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Changes in vegetation of the Mszar Bogdaniec nature reserve

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Abstract: Changes of vegetation in forests and wetlands require continuous monitoring and evaluation. Due to the lack of in-depth knowledge, it is still very challenging to predict and record vegetation changes. This study attempts to evaluate changes in forest and transitional bog vegetation over 14 years in the Mszar Bogdaniec nature reserve (West Poland; 21.98 ha). We described the current vegetation using 50 phytosociological relevés conducted in 2012 and 2013. Moreover, we calculated and compared ecological indices describing ecological traits of the vegetation in two different times. We also used Detrended Correspondence Analysis (DCA) to assess changes in floral composition. Most of the studied vegetation traits did not change significantly during the last 14 years. Statistically significant changes occured in the proportion of mosses and cover of the herb layer, both of which increased, as well as species richness in forest plant communities, and the cover of species from *Scheuchzerio-Caricetea* class in peat bog plant communities, both of which decreased. The current state of the vegetation is a result of former human activity such as drainage and planting monoculture tree stands. The observed changes during the last 14 years were fluctuations rather than direct changes. Encroachment of the woody species into transitional bog is a fluctuation, which may be secondary succession in the long-term.

Keywords: transitional bog, *Vaccinio uliginosi-Betuletum pubescentis*, degeneration, vegetation dynamics, fluctuation

1. Introduction

Terrestrial ecosystems have been impacted by human activity for many centuries. The main threats to biodiversity according to the HIPPO model (Wilson 2002) include: habitat destruction, introduction of alien species, pollution, human population growth and overexploitation of resources. The pressure of humans strongly affects forest ecosystems, particularly resulting in occurrence of various types of forest plant communities degeneration. Vegetation degeneration is manifested by the loss of stenotopic taxa, and their replacement by eurytopic taxa (Olaczek 1974; Faliński 1988). Thus, degeneration can be identified as the phytocoenotic aspect of the process known in Western literature as biotic homogenisation – the decreasing diversity of species and functional ecosystems, associated with the loss of biodiversity (Olden et al. 2004; Chen et al. 2010).

One of the ecosystems most vulnerable to the adverse effects of human activity are peat bogs (Ilnicki 2002; Parish et al. 2008). The existence of peat bogs depends on water availability, i.e. changes in ground water table level may cause the mineralization process of peat bogs. Peat bogs have often been drained to increase the area of agricultural crops or the productivity of forests. They have often been subject to peat extraction, which is used in gardening or nurseries, for fuel or as sources of chemical compounds used in cosmetics and medicine (Ilnicki 2002; Pawlaczyk et al. 2002; Parish et al. 2008). In Poland, both raised and transitional bogs constitute only 7.3% of the total area of peatlands (Ilnicki 2002), which means that they require special protection, particularly as most of them have been heavily transformed by human activity (Jasnowski 1972).

Due to their high share of stenotopic species, the vegetation of peat bogs is being transformed due to changes in the way they are managed, which is often linked to their drainage (El-

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lenberg 1988; Herbich, Herbichowa 2002; Parish et al. 2008). Draining results in the cessation of peat accumulation, the disappearance of peat producing species and the encroachment of species associated with moist and fresh habitats, with higher (in relation to typical raised bog species) trophic requirements that contribute to an increased nutrients availability and habitat transformation (Laine et al. 1995; Pawlaczyk et al. 2002; Kujawa-Pawlaczyk, Pawlaczyk 2005). A particularly significant impact on the transformation of vegetation in raised bogs is the encroachment of woody plants, leading to a change in the type of plant community at the site (Laine et al. 1995; Macdonald, Yin 1999; Pawlaczyk et al. 2002; Dyderski et al. 2015a).

The human impact on peat bog ecosystems was often described on the basis of a record of its status made during a single study or inventory. Not many studies investigate the issue of changes in the contemporary vegetation of peatlands. For example, Herbich (2001) studied changes in the vegetation at the Staniszewskie Błota nature reserve for over 30 years, and Czerepko (2008) – the changes in vegetation and the tree stand structure of the swamp forests in Białowieża Forest at permanent experimental plots. Kopeć et al. (2014) studied the dynamics of vegetation in alder and riparian forests over 50 years to determine the effect of changes in water conditions on plant communities. However, research in the field of vegetation dynamics lacks studies that would indicate the period of time after which the first, measureable, directional changes in phytocoenosis can be perceived.

The aim of this study is to determine the changes that have occurred in the plant communities of the Mszar Bogdaniec nature reserve for the period of 1999 to 2012/13. The initial state of the study site's vegetation was presented in an environmental protection plan (Maciantowicz et al. 1999). This reserve, because of its known history of human pressure and existing detailed inventory of vegetation, provides good source material to describe the anthropogenic alteration of the vegetation.

2. Materials and methods

The study was conducted in the Mszar Bogdaniec nature reserve, located in the southern part of the Wielkopolska region of Poland (51°40'35''N, 17°21'19''E, 115 m above sea level). The reserve has an area of 21.98 hectares, including 4.95 hectares of raised and transitional peat bog – the reason for establishing the reserve in 1995 (Zarządzenie 1996; Maciantowicz et al. 1999). The remainder of the reserve has pine tree stands constituting a buffer zone between mixed forests (commercial forests) and the peat bog. No work related to forest management has been conducted in the protected area since the reserve was established. At the

