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HUMIC SUBSTANCES IN THE ENVIRONMENT

The impact of restoration processes on the selected soil properties and organic matter transformation of mountain fens under *Caltho-Alnetum* community in the Babiogórski National Park in Outer Flysch Carpathians, Poland

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Abstract

Purpose The objective of this study was to determine the impact of restoration processes on the selected soil properties and organic matter transformation of mountain fens under the *Caltho-Alnetum* community in the Babiogórski National Park in Outer Flysch Carpathians.

Materials and methods Restoration processes were conducted on three degraded mountain fens in the Babiogórski National Park in Outer Flysch Carpathians, Poland. The degradation degree of soils was the criterion for the selection of habitats for further studies. To determine the influence of restoration processes on mountain fen soil properties and organic matter transformation, samples were collected in 2011 and 2013. The soil samples were assayed for pH, base cation concentration, hydrolytic acidity, organic carbon and total nitrogen content, total exchangeable base cation concentration, cation exchange capacity, and base saturation. Organic matter fractions were extracted by IHSS method. Quantitative and qualitative study of organic matter was based on fraction composition analysis and the ratio of humic acid carbon to fulvic acid carbon. The research results were statistically verified.

Results and discussion Based on morphological and chemical properties, the studied mountain fen soils can be classified as Sapric Dranic Eutric Histosols and Sapric Dranic Dystric Histosols according to WRB guidelines (2015). Before restoration processes, the mountain fen soils subjected to a different water regime showed various contents of total nitrogen and organic carbon. The decreasing of the groundwater level was reflected in pH, calcium ion content, exchangeable base cation concentration, and base saturation. The increase of the groundwater level had influence on chemical properties of mountain fen soils such as pH, total exchangeable base cation concentration, hydrolytic acidity, cation exchange capacity, and base saturation. Three-year restoration processes did not cause significant changes in the composition of humic substance fractions.

Conclusions Mountain fens under *Caltho-Alnetum* community are priority habitats in Babiogórski National Park in Outer Flysch Carpathians, Poland. These habitats responded to restoration processes in varying degrees depending on the extent of their degradation. The least degraded mountain fen was characterized by a short response time on the restoration processes. The reaction of higher degraded habitats was weaker.

Keywords Drainage · Mountain peatlands · Organic matter · Restoration technique

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1 Introduction

Four thousand million hectares of peatlands are found in at least 180 countries and cover around 3% of the world's land area (McCartney et al. 2010). These habitats are the place of occurrence of flora and fauna various species which are rare, imperiled, and included in the IUCN red list of flora and fauna (IUCN 2016). Unfortunately, in recent decades, these environments are degraded by the following processes: agriculture and forestry (He et al. 2016; Regina et al. 2016), drainage (Jauhiainen et al.

2002; Benavides 2014), commercial extraction (Alexander et al. 2008; Waddington et al. 2008), pollutant atmospheric deposition (Zadrożny et al. 2015), and fires (van der Werf et al. 2010). The above phenomena led to strong transformation of many valuable peatlands also in Poland and negatively affected not only on the direction of plant succession in these areas and composition of flora and fauna species, but also the distribution of organic matter in soil (Szafranek-Nakonieczna and Stępniewska 2014; Sterzyńska et al. 2015; Glina et al. 2016).

An improvement of environmental conditions in degraded peatlands is essential. On the plains, restoration processes of hydrogenic habitats include removal of the peaty-muck surface layer in range of few to several tens of centimeters depending on the degree of the parent material transformation by muck-forming process. After that, the groundwater level is increased, and characteristic plant species for these habitats are reintroduced (Shumann and Joosten 2008; Klimkowska et al. 2010). In the case of hydrogenic habitats situated in inaccessible mountain areas, the removal of the peaty-muck surface layer is very difficult and in some instances, impossible. Conditions in these habitats (slope inclination, significant height above sea level, and presence of protected plant species near habitats) prevent any use of machines. Apart from technical difficulties, another obstacle is the transportation of the material and its depositing. For the reasons set out above, restoration processes of mountain fens involved blocking the outflow of water from drainage ditches without removing the peaty-muck surface layer (Schimelpfenig et al. 2014; Grand-Clement et al. 2015; Cooper et al. 2017).

