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Original Research

Dynamics of Semi-Natural Vegetation with a Focus on *Molinion* Meadows after 50 Years of Strict Protection

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Abstract

Semi-natural ecosystems in Poland and all over Europe have become endangered due to succession. A more effective plan of protection of these ecosystems can only be developed when based on thorough knowledge of the habitat requirements, successional pathways and related threats. Studies conducted in a nature reserve were aimed at defining the most important changes observed in non-forest communities under uninterrupted secondary succession conditions since a reserve was erected.

Several years of strict protection within the reserve resulted in the partial disappearance of non-forest habitats. Their area is now three times smaller than it was in the mid-20th century. Meadows described in the 1960s have undergone different transformations. The meadows have been replaced with initial forest communities that belong to the dynamic circle of riparian, alder, and oak-hornbeam forests.

Keywords: dynamic tendency, succession, non-forest vegetation, strict nature reserve, purple moor-grass

Introduction

Protection and restoration of semi-natural wet meadows requires thorough knowledge of successional pathways and the phytocoenoses' response to various types of disturbances [1]. In Europe, low productive wet meadows have a high conservation value because they are habitat to many valuable and protected plant and animal species [2, 3]. The majority of the meadows are semi-natural and depend on management [4]. Today, the largest threats to wet meadows are the intensification of agriculture and abandonment of less productive meadow types, which results in secondary succession [1, 5, 6]. One of the results of succession is the disappearance of heliophilous species and the formation of scrub- and forest species more adapted to poor light conditions. In the case of one of the most endangered non-forest communities, such as purple moor-grass meadows of the alliance *Molinion* Koch 1926, succession also results in a significant decrease of floristic diversity [7] and is related to the disappearance of many valuable and protected species [8, 9].

One of the most famous sites of fen meadows (*Molinion*) in Świętokrzyska is the Świnia Góra (SG) Nature Reserve [10]. It is one of the most valuable protected forest areas in Poland, with small patches of grassland (clearings) that significantly contribute to its biocenotic diversity [11]. It is located ca. 11 km SW from the city of

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Skarżysko-Kamienna and 5 km from both public roads and cultural and agricultural development. Local vegetation has been strictly protected for over 50 years. Before that, the important impact on vegetation of the reserve had excavations sites that were actively used until the beginning of the 19th century.

In 1958-63 Fabijanowski and Zarzycki [10] conducted detailed phytosociological studies in the SG nature reserve. They recorded several phytosociological relevés and constructed a vegetation map. Seven grassland communities existed within the forest, covering an area of slightly more than 2 ha. In the 1950s the clearings harboured many valuable vascular plants such as *Iris sibirica*, *Gentiana pneumonanthe*, *Gladiolus imbricatus,* or *Trollius europaeus*. In 1956, three years after the area became strictly protected, the regular mowing was stopped and secondary succession started. This process was interrupted only once in the 1970s, when the meadows were mown. After that the meadows were abandoned. Phytosociological studies were repeated using the Braun-Blanquet method after 50 years of protection.

The present work aims at defining the directions and rate of changes in non-forest ecosystems, with special attention paid to:

(i) the changes in the clearings that vegetation caused through a lack of use
(ii) purple moor-grass meadows succession directions
(iii) determining the species that are stable within the phytocoenoses despite the ongoing succession.

The following hypotheses were made:

1. Due to the fact that the ecological amplitude of characteristic species is narrow for associations and it increases from association to class, it was assumed that as a result of the occurring changes the first species to disappear would be those characteristic of the lowest syntaxonomic units (alliance and association).
2. Due to the fact that purple moor-grass meadows are regarded as belonging to the dynamic circle of riparian forests [12], in the course of their succession it is deciduous forest (especially riparian forest) species that will appear and dominate.

Methods

The basic reference material used for the analysis of forest clearings vegetation changes was the data collected between 1958 and 1963, and published by Fabijanowski and Zarzycki [10]. The vegetation map contained in the book was constructed at the scale of 1:1000, and the phytocoenoses were mainly classified as associations. A total of 8 phytosociological relevés were recorded of the clearings, and their locations were recorded on that map [10].

Floristic records were taken during field studies carried out in 2008 and 2009, and a new vegetation map was made at a scale of 1:1000 using a traditional topographic method [13] and a GPS data collector. The area analyzed was one where non-forest communities were recorded on the map of actual vegetation created between 1958-63 [10]. The mapped units were indicated on the aerial photograph. To define changes of the flora and vegetation within the clearings, a full record of their present flora was taken and 18 phytosociological relevés were recorded using the Braun-Blanquet method to determine plant communities. Among this number eight relevés were recorded of the clearings at the same sites where the tests of 1958-63 had been carried out. They were used to compare floristic changes between historical and current phytocoenoses. Determination of the points was possible because the raster maps presenting the historic vegetation of the reserve and the location of phytososiological relevés were digitalized and corrected in GIS.