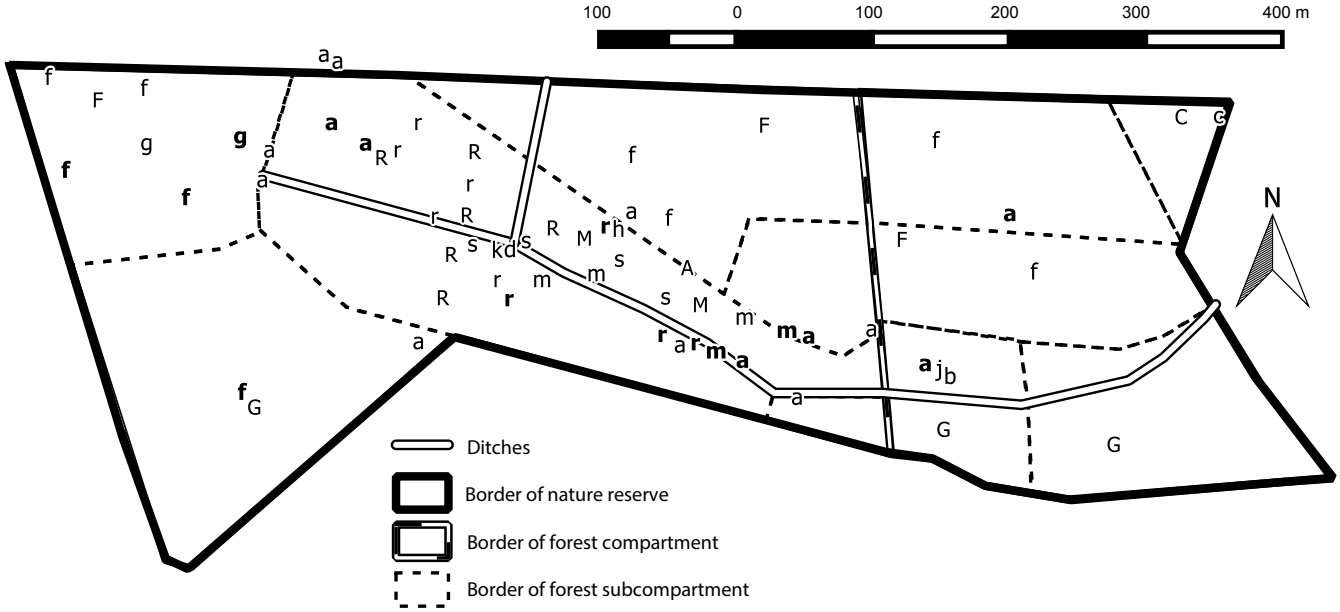

Figure 1. Distribution of relevés in the Mszar Bogdaniec nature reserve. Letters indicate plant communities: a – *Vaccinio uliginosi-Betuletum pubescentis* juv., b – *Bidenti-Polygonetum hydropipers*, c – *Fraxino-Alnetum*, d – *Phragmitetum australis*, f – *Pinus-Padus*, g – *Pinus-Picea*, h – *Ranunculo-Juncetum bulbosae*, j – *Rumici-Alopecuretum aequalis*, k – *Scirpetum lacustris*, m – *Sphagno recurvi-Eriophoretum angustifolii*, r – *Sphagno recurvi-Eriophoretum vaginati*, s – *Sphagno-Juncetum effusi*. Small letters indicate relevés conducted in 2012/13, capital letters indicate relevés conducted in 1999 by Maciantowicz et al. (1999). Bolded letters indicate relevés from 2012/13, which were used for comparative analysis.

beginning of the 20th century, the bog was drained by a band of trenches around its perimeter and two 6 m wide drainage ditches crossing the bog (Fig. 1). In the mid-20th century, the south-eastern part of the bog, the so-called 'unproductive wasteland', was prepared and planted with Scots pine. American black cherry was introduced to the surrounding forests, where it quickly spread (Maciantowicz et al. 1999).

The vegetation in the peat bog area of the reserve was described by Dyderski et al. (2015a). The forested area of the reserve is dominated by secondary forest communities (SFC) of the following types: *Pinus-Padus* and *Pinus-Picea*, which in places transitions to the bog birch forest community *Vaccinio uliginosi-Betuletum pubescentis*. These communities are found in an area of 16.6 ha. A riparian ash and alder forest *Fraxino-Alnetum* community occupies a small patch on the edge of the reserve (0.43 ha in the NE part). The *Pinus-Picea* SFC is the result of spruce and pine planting in a fresh and moist mixed coniferous habitat. Its tree stand consists of pine with spruce, *Padus serotina* appearing in the a2 layer, and coniferous forest species in the forest floor, such as, among others, *Dicranum scoparium*, *Pleurozium schreberi*, *Pseudoscleropodium purum* and *Vaccinium myrtillus*, indicating membership of this SFC to the *Vaccinio-Piceetea* class and *Dicrano-Pinion* alliance. Patches of *Pinus-Picea* are transforming into the juvenile form of the *Vaccinio uliginosi-Betuletum pubescentis* community closer to the bog. The *Pinus-Padus* SFC stands are comprised of Scots pine, accompanied by *Padus serotina*, present in the understory in all relevés, as well as in the a2 layers of some. The forest floor layer of the community consists of, among others, *Brachythecium rutabulum*, *Dicranum undulatum* (= *D. polysetum*), *Dryopteris carthusiana*, *Hypnum cupressiforme*, *Pleurozium schreberi*, *Pteridium aqulinum* and *Vaccinium myrtillus*.

