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The impact of activities within an agri-environment scheme on the habitat condition of hay meadows and its alignment with Natura 2000 objectives

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ABSTRACT

Extensively managed grasslands are biodiversity hotspots. To help preserve them, agri-environment schemes have been established. This study evaluates whether the management under an agri-environmental scheme implemented in Wallonia, southern Belgium, fulfils Natura 2000 conservation objectives, particularly for hay meadows. The management agreement dedicated to meadow conservation in Wallonia is the "Grassland with High Biological Value" (MC4) scheme. Changes in vegetation communities were investigated across a set of 103 hay meadows under MC4 selected in Wallonia and surveyed between 1998 and 2023. Although species richness did not change significantly, there was a significant increase in the number and cover of typical species. Indicators linked to habitat degradation showed a significant decrease. At the same time, it was found that species linked to meadow quality were associated with meadows committed under MC4 for a minimum of 8 years, while nitrophilous species and species linked to intensive grazing were associated with meadows that were more recently committed under MC4. Species indicative of hay meadows with a higher Ellenberg N-index also declined in number over time. Although improvements were observed in certain criteria, the total degree of conservation of the meadows showed only modest positive outcomes. Our results suggest that the MC4 management steers some meadows towards more oligotrophic habitats than the hay meadows of habitat 6510. Depending on the meadows and the objectives, i.e. to maintain the meadows of habitat 6510 or transition to other types of habitats of high biological value, a low level of fertilisation could be considered.

1. Introduction

Due to their high levels of floristic diversity, temperate semi-natural grasslands play an important role in species conservation (Marriott et al., 2004). Bruchmann and Hobohm (2010) affirm that this type of habitat contains the second-largest numbers of endemic plants in Europe. At a small scale (< 50 m^2), European managed temperate grasslands have been demonstrated to surpass all other ecosystems worldwide in terms of vascular plant species richness (Wilson et al., 2012).

Human activity, through extensive land use from the Neolithic period to the 19th century, has profoundly shaped landscapes and enabled the emergence of a vast diversity of habitats and species (Poschlod et al., 2005). Over time, different types of grassland developed, depending on soil nutrient levels and moisture (Hejcman et al., 2014), altitude, climate and local agricultural tradition, which influenced the species that established there spontaneously (Küster & Keenleyside, 2009; Rodríguez-Rojo et al., 2017). Traditional practices, such as mowing with subsequent removal of hay, extensive grazing and organic fertilisation at low levels through dung restitution and traditional irrigation resulted in open areas, with variable soil nutrient levels and led to the creation of particular habitats that stand out from their landscape context (Brzank et al., 2019; Eriksson et al., 2002; Leibundgut, 2004; Lessard-Therrien et al., 2017). The extensive management of semi-natural grasslands has allowed a wide variety of species to thrive, enhancing the biodiversity of these habitats (Isselstein et al., 2005). Since 1950, under the influence of the European Common Agricultural Policy (CAP) and with the arrival of mineral fertilisers on the market, farming practices have evolved towards a more intensive system (Poschlod et al., 2009). As a result, traditional grasslands have been abandoned, intensified or converted into arable land (Blackstock et al., 1999; Veen et al., 2009; Wallisdevries et al., 2002). Species-rich

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grassland areas declined sharply in Europe since the 20th century, as well as the biological quality of the remaining areas (Eriksson et al., 2002; Walker et al., 2004). The large number of typical species was replaced by a few generalist species which resulted in a significant loss of species diversity within these habitats (Gaujour et al., 2012; Mckinney & Lockwood, 1999).

Given the threats they face and their high conservation value, several semi-natural grassland formations were recognised as “Habitat Types of Community interest” (HCI) at the European scale. This status stems from the Council directive 92/43/EEC on the conservation of natural habitats and wild fauna and flora adopted by the European Commission in 1992. This directive establishes a common framework for Member States to ensure biodiversity through the protection and management of natural habitats and species of Community interest (Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora, 2013).

Within each member state, various conservation efforts have been devised, notably through agri-environment schemes (AES). AES stem from the European Common Agricultural Policy (CAP) and, their implementation has been compulsory for Member States since 1992. They are designed to encourage farmers to implement practices favourable to environmental protection, heritage conservation (animal or plant), and landscape maintenance in agricultural areas. In return, farmers receive financial compensation. Each Member State establishes specific AES, considering the particularities of their agricultural economies and their respective environmental contexts. The AES dedicated to meadow conservation in Wallonia (southern Belgium region) is the Grassland with High Biological Value (MC4) scheme. It was introduced in 2005. The aim is to maintain or improve species-rich grasslands. Inclusion in the MC4 scheme relies on a diagnosis by an expert that certifies its high biological value, either due to the presence of threatened plant communities or animal species. Farmers who commit to the scheme follow a set of specifications that ensure extensive use of the grasslands and that depends on habitat type. Specifications for mown mesophilous grasslands include mowing after 1st July with maintenance of a 10% unmown refuge area, no fertilisation or soil improving and no pesticide use. A second cut or grazing is permitted at the end of the season. In this last case, livestock may not be fed on the plot. Among HCI’s, habitat 6510 (lowland hay meadow) aligns most closely with this MC4 management scheme. Due to their diverse trophic contexts, hay meadows rank among Europe’s most floristically rich agricultural lands. These meadows span eutrophic, nitrophilous situations to *meso*-oligotrophic contexts, bordering low-nutrient hay meadows, whether neutrocalcicolous or acidicline (Maciejewski et al., 2015). In 2023, almost 12000 ha of grasslands were included in the scheme in Wallonia, mostly in the southern part of the region. This represents a public payment of ca. 4 M euros/year. As a public spending, AES needs to be monitored for their effectiveness regarding their environmental objectives.