Comparative analysis of both historic and present records began with the critical assessment and reclassification of historic phytosociological relevés. Then both historic and current maps were used to compare the area occupied by phytocoenoses in the past and present. The maps were overlain and then the dynamic tendencies were defined and succession series were assessed.

Penetrating, disappearing, and constant species in the analyzed phytocoenoses were listed *via* the comparison of phytosociological relevés from the two periods. The average percentage cover was calculated for species from individual phytosociological classes. The floras of the endangered species of 1958-63 and those presently found within the clearings were compared. Flora analysis was performed with special attention paid to protected [14], and endangered [15, 16] species. Phytosociological relevés also were used to calculate mean Ellenberger moisture (F), light (L), and nutrient status (N) values [17].

A cover index was used to assess abundance changes in phytocoenoses and was calculated according to the following formula [18]:

$$Wp = \frac{\sum \overline{pp}}{n} \times 100\%$$

...where:

pp – cover percentage of individual species (we took following value for individual cover indices: 5 – 87.5; 4 – 62.5; 3 – 37.5; 2 – 17.5; 1 – 5; ±0.5);

n – number of relevés

For the cover value +, a value of 0.5 was adopted (instead of a value of 0.1 adopted by most of the authors) to give greater importance to the accidental species that often play an important role in the succession process. Current and historic values of the above indices were compared, but due to a small number of samples it was impossible to determine the relevance of differences between them using statistical tests. The names of the species were provided by information from Flowering Plants and Pteridophytes of Poland. A Checklist [19], and the phytosociological affiliation of the species as well as names of all syntaxa was made according to Matuszkiewicz [12].

Table 1. Changes in plant communities of clearings between 1958 and 2009.

Plant community	1958-1963		2008-2009		Dynamic tendency
	Number of phytocoenoses	Area [m²]	Number of phytocoenoses	Area [m²]	
Mosaic of wet and fresh meadow	3	7,974	-	-	↓
Wet meadow with cabbage thistle (community with *Cirsium oleraceum* and *Angelico-Cirsietum*)	2	2,287	-	-	↓
Purple moor-grass meadows *Molinietum caeruleae nardetosum*	2	6,887	-	-	↓
Purple moor-grass meadows *Molinietum caeruleae typicum*	-	-	4	1,043	↑
Mat-grass and hath rush community (*Nardo-Juncetum*)	1	870	-	-	↓
Fen community of *Scheuchzerio-Caricetea nigrae* class	1	143	2	164	↑↓
Community of *Filipendulion* alliance	1	470	7	3,045	↑
Common reed community of *Phragmition* alliance	1	845	1	467	↓
Willow scrub and forest community from of *Alnetea glutinosae* class	1	1,057	5	4,013	↑
Initial riparian forest (*Fraxino-Alnetum*)	-	-	2	1,074	↑
Oak-hornbeam forest (*Tilio-Carpinetum*)	-	-	4	5,298	↑
Coniferous forest communities of *Vaccinio-Piceetea* class	2	341	9	5,770	↑
Total	14	20,874	34	20,874	

↓ – decreasing area of phytosocological unit, ↑ – increasing area of phytosocological unit, ↑↓ – constant area of phytosocological unit

Results

Three forest clearings studied cover only 2.03 ha in total, which is only 4% of the nature reserve total area. Ten plant communities were found on this very small area around the end of the 1950s. In that time the largest area was occupied by meadows of various phytosociological affiliation, but the *Molinietum caeruleae* phytocoenoses covered the largest area (Table 1). Forest communities (alder and conifer forests) only covered approximately 0.15 ha of the area and formed small enclaves of forest vegetation within the clearings. Studies conducted in the years 2008-09 revealed 16 plant communities within the studied area. Over the last 50 years the total area of non-forest phytocoenoses decreased from 1.8 ha to 0.6 ha, while the number of meadow ecosystems declined from 1.6 to 0.1 ha.

The most valuable community type (*Molinion*) decreased considerably. Within the last 50 years this meadow type changed into 6 different plant communities (Fig. 1).

However, purple moor-grass meadows are now found within the clearings not only because of the constancy of community (fluctuation) of *Molinietum caeruleae nardetosum* phytocoenoses, but also as a result of processes occurring within patches of other non-forest communities (Fig. 1).

Maps of the actual vegetation from the 2 analyzed periods were overlaid, and a map of dynamic tendencies was drawn up (Fig. 2). The analyses performed revealed two ecological processes within the area – dominant secondary succession (84% of the analyzed area) and fluctuation (16% of the analyzed area). Succession results in the development of several individual forest communities: alder, oak-hornbeam forests. and upland mixed conifer forests.

Several relevés recorded in the same places after 50 years showed constant, disappearing and new groups of species in the area (Table 2). Among the constant species within the clearings, taxa related with *Calthion* meadows were dominant. The species that disappeared most quickly from the clearings were common meadow species; those related with fresh meadows and those characteristic for *Nardetalia* meadows and fens (Table 2). A large group of euthrophic deciduous forest species also appeared (Fig. 3). It is also seen in the value of mean nutrient status (N), which has significantly increased (Table 2).