Peatland drainage, extraction, and restoration have large impact on their water and soil chemistry as well as soil organic matter accumulation or/and transformation (Nicia et al. 2010; Strack et al. 2011; Grand-Clement et al. 2015). Humic substances such as humic acids, fulvic acids, and humins are generally the dominant fraction of soil organic matter. They are an excellent indicator showing the degradation degree of peatlands. These substances are connected with very important processes occurring in peatlands such as respiration (Szafranek-Nakonieczna and Stępniewska 2014; He et al. 2016), denitrification (Hernandez and Mitsch 2007), and phosphorus sorption (Marton and Roberts 2014). Besides, humic substances very well indicate the differences between restored and natural peatlands (Bruland and Richardson 2006).

The objective of this study was to determine the impact of restoration processes on the selected soil properties and organic matter transformation of mountain fens under the *Caltho-Alnetum* community in the Babiogórski National Park in Outer Flysch Carpathians.

2 Materials and methods

2.1 Study sites

The study covered a three degraded habitats of *Caltho-Alnetum* in the Babiogórski National Park in Outer Flysch Carpathians, Poland (Fig. 1). These mountain fens are characterized by small size because they are limited by steep slopes and small size of watersheds supporting them. The degradation degree of peat soils was the criterion for the selection of habitats for further studies. The least degraded habitat was mountain fen "Za Szałasem," which was drainage ditches about 0.4 m in depth. In the central part of the habitat, the groundwater level before restoration was about 15–20 cm from ground surface. The second mountain fen "Pod Dolnym Płajem" was drainage ditches about 0.7 m in depth, and the groundwater level in its central part was about 35 cm from the ground surface. The third of mountain fen "Markowe Rówienki" was drainage ditches about 0.9 m in the deepest depth, and the groundwater level before restoration process was the lowest (65 cm from ground surface).

Before restoration processes, peaty-muck surface layer in studied mountain fen soils was observed.

2.2 Restoration approach and planning

The mountain fens under the *Caltho-Alnetum* community are a subtype (91E0-7) of the habitat (91E0) mentioned in the annex to the 1st European Union Habitats Directive (Council Directive 92/43/EEC 1992) as priority habitats. Prior to the protection of the national park, these habitats have been dehydrated to increase the productivity of the trees (Nicia et al. 2010). According to the records protection strategy plan of Babiogórski National Park, the area of habitats marked with * 91E0-7 code, which include restored habitats, is 38.87 ha, which constitutes 1.15% of its area. To prevent their further degradation, it was necessary to instigate restoration processes aimed at gradually natural water conditions (Nicia and Bejger 2012).

The mountain fens under *Caltho-Alnetum* community in the Babiogórski National Park are surrounded with other precious habitats, e.g., *Dentario glandulosae-Fagetum*, *Abieti-Piceetum*, *Luzulo luzuloidis-Fagetum*, and *Galio-Abietetum*, which during the removal of the peaty-muck surface layer, may be exposed to destruction. Therefore, restoration processes of mountain fens involved blocking the outflow of water from drainage ditches without removing the peaty-muck surface layer (Schimelpfenig et al. 2014; Grand-Clement et al. 2015; Cooper et al. 2017). To prevent introducing foreign materials to habitats undergoing restoration process, e.g., concrete, and to reduce negative impact on the natural environment, valves blocking the

