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ORIGINAL RESEARCH PAPER

Conservation status and trends in the transformation of *Molinia* meadows in the Łąki w Komborni Natura 2000 site, SE Poland

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Abstract

The aim of this study was to provide a phytosociological and ecological characterization of meadow communities in the Łąki w Komborni Natura 2000 site (SE Poland), assess the trends in their transformation, and indicate the major threats impacting on their conservation. The study was conducted in 2015–2016. Three types of meadow communities were distinguished (alliances *Molinion*, *Arrhenatherion*, *Filipendulion*), due to the absence of the species characteristic for associations. The species richness noted per relevé differed significantly between the types of meadows (Kruskal–Wallis test: $H = 21.65$, $p < 0.05$). The highest floristic biodiversity ($H' = 2.99$) was noted for the meadow patches classified as in the *Molinion* alliance and the lowest ($H' = 2.50$) was found for the patches from the *Filipendulion* alliance. Mean values of the ecological indicators (F, R, N) differed between the meadow communities. The greatest disparity was noted for the mean values of the soil moisture indicator (from 6.42 to 7.45). Patches classified in the *Filipendulion* alliance were developed on the wettest soil substratum, whereas the patches classified in the *Arrhenatherion* alliance were predominant on a relatively dry substratum. The abandonment of traditional management practices (grazing, mowing) has contributed to transformation of the *Molinia* meadows, disappearance of characteristic species and succession of shrubs. The *Molinia* meadow habitat should be conserved by improvement of protection measures (appropriate mowing regime and removal of biomass) to conserve a high species richness and the rare and protected plant species.

Keywords

meadow community; conservation; secondary succession; species diversity; *Molinia* meadows

Introduction

Meadows represent semi-natural communities associated with human activity; they play an important role in the conservation of biodiversity in the agricultural landscape [1–6]. The origin and conservation of meadow communities largely depends on the conditions of the natural habitat (soil type, climate, etc.), the type and intensity of management practices, i.e., the use of fertilizers, the mowing time, and the mowing regime [7–12]. Since the second half of the twentieth century, the area of meadows in European countries has been reduced drastically [13–15]. Since the 1990s, radical economic reforms have resulted in changes in the agriculture sector in Poland. The economic changeovers impacted on environmental changes, modified crops and agricultural landscape structure [16–19]. Habitat degradation (e.g., changes in water relations) and the abandonment or intensification of management in meadows lead to floristic changes in meadow communities [10,20,21].

Molinia meadows (the *Molinion* alliance, the *Molinietalia* order, the *Molinio-Arrhenatheretea* class [22]) are mainly present in Eastern and Central Europe [1,2,4]. In Poland, *Molinia* meadows are found in the lowland and lower mountainous regions; the environmental optimum for the development is in the western part of the country. In the Lublin Upland (SE Poland), the presence of calcareous species is characteristic. In the north-east of Poland, the *Molinia* meadows are represented by transitional communities. Regional variability and floristic differentiation allow the recognition of lower syntaxonomic units (sub-associations and variants), which results from the wide range of habitat type associated with *Molinia* meadows [3,23,24].

Progressive degradation of *Molinia* meadows and reduction of their area in Europe have posed a serious threat to species diversity (insects, birds, mammals, and plants) [25–28]. In order to save genetic, species, and biocenoses diversity of semi-natural *Molinia* meadows, meadows have been included in the list of habitat areas (Council Directive), protected under the European ecological network Natura 2000, as habitat type 6410 [29,30]. Active steps for the conservation of *Molinia* meadows are clearly needed and so regular monitoring and identification of the current condition of habitat and floristic diversity is of great importance to predict the scale of changes and direction of transformation [3,23].

The aim of the present study was to (***i***) present the phytosociological and ecological characterization of the meadow phytocoenoses in the Łąki w Komborni Natura 2000 site, (***ii***) identify the trends in the transformations, and (***iii***) indicate the main threats that may lead to the disappearance of *Molinia* meadows.