Concerning HCI’s, monitoring is mandatory for EU member states. It involves assessments of the condition of these habitats, determined by three main criteria: the habitat structure, the habitat’s floristic composition, and an analysis of threats and disturbances. For grassland habitats, assessments focus on species composition, structural elements, and the presence of indicator species for disturbances (Couvreur et al., 2021). Based on these parameters, the Walloon administration developed a tool using four criteria with specific thresholds to evaluate the degree of conservation of hay meadows, following the Natura 2000 standard data form.

Using such official, regional tools to assess the impact of an agri-environmental scheme is consistent as it evaluates the synergies in the application of two EU policies, i.e. the CAP and the Habitats Directive. This approach however needs to be completed by a more general assessment of plant communities, to broaden the scope and permit comparison with existing studies throughout Europe.

Previous monitoring studies on the changes of the plant species composition and richness of extensively managed meadows or meadows following an AES have come to inconsistent conclusions, depending on the study sites (Dicks et al., 2013). The response of the plant composition to change in management may be delayed, so a long period is sometimes needed to detect a significant change in the degree of conservation of meadows (Helm et al., 2006). For this reason, it is worth carrying out long-term studies. Combining a long-term study on conservation aspects with a large number of experimental plots would give a broader view on these.

In this study, changes in plant communities in more than 100 hay meadows included in the AES grasslands of high biological value (MC4) were investigated over different time scales (from 4 to 15 years). Our objective is to verify whether MC4 management aligns with Natura 2000 goals, particularly those related to lowland hay meadows (habitat 6510). To this end, we hypothesised that over time the degree of conservation of the meadows under MC4 management will improve, i.e. hay meadow characteristic species will increase in number and cover, while species linked to intensive meadows will decrease, or at least that meadows in a favourable degree of conservation at the time of their commitment maintain it.

2. Material and methods

A set of 103 meadows with the habitat code 6510 « Lowland hay meadows » in the EU Habitats Directive was selected in Wallonia (Southern Belgium). All meadows fell under AES dedicated to meadow conservation (Grassland with High Biological Value MC4 scheme).

The data used come from phytosociological relevés conducted between 1998 and 2023 and have been stored in the taxonomic and biogeographic database of the University of Liège. We considered meadows that were surveyed at least twice, with a minimum time interval of 4 years between the first and the last survey (Fig. 1). The time between first and last survey varied from 4 to 15 years within the selected meadows. Additional information, including the complete list of surveyed meadows and their survey years, is available in the appendix (Supplementary Table 1). The meadows were not all monitored in the same years or with the same time interval, which is why it was decided to assign the designation ‘Year 1′ to the first year of the survey, ‘Year 2′ to the year of the survey carried out one year after the first survey, ‘Year 3′ to the year of the survey carried out 2 years after the 1st survey, … up to ‘Year 15′.

The survey involved identifying the plant species present in 5 m^2 plots, a field approach consisting of identifying the vegetation within a circle of 1.25 m radius around the operator was used, and estimating their abundance using the Braun-Blanquet scale for plant cover-

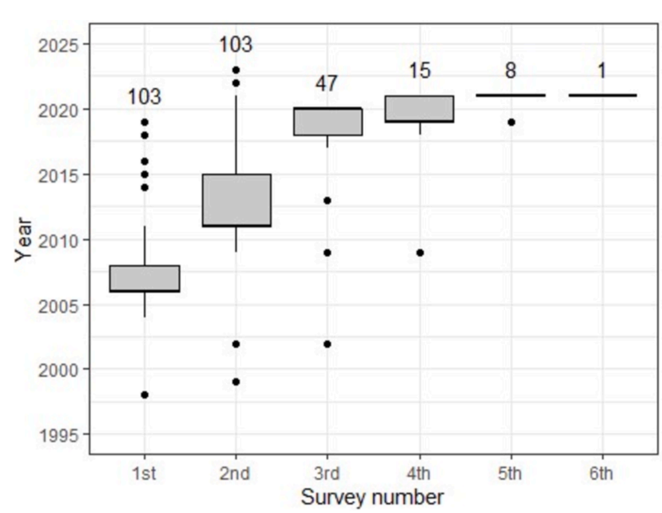

Fig. 1. Number of monitoring operations for the 103 meadows and their distribution between 1998 and 2023.