Abundance changes also involved a large group of valuable and protected species (Table 3). The repeated studies revealed that the area is now inhabited by numerous protected species of vascular plants related to forest ecosystems. Valuable meadow species are disappearing from the clearings or have totally died, except for the *Trollius europaeus,* whose cover area within the nature reserve has increased over the last 50 years.

Discussion

Changing of Non-Forest Ecosystem Vegetation Caused Through a Lack of Use

Secondary succession is the most frequently observed ecological process in phytocoenoses of the analyzed non-forest communities. Generally, it is similar to the succession described for meadows in other regions of Poland [20-23] and Europe [24, 25]. However in the case of SG Nature Reserve some part of meadow phytocenoses seem to be constant (Figs. 1, 2). In fact, two ecological processes were observed – fluctuation and secondary succession.

Fluctuation between the phytocoenoses within the *Molinion* alliance, resulting in minor transformances comprising only the change of the subassociation (from *Molinietum caeruleae nardetosum* to *Molinietum caeruleae typicum*), was observed on numerous occasions. Zalewska [26] points out that dry meadow species (of *Nardo-Callunetea*, *Festuco-Brometea*, *Koelerio-Corynephoretea* classes) or expansive species such as *Deschampsia caespitosa* [9] appear within purple moor-grass meadows on drier habitats and soils with higher mineral contents. Because the area is marshy, hygrophilous species characteristic for the *Scheuchzerio-Caricetea nigrae* class and for the order *Molinietalia* are very abundant, while fresh meadow species of the order *Arrhenatheretalia* and dry meadow species are scarce. This type of reaction to secondary paludification was also observed in other parts of Poland [22-28]. The same processes occur in the *Calthion* meadows. Due to lack of use and secondary paludification, wet meadows are changed into rushes – *Phragmition* and *Magnocaricion* [25]. The fluctuation process also involves the transformation of other meadow communities (e.g. *Angelico-Cirsietum oleracei*) into *Molinion* meadow phytocoenoses (Fig 1). In the event of *Angelico-Cirsietum oleracei*, a community that must be mown twice a year, the most likely reason behind the change is that the mowing was discontinued and therefore species flowering late in the summer and related with *Molinion* meadows are promoted [8].

An interesting phenomenon observed in the SG Nature Reserve is also the process of transformation of other non-forest communities into *Molinion* meadows (Figs. 1, 2). The biggest existing patch of *Molinion* meadow developed as a result of the transformation of *Nardo-Junectum* phytocoenoses which, probably due to the discontinued extensive grazing, i.e. human pressure, were subject to dynamic processes. Based on changes occurring within other patches one may presume that subsequent changes will result in the appearance of scrub and forest communities, and thus they will be successional in nature. However, it is too early to talk about this process because the phytocoenosis transforms because of propagules of the *Molinion* meadow species present in the 1950s in the *Nardo-Juncetum* community, and not those from outside the phytocoenosis [29]. Mat grass communities are formed in the areas grazed after conifer forests or boggy conifer forests are cut, as a result of pasture and meadow communities from the *Molinietalia* order being dried or fen communities being dried out or grazed [30]. According to Perzanowska [30], during the last 30 years patches of mat grass have been noted as having disappeared, which is due to discontinuance of livestock grazing on the area and the groundwater level being locally lower. In the event of the SG Nature Reserve, the reason for their disappearance is discontinuance of livestock grazing on the area, yet there is not enough data to conclude that the groundwater level is lower, too.