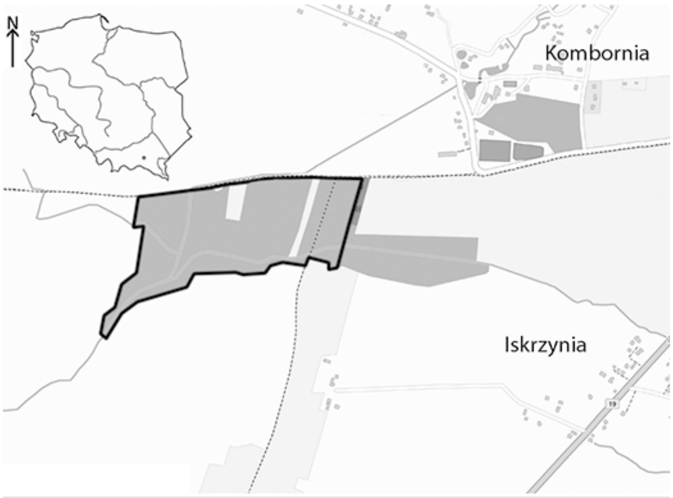

Fig. 1 Locality of the study area Łąki w Komborni Natura 2000. Source: OpenStreetMap authors.

Material and methods

The meadows are situated in Iskrzynia village (49°41′48″ N, 21°51′23″ E) (SE Poland) in the area of the Łąki w Komborni Natura 2000 site (PLH 180042) (Fig. 1). According to the physicogeographical regionalization, the area is classified as part of the Jasielsko-Krośnieńska Basin mesoregion and Środkowobeskidzkie Foothills macroregion in the Outer Western Carpathians [31]. The *Molinia* meadow (classified within the *Molinion caeruleae* alliance) is protected under the Natura 2000 network (habitat 6410). This meadow complex, 13.14 ha in total, is located in a periodically flooded valley of an unnamed creek. In the past, the area was used as pastures and hay meadows but mowing and grazing were abandoned approximately a decade ago (http://natura2000.gdos.gov.pl).

A field survey was conducted during 2015–2016. Observations were made from May to mid-August when the spring flora was still present and recognizable and seedlings of summer species were also identifiable. Sixty phytosociological relevés were recorded using the Braun-Blanquet method [32]. These relevés were selected in homogenous patches of vegetation (100 m^2 each). The geographic position of each relevé was recorded with a differential GPS. Syntaxonomic units were described according to Matuszkiewicz [22]; the nomenclature of vascular plants was based on Mirek et al. [33] and for mosses followed Ochyra et al. [34].

The relevés data were entered in Turboveg [35]. The data were subjected to hierarchical numeric classification based on species presence/absence (binary scale 0, 1) and abundance (Braun-Blanquet's 7-point scale: r = 0.1, "+" = 0.5). Differences between the relevés were calculated with the Jaccard formula (qualitative data) and its counterpart, the Ružička formula (quantitative data). Grouping was performed with WPGMA [36]. Calculations were carried out using the SYN-TAX 2000 package [37]. The graph presenting the grouping of the phytosociological relevés was plotted by comparison of two dendrograms in accordance with the full correspondence principle [38].

Habitat characteristics was determined using the Ellenberg's indicator values adapted to Polish conditions (EIV) [39] taking into account three ecological soil indicators – soil moisture (F), soil/water pH (R), and nitrogen content (N).

For each plant community (type of meadow), the following indices were calculated: (***i***) species richness – $S = n_i$, where n_i = species i, (***ii***) species diversity from the Shannon–Wiener index [40] – $H' = -\sum p_i \log_2 p_i$, where p_i = frequency of the species i, and (***iii***) species evenness with the Pielou index [41] – $J' = H' / \ln S$, defined as the ratio of the observed diversity to the maximum diversity, where: S = the number of species and $H_{max} = \ln S$. J' is constrained between 0 and 1; the less the variation in communities between the species, the higher is the J' value. The JUICE 7.0 package [42] was used to calculate average Ellenberg indicator values for each relevé and the indices.

All tabulated data were expressed as means with their standard deviations (*SD*). Non-parametric analyses of variance were applied using Kruskal–Wallis tests to assess differences between the type of plant communities in their values of diversity indices (S, H', J') and in ecological indicators (F, R, N). To analyze sample pairs for significant differences (*Molinion* and *Filipendulion* alliance) the Mann–Whitney U test were used [43]. The level of statistical significance to measure the differences between the means for all the analyses performed was set at $p < 0.05$. The statistical software package (ver. 10) developed by StatSoft Cracow, Poland was employed for all the analyses.