abundance (Braun-Blanquet et al., 1932; Wikum & Shanholtzer, 1978). The number of plots in each meadow depended on its surface, i.e. 2 plots/ha. All surveys were conducted by the same person (S. Rouxhet) from the end of May to early July of the years concerned. To ensure consistency in survey locations across years, GPS coordinates of the plots were recorded in the first year and reused in subsequent years. To avoid heterogeneous features in meadows (e.g. wet areas, rocky outcrops), only plots that sheltered at least three typical hay meadows species (merged from different surveys) were considered. The Braun-Blanquet values were converted into percentages according to their class median for analysis. The cover values at the plot level were averaged to obtain cover values for each species in each surveyed year at the meadow level. To compare the habitat degree of conservation over the study period, several indicators were considered: i) species richness, ii) the mean Ellenberg N-index weighted by species cover, (the scale gives a value from 1 for plants preferring the most oligotrophic conditions to 9 for plants of the most eutrophic conditions for all species recorded: see Ellenberg et al. (1992)), and iii) the four criteria used by the Walloon administration for the six-yearly EU reporting on the "Lowland Hay Meadows" habitat degree of conservation (Table 1 and Supplementary Table 2). These criteria, associated species lists, and thresholds for degree of conservation levels are used by the Department for Nature and Agriculture (DEMNA) Study of the Walloon administration in the six-yearly Natura 2000 evaluation. Species nomenclature follows Lambinon et al. (2004).

To investigate the change in plant communities over time, a principal coordinate analysis (PCoA) based on Bray-Curtis dissimilarity index was performed using the R-package "vegan" (Oksanen et al., 2022). We used mixed linear models to test for the effect of time on the different indicators. In all models, we used time within site as the random effect, i.e. considering repeated measures within the same sites. For count indices, i.e. species richness and number of characteristic species, we computed models for the Poisson distribution using the "glmer" function in the "lme4" R-package (Bates et al. 2015). For the other indices, we used the "lme" function in the "nlme" R-package (Pinheiro et al., 2023). Proportion indices were arcsine-transformed to improve their normality. Model effects were tested by ANOVA. The models used in this analysis are detailed in the supplementary materials (Supplementary Code 1). The "ggplot2" package was used to generate plots (Wickham, 2016). All analyses were performed using R statistical software version 4.3.2 (R Core Team, 2023).

Table 1
Criteria and thresholds for the determination of "Lowland Hay Meadows" habitat degree of conservation in Wallonia. A: Excellent, B: Good, C: Reduced, D: Not a lowland hay meadow.

Criterion	Degree of conservation			
	A	B	C	D
Criterion 1: number of characteristic species	≥ 7	4–6	3	< 3
Criterion 2: cover of characteristic species + other indicators of habitat quality	$>$ 50%	$\leq$ 50% and $>$ 25%	$\leq$ 25% and $>$ 10%	$\leq$ 10%
Criterion 3: cover of nitrophilous species	$<$ 10%	$\geq$ 10% and $<$ 30%	$\geq$ 30%	
Criterion 4: cover of high grazing intensity species	$<$ 40%	$\geq$ 40% and $<$ 60%	$\geq$ 60%	

The term 'cover' for criteria 2, 3, and 4 corresponds to the sum of the individual cover of the species specified in each of these criteria.
Total degree of conservation corresponds to the worst degree of conservation of all the indicators;
*See species lists in Supplementary Table 2.

3. Results

A preliminary analysis of the biological quality of the meadows during their first year of commitment (Year 1), based on the previously presented indicators and criteria, reveals substantial variability among the meadows at the time of their commitment. Their diversity of values during the first year is summarised in Table 2.

The ANOVA performed on the relevé data of various plant species revealed a significant increase in the number of species characteristic of hay meadows ($p = 0.002$) over the fifteen years studied (Fig. 2). An extrapolation of these data over time shows the arrival of an additional characteristic species of hay meadows after fifteen years of management under this AES. Species richness tends to increase, but this trend is not significant ($p = 0.308$). The cover of the characteristic species and of species indicative of habitat quality increased significantly over the period studied ($p < 0.001$).

Analysis of the habitat degradation indices shows that the cover of nitrophilous species and that of species indicative of intensive grazing show a significant downward trend ($p = 0.001$ and $p < 0.001$ respectively). Similarly, the Ellenberg N-index for plant communities in the surveys decreases significantly over time ($p < 0.001$).

The PCoA conducted on the cover data for the flora of the studied meadows shows that relevés from meadows committed for a longer duration tended to have negative coordinates on axes 1 and 2 of the PCoA (Fig. 3a). The majority of relevés with commitments dating back more than 10 years are indeed in the quadrant with both negative coordinates on axes 1 and 2. On the other hand, relevés carried out in the first years of MC4 management are much more scattered, while rarely having negative coordinates for both axes simultaneously. The representation of the correlation between time and the PCoA axes clearly demonstrates an age-related progression towards negative values on both axes. The remaining variation was largely explained by the natural variation of the plant communities due to altitude, with the occurrence of sub-mountain species such as *Meum athamanticum* and *Geranium sylvaticum* at higher elevations.