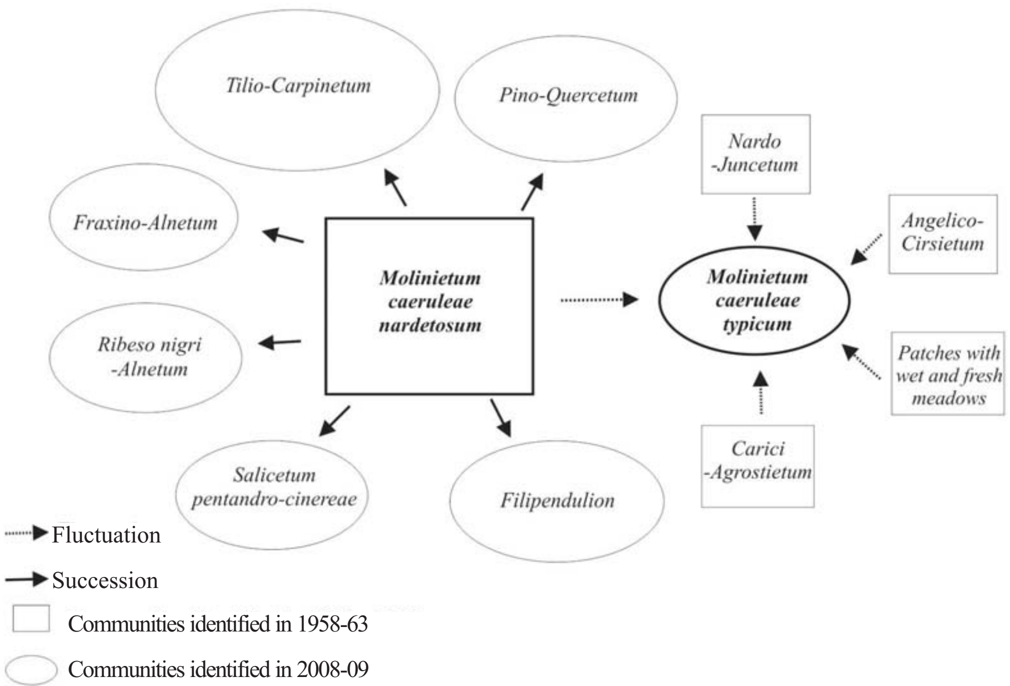

Fig. 1. Dynamic processes and their directions of purple moor-grass meadows *Molinietum caeruleae* (size of squares and ellipses shows approximately relations between areas of communities).

Table 2. Species dynamics and ecological indicator values within the nature reserve's forest clearings based on phytosociological relevés.

Year	1958-63		2008-09	
Number of relevés	8		8	
Number of species in the table	129		124	
Average number of species in a relevé	42		38	
Ecological indicator values L	6.84		5.89	
F	6.87		7.06	
N	3.74		4.9	
Species	Cover index	Constancy	Cover index	Constancy
Ch.All. *Molinion*				
Selinum carvifolia	+-2	IV	+-2	III
Gentiana pneumonanthe	+-2	IV	+-1	II
Betonica officinalis	+-3	III	+-2	III
Iris sibirica	+	III	+-2	II
Gladiolus imbricatus	+	III	+-1	II
Succisa pratensis	1-3	III	+	II
Serratula tinctoria	+-1	II	+-2	II
Molinia caeulea	+-1	II	-	-
Galium boreale	+	I	-	-
Ophioglossum vulgatum	+	I	+-1	II
Ch. All. *Calthion*				
Scirpus sylvaticus	+-1	V	+-3	IV
Myosotis palustris	+	IV	+-2	V
Juncus effussus	+-1	IV	+-2	IV
Crepis paludosa	+	III	1-3	V
Cirsium oleraceum	4-5	II	+	I
Cirsium rivulare	+-1	II	+-1	II
Caltha palustris	+	II	+-1	II
Juncus conglomeratus	+-1	IV	+	I
Trollius europaeus	+	I	+-1	III
Dactylorhiza majalis	-	-	+-1	II
Ch. All. *Filipendulion*				
Lysimachia vulgaris	+-1	IV	1-3	V
Filipendula ulmaria	1-5	II	+-2	IV
Lythrum salicaria	+-1	II	1	II
Geranium palustre	+-2	II	+	I
Thalictrum flavum	+-2	III	-	-
Hypericum tetrapterum	-	-	1-2	II

Table 2. Continued.

Year	1958-63		2008-09	
Species	Cover index	Constancy	Cover index	Constancy
Ch. O. *Molinietalia*				
Deschampsia caespitosa	+-2	III	+-1	II
Equisetum palustre	+-1	III	1	II
Galium uliginosum	+-1	III	+	I
Lychnis flos-cuculi	+	II	+-1	IV
Lotus uliginosus	+	II	1-2	II
Cirsium palustre	+	II	+	I
Rhinanthus serotinus	+	II	-	-
Alopecurus pratensis	-	-	+-1	II
Ch. O. *Arrhenetheretalia*				
Leucanthemum vulgare	+-2	IV	-	-
Achillea millefolium	+-1	II	-	-
Lotus corniculatus	+-1	II	-	-
Trifolium montanum	+-1	II	-	-
Trifolium repens	+	II	-	-
Cynosurus cristatus	+	I	-	-
Alchemilla gracilis	+	I	-	-
Heracleum sphondylium	+	I	-	-
Pimpinella major	-	-	1	I
Dactylis glomerata	-	-	+-2	II
Ch. Cl. *Molinio-Arrhenetheretea*				
Lathyrus pratensis	+	IV	+-1	III
Rumex acetosa	+	II	+-1	II
Agrostis stolonifera	1-2	II	1	I
Lysimachia nummularia	+-2	II	2	I
Vicia cracca	+	II	1	I
Centaurea jacea	+-1	II	1	I
Festuca rubra	+-2	IV	-	-
Holcus lanatus	1-2	IV	-	-
Ranunculus acris	+-2	IV	-	-
Leontodon hispidus	2	III	-	-
Plantago lanceolata	+-2	III	-	-
Carex hirta	+	II	-	-
Euphrasia rostkoviana	+-1	II	-	-
Festuca pratensis	+	II	-	-
Prunella vulgaris	+-1	II	-	-
Avenula pubescens	+	I	-	-
Phleum pratense	+	I	-	-
Ranunculus repens	-	-	+-3	III

Table 2. Continued.