Results

The numerical analysis distinguished three types of habitats, which were assigned a rank of an alliance due to the absence of species characteristic for associations and the substantial transformations of the phytocoenoses. These types included: 1 – community of the *Molinion* alliance, 2 – community of the *Arrhenatherion* alliance, and 3 – community of the *Filipendulion* alliance (Fig. 2, Fig. 3).

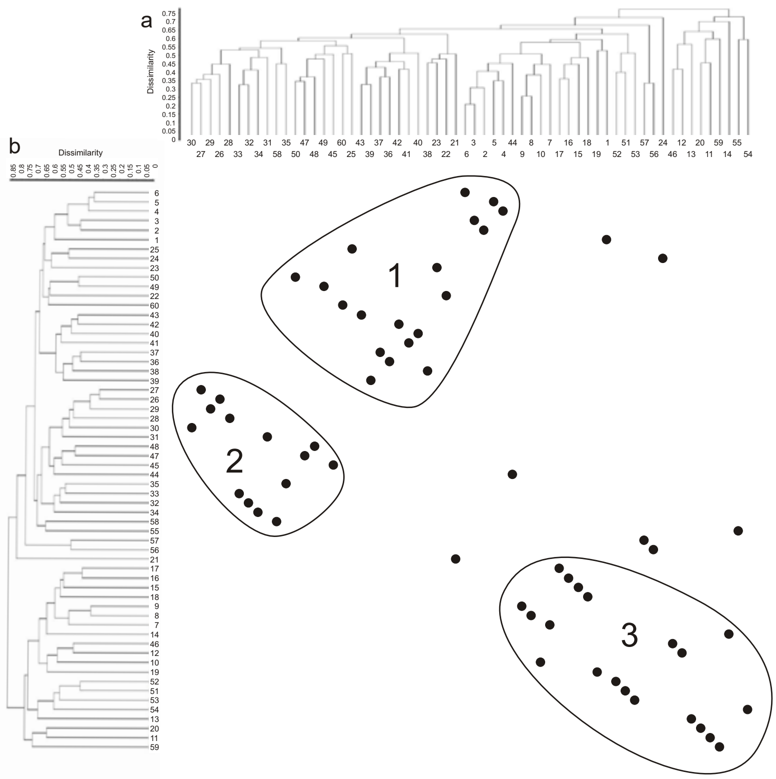

Fig. 2 Classification of relevés of the meadow communities in the Łąki w Komborni Natura 2000 site. **a** Dendrogram constructed on the basis of species presence/absence. **b** Dendrogram constructed on the basis of species abundance. 1 – community of the *Molinion* alliance; 2 – community of the *Arrhenatherion* alliance; 3 – community of the *Filipendulion* alliance.

Fig. 3 Seasonal changes of meadows in the Łąki w Komborni Natura 2000 site from spring to late summer.

Tab. 1 Variation in the mean parameters of meadow phytocoenoses.

Traits	Vegetation type (= meadow alliance)					
	Molinion		*Arrhenatherion*		*Filipendulion*	
	$n = 19$		$n = 14$		$n = 20$	
	mean	±*SD*	mean	±*SD*	mean	±*SD*
Species richness (*S*)	40.30[b]	5.60	37.60[b]	7.60	29.10[a]	4.80
Diversity (*H'*)	2.99[b]	0.20	2.78[b]	0.30	2.49[a]	0.30
Evenness (*J'*)	0.97[c]	0.01	0.80[a]	0.01	0.95[b]	0.01

The values indicated by the same small letter are not statistically different between the types of meadow vegetation (Kruskal–Wallis tests have been applied).

The number of species per relevé ranged from 15 to 53 (mean = 35.3 ±8.1 *SD*) (Tab. 1, Tab. 2). Species richness noted in the relevés differed between the types of meadows (Kruskal–Wallis test: $H = 21.65$, $p < 0.05$). The highest number of species was recorded in the community of the *Molinion* alliance, and the lowest number in the community of the *Filipendulion* alliance (Tab. 2). The species diversity differed between the *Molinion* alliance and the *Filipendulion* alliance (*H'* index: $Z = 4.49$, $p < 0.05$). The evenness index differed between the types of plant communities (*J'* index: $H = 45.88$, $p < 0.05$) (Tab. 1). The values of *S* and *H'* indices did not differ between *Molinion* and *Arrhenatherion* patches.