The projection, on the same plane as the PCoA, of the species used to determine the "Lowland hay meadows" habitat degree of conservation in Wallonia shows a slight separation of species according to some of their characteristics (Fig. 3b). The species most represented in the negative values of the two axes are characteristic species of hay meadows and species indicative of the good quality of the habitat. *Sanguisorba minor*, *Bromus erectus,* and *Briza media* are the indicator plant species of biological quality with the most negative coordinates on both axis 1 and axis 2, also due to their higher occurrence at lower elevations. In the most positive values, species indicative of high grazing intensity and nitrophilous species, i.e. indicative of habitat degradation, are observed.

The criteria initially defined and shown in Table 1 have a varied impact on the overall degree of conservation (Fig. 4a). In the first year of relevés for all the meadows, 29.1% of the number of hay meadows had status A in terms of the number of species characteristic of hay meadows.

Table 2
Status of biological quality indicators in the first year of relevés for 103 meadows.

Conservation indicators	Mean	1st quartile	Median	3rd quartile
Species richness	30.2	26	31	33
Ellenberg N-index	5.4	5.2	5.4	5.8
Number of characteristic species	5.3	3	5	7
Cover of characteristic species + other indicators of habitat quality	20.1	8.4	15.6	26.8
Cover of nitrophilous species	7.1	1.7	4.9	10.5
Cover of high grazing intensity species	14.4	6.4	13.7	19.7

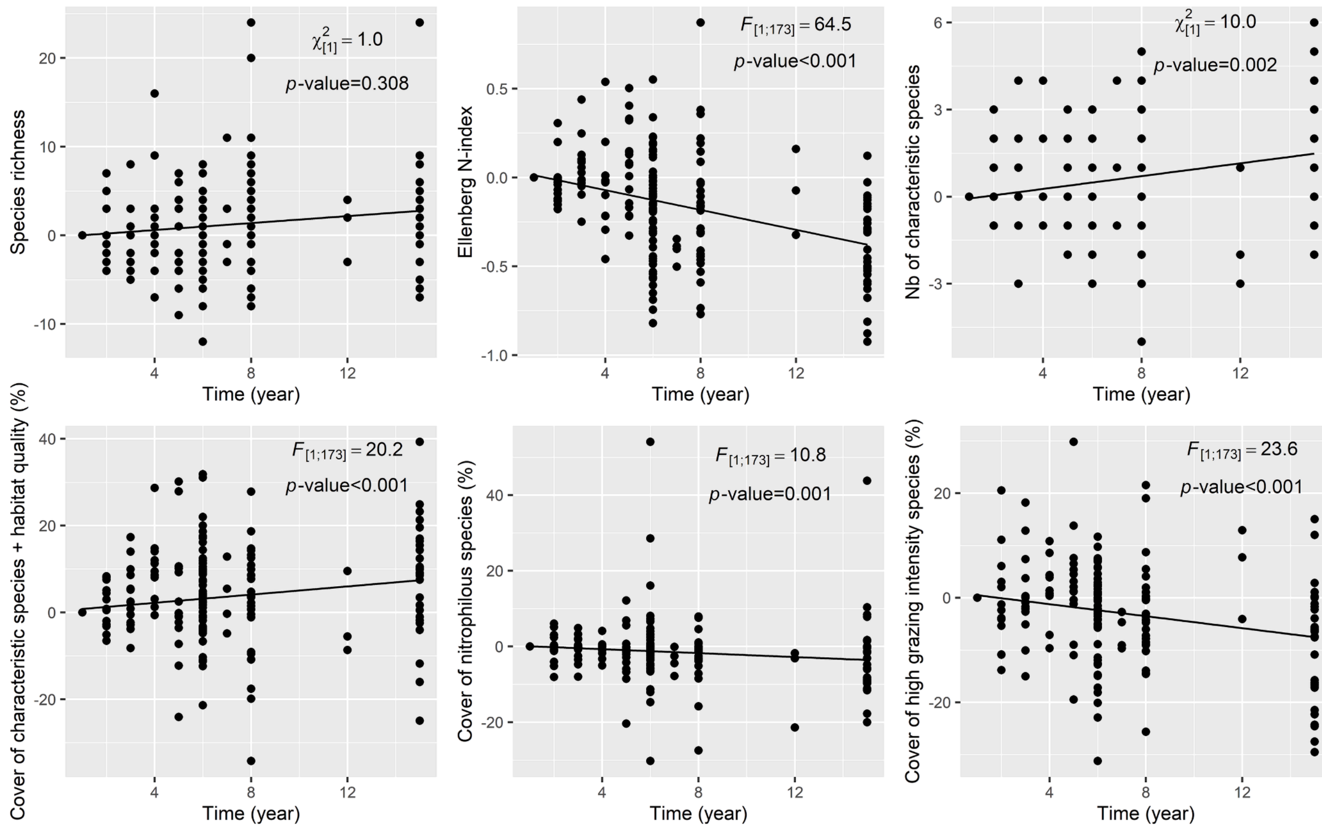

Fig. 2. Evolution of biological quality indicators in meadows over time. Each point represents a relevé, shown as the difference relative to the first year of relevés for the meadow committed to the AES (Δ-values). The x-axis represents the time elapsed since the first survey was taken and the y-axis represents each biological quality indicator in meadows.