In 2012 and 2013, 50 phytosociological relevés were made using the Braun-Blanquet method in order to characterize the vegetation of the study site. The areas of the relevés ranged from 1 (alluvial therophytes communities) to 300 m^2 (forest communities). The criteria for distinguishing plant communities and the syntaxonomic nomenclature were taken from Ratyńska et al. (2011), while the names of plant taxa are from Szwed et al. (1999). The phytosociological work of the reserve's peat bog area was presented by Dyderski et al. (2015a). Due to the small number of phytosociological relevés available in the reserve's protection plan (Maciantowicz et al. 1999), using all of the phytosociological records from 2012/13 would result in an overrepresentation of new relevés in relation to those from 1999 (15 relevés). For this reason, 10 relevés (out of 20) of those from 2012 and 2013 were randomly selected from the peat bog and 6 (out of 18) relevés of those from the tree stands around the bog. Relevés with an area of less than 25 m^2 were excluded from the random selection because the protection plan included relevés made of just such total areas, and stratified sampling was also used. In each of the syntaxa distinguished by Dyderski et al. (2015a) and represented by relevés of an area larger than 25 m^2, a proportional number of relevés was randomly selected to the total number of relevés in the set (Table 1). Even though the protection plan contained 9 relevés from the bog, 10 relevés were chosen to preserve the proportion of the share of relevés representing the distinguished communities (0.2/0.2/0.4/0.2). In order to analyze the relevés from 2012/13, 16 out of 50 areas were used (Table 1, Fig. 1). The *random select* function of the Turboveg program was used to choose specific associations from a given number of relevés from the set used to prepare the database of phytosociological relevés (Hennekens, Schaminée 2001). Due to the use of different cover scales (traditional, 7-point and 9-point Braun-Blanquet scale) in the reserve's protection plan, the cover values were configured to a 7-point scale: 'r', '+', '1', '3', '4' and '5' remained unchanged, whereas '2m', '2a' and '2b' were replaced by '2'. The remaining relevés made in 2012 and 2013 were used to describe the actual vegetation for this study, and they were also included in the Polish Vegetation Database (Kącki, Śliwiński 2012).

For each phytosociological relevé, we calculated the average weighted of species abundances Ellenberg's ecological indicator values (Ellenberg, Leuschner 2010), the share of species characteristic for the individual syntaxonomic unit according to Ratyńska et al. (2011), the share of alien and native species (according to Tokarska-Guzik et al. 2012), as well as the share of life forms, species richness and the Shannon-Wiener diversity index. To evaluate the diversity of the floristic composition of the vegetation between the two time periods, the detrended compatibility analysis (DCA) was used. The coefficient of determination R^2 for each variable with the location of points in ordinal space was determined with the *envfit* function from *vegan* package (Oksanen et al. 2013), which set a vector indicating the direction of growth of a given feature's value. Statistical significance was determined by the permutation test based on 999 iterations, implemented in the *vegan* package (Oksanen et al. 2013). These analyses were performed on the phytosociological data without taking into account tree and shrub layers (cf. Kasprowicz 2010; Dyderski et al. 2015b). The Kruskal-Wallis test was used to determine changes in the environmental indicators, whereas the t-test, after the Bliss transformation (Biecek 2013), was used to assess changes in the average cover of each species between the two studies. Statistical analyses were performed in R (R Core Team 2015).

3. Results

The Mszar Bogdaniec nature reserve consists of 12 plant communities, including 10 plant associations, representing 7 phytosociological classes (Table 1). Of these, the lar-

gest area of the reserve was occupied by forest communities (approx. 85%). The reserve was divided into the bog area (forest compartment 142c; 4.95 ha) and forest, which constituted a buffer zone for the bog.

In terms of forest species cover, statistically significant ($p<0.05$) average decreases were noted for *Sorbus aucuparia*, *Impatiens parviflora* and *Trientalis europaea*, as well as for seedlings of *Pinus sylvestris* and *Quercus robur*, while the spruce forest floor layer increased its average cover (Table 2). The remaining differences in cover species were not statistically significant ($p>0.05$), although it is worth noting the absence of sedges in the forest floor and a reduction in the cover of *Rubus* spp. There was a statistically insignificant increase in the cover of *Brachythecium rutabulum* (not noted previously), *Polytrichum commune* and *Pseudoscleropodium purum* in the moss layer. In the bog vegetation, we found statistically significant ($p<0.05$) reductions in the average cover of *Agrostis canina*, seedlings of *Betula pendula*, as well as *Sphagnum fallax* and *S. russowi* (Table 2). Other changes noted in cover species were not statistically significant ($p>0.05$). However, it is worth noting an increase in the share of *Betula pubescens*, as well as the appearance of the neophyte *Erechtites hieracifolia*. Among the sphagna, we noted an increase in the cover of *S. imbriatum*.

Analysis of the ecological indicators describing the studied phytocoenoses (Table 3) showed that for most indicators, the differences between the relevés carried out in 1999 and 2012/13 were not statistically significant ($p>0.05$). In forest communities, the share of mosses increased in a statistically significaly, while the average number of species listed in the relevés decreased. Despite the lack of statistical significance ($p=0.051$), quite a significant decrease was found in the tree layer cover (from 89.2±4.9 to 66.7±9.5%). In the peat bog communities, statistically significant decreases were found in the share of species from the *Scheuchzerio-Caricetea* class and increases in the cover of the herb layer. Moss layer cover decreased from 33.9±10.1% to 17.0±6.6%, but these differences were not statistically significant.