Year	1958-63		2008-09	
Species	Cover index	Constancy	Cover index	Constancy
Ch. Cl. *Nardo-Callunetea*				
Potentilla erecta	1-2	IV	1	II
Nardus stricta	3-4	III	-	-
Polygala vulgaris	+-1	III	-	-
Danthonia decubens	1-2	II	-	-
Luzula multiflora	+-1	II	-	-
Agrostis capillaris	+-1	II	-	-
Pedicularis silvatica	+-1	II	-	-
Juncus squarrosus	+-1	II	-	-
Veronica officinalis	+-1	II	-	-
Sporadic species (constancy I) present only in 1963: *Carex pilulifera* +, *Luzula campestris* 1, *Viola canina* +				
Ch.Cl. *Phragmitetea*				
Galium palustre	2	I	1-2	IV
Glyceria fluitans	+	I	1	I
Equisetum fluviatile	+	II	-	-
Scutellaria galericulata	-	-	+-1	II
Sporadic species (constancy I) present only in 1963: *Rumex hydrolapathum* +				
Sporadic species (constancy I) present only in 2009: *Lysimachia tyrsiflora* +, *Phalaris arundinacea* 1, *Poa palustris* 1				
Ch.Cl. *Scheuchzerio-Caricetea nigrae*				
Valeriana simplicifolia	+-2	II	1-2	III
Veronica scutellata	1	I	1	I
Viola palustris	+	I	1	I
Carex nigra	+-4	III	-	-
Carex flava	+-1	II	-	-
Agrostis canina	+-3	II	-	-
Carex echinata	+	II	-	-
Sporadic species (constancy I) present only in1963: *Carex canescens* +, *Epipactis palustris* 1, *Eriophorum latifolium* +, *Juncus articulatus* +				
Sporadic species (constancy I) present only in 2009: *Ranunculus flammula 1*				
Ch. Cl. *Querco-Fagetea*				
Astrantia major	+	II	-	-
Carpinus betulus	+	II	+-1	II
Ranunculus auricomus	+	II	+-1	III
Carex sylvatica	+	I	2	I
Paris quadrifolia	+	I	+-1	II
Anemone nemorosa	+	I	1	III
Impatiens noli-tangere	+	I	+-2	III

Table 2. Continued.

Year	1958-63		2008-09	
Species	Cover index	Constancy	Cover index	Constancy
Aegopodium podagraria	-	-	+-2	II
Asarum europaeum	-	-	1-3	II
Sanicula europaea	-	-	+-1	II
Circaea lutetiana	-	-	1	II
Festuca gigantea	-	-	+-1	II
Acer pseudoplatanus b	-	-	1	II
Daphne mezereum	-	-	+-1	II
Stachys sylvatica	-	-	+-2	II
Viola reichenbachiana	-	-	+-1	II
Fagus sylvatica c	-	-	+-1	II
Fraxinus excelsior c	-	-	+-3	III
Acer pseudoplatanus c	-	-	+-1	IV
Sporadic species (constancy I) present only in 1963: *Galium schultesii* +				
Sporadic species (constancy I) present only in 2009: *Acer platanoides c* +, *Carex remota* +, *Carpinus betulus c*1, *Chrysosplenium alternifolium 1, Circaea alpina 1, Fagus sylvatica b 1, Fraxinus excelsior a* 1, *b* 2, *Galeobdolon luteum* +, *Poa nemoralis* 2, *Primula veris* 2, *Pulmonaria obscura* +, *Scrophularia nodosa* 1, *Tilia cordata c* +				
Ch. Cl. *Alnetea glutinosae*				
Salix cinerea c	+	II	1-2	II
Lycopus europaeus	+	I	1-2	III
Alnus glutinos a	-	-	2	I
Salix cinerea b	-	-	2-5	II
Solanum dulcamara	-	-	+-1	IV
Others:				
Equisetum sylvaticum	+-2	IV	1-3	IV
Geum rivale	+-2	IV	+-3	IV
Carex pallescens	1-2	IV	+-1	II
Carex panicea	1-2	IV	+-1	II
Briza media	+-2	IV	-	-
Alchemilla acutiloba	+-2	IV	-	-
Alchemilla glabra	+-2	III	+-1	II
Anthoxanthum odoratum	+-1	III	-	-
Hypericum maculatum	+	III	-	-
Ajuga reptans	+	II	+-2	IV
Veronica chamaedrys	+	II	+-1	II
Centaurea phrygia	2	II	2	I
Betula pendula c	+	II	-	-
Hieracium sp.	+	II	-	-
Hypericum perforatum	+	II	-	-

Table 2. Continued.