Examining the last year for each of the meadows during which relevés were carried out, this percentage increases to 42.7%. The cover of characteristic species and species indicative of habitat quality slightly changed the degree of conservation for status A (from 7.8% to 8.7%). Within this criterion, a deterioration of almost half of the condition of the meadows from status B to status C is noted between the initial year and the final year (Supplementary Table 3). This deterioration is balanced by the strong increase in the number of meadows progressing from status C to status B and is therefore not apparent in Fig. 4a. Regarding the abundance of nitrophilous species, the degree of conservation improved from 73.8 to 89.3% for status A.

When synthesising the criteria, i.e. taking the worst condition of all the indicators to obtain the total degree of conservation, a general trend of positive change in this one is observed: 3.9% of meadows initially had status A, increasing to 6.8% in the last year of relevés. For status B, the degree of conservation increased from 22.3% to 30.1%, while for status C, this increase is very slight (+ 1%). The transition matrices reveal the same phenomenon as for the criterion of cover of characteristic species and species indicative of habitat quality: a degradation of meadows from status B to status C is dissimulated by an improvement in meadows from status C to status B (Supplementary Table 3). Status D, meanwhile, decreased by 11.6%. In other words, 11,6% of meadows that were not initially hay meadows according to the standard Natura 2000 criteria and thresholds could be considered as such once they had been managed in accordance with MC4.

When examining the change in degree of conservation after three different time steps, the majority of meadows retained the same degree of conservation as at the initial state (Fig. 4b). This trend is generally valid whatever the degree of conservation category (A, B, C or D) or the time step. However, it is the meadows with the best condition (status A) that are most likely to be maintained in their initial state, generally with a maintenance rate of over 70% (Supplementary Table 3). The improvement in the degree of conservation of all the criteria, as well as in the degree of conservation, compared with the initial status, is more pronounced in meadows studied between 8 and 15 years after the MC4 commitment (Fig. 4b). Notably, it was predominantly within this last time step (comprising meadows in their 8th to 15th year of evolution) that those initially classified as condition D, exhibited an improvement, with 45.5% advancing to condition C and 13.6% further improving to condition B (Supplementary Table 3).

4. Discussion

In our study sites, the evolution in the plant composition of meadows committed to the agri-environment scheme dedicated to high nature value meadows (MC4) was studied at different time steps. A change in this composition was mainly highlighted in meadows that had a long-term commitment (between 8 and 15 years). This is demonstrated by their stronger correlation with quality indicator species and by their trend to shift towards species that require low nitrogen levels. However, this change does not clearly translate into an improvement in degree of conservation. This makes it possible to discuss our objective of verifying whether MC4 management is in line with Nature 2000 goals. This also raises questions about the sole use of indicators and underscores the importance of comprehensive field monitoring.

The greatest improvement in the degree of conservation, measured by the indicator "Number of characteristic species", is seen in the class of meadows with the longest-term commitment (surveys carried out between the 8th to 15th year of MC4 management). Using scenario modelling, West et al. (2023) estimate that 5 years of AES provide only a limited benefit on plant diversity and that the time required to lead to desirable changes in the plant assemblage is 10 years. This is consistent

