic category, the variation after abandonment showed a tendency towards a neutral reaction.

The vegetation analysed in the hay meadow included some species typical of the *Arrhenatheretalia* order of the *Molinio-Arrhenatheretea* class. This vegetation can be described as hygrophilous, meso-hygrophilous or mesophilous meadows which are found in the Mediterranean macro-bioclimate. These communities usually grow on soils that are mineral to variably rich in organic matter and include strongly manured to un-manured meadows [36]. The absence of species that are commonly found in the *Arrhenatheretalia* order, especially *Arrenatherum eliatus* (L.) P. Beauv. ex J. & C. Presl [37], could be related to the fact that the HM was not fertilized, as in fact *Arrhenatherum elatius* and the vegetation of the *Arrhenatherion alliance* is associated with fertilized meadows.

After the three-year abandonment, the sampled AM plots were much more uneven than the HM plots, with no clear dominating species in any of the sampled plots. On the other hand, in HM, *A. odoratum* showed high soil cover (abundance)in almost all the sampled plots.

Anthoxanthum odoratum is a perennial, low productive grass, which is tolerant to soil low nitrogen and acidic conditions, and with a noticeable scent. At low elevations, *A. odoratum* is often found in manured meadows belonging to the semi-natural class of *Molinio-Arrhenatheretea* Tüxen 1937.

Interestingly, other species such as *G. fragilis*, *S. flos-cuculi*, *L. arundinaceum*, *D. carota* subsp. *carota*, *G. verum* and *T. campestre* were much more related with the HM plot. The presence of *G. fragilis* highlights the alliance between *Gaudinio fragilis* and *Hordeion bulbosi* Galàn, Deil, Haug & Vicente 1997, *S. flos-cuculi* of the *Molinion caeruleae* koch 1926 alliance; *L. arundinaceum* of the *Arrhenatherion elatioris* Koch 1926 alliance, while the others were often abundant in the class *Molinio-Arrhenatheretea*.

The once-a-year mowing and subsequent removal of the above-ground biomass led to the development of small species (*T. campestre*) and late-flowering species (*L. tuberosus*) as well as non-clonal species (*G. fragilis*), due to the creation of gaps in the vegetation [38].

On the other hand, the three-year abandonment was not enough to create a mature and more homogeneous vegetation, although the possible small pedo-climatic differences among plots could have contributed to the floristic composition observed. In the AM, species of the *Molinio-Arrhenatheretea* class were less abundant, while other species of a different, species-poor vegetation class were subjected to a significant increase in their soil coverage in many AM plots. As regards *D. glomerata* subsp. *glomerata*, diagnostic species of the semi-ruderal and mesic alliance *Convolvulo arvensis-Agropyrion repentis* Görs 1966 which, in turn, belongs to the nitrofilous class *Artemisietea vulgaris* Lohmeyer, Preising & Tüxen ex Von Rochow 1951, were much more represented in AM. This could be consistent with the slightly higher N_{tot} content and, being a typical vegetation of disturbed habitats, with the fact that it had only been abandoned for three years.

Similarly, other species that are often found in *Artemisietea vulgaris,* such as *A. stolonifera,* were much more abundant in AM. The relatively abundant presence of *P. reptans* in AM, a species that is usually related to *Molinio-Arrhenatheretea*, could be explained by the sub-humid nature of the studied area, as well as its suitability for disturbed habitats and the moderate non-homogeneity of the AM plots. In fact, *P. reptans* showed only a slight relation with *D. glomerata* in AM. Moreover, the presence of *S. minor* subsp. *balearica* may seem inconsistent, as this species grows in relatively dry environments. In any case, *S. minor subsp. balearica* in the RDA is not related to the species adapted to humid conditions, thus resulting in the unevenness of the AM. The prevalence of species that are related to species-poor vegetation suggests the beginning of a process leading to the competitive exclusion of species with a less competitive ability and in the long term to a sort of habitat homogenization in AM [39]. Species typical of wetlands found in the AM, e.g., *L. salicaria,* although in low abundance, suggest that an initial spread of such species in the wettest parts of the study area was able to increase as long as the meadow remained abandoned. Similarly, species, common near the edges where there was no mowing, such as *A. eupatoria*, *F. vulgaris*, started to spread after abandonment [40].