In total, 96 species (ranging from 29 to 50 species per relevé, including 11 characteristic and distinguishing species for the alliance) were recorded in 19 phytosociological relevés classified as the community of the *Molinion* alliance. The highest constancy degree (S = V) and cover coefficients were found for *Galium boreale* and *Betonica officinalis*; lower frequency (S = III) were noted for *Selinum carvifolia*, *Gladiolus imbricatus*, *Carex tomentosa*, *Succisa pratensis*, *Briza media*, and *Potentilla erecta* as well as *Sanguisorba officinalis* and *Serratula tinctoria*, which are strongly associated with *Molinia* meadows. The *Molinia caeruleae* was present in only one relevé (S = I) (Tab. 2).

In total, 90 species (from 28 to 53 species per relevé) were found in the community of the *Arrhenatherion* alliance (14 relevés). The *Molinion* alliance was represented by four characteristic species. The highest constancy degree (S = V) with a moderate cover coefficient was found for *Selinum carvifolia* and *Galium boreale*. The presence of a relatively large group of species of the *Arrhenatherion* alliance and *Arrhenatheretalia* order characterized by high cover rates indicates that these patches can be classified into *Arrhenatherion* (Tab. 2).

The community of the *Filipendulion* alliance was described in 20 phytosociological relevés comprising in total 88 species (ranging from 15 to 40 species per relevé). The patches were dominated by characteristic species for the alliance. High cover and consistency rates were found for *Filipendula ulmaria* and *Veronica longifolia* (S = V) as well as *Lythrum salicaria* and *Geranium palustre* (S = IV, III). An important role was also played by species from the *Molinietalia* order (*Sanguisorba officinalis*, *Lychnis flos-cuculi*, *Angelica sylvestris*, *Trollius europaeus*, *Deschampsia caespitosa*, *Serratula tinctoria*). A low constancy degree and cover coefficient value (S = III, II) was characteristic for *Selinum carvifolia*, *Galium boreale*, *Betonica officinalis*, *Succisa pratensis*, and *Gladiolus imbricatus* (Tab. 2). The community of the *Filipendulion* alliance exhibited clear floristic impoverishment manifested by the disappearance of characteristic species of the *Molinion* alliance.

The values of ecological indices, i.e., soil moisture (F), soil/water pH (R), and nitrogen content (N), differed between the type of plant communities (Fig. 4). The main ecological factor for distinguishing the habitat among meadow communities was moisture. The community of the *Filipendulion* alliance has developed on the wettest soil (F = 7.45). The patches of the *Molinion* alliance are associated with the driest soil (F = 6.42). The soil pH value (R) ranged from 6.78 to 7.40; the highest pH was for the patches classified in the community of the *Arrhenatherion* alliance, which indicates the

Tab. 2 Constancy degree, and cover coefficient of the characteristic species for *Molinion*, *Arrhenatherion*, and *Filipendulion* alliances.