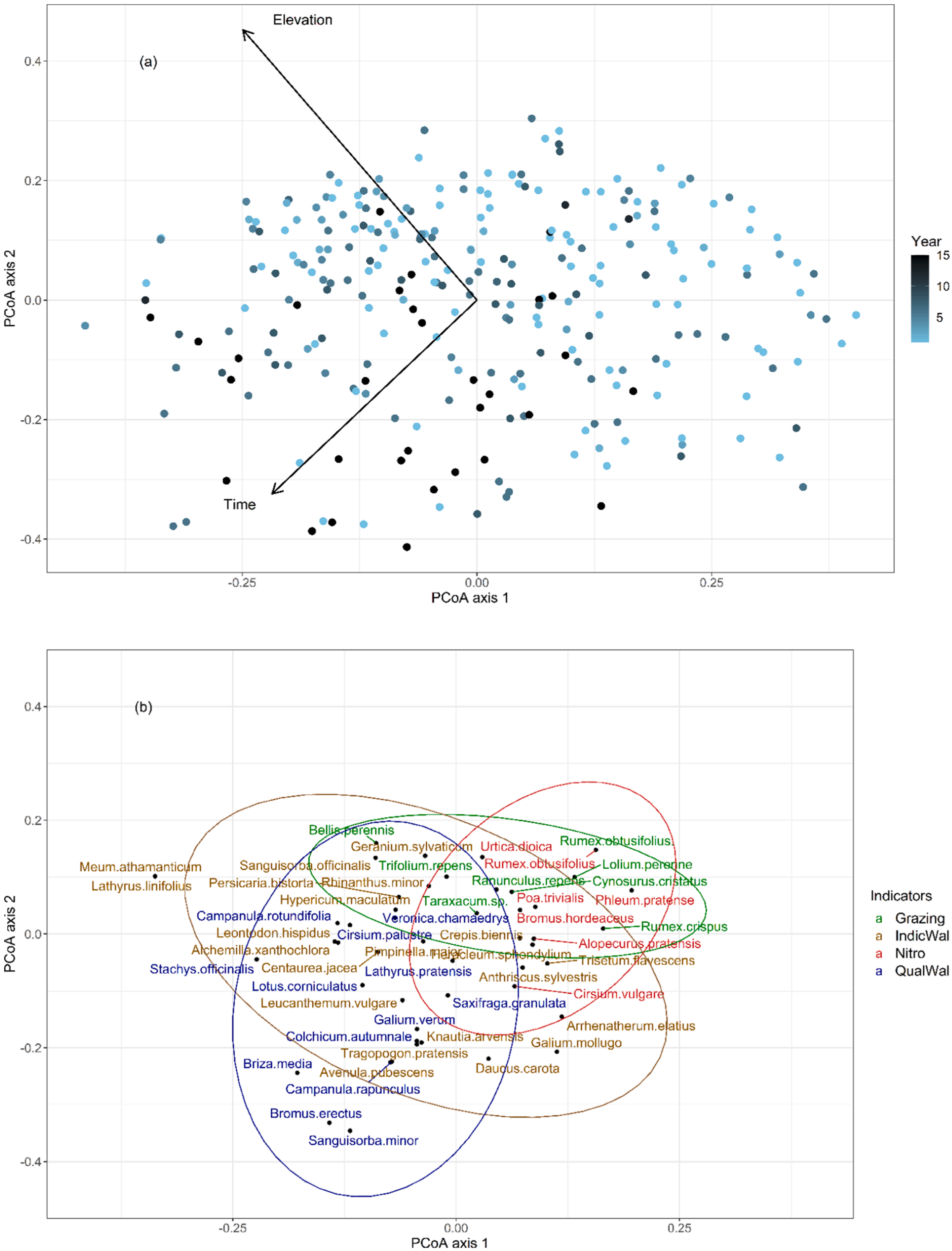

Fig. 3. PCoA of the 103 hay meadows, based on species cover data. (a) The colour of the dots represents the time that has elapsed since management began. Lighter points correspond to surveys carried out in the first few years after MC4 was introduced, while darker points correspond to surveys carried out after around ten years under MC4. The arrows represent the correlation between the PCoA axes and time on the one hand, and the correlation between the PCoA axes and elevation on the other. (b) Projection, in the same plane, of the species present in the surveys and the list of species indicative of intensive grazing (Grazing), the list of species characteristic of habitat 6510 'hay meadow' (Indicwal), the list of nitrophilous species (Nitro) or the list of species typical of and indicative of the quality of habitat 6510 'hay meadow' (Qualwal).