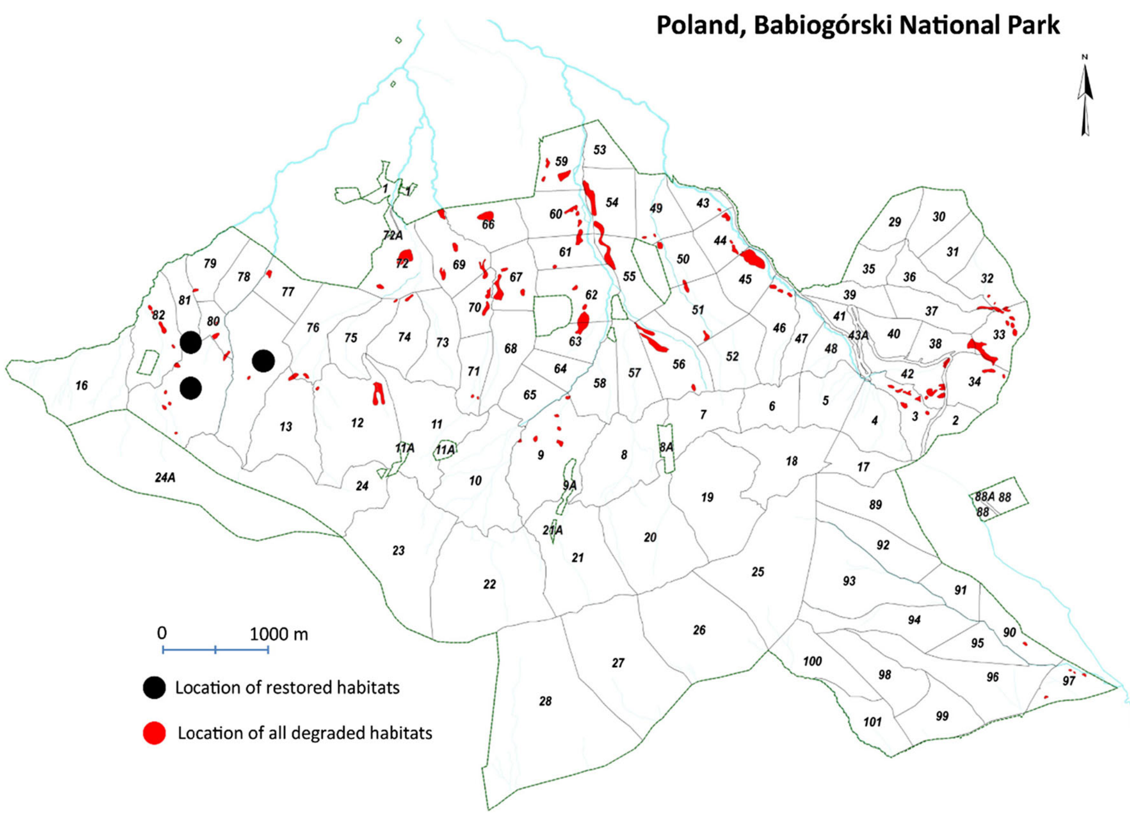

Fig. 1 Location map of mountain fens under *Caltho-Alnetum* community in Babiogórski National Park, Poland

outflow of water from drainage ditches were made of dried spruce and ash trees, which were introduced to these habitats in the 1960s and 1970s (Fig. 2). Valves have different heights depending on the depth. During restoration processes, the height of the valves was gradually increased about 0.05–0.15 m per year, reaching in the most degraded area almost 0.6 m. The number of valves was varied depending on the slope of the restored habitats. In the area of low slope (1–3%), there were two to three valves per ten running meters of drainage ditch, while in the area with higher slope (3%), even five to seven valves were used. Over time, the valves decreased the outflow of water from drainage ditches more and more effectively, due to their blocking by leaves from trees as well as due to their muddied.

2.3 Sampling and analysis

Representative soil samples were collected from the surface layer (0–18 cm) twice: before restoration processes started in 2011 and exactly from the same places after the restoration processes in 2013. The collected soil samples were transported directly to the laboratory, air-dried, and milled. To control the increasing groundwater level, piezometers were installed near each soil profile.

In the soil samples, the following properties were determined:

- pH in a 1:2.5 (*w*/*v*) soil: water suspension and 1 mol dm^{-3} KCl solution, using the potentiometric method (Tan 2005),
- the base cation (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) concentration, after extraction with 1 mol dm^{3} CH_3COOHN_4 solution (Tan 2005), individual cations were determined by atomic emission spectrometry with inductively coupled plasma (ICP-OES) using Perkin Elmer Optima 7300DV optical emission spectrometer. Plasma gas-flow was 15 dm^{3} min^{-1}, external gas flow—0.2 dm^{3} min^{-1}, and nebulizing gas flow—0.6 dm^{3} min^{-1}. Calibration was carried out using certified reference material ERM®-CD 281.
- the hydrolytic acidity (H_h) using 1 mol dm^{-3} CH_3COONa solution (Klute 1986),
- the content of organic carbon (C_{org}) using Orłow and Grindel's spectrophotometric method (Orłow et al. 1969), and
- the content of total nitrogen (N_{tot}) using LECO CNS 2000 automatic analyzer (LECO 1996).

Total exchangeable base (TEB) cation concentration, cation exchange capacity (CEC), and base saturation (BS) percentage were calculated as follows:

$$TEB = \left[Ca^{2+}\right] + \left[Mg^{2+}\right] + \left[K^{+}\right] + \left[Na^{+}\right];$$

Fig. 2 Blocking the outflow of water from drainage ditches in studied mountain fens

$CEC = TEB + H_h$;

$BS[\%] = TEB/CEC \times 100$

Quantitative and qualitative study of organic matter was based on fraction composition analysis and the ratio of humic acid carbon to fulvic acid carbon. Extraction of organic matter fractions was performed using procedure recommended by International Humic Substances Society (Tan 2005). Determination of carbon in extracts with the Orłow and Grindel's spectrophotometric method (Orłow et al. 1969) was the basis defining the following fractions of organic matter:

– C_{SH}—humic substance carbon (in alkaline solution after extraction of 0.1 M NaOH; *m*/*V* = 1:10; time extraction = 4 h),
– C_{HA}—humic acid carbon (in solution, after acidification of humic substances by 6 M HCl to pH = 1.5, humic acids were precipitated, separated, and next diluted in 0.1 M NaOH),
– C_{FA}—fulvic acid carbon was calculated by difference $[C_{SH} - C_{HA}]$, and
– C_{NE}—not extractable organic carbon defined as humins was calculated by difference $[C_{org} - C_{SH}]$.