Year	1958-63		2008-09	
Species	Cover index	Constancy	Cover index	Constancy
Linum catharticum	+-2	II	-	-
Pimpinella saxifraga	+	II	-	-
Solidago virgaurea	+	II	-	-
Galium verum	+	II	-	-
Pinus sylvestris c	+	II	-	-
Vaccinum myrtillus	+	II	-	-
Glechoma hederacea	+	II	-	-
Populus tremula c	+	I	1	II
Cardamine amara	+	I	+	I
Vicia sepium	+	I	1	I
Betula pubescens a	+	I	1	I
Thalictrum lucidum	-	-	+-2	IV
Rubus idaeus	-	-	+-1	III
Equisetum arvense	-	-	+-1	III
Dryopteris carthusiana	-	-	+-1	III
Galeopsis tetrahit	-	-		II
Mentha arvensis	-	-	+-1	II
Agrostis sp.	-	-	1-2	II
Listera ovata	-	-	+-1	II
Oxalis acetosella	-	-	1	II
Quercus robur c	-	-	+	II
Polygonatum verticillatum	-	-	+-1	II
Urtica dioica	-	-	2-3	II
Sporadic species (constancy I) present only in 1963: *Epilobium palustre* 1, *Larix europaea c* +, *Melampyrum nemorosum* +, *Ononis arvensis* +, *Stellaria graminea* +				
Sporadic species (constancy I) present only in 2009: *Abies alba c* +, *b* 1, *Agrostis alba* 1, *Alchemilla monticida 1, Athyrium filix-femina 1, Carex glauca* +, *Eleocharis uniglumis* +, *Eupatorium cannabinum* 1, *Fragaria vesca* +, *Frangula alnus c* +, *Hedera helix* 1, *Luzula pilosa* +, *Majanthemum bifolium* +, *Mycelis muralis* +, *Quercus sessilis c* +, *Rubus sp.* 1, *Sambucus nigra c* +, *Senecio ovatus* 1.				

Purple Moor-Grass Meadows Succession Directions

Succession of *Molinion* meadows usually comes into a *Filipendulion* community and subsequently into *Fraxino-Alnetum*. Such succession, observed also within the SG Nature Reserve (Fig. 1), may be classified as a typical recreative succession [31]. The situation is different when it comes to patches being transformed into willow scrubs (*Salicetum pentandro-cinereae*) that belong to a dynamic circle of alder and *Tilio-Carpinetum* oak-hornbeam forest phytocoenosis (Fig. 1). *Molinion* meadows' successional pathways, other than those widely described [12], may be the effect of several factors acting simultaneously. They are affected by the region's specific features, or local disturbances within either the habitat or surroundings [32]. *Molinion* meadows within the Suchedniowski Plateau and Gielniowski Hill are relatively frequent, occur at various sites, and have high floristic diversity [33]. They occurred within riparian, alder, and oak-hornbeam forests as well as within upland mixed conifer forests. Such a wide range of occurrence of purple moor-grass meadows has also been observed within the SG Nature Reserve, where habitat conditions have changed due to human impact and in particular collapsed abandoned excavations sites found within Reserve that were actively used until the beginning of the 19th century. Many excavations in the now protected forest resulted in major changes in water relations (between the local marshes and dry areas). This, in turn, may result in *Molinion* meadows being transformed into forest communities other than those originally found in the SG Nature Reserve (into alder forests in the case of marshes and oak-hornbeam forests in the case of the dry areas). This process is called secondary creative succession [28, 32]. This type of secondary succession in non-forest communities, resulting from the change in the water conditions, was observed (for example) in Kampinoski National Park [23, 28]. Clearings in the immediate neighborhood of purple moor-grass meadows are another factor that influences their successional pathway. Studies conducted in Moravy prove that the immediate neighborhood and thus the availability of propagules influence meadow ecosystem succession to a large degree [32]. The nature reserve's forest clearings are clear evidence of this. In their immediate neighborhood there are alder and oak-hornbeam forest phytocoenoses and these successional pathways are dominant in the *Molinion* meadows analyzed.

Species Changing

In the relation to the first hypothesis our research shows that some species from lowest syntaxonomic units disappeared, but not those connected with the purple-moor grass meadows. They stay quite constant (Table 2) as well as many plants generally connected with wet meadows. Species such as *Lychnis flos-cuculi*, *Galium palustre*, and flowering plant species of the *Filipendulion* alliance, despite being shadowed by bushes, stay until forest communities appear and therefore they are present in all succession stages. The above phenomenon was also observed by Falińska [20, 21] and Rosenthal [25]. *Filipendula ulmaria* appears first on meadows when the mowing has stopped [29, 34]. Abandonment may also result in the dominance of *Urtica dioica* [35], especially within patches adjacent to forests [36].