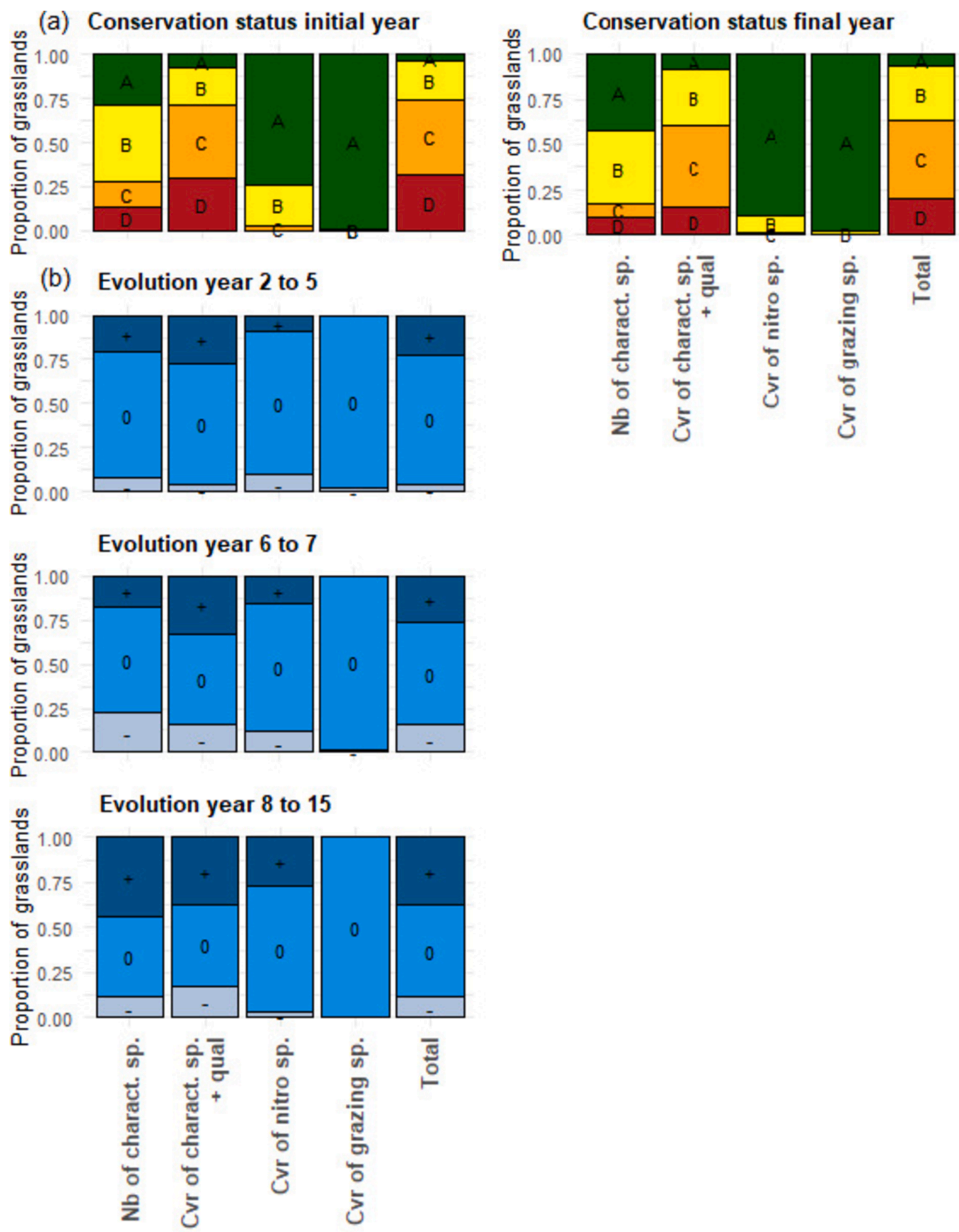

Fig. 4. Degree of conservation of the 103 meadows committed to MC4 in relation to the criteria and thresholds shown in Table 1. (a) During the first and last relevés conducted on each meadow. (b) Evolution of the degree of conservation of the meadows, based on relevés carried out between the 2nd and 5th year of MC4 management (n = 54), between the 6th to 7th year of MC4 management (n = 58) and between the 8th to 15th year of MC4 management (n = 62), compared with the initial year. "- ": degradation; "0": stable, "+": improvement.

with the idea that the response of plant composition in terms of colonisation and extinction is delayed in relation to environmental changes in grassland ecosystems (Helm et al., 2006; Piqueray et al., 2011).

Our results reveal stability over time in species richness. In line with similar conclusions, Starr-Keddle (2022) pointed out that hay meadows rarely increase in botanical diversity without active restoration actions, such as seed addition using green hay transfer, although this is highly dependent on the initial plant composition. Species characteristic of hay meadows have become more numerous and to cover a greater proportion of the meadows. However, it should be noted that this general trend to an increased cover may mask the decline of some particular species. Indeed, *Geranium sylvaticum*, *Heracleum sphondylium*, *Anthriscus sylvestris*, *Arrhenatherum elatius*, *Crepis biennis* and *Trisetum flavescens* tended to decline over time (result not shown). These species, although indicative of hay meadows, are also relatively nitrophilous. Their decline demonstrates the impoverishment of hay meadow soil over the years. Piqueray et al. (2016) also highlighted this soil impoverishment and attributed it to traditional hay removal practices.

Additionally, the PCoA and ANOVA revealed a decline over time in species indicative of habitat degradation. *Rumex obtusifolius*, *Rumex crispus*, *Phleum pratense*, *Poa trivialis*, *Ranunculus repens,* and *Lolium perenne* are associated with meadows recently committed to MC4. The restrictions of the AES on the application of fertilisers have limited the growth of these competitive species. Conversely, the species most associated with long-term committed meadows are those indicating the quality of the meadow that are more oligotrophic, such as *Sanguisorba minor*, *Bromus erectus,* and *Briza media*.

This change in vegetation towards more oligotrophic environments can also be seen in the significant reduction in the Ellenberg N-index of plant communities surveyed. It is worth noting that the Ellenberg N-index may have been strongly affected by the increasing presence over time of species such as *Festuca rubra* or *Anthoxanthum odoratum*. Their rate of cover increased significantly over time ($p < 0.001$ in both cases). These species are particularly well suited to cutting and have the ability to spread rapidly, thus covering a larger area in a short time (L. Pavlů et al., 2011). They are associated with low levels of nutrient inputs (Ó hUallacháin et al., 2016). *Festuca rubra* adapts particularly well to meadows managed by low inputs (V. Pavlů et al., 2012). These characteristics allow them to pull the Ellenberg N-index down for long-term committed meadows. Although they are considered positive from a conservation point of view, *Festuca rubra* or *Anthoxanthum odoratum* are not included in the list of species indicative of hay meadows. Therefore, they do not improve the degree of conservation of the meadows according to Walloon administration's criteria. The small number of meadows achieving the final condition A for the indicator "Cover of characteristic species and of species indicative of habitat quality" may be due to the presence of these species, which spread rapidly in oligotrophic conditions. Similarly, this may also explain the degradation of meadows in condition B for this same indicator, which then inflates the number of meadows in the condition C. This degradation should therefore be interpreted with caution, as it could reflect an increase in meadows species that are also of interest from a conservation perspective.