2.4 Statistical analysis

The results from the 3-year observations (2011–2013) were statistically analyzed using the Statistica 10.0 software. Prior to analysis, the soil and water data were checked for normal distribution and homogeneity of variances. Among the data, one-way ANOVA and Tukey's HSD test ($P \leq 0.05$) were used to determine significant differences.

3 Results

Based on morphological and chemical properties of the studied mountain fen soils, according to WRB guidelines (2015), soils in mountain fens "Za Szałasem" and "Pod Dolnym Płajem" can be classified as Sapric Dranic Eutric Histosols and in mountain fen "Markowe Rówienki" as Sapric Dranic Dystric Histosols.

Data from the physicochemical analyses before and after restoration processes of the studied mountain fen soils are presented in Table 1.

The best results in relation to increasing of the groundwater level were achieved in the least degraded mountain fen "Za Szałasem," where the groundwater level in the soil of this fen increased to the level close to the natural conditions and was about 0.05 m (Table 1). In more degraded mountain fens ("Pod Dolnym Płajem" and "Markowe Rówienki"), the groundwater level increased to 0.08 and 0.35 m, respectively. Due to the danger of erosion in mountain fens "Pod Dolnym Płajem" and "Markowe Rówienki," the groundwater level was not further increased during the restoration processes.

The all studied mountain fen soils responded to the restoration processes by increasing the C_{org}, C/N, and pH values (Table 1). Unfortunately, in the case of C_{org} and C/N values, the differences were not statistically significant. In the case of pH values, differences were statistically significant only in the case of the low degraded mountain fen "Za Szałasem." The statistically significant increase in pH measured in KCl was

Table 1 Selected physicochemical properties of mountain fen soils before ($n = 9$) and after ($n = 9$) restoration processes

Year	Water level	C_{org}	N_{tot}	C/N	pH		Na	K	Ca	Mg	TEB	H_h	CEC	BS
	(m)	(g kg^{-1})			H_2O	KCl	(mmol$^+$ kg^{-1})							(%)
Mountain fen "Za Szałasem"—low degraded														
2011	0.15	344.3^{a*}	21.2^a	16.3^a	6.1^b	5.7^b	1.9^a	3.1^b	630.2^b	45.6^b	680.8^b	154.3^a	835.1^b	81.5^b
2013	0.05	358.7^a	17.6^b	20.4^a	6.4^a	5.9^a	2.0^a	4.5^a	658.6^a	54.2^a	719.3^a	144.2^b	863.5^a	83.3^a
Mountain fen "Pod Dolnym Płajem"—moderate degraded														
2011	0.35	319.7^a	18.6^a	17.2^a	5.4^a	5.1^b	2.1^a	3.0^b	610.4^a	55.6^a	671.1^a	364.8^a	1035.8^a	64.9^b
2013	0.08	345.7^a	17.5^a	19.8^a	5.5^a	5.2^a	2.1^a	5.0^a	634.6^a	56.8^a	698.5^a	323.9^b	1022.4^a	68.3^a
Mountain fen "Markowe Rówienki"—high degraded														
2011	0.65	278.4^a	17.1^a	16.2^a	5.1^a	5.0^a	2.2^a	3.0^a	156.0^a	25.4^a	186.6^a	244.7^a	431.4^a	43.3^a
2013	0.41	281.3^a	16.5^b	17.0^a	5.2^a	5.1^a	2.2^a	3.1^a	165.9^a	24.5^a	195.7^a	245.4^a	441.1^a	44.4^a

C_{org} organic carbon content, N_{tot} total nitrogen content, H_h hydrolytic acidity, *TEB* exchangeable base cation concentration, *CEC* cation exchange capacity, *BS* base saturation

* Means with the same letter are not significantly different using Tukey's HSD test ($P < 0.05$)

recorded in the case of the moderate degraded mountain fen "Pod Dolny Płajem." Also in the case of the high degraded mountain fen "Markowe Rówienki," an increase in the pH value measured in aqueous solution and KCl was noted but was not statistically significant.