The differences in plant composition between AM and HM, highlighted by RDA, could also be related to the effects of litter accumulation after mowing had ceased. In fact, litter accumulation causes a shift in species composition as it negatively affects the seedling recruitment of many annuals, leading to a reduction of species richness in AM. This is due to the interception of light and the creation of a physical barrier, leading to a decrease in the number of seedlings per area unit. The same effect may also have been caused by the lower light availability (PAR) observed in AM [41]. Tolerance to litter accumulation, however, enhances the plant establishment of woody and clonal species because of better water conditions and reduced competition from other species [42].

In the hay meadow, the once-a-year mowing favoured the establishment of new individuals of some species, the persistence of others, and the faster growth of smaller species, such as *A. odoratum*, *D. carota* subsp. *carota*, *G. fragilis*, *L. ircutianum*, *P. lanceolata*, *S. flos-cuculi*, *T. campestre,* resulting in a high plant richness [13,43].

In both HM and AM, perennial forbs and graminoids were the most abundant, with the latter being mainly represented by perennials. The low percentage of annuals in HM and AM plots is consistent with the mowing period that did not allow an abundant growth as well as with the high presence of perennials in both *Molinio-Arrhenatheretea* and *Artemisietea vulgaris* classes. The cessation of mowing increased the percentage of perennial forbs, suggesting that the annuals found in the HM are tolerant to this management technique and are slightly favoured when allowed to colonize areas with a lower competition exerted by certain perennials related to the *Artemisietea vulgaris* class.

In the case of short-term abandonment, natural succession had begun, as demonstrated by the differences in the species compositions of the two plant communities, leading to a higher number of species in AM [44] The increase in species could be related to the higher abundance of species typical of the *Artemisietea vulgaris,* which came from the neighbouring area into the unmown meadow.

The effects of short-term abandonment on soil properties, i.e., pH, soil nitrogen and organic content, confirm the key role of soil chemical properties in influencing the vegetation in managed grasslands [45–47]. The vegetation also affects the soil properties with a feedback mechanism [3]. Some functional types, such as forbs, are effective in increasing the content of carbon and nitrogen in grassland soils [48]. In our study, pH, Corg and N were the soil properties that correlated negatively with species richness, as found in recently abandoned pastures [49], while other authors have reported that species richness is not influenced e.g., by pH values [50]. In AM, the increased litter deposition due to the lack of mowing and hay removal led to an increase in soil organic matter content and to higher values of N_{tot} and $C_{org,}$ in Mediterranean grasslands, as land abandonment, leads to a quick increase in SOC [51]. The changes in soil properties correlated with the changes in species composition, suggesting that the cessation of mowing could be responsible for the short-term increase in some perennial forbs such as *A. stolonifera*, *D. glomerata*, *H. perforatum*, *P. reptans* and *S. minor* subsp. *balearica* [15].

5. Conclusions

Our results highlight the changes in the floristic composition and abundance of species together with the soil parameters and litter accumulation during the first phases of the abandonment of a sub humid meadow located at the border of Mediterranean and Oceanic climates. The hay meadow near the Fucecchio marshes, managed only by a once-a-year mowing, is a relatively species-rich habitat that is dependent on human agricultural activity.

Mowing in May or June led to the persistence of hay species with different functionalities, increasing annuals, as well as to the modification of certain soil conditions with a slightly lower pH and nitrogen content, thus making it suitable for conservation and agriculturally/economically viable for the production of hay. In contrast, short-term abandonment increased the abundance of perennial and woody species, modifying the plant community structure in terms of species composition and functionality. In the early phase of vegetation succession, the species richness decreased in the abandoned meadow. At the same time, abandonment led to an increase in litter accumulation and a moderate increase in total nitrogen, soil organic matter and pH.

Further studies should investigate subsequent changes in the vegetation of the abandoned meadow together with the plant-soil relationships during the natural succession. The species that are most affected by mowing abandonment should be identified so that they can be used as indicators of vegetation homogenization in these particular pedoclimatic conditions. Since such ecosystems provide services to the local population and are influenced by field and landscape factors, an investigation into the relationship between local communities and small-scale economies based on grasslands and meadows could be of great interest in order to make grassland conservation a priority.

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