The DCA analysis (Fig. 2, Table 4) indicates that changes in the vegetation of the reserve's forest are rather fluctuations than a directional change – the points representing the relevés from the two time periods are close to each other, with the exception of one point, shifted towards the peat bog communities. It illustrates the *Pinus-Picea* community, which experienced the encroachment of peat bog species and numerous natural regeneration of downy birch as a result of the spruces mortality. Vectors representing the share of chamaephytes, share of species from the *Querco-Fagetea*, *Quercetea robori-petraeae* and *Vaccinio-Piceetea* classes, tree and shrub layer cover, the richness and diversity of species, and the Ellenberg indicator value of humidity are faced in the direction of points representing forest vegetation. More diversity is

Table 1. List of syntaxa recorded in the Mszar Bogdaniec nature reserve

Syntaxon	Number of relevés conducted in 2012/2013	Number of relevés used in comparative analysis	Number of relevés conducted in 1999
Vaccinio uliginosi-Betuletum pubescentis Libbert 1933 em. R. Tx. 1937 juv.	15	5	1
LZZ *Pinus-Padus*	9	3	3
LZZ *Pinus-Picea*	2	2	3
Fraxino-Alnetum W.Mat 1952	1	0	1
Ranunculo-Juncetum bulbosi Oberd. 1957	1	0	0
Phragmitetum communis Kaiser 1926	1	0	0
Scirpetum lacustris (Allorge 1922) Chouard 1924	1	0	0
Sphagno-Juncetum effusi Dziubałtowski 1928 nom. invers. propos.	4	0	0
Sphagno recurvi-Eriophoretum angustifolii Hueck 1925 nom. invers. et nom. mut.	5	2	2
Sphagno recurvi-Eriophoretum vaginati Hueck 1925 nom. invers.	9	4	6
Bidenti-Polygonetum hydropiperis (Miljan 1933) Lohmeyer in R. Tx. 1950 nom. invers.	1	0	0
Rumici-Alopecuretum aequalis Cîrtu 1972	1	0	0

Table 2. Changes in cover of species occurring in phytosociological relevés in Mszar Bogdaniec nature reserve

Species	Forest plant communities				Peat bog plant communities			
	1999[1]		2012/13[2]		1999[1]		2012/13[2]	
	n = 6		*n* = 6		*n* = 9		*n* = 10	
Alnus glutinosa a1	.	.	17	3	.	.	.	.
Betula pendula a1	17	1	.	.	22	+	.	.
Betula pubescens a1	.	.	17	3	.	.	.	.
Picea abies a1	50	2-4	17	2	.	.	.	.
Pinus sylvestris a1	100	1-5	83	2-5	11	1	.	.
Quercus robur a1	.	.	17	2-5	.	.	.	.
Betula pendula a2	17	r	.	.	.	.	.	.
Padus serotina a2	33	3-4	.	.	.	.	.	.
Picea abies a2	50	r-3	17	2	.	.	.	.
Sorbus aucuparia a2	17	r	.	.	.	.	.	.
Betula pendula b	33	r	.	.	67	+-1	20	1-2
Betula pubescens b	.	.	17	1	33	+	40	1-4
Frangula alnus b	67	2	50	1-3	67	+-4	30	1-3
Padus serotina b	67	r-3	83	1-4	.	.	.	.
Picea abies b	**.**	**.**	**67**	**1-2**	.	.	.	.
Pinus sylvestris b	.	.	17	2	78	r-1	30	2
Sorbus aucuparia b	**83**	**r**	**.**	**.**	.	.	.	.
Agrostis canina	.	.	.	.	**56**	**+-1**	**.**	**.**
Anthoxanthum odoratum	17	+	.	.	.	.	.	.
Betula pendula	50	r-1	.	.	**78**	+-1	10	r
Betula pubescens	.	.	17	+	33	+	70	r-2
Bidens frondosa	.	.	.	.	.	.	10	1
Calamagrostis arundinacea	33	2	.	.	.	.	.	.
Carex canescens	.	.	.	.	33	-1	30	1-2
Carex lepidocarpa	17	+	.	.	.	.	.	.
Carex leporina	33	+	.	.	.	.	.	.
Carex sp.	17	1	.	.	.	.	.	.
Deschampsia flexuosa	17	+	.	.	.	.	.	.
Dryopteris carthusiana	100	r-3	83	r-3	22	r	.	.
Erechtites hieracifolia	.	.	17	r	.	.	40	1-2
Eriophorum angustifolium	.	.	.	.	44	+-5	60	1-4
Eriophorum vaginatum	.	.	.	.	89	1-5	70	1-5

Species	Forest plant communities				Peat bog plant communities			
	1999[1]		2012/13[2]		1999[1]		2012/13[2]	
	n = 6		*n* = 6		*n* = 9		*n* = 10	
Frangula alnus	50	2-3	67	r-2	67	+-2	80	r-2
Galeopsis pubescens	.	.	17	+	.	.	.	.
Galeopsis tetrahit	17	r	.	.	.	.	.	.
Hydrocotyle vulgaris	.	.	.	.	.	.	40	+-2
Impatiens parviflora	**83**	**+-3**	**33**	**1-2**	.	.	.	.
Juncus effusus	.	.	.	.	22	1	.	.
Luzula pilosa	17	r	.	.	.	.	.	.
Lysimachia vulgaris	17	r	.	.	.	.	.	.
Moehringia trinervia	17	+	.	.	.	.	.	.
Molinia caerulea	83	1-4	50	2-4	56	+-5	80	1-5
Oxalis acetosella	50	3	33	1-3	.	.	.	.
Padus serotina	50	1-3	67	+-3	.	.	30	r-1
Picea abies	50	+-2	17	1	11	r	.	.
Pinus sylvestris	**83**	**r-1**	**17**	**r**	78	r-1	50	r-+
Poa nemoralis	.	.	33	r-1	.	.	.	.
Poa trivialis	.	.	17	r	.	.	.	.
Polygonum minus	.	.	.	.	.	.	10	+
Populus tremula	17	r	.	.	.	.	.	.
Pteridium aquilinum	67	1-4	67	2-3	.	.	.	.
Quercus petraea	.	.	33	r	.	.	.	.
Quercus robur	**100**	**r-1**	**17**	**r**	.	.	.	.
Quercus rubra	17	r	.	.	.	.	.	.
Rubus idaeus	50	r-2	17	r	.	.	.	.
Rubus plicatus	.	.	.	.	.	.	10	+
Rubus sp.	50	r-1	.	.	.	.	.	.
Rubus ×corylifolius	.	.	17	1	.	.	.	.
Rumex acetosa	17	r	.	.	.	.	.	.
Salix aurita	.	.	.	.	11	r	.	.
Stellaria media	50	r-+	.	.	.	.	.	.
Trientalis europaea	**67**	**+-1**	**.**	**.**	.	.	.	.
Urtica dioica	.	.	.	.	.	.	10	+
Vaccinium myrtillus	67	2-3	83	+-5	33	+	20	r
Vaccinium vitis-idaea	33	+-1	33	2	.	.	.	.