Communities	*Molinion*		*Arrhenatherion*		*Filipendulion*	
Number of relevés	19		14		20	
Total number of species	96		90		88	
Range number of species	29–50		28–53		15–40	
	S	D	S	D	S	D
ChAll. *Molinion caeruleae*, *ChO. *Molinietalia caeruleae*						
Galium boreale	V	2018.4	V	503.6	II	200.0
Betonica officinalis	V	1650.0	IV	375.0	II	35.0
Gladiolus imbricatus	III	271.0	I	39.3	II	10.0
Selinum carvifolia	III	250.0	V	242.9	III	120.0
**Sanguisorba officinalis*	III	521.0	III	532.1	V	455.0
**Serratula tinctoria*	III	252.6	II	42.9	III	172.5
Briza media	III	76.3	I	3.6	I	2.5
Potentilla erecta	III	73.7	I	7.1	I	10.0
Carex tomentosa	III	71.0	I	3.6	I	32.5
**Climacium dendroides* d	III	21.0	I	3.6	I	7.5
Succisa pratensis	II	10.5	-	-	II	57.5
Molinia caeruleae	I	26.3	-	-	-	-
Carex flava	I	5.3	II	10.7	-	-
Fissidens adianthoides d	I	2.6	-	-	-	-
Total cover coefficient	5249.7		1764.4		1102.5	
ChAll. *Filipendulion ulmariae*						
Filipendula ulmaria	V	2315.8	V	1985.7	V	3037.5
Veronica longifolia	IV	192.1	V	657.1	V	1082.5
Geranium palustre	III	342.1	V	2517.9	III	1237.5
Lythrum salicaria	III	21.0	III	25.0	IV	55.0
Lysimachia vulgaris	II	39.5	I	35.7	II	10.0
Hypericum tetrapterum	-	-	I	3.6	-	-
Valeriana officinalis	I	2.6	-	-	-	-
Total cover coefficient	2913.1		5225.0		5422.5	
ChAll. *Arrhenatherion elatioris*, *ChO. *Arrhenatheretalia elatioris*						
Geranium pratense	IV	1460.5	V	2028.6	V	150.0
Galium mollugo	V	378.9	V	639.3	IV	102.5
**Pimpinella major*	V	623.7	IV	828.6	II	60.0
Alchemilla monticola	IV	200.0	IV	164.3	IV	100.0
**Heracleum sphondylium*	V	186.8	IV	167.9	IV	30.0

Tab. 2 Continued

Arrhenatherum elatius	IV	894.7	IV	250.3	I	10.0
**Achillea millefolium*	V	89.5	IV	35.7	II	12.5
**Leucanthemum vulgare*	II	18.4	IV	32.1	II	15.0
**Dactylis glomerata*	V	136.8	III	153.6	I	10.0
Campanula patula	IV	28.9	III	25.0	III	25.0
Knautia arvensis	III	21	I	7.1	I	2.5
**Trisetum flavescens*	I	5.3	II	50.0	-	-
Crepis biennis	-	-	I	3.6	-	-
Tragopogon orientalis	I	2.6	-	-	-	-
Total cover coefficient	4047.1		4386.1		517.5	

Explanations: S – constancy degree; D – cover coefficient; d – moss; * – species characteristic of order.

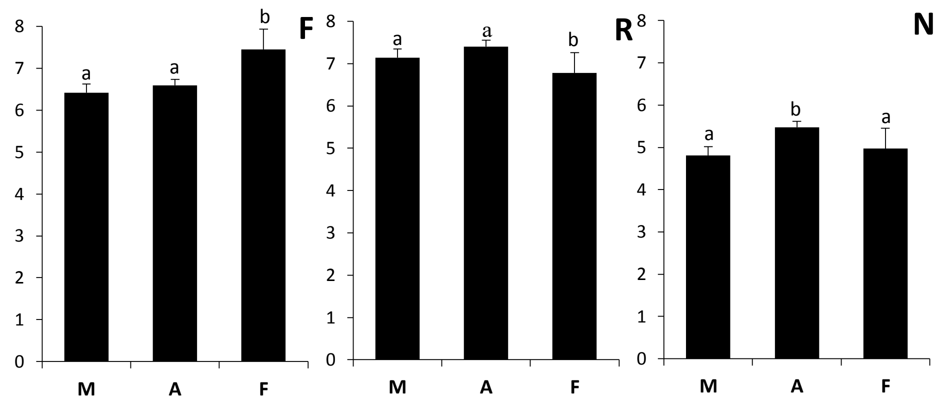

Fig. 4 Mean values (±*SD*) of the ecological indicators (F – moisture; R – soil reaction; N – nitrogen content). The values indicated with different small letters vary significantly between the types of meadows according to the Kruskal–Wallis test (M – *Molinion* alliance; A – *Arrhenatherion* alliance; F – *Filipendulion* alliance).

neutral to slightly alkaline soil reactivity. The N content of soil differed significantly between the *Molinion* (N = 4.81) and *Arrhenatherion* (N = 5.47) communities.