In its current form, the MC4 management therefore tends to steer hay meadows towards more oligotrophic variants of this habitat, or even towards more oligotrophic habitats. Indeed, in some cases, we observed the development of some species characteristic of species-rich oligotrophic grasslands, either acidic grasslands (HCI 6230), e.g. *Galium saxatile* and *Potentilla erecta,* or calcareous grasslands (HCI 6210), e.g. *Bromus erectus* and *Carex flacca*, depending on the soil substrate. This trend is not necessarily problematic from a conservation point of view, as oligotrophic habitats also have high biological value. They even have a higher biological value than hay meadows, when they are particularly species rich. This, however, necessitates that a large number of species typical for these habitats can colonise the site. This is only likely when other habitat areas are present in the close vicinity, as most of these species have very limited dispersal abilities (Poschlod et al., 1998). When this condition is not met, only species-poor oligotrophic grasslands can be expected, and maintaining 6510 can be a desirable objective. For that, adapting the MC4 management protocol by incorporating a low level of organic fertilisation could be considered to preserve hay meadows. Indeed, traditional hay meadows are typically regarded as mesotrophic environments with a certain level of nutrient availability (Critchley et al., 2002). Level of fertilisation should be adapted in order to favour the mesotrophic typical species, such as *A. elatius*, *C. biennis, H. sphondylium*, without leading to an overdevelopment of nitrophilous species. Furthermore, the AES supporting the maintenance of habitat 6510 could be based on a mowing system aligned with the phenological stage of the plants, rather than a first mowing at a fixed date. In this case, a result-based AES, where payments are linked to the maintenance of the habitat rather than adherence to a fixed mowing date, would seem more appropriate.

The use of indicators is a preliminary approach to diagnosing the condition of meadows. However, comprehensive monitoring of all plant species present remains necessary, as indicators do not always directly reflect what is happening in the field. Furthermore, the distribution into four conditions (A, B, C or D) does not capture improvements in the degree of conservation of meadows that initially had A status. In fact, the initial degree of conservation plays an important role in the analysis, some meadows involved in MC4 were already in a very good degree of conservation, preventing them from progressing towards a better condition. We also note that a small number of them transition to condition B, which could be explained for some by this change in vegetation towards a more oligotrophic habitat.

The PCoA revealed that a large proportion of the variation was due to altitude, resulting in the appearance of montane species, while others are more associated with lower altitudes. This distribution in the PCoA reflects a natural variation in habitat according to altitude, despite the relatively narrow altitude range within which the surveys are spread (130 m-600 m). *Geranium sylvaticum*, *Persicaria bistorta*, *Meum athamanticum,* and *Lathyrus linifolius*, tend to be found at higher altitudes in Wallonia, due to certain mountain characteristics or their attraction to more acidic soils. Indeed, the Ardennes bedrock at the highest altitudes in Belgium is made up of acid rock. *Rhinanthus minor*, which grows on drier, poorer soils, is very close to these sub-mountain species within the PCoA.

The maintenance of the total degree of conservation over time for hay meadows under an AES has also been demonstrated in other long-term studies of plant community change. In a study by Sullivan et al. (2018), the results obtained were similar to those in this study: the grassland plant community was maintained by low-intensity management, while there was a decline in species linked to intensive grassland management. Regarding soil fertility, the most marked turnover of species suggests a reduction in soil fertility. Conversely, in a survey of 116 hay meadows with quadrats allocated in three different grassland types (species-rich, modified species-rich, or degraded), Critchley et al. (2007) showed contrasting results. Total species richness was maintained by the 15 years of low-intensity management under the Environmentally Sensitive Areas AES, but forbs richness was not. Moreover, Ellenberg N-values increased in the modified types despite AES management. The author hypothesised an increase in grazing intensity to explain these results, given the change in species composition. In the most degraded sites, however, a reversion towards the target community was observed.

5. Conclusion

By monitoring around a hundred meadows, this study highlights that a choice has to be made in the management of the AES dedicated to high nature values meadows (MC4) used in Wallonia. Indeed, a shift in vegetation, from species indicative of habitat degradation to those indicative of habitat quality was observed. But this change is not always towards the characteristic species targeted, as the most nitrophilous of them tend to regress over time. Moreover, a significant decrease in the Ellenberg N-index, along with a reduction in the cover of nitrophilous species, suggests soil impoverishment. Although the MC4 management regime improves the degree of conservation mainly in meadows that have been under agri-environmental schemes (AES) for at least 8 years, it also pushes some of these meadows towards more oligotrophic habitats. To promote the preservation of habitat 6510 and thereby align with a Natura 2000 objective, incorporating light fertilisation into the current MC4 management could be considered. However, the very nutrient-poor meadows resulting from the absence of fertilisation are also habitats of significant biological interest. This underscores the need for comprehensive field monitoring and long-term species analysis to better understand the evolution of the degree of conservation of hay meadows.

CRediT authorship contribution statement

Emilie Cordier: Writing – review & editing, Writing – original draft, Formal analysis. **Serge Rouxhet:** Investigation. **Grégory Mahy:** Writing – review & editing. **Julien Piqueray:** Writing – review & editing, Supervision.

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.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2025.126834.

Data availability

Data will be made available on request.

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