Species	Forest plant communities				Peat bog plant communities			
	1999[1]		2012/13[2]		1999[1]		2012/13[2]	
	n = 6		*n* = 6		*n* = 9		*n* = 10	
Amblystegium serpens d	.	.	.	.	22	+-2	.	.
Aulacomnium androgynum d	.	.	.	.	.	.	10	+
Brachythecium rutabulum d	.	.	50	-2	.	.	.	.
Calliergon cordifolium d	.	.	.	.	11	2	.	.
Calliergon giganteum d	.	.	.	.	22	1	.	.
Calliergon stramineum d	.	.	.	.	11	1	.	.
Dicranum undulatum (= *D. polysetum*) d	.	.	33	2-3	.	.	.	.
Drepanocladus aduncus d	.	.	.	.	11	2	.	.
Hypnum cupressiforme d	67	2-3	33	1-2	.	.	.	.
Leucobryum glaucum d	33	+-1	33	2-3	.	.	.	.
Pleurozium schreberi d	.	.	33	2-3	.	.	.	.
Pohlia nutans d	17	+	17	+	.	.	30	r-1
Polytrichastrum formosum d	33	+	.	.	.	.	.	.
Polytrichum commune d	.	.	33	+-1	.	.	.	.
Polytrichum strictum d	.	.	.	.	11	2	.	.
Pseudoscleropodium purum d	.	.	50	1-2	.	.	.	.
Sphagnum cuspidatum d	.	.	.	.	33	1-2	30	1-2
Sphagnum fallax d	.	.	.	.	**89**	**1-5**	**30**	**+-1**
Sphagnum fimbriatum d	.	.	17	+	11	2	50	+-2
Sphagnum girgensohnii d	.	.	.	.	11	2	.	.
Sphagnum palustre d	.	.	.	.	.	.	10	1
Sphagnum russowii d	.	.	.	.	**56**	**1-2**	**.**	**.**
Warnstorfia fluitans d	.	.	.	.	11	2	.	.

1 – relevés conducted by Maciantowicz et al. (1999), 2 – relevés conducted by the authors; left column shows species frequency (%), right – range of cover in Braun-Blanquet's scale. Values for species, which mean cover differed statistically significantly ($p < 0.05$) between two inventories, based on t-Student test after Bliss transformation, were bolded.

seen within the group in the case of points representing peat bog vegetation, whereas the points representing the relevés from 2012/13 are shifted towards the group depicting forest vegetation. Vectors representing the share of hemicryptophytes, species of the *Scheuchzerio-Caricetea* and *Oxycocco-Sphagnetea* classes, and the share of native species are turned in their direction. Vectors defining the Ellenberg indicator values of light, trophic levels and soil pH were turned in a direction where there were no points representing the phyto-sociological relevés.

4. Discussion

Twelve plant communities undergoing processes of degeneration and regeneration (cf. Materials and Methods) were observed in the Mszar Bogdaniec nature reserve. Compared to 14 years ago (Maciantowicz et al. 1999), there was little change in the vegetation, and those that existed had the character of fluctuations rather than of directional changes, as only a few of the indicators of the changes were found to be statistically significant.

Table 3. Changes in ecological indices describing forest and peat bog plant communities in the Mszar Bogdaniec nature reserve in 1999 and 2012/13