The results of our research show that the large group of euthrophic deciduous forest species appeared (Fig. 3, Table 3) but not those connected with riparian forest. This fact gives the next evidence that *Molinion* meadows could

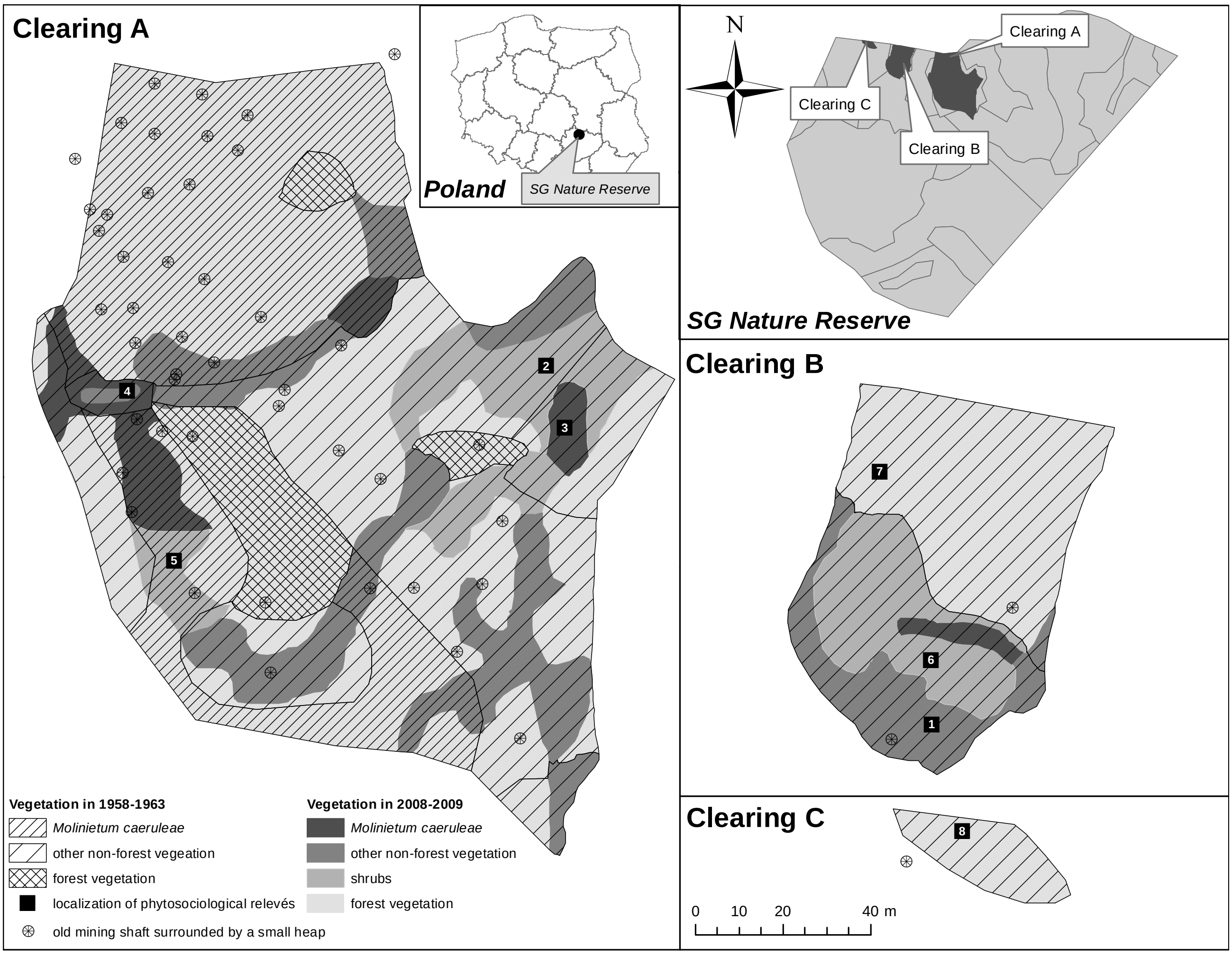

Fig. 2. Changes in clearing vegetation in the Świnia Góra (SG) Nature Reserve.

belong to the other dynamic circle. Appearance of numerous species of rich non-conifer forests also has been observed often.

Discontinuance of use also affected the abundance of certain valuable species related to *Molinion* meadows. The number of *Gentiana pneumonanthe*, *Gladiolus imbricatus*, and *Iris sibirica* decreased slightly. *Epipactis palustris*, the species related to poor fens, disappeared completely from the reserve [11]. Generally, non-forest plants are the largest group from protected species that disappeared from the area of SG Natural Reserve [11] (Table 3). It is also connected with changing light conditions. Mean value of light indicator has decreased from 6.84 to 5.89 (Table 2), while all non-forest protected species found in the clearings of the reserve have that value from 7 to 8 [17]. The only exception is *Listera ovata* with light indicator value 6.

The problem of protection and the partial disappearance of meadow vegetation within nature reserves has been observed for many years in many regions of Poland [35, 37-39] and Europe [40, 41]. Knowledge of the secondary succession mechanism on abandoned meadows is necessary to adequately plan active protection activities, such as the frequency of grass swaths [7]. It must be remembered that while mowing meadow patches adjacent to forests is recommenced after a few years' break (i.e. when the succession process has already started), overgrowing can be considerably accelerated by active protection instead of being stopped. Seedlings of alders and other light-seeded forest species develop in places uncovered by mowing [42].