Discussion

Degradation of *Molinia* meadows results in a decline in species richness and reduction of species characteristic of typical phytocoenoses, which makes the classification of the patches studied into alliances difficult. The meadow complex under study forms a mosaic of transitional communities, in which species characteristic of *Molinia* meadows occur with low frequency and abundance. The conservation status of the meadow complex Łąki w Komborni (habitat 6410) has thus been evaluated as unsatisfactory (U1). The low evaluation of the habitat is related to the high degree of fragmentation of patches, a low number of species characteristic for the *Molinia* meadows, a low cover of characteristic species, the expansion of tall herbs and grasses and the encroachment of willow and alder shrubs (http://natura2000.gdos.gov.pl).

In our study area, the community of the *Molinion* alliance did not exhibit typical features of the *Molinietum caeruleae* association described in other regions of Poland [3,7,44,45]. Our *Molinion* patches have been typified by a relatively high number of characteristic species of the alliance, D = 5249.7 (Tab. 2), and a negligible share of the indicator species *Molinia caerulea*. Despite the high sharing of species of the *Filipendulion* and *Arrhenatherion* alliances, species characteristic of the *Molinion* alliance predominated in the community and formed compact homogeneous patches. We assume that non-mowed patches of *Molinia* meadow are subject to succession process and so transform into tall herb communities or a community with *Phragmites australis*, or into one dominated by tall sedges (*Magnocaricion* alliance). A predominance of *Magnocaricion* was observed in locally flooded areas of the complex studied.

The community of the *Arrhenatherion* alliance represented a very poor form of a *Molinia* meadow. The presence of a large group of mesic meadow species with a twofold higher cover coefficient than that of *Molinia* meadow species (D = 4386.1 and D = 1764.4, respectively) clearly resembles communities of the *Arrhenatherion* alliance (Tab. 2). Similar results indicating transitional stages between wet and mesic meadows were reported for Niepołomicka Primeval Forest, S Poland [7] and Wielickie Foothills, S Poland [10]. Presumably, the appearance of communities of the *Arrhenatherion* alliance in the study area was related to the drainage of this area and subsequent changes in soil water balance. In some patches, the development of expansive grass species (e.g., *Deschampsia caespitosa*, *Phalaris arundinacea*) was noted, which resulted in the decline in species richness. A similar process of transformation of *Molinia* meadows into *Arrhenatherion* meadows, connected with changes in the hydrological soil conditions, was described by Grynia [46]. As suggested by this author, the changes tend to be irreversible and lead to degradation of biocenosis.

In the herb community of the *Filipendulion* alliance, *Filipendula ulmaria* was a dominant species. The total cover of the species from the alliance (D = 5422.5) was higher than that of representatives of the other syntaxonomic groups (Tab. 2). The species of the *Molinietalia* order, *Molinio-Arrhenatheretea* class, and *Phragmitetea* class were also found. Herb communities dominated by *Filipendula ulmaria* are usually floristically poor [47]. In our study area, the patches classified in *Filipendulion* alliance are rich in species. Moreover, the share of species of the *Molinion* alliance clearly indicates a consecutive succession stage of *Molinia* meadows, being unmanaged for at least a decade. Such directions of *Molinia* meadow transformation have been reported by, e.g., Dubiel [48] and Suder [45]. In the community of *Filipendulion* alliance, the shrub species (*Alnus glutinosa*, *Salix cinerea*, *Padus avium*) have all been noted, therefore we assume that intervention is required to stop further development of willow and alder shrubs. A similar process of succession was observed in the meadows described by other authors [49–52].

In our study, the number of species recorded in the community of the *Molinion* alliance was lower than that reported in this meadow type developed in other regions of Poland [44,53,54]. It is probable that the disparity is related to the size of samples, the insular occurrence of *Molinia* meadows in the south of Poland, and the degeneration of the habitat in the study site.

It is clear that *Molinia* meadows disappear at a fast rate due to any lack of adequate management (intensification or abandonment), excessive drainage of habitats and changes in hydrological regime [18,21,55–58]. Mowing of the meadow complex Łąki w Komborni ceased approximately a decade ago. Our floristic study indicates that a lack of management results in reduction of the number of diagnostic species, evident impoverishment of plant community structure and diversity, and establishment of the next succession stage. Currently, typical *Molinia* meadows have remained in small areas, (ca. 7.17 ha). The changes in the floristic composition of meadow patches hamper their assignment to an association.