Indicator	Forest plant communities						Peat bog plant communities					
	1999, *n* = 6		2012/13, *n* = 6				1999, *n* = 9		2012/13, *n* = 10			
	mean	SE	mean	SE	χ^2	*p*	mean	SE	mean	SE	χ^2	*p*
Share of native species	0.807	0.017	0.769	0.044	1.087	0.300	0.993	0.007	0.897	0.052	2.496	0.114
Cover share of phytosociological classes:												
- *Vaccinio-Piceetea*	0.386	0.046	0.495	0.112	0.410	0.522	0.052	0.016	0.151	0.059	0.963	0.326
- *Quercetea robori-petraeae*	0.157	0.047	0.071	0.032	2.084	0.149	0.000	0.000	0.002	0.002	0.900	0.343
- *Oxycocco-Sphagnetea*	0.000	0.000	0.000	0.000	-	-	0.310	0.073	0.259	0.091	0.428	0.513
- *Scheuchzerio-Caricetea*	0.002	0.002	0.004	0.003	0.398	0.528	**0.407**	**0.092**	**0.213**	**0.085**	**4.167**	**0.041**
Share of life forms:												
- phanerophytes	0.519	0.037	0.463	0.054	0.521	0.470	0.427	0.062	0.399	0.046	0.107	0.744
- geophytes	0.089	0.010	0.066	0.024	0.103	0.748	0.071	0.037	0.072	0.020	0.421	0.516
- hemicryptophytes	0.180	0.032	0.131	0.017	0.648	0.421	0.242	0.017	0.271	0.034	0.672	0.412
- chamaephytes	0.059	0.023	0.084	0.022	1.279	0.258	0.021	0.011	0.020	0.014	0.100	0.752
- mosses	0.08	0.02	0.21	0.06	4.035	0.045	0.24	0.06	0.16	0.04	0.815	0.367
Species richness	**17.17**	**1.30**	**12.83**	**1.05**	**4.914**	**0.027**	9.33	1.07	8.20	0.49	1.244	0.265
Shannon's diversity index	2.18	0.12	2.00	0.10	0.923	0.337	1.55	0.17	1.35	0.08	1.927	0.165
Ellenberg's indicator values:												
- fertility	6.54	0.14	6.56	0.21	0.026	0.873	5.93	0.24	6.15	0.17	0.667	0.414
- moisture	4.00	0.29	4.67	0.40	1.641	0.200	3.37	0.16	3.38	0.29	0.354	0.552
- light	6.54	0.14	6.56	0.21	0.026	0.873	5.93	0.24	6.15	0.17	0.667	0.414
- soil reaction	7.17	0.33	7.58	0.32	.256	0.262	6.04	0.31	7.06	0.38	2.836	0.092
Vegetation layers cover:												
- trees	89.17	4.90	66.67	9.55	3.812	0.051	0.67	0.55	0.00	0.00	2.346	0.126
- shrubs	35.00	7.64	35.00	4.28	0.000	1.000	14.67	7.42	24.00	9.09	0.007	0.933
- herbs	74.17	11.58	67.50	8.83	0.532	0.466	**70.00**	**5.77**	**82.50**	**8.86**	**3.976**	**0.046**
- mosses	22.50	8.34	18.33	7.60	0.059	0.809	33.89	10.06	17.00	6.63	1.859	0.173

Significance of differences between values of indicators in different terms of inventories were verified by Kruskal-Wallis test (value of test statistic χ^2 and significance level *p*), differences which were statistically significant ($p < 0.05$) were bolded

The currently existing vegetation of the reserve is the result of former human pressure, which is indicated by degenerative processes. The main evidence of vegetation degeneration is the presence of secondary forest communities inconsistent with the potential natural vegetation, which, according to Maciantowicz et al. (1999), consists of mainly *Querco roboris-Pinetum molinietosum* and *Fago-Quercetum molinietosum*, and in the classification of Ratyńska et al. (2011), *Calamagrostio arundinaceae-Quercetum petraeae molinietosum*. Monocultures of pine and spruce of 55 to 90 years of age are the result of former forest management. Planting coniferous species in more fertile habitats causes their acidification and augments the process of nutrient leaching deeper into the soil profile (Binkley, Valentine 1991; Binkley, Giardina 1998). This causes pinetization (Olaczek 1974), with species of the *Vaccinio-Piceetea* class becoming

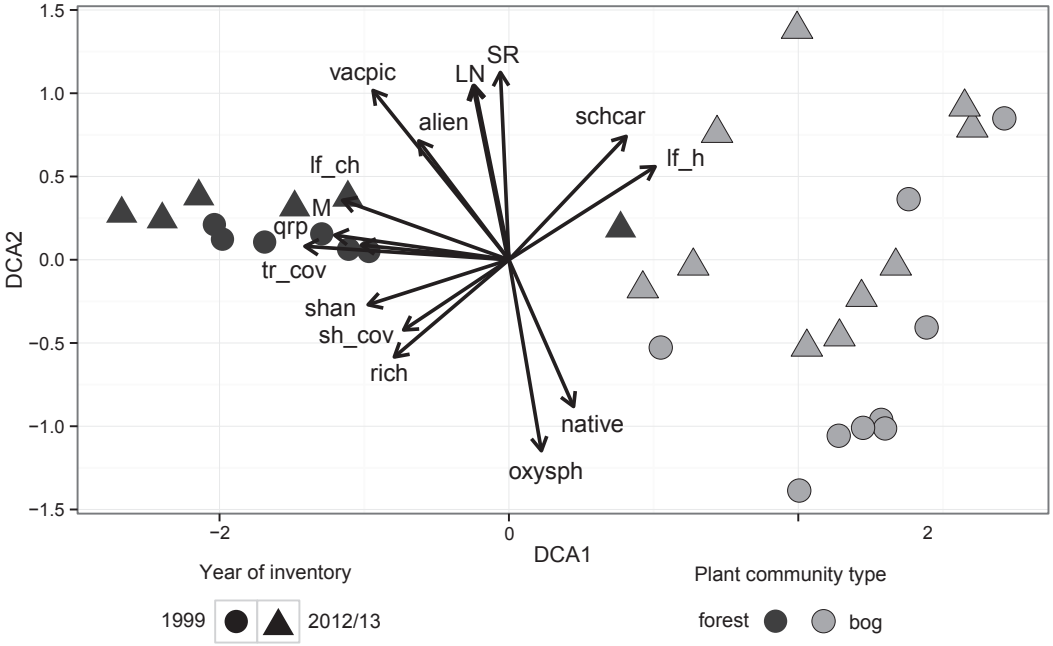

Figure 2. Result of Detrended Correspondence Analysis of vegetation from Mszar Bogdaniec nature reserve – relevés from 1999 (Maciantowicz et al. 1999; circles) and from 2012/13 (triangles). Axis parameters: DCA1: eigenvalue 0.8528; DCA2: eigenvalue 0.4696. On the plot there are only variables, which were statistically significantly ($p<0.05$) correlated with ordination result, their abbreviations are explained in Table 2

dominant in the forest floor layer, and a small number of *Quercetea robori-petraeae* class species providing habitats with slightly higher fertility. However, the mere presence of pine cannot be perceived as a manifestation of negative impact, because it forms a proportionally large share of the species composition of both associations constituting the potential natural vegetation (especially of *Querco roboris-Pinetum*) (Matuszkiewicz 2005; Ratyńska et al. 2011). In the case of spruce, we observed its mortality, which is related to the age of the tree stands and the cessation of management activities. This is also occurring in the adjacent Baszków nature reserve (Gdula et al. 2014).