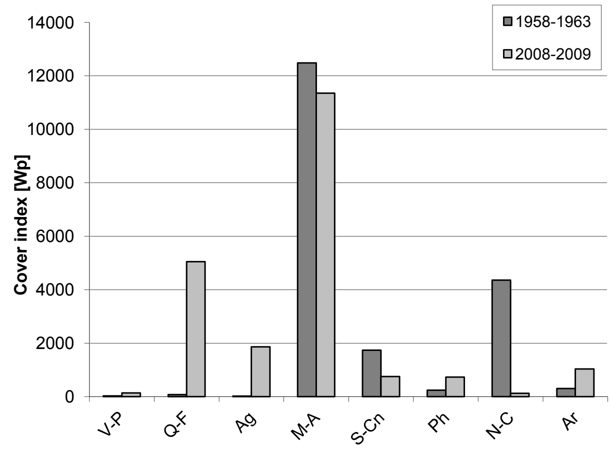

Fig. 3. Comparison of the sum of average cover indices for species characteristic of various phytosociological classes. V-P – *Vaccinio-Piceetea*, Q-F – *Querco-Fagatea*, Ag – *Alnetea glutinosae*, M-A – *Molinio-Arrhenatheretea*, S-Cn – *Scheuchzerio-Caricetea nigrae*, Ph – *Phragmitetea*, N-C – *Nardo-Callunetea*, Ar – *Artemisietea* vulgaris.

Table 3. Valuable and protected species dynamics within the nature reserve's forest clearings based on phytosociological relevés.

No.	Name of species	Species protection*	Categories of threats		Number of occurrence in relevés		Dynamic tendency
			1	2	1958-63	2008-09	
Non-forest communities species							
1	*Dactylorhiza majalis*	Ch			-	2	+
2	*Epipactis palustris*	Ch	V	VU	1	-	-
3	*Gentiana pneumonanthe*	Ch	V	VU	5	3	-
4	*Gladiolus imbricatus*	Ch		VU	4	3	-
5	*Iris sibirica*	Ch	V	VU	4	2	-
6	*Ophioglossum vulgatum*	Ch	V	VU	1	2	+
7	*Pedicularis silvatica*	Ch		VU	3	-	-
8	*Primula veris*	czCh			-	1	+
9	*Trollius europaeus*	Ch		NT	1	4	+
Forest communities species							
1	*Asarum europaeum*	czCh			-	3	+
2	*Daphne mezereum*	Ch			-	3	+
3	*Frangula alnus*	czCh			-	1	+
4	*Hedera helix*	czCh			-	1	+
5	*Listera ovata*	Ch		VU	-	2	+

Ch – species covered by strict protection, czCh – species partially protected [14], 1 – threatened in Poland [15], 2 – threatened in Małopolska Upland [16].

Conclusions

Strict protection afforded for the last 50 years to the analyzed clearings resulted in the gradual transformation of non-forest communities into scrubs and forest communities. This process takes place at a different rate and goes in different directions in individual patches even within one initial community. Such a large diversification of dynamic processes may be due to occasional conservation works (mowing of meadow patches) carried out in the 1970s. Dynamic processes are varied also because of the largely mosaic character of habitats due to the collapsed abandoned excavation sites that were used until the early 19th century. Succession resulted in the disappearance of *Nardetalia* meadow species of the *Nardo-Callunetea* class, poor fens of the *Scheuzerio-Caricetea nigrae* class, as well as fresh meadow and common meadow species. Species belonging to wet meadows (both *Molinion* and *Calthion*) proved quite stable. This is confirmed by the results of floristic research in the whole reserve [11]. They can still be found not only in other non-forest communities but also quite often within patches where the understorey level and stand had already developed and the phytocoenosis is forest-like. Stands of the subassociation *Molinietum caeruleae nardetosum strictae* transformed into herb communities (*Filipendulion*), scrubs (*Salicetum pentandro-cinereae*), riparian (*Fraxino-Alnetum*), and oak-hornbeam-spruce forests (*Tilio-Carpinetum*). Some of the patches (probably due to mowing in the 1970s) remained meadows. Meadow species can be found in phytocoenoses of both forest communities, with more of them recorded in moist oak-hornbeam forest phytocoenoses (*Tilio-Carpinetum stachyetosum*). Out of several meadow communities inhabiting the nature reserve in the 1950s, only small patches of purple moor-grass meadows have remained, although today they should be classified as *Molinietum caeruleae typicum*. However, they were formed not only from the *Nardo-Juncetum* phytocoenoses, but also as a result of the fluctuation of other non-forest communities such as *Angelico-Cirsietum*.

The SG Nature Reserve is a perfect research area because it is not exposed to direct human pressure. Meadow succession should continue undisturbed by human activity, and the results obtained will be an important contribution to the knowledge of successional pathways; for example, of *Molinion* meadows, which are a habitat for many valuable species across Europe.

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