In some patches, the dominance of herb species from the *Filipendulion* alliance was observed. As reported by Falińska [59] for *Filipendula ulmaria*, which is an expansive species classified as a long-term succession promoter, locally and in waterlogged stands, we noted a considerable share of species from the *Calthion* alliance (*Cirsium rivulare*) and expansion of *Phragmites australis* and *Carex gracilis*. Such floristic changes have been also reported by other authors [48,60]. The floristic composition of meadows depends not only on type and regime of management, but also on edaphic and moisture conditions of the habitat [56]. In this study, we used the Ellenberg's indicator values (soil moisture, N content, pH) to assess the habitat conditions that are associated with particular types of plant communities. These indicators are widely used to describe habitat conditions and changes and are considered by many authors to be the most important factors determining wet grassland species composition [53,61–64]. Presumably, the changes in moisture conditions documented for our study area induced changes in the vegetation and encouraged the development of plant communities of the *Filipendulion* alliance. Moreover, due to the abandonment of management (mowing, grazing), the remaining plant biomass is degraded and the substrate is enriched with nitrogen (N) [53,63]. We observed encroachment of the nitrophilous species (e.g., *Urtica dioica*) into several patches of the *Arrhenatherion* alliance within the Łąki w Komborni.

Some authors stress the importance of maintaining the *Molinia* meadow habitat (6410) and the need for protection thereof on the European scale [52,65,66]. Extensive management (grazing, mowing, and removal of biomass) is recommended to enable the preservation of species richness (rare and threatened taxa) and their unique species composition [44,67–71].

Conclusions

Based on the analysis of the phytosociological relevés and ecological indicator values (EIV), we assume that Łąki w Komborni has been subjected to considerable changes. The current floristic composition of communities (*Molinion*, *Arrhenatherion*, *Filipendulion*) is a result of abandonment of management (mowing, grazing), which significantly limited the number of diagnostic species for *Molinia* meadows. Tall herb occurrences and encroachment of shrubs are worrying problems. Management to conserve the characteristic floristic composition and structure of *Molinia* meadows is urgently needed.

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Stan zachowania i kierunki przemian łąk trzęślicowych na obszarze Natura 2000 Łąki w Komborni (Polska południowo-wschodnia)

Streszczenie

Celem pracy była charakterystyka fitosocjologiczna i ekologiczna zbiorowisk łąkowych na obszarze Natura 2000 Łąki w Komborni (SE Polska) oraz ocena kierunków zmian wraz ze wskazaniem głównych zagrożeń. Badania przeprowadzono w latach 2015–2016. W kompleksie wyróżniono trzy typy zbiorowisk, które ze względu na brak gatunków charakterystycznych dla zespołów oraz znaczne przekształcenia fitocenoz podano w randze związku (*Molinion*, *Arrhenatherion*, *Filipendulion*). Zbiorowiska różniły się bogactwem gatunkowym ($H = 21.65$, $p < 0.05$). Najwyższą bioróżnorodność florystyczną ($H' = 2.99$) miały płaty ze związku *Molinion*, a najniższą ($H' = 2.50$) ze związku *Filipendulion*. Średnie wartości wskaźników ekologicznych (F, R, N) były różne dla wydzielonych zbiorowisk. Największe różnice zanotowano w średnich wartościach wskaźnika wilgotności gleby (od 6.42 do 7.45). Na podłożu najbardziej wilgotnym dominowo zbiorowisko z *Filipendulion*, a na stosunkowo suchym zbiorowisko z *Arrhenaterion*. Brak tradycyjnego użytkowania (wypas, koszenie) spowodowało przekształcanie łąk trzęślicowych, zanik gatunków charakterystycznych oraz postępujący proces sukcesji. Z uwagi na duże bogactwo gatunkowe, obecność rzadkich i chronionych taksonów istnieje potrzeba zachowania siedliska łąk trzęślicowych na badanym terenie wraz z koniecznością wprowadzenia zabiegów ochronnych (koszenie, usuwanie biomasy).