Another important degeneration process is neophytization (Olaczek 1974), mainly related to the presence of *Padus serotina* and *Impatiens parviflora*, whose share is not very high. In a number of patches, black cherry is an important component of the shrub and forest floor layers, and is even encroaching into the tree layer. The *Pinus-Padus* community has been reported from many areas of the country, and the wide range of habitats it occupies (Halarewicz 2012) proves its attraction to pine stands growing in excessively fertile habitats (Zerbe, Wirth 2006; Jagodziński et al. 2015). The Mszar Bogdaniec reserve is also being significantly impacted by the spreading dominance of black cherry, which avoids spruce, occurring more frequently under pines, where there is more light (Knight et al. 2008). Neophytization also includes the encroachment of *Erechtites hieracifolia* – a North American neophyte that has been recently appearing in clearings and bogs in Poland (Tokarska-Guzik et al. 2009, 2012; Dyderski et al. 2015a).

The drainage of the peat bog is the result of efforts to drain the area by means of drainage ditches dug at the beginning of the twentieth century. It has irreversibly changed the peat deposits, as well as in the vegetation of the reserve (Maciantowicz et al. 1999; Dyderski et al. 2015a). The potential natural vegetation of the bog determined by Maciantowicz et al. (1999) as *Sphagnetum magellanici* (*Andromedo-Sphagnetum magellanici* according to Ratyńska et al. 2011) has been replaced by communities of further stages of succession – *Sphagno recurvi-Eriophoretum vaginati*, *Sphagno recurvi-Eriophoretum angustifolii* and the dynamically encroaching *Vaccinio uliginosi-Betuletum pubescentis* (Dyderski et al. 2015a). Draining peat bogs begins the process of peat mineralization, increasing the availability of nitrogen for plants, whose deficit limits the occurrence of most plant species. This allows species, usually stronger competitors, to become dominant and displace the most valuable elements of a peat bog's phytocoenosis – species with a narrow ecological amplitudes (Herbich 2001; Parish et al. 2008; Kollmann, Rasmussen 2012). Such a species is *Molinia cae-*

Table 4. Parameters of environmental variables fitted to DCA analysis of vegetation from Mszar Bogdaniec nature reserve – relevés from 1999 (Maciantowicz et al. 1999) and from 2012/13

Variable	Abbreviation	DCA1	DCA2	r^2	*p*	
Share of native species	native	0.45208	-0.89198	0.4341	0.005	**
Share of alien species	alien	-0.65722	0.75370	0.3989	0.013	*
Cover share of phytosociological classes:						
- *Vaccinio-Piceetea*	vacpic	-0.67853	0.73458	0.8515	0.001	***
- *Quercetea robori-petraeae*	qrp	-0.99633	0.08564	0.4639	0.002	**
- *Oxycocco-Sphagnetea*	oxysph	0.19192	-0.98141	0.6072	0.001	***
- *Scheuchzerio-Caricetea*	schcar	0.73795	0.67485	0.5359	0.001	***
Share of life forms:						
- phanerophytes	lf_f	-0.3316	-0.94342	0.0092	0.919	
- geophytes	lf_g	0.08434	0.99644	0.1713	0.182	
- hemicryptophytes	lf_h	0.87502	0.48408	0.5928	0.001	***
- chamaephytes	lf_ch	-0.95497	0.29670	0.6445	0.001	***
- mosses	lf_moss	-0.10489	-0.99448	0.0639	0.544	
Species richness	rich	-0.80483	-0.59351	0.4304	0.009	**
Shannon's diversity index	shan	-0.96357	-0.26747	0.4535	0.011	*
Ellenberg's indicator values:						
- fertility	N	-0.22655	0.97400	0.5084	0.002	**
- moisture	M	-0.99257	0.12166	0.6545	0.001	***
- light	L	-0.22655	0.97400	0.5084	0.002	**
- soil reaction	SR	-0.05212	0.99864	0.564	0.001	***
Vegetation layers cover:						
- trees	cov_tr	-0.99836	0.05721	0.8866	0.001	***
- shrubs	cov_sh	-0.86513	-0.50155	0.3143	0.037	*
- herbs	cov_he	-0.08568	-0.99632	0.031	0.768	
- mosses	cov_mo	-0.15783	-0.98747	0.2207	0.095	

Coefficient of determination r^2 and significance level p (*p<0.05; **p<0.01; ***p<0.001) were computed by permutation test (999 iterations)

rulea, which occurs with high frequency in the studied phytocoenosis (Herbich 2001; Limpens et al. 2003). Moreover, dehydration increases the encroachment of woody species, for which a high level of ground water is the main limiting factor for growth (Macdonald, Yin 1999; Vitas, Erlickytė 2007; Eckstein et al. 2011). Due to the broad scope of this issue, the encroachment of trees and shrubs in the bog at the study site, along with the environmental consequences of this, was thoroughly discussed by Dyderski et al. (2015a) in a separate paper.

The decreasing number of spruces in the tree stand and the encroachment of *Betula pubescens* in the gaps, leading to the formation of a juvenile form of bog birch forest *Vaccinio uliginosi-Betuletum pubescentis* in patches of *Pinus-Picea* SFC near the bog, as opposed to patches of this community placed closer to the reserve's borders, can be considered a

symptom of regeneration. The patches of this community are forming laggs of raised and transitional bogs (Ellenberg 1988; Herbich, Herbichowa 2002; Ratyńska et al. 2011), hence the presence of this system may indicate a return to a state similar to the systems described from sites that have undergone less intense human pressure.

Although there were no statistically significant differences for most of the environmental indicators characterizing the forest vegetation of the reserve between the phytosociological relevés made in 1999 and 2012/13, we noted a larger share (though still statistically insignificant due to the high variability and small number of observations) of chamaephytes and shrubs species of the *Vaccinio-Piceetea* class, which may indicate the progressive replacement of forest floor plants from deciduous forests with those of coniferous forests (Olaczek 1974). This may also be seen in the lower shares of species requiring higher soil fertility and pH, for example, *Calamagrostis arundinacea* or *Impatiens parviflora*. The statistically significant reduction of the share and cover of naturally regenerating pine and pedunculate oak as well as rowan saplings can be explained by the increase in cover of spruce saplings in patches further away from the bog, which, like downy birch, took advantage of the spruce dieback in the main stand, but increased the shading of the forest floor. This may have also affected the reduction of *I. parviflora* cover (Chmura 2014). The reported changes are mostly fluctuations (Faliński 1988), whereas only the encroachment of a bog birch woodland in the deteriorating tree stands with a high share of spruce can be regarded as regeneration.

The lack of statistically significant differences between most of the indicators characterizing the peat bog vegetation in 1999 and 2012/13 suggests that changes in the vegetation of the studied bog are fluctuations rather than directional changes, regardless of the encroachment of woody plants (Dyderski et al. 2015a). This may indicate cyclical, long-term fluctuations in groundwater levels associated with variations in atmospheric precipitation, suggested by Maciantowicz et al. (1999), or the long duration of the encroachment of woody plants in a bog.

Studies conducted at the 'Brzozowe Bagno koło Czaplinka' nature reserve indicate that a drained non-forested peat bog can become covered with a dense tree stand in less than a hundred years (Jagodziński et al. unpublished). Maciantowicz et al. (1999) pointed to the diversity of the woody plant cover in the bog in the past, which may confirm the hypothesis regarding fluctuations. Monitoring the water level at the water gate (built as a result of the protection plan) since 2000 shows that fluctuations occur, although in recent years (2011, 2012 and 2013), the valve was zero (Krotoszyn Forest District, unpublished), suggesting an outflow of water from the peat bog. The reduction of the share of silver birch in favor of downy birch in the shrub layer, which more often occurs in the bog communities of forests (Herbich, Herbichowa 2002; Ratyńska et al. 2011) and tolerates flooding better (Niinemets, Valladares 2006), may indicate, however, both a fluctuation as well as the beginning of a directional change, as *B. pubescens* will be more likely to survive periods of higher groundwater levels. For this reason, despite the fact that after 14 years the changes in the bog vegetation are characteristic of fluctuations, they are most likely to turn into secondary succession in the long term.

We found that after 14 years, changes in the vegetation of the study area are more characteristic of a fluctuation than a directional change. We also found the existence of both regenerative processes (the encroachment of a bog birch forest under the declining spruce stand near the bog) and new degenerative factors (the *Erechtites hieracifolia* invasion). The results show that in 20 years of mainly conservation protection (not counting the felling of individual trees and construction of a valve), the state of the vegetation has not significantly changed. Rare and endangered species of plants (including sphagna) and plant communities still exist in the study area. Due to the drastic changes in the water level, it is probably impossible to restore the state of the bog to its condition before the drainage ditches were constructed in the early twentieth century. However, the existing documentation and the research material gathered about the reserve makes it a good study site on the rate at which peat bogs are overgrown by forest plant communities. Because the nature reserve does not have significantly endangered national or regional species, the best solution would be to cease conducting the protective treatments of removing encroaching trees and shrubs (Kujawa-Pawlaczyk, Pawlaczyk 2005). This would enable researchers to monitor the processes occurring when a bog is spontaneously being overgrown, which will contribute to better knowledge about the pace with which such sites undergo this change.

5. Summary and conclusions

The majority of changes in the indicators describing the floristic composition of plant communities in the Mszar Bogdaniec nature reserve during the study period were not statistically significant and were mainly fluctuations.

There was a statistically significant increase in the share of mosses in the forest communities and a reduction in the average number of species noted in the relevé. A significant decrease in the share of *Scheuchzerio-Caricetea* class species and an increase in the cover of the herb layer were found in the peat bog community.

The state of the vegetation of the studied nature reserve is the result of human activity from the first half of the twentieth century. The most important anthropogenic factors,

which caused the changes include draining the peatlands, the planting of pine and spruce monocultures and the introduction of black cherry. Some patches of the semi-natural *Pinus-Picea* forest communities located in the vicinity of the bog are spontaneously transforming into an initial form of *Vaccinio uliginosi-Betuletum pubescentis*, which has the character of a process of regeneration.

Changes in the floristic composition of the peat bog communities are characteristic of fluctuations, although in the long term, the overgrowth occurring in the bog may turn into secondary succession.

Conflicts of interest

The authors declare no conflicts of interest.

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Authors' contribution

M.K.D. – concept and choice of methods, data collection and analysis, literature review, manuscript preparation, A.M.J. – concept and choice of methods, literature review, manuscript preparation.

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