The higher groundwater level was also reflected in the sorption properties of the mountain fen soils (Table 1). This influence was most visible in the mountain fen "Za Szałasem"—which was characterized by the lowest degree of degradation. In comparison to 2011, surface layers showed higher concentration of K^+, Ca^{2+}, and Mg^{2+} in the sorption complex, and higher TEB, CEC, and BS. Decrease was recorded regarding H_h in soil surface layers. These differences were statistically significant. Likewise, the moderate degraded soils responded to the increased groundwater level. However, statistically significant differences were noted only in the case of K^+, H_h, and BS. The most degraded soil responded in the least visible way to the restoration processes. In comparison to 2011, surface layers showed higher concentration of K^+ and Ca^{2+} in the sorption complex, and higher TEB, CEC, H_h, and BS. Unfortunately, these differences were not statistically significant.

In Table 2, data from carbon distribution of organic matter fractions of studied mountain fen soils before and after restoration processes are presented.

In the fractions of soil organic matter, the humins dominated over humic acids and fulvic acids before and after restoration processes (Table 2). In the case of the low and moderate degraded mountain fen soils, C_{NE} content was two to three times higher than C_{FA} and C_{HA} content before and after restoration processes. C_{NE} content of high degraded mountain fen soils was three times higher only in the case of C_{HA} content before and after restoration processes. The highest value of C_{HA}/C_{FA} was found in mountain fen "Za Szałasem" of the low degradation degree, whereas the lowest value of C_{HA}/CFA was found in mountain fen soils "Markowe Rówienki" of the significant degradation.

It was not noted the statistically significant changes in the content of humic substances and their fractions after 3-year restoration processes in the all studied mountain fen soils (Table 2).

4 Discussion

The impact of restoration processes on the selected soil properties and organic matter transformation of mountain fens under the Caltho-Alnetum community in the Babiogórski National Park in Outer Flysch Carpathians, Poland, was

Table 2 Carbon distribution of organic matter fractions of mountain fen before ($n = 9$) and after ($n = 9$) restoration processes

Year	C_{SH} (g kg^{-1})	Extraction yield (% C_{org})	C_{HA} (g kg^{-1})	C_{FA}	C_{NE}	C_{HA}/C_{FA}
Mountain fen "Za Szałasem"—low degraded						
2011	141.5^{a*}	41.1^a	67.0^a	74.5^a	202.8^a	0.89^a
2013	140.5^a	39.2^a	67.1^a	73.5^a	218.0^a	0.93^a
Mountain fen "Pod Dolnym Płajem"—moderate degraded						
2011	142.3^a	44.5^a	64.8^a	77.5^a	177.4^a	0.83^a
2013	141.4^a	40.9^a	65.1^a	76.3^a	204.3^a	0.84^a
Mountain fen "Markowe Rówienki"—high degraded						
2011	146.5^a	44.5^a	50.0^a	96.5^a	131.9^a	0.52^a
2013	145.2^a	51.3^a	50.0^a	95.3^a	136.1^a	0.52^a

C_{SH} humic substances carbon content, C_{HA} humic acids carbon content, C_{FA} fulvic acid carbon content, C_{NE} humin carbon content

* Means with the same letter are not significantly different using Tukey's HSD test ($P < 0.05$)

determined. Before restoration processes, the mountain fen soils subjected to a different water regime showed various content of total nitrogen and organic carbon. Most probably, the reason was that processes and mechanisms taking place in soil of these habitats differed. It was established that the total nitrogen concentration decreases with the increase of degradation degree of the studied mountain fen soils. This indicates a gradual loss of the capacity to retain and accumulate nitrogen in soil (Gao et al. 2009; Glina et al. 2016). Value of organic carbon about 30 g kg^{-1} is a characteristic for mountain fen soils (e.g., Chimner et al. 2010). In peatlands of natural water conditions, the increase of organic carbon content is the result of the accumulation of organic matter from remains of plants growing in the habitat. However, in the case of studied mountain fen soils, the observed increase in the organic carbon content (not statistically significant) cannot be the result of restoration processes only. While taking into account the rate of organic matter accumulation in mountain fen soils, it was not possible to observe the increase in the organic carbon content in surface layers of nearly 4% comparing to the initial level within 3 years. Earlier study conducted by Nicia and Miechówka (2004) and Nicia and Niemyska-Łukaszuk (2008) on the mountain fen soils showed on the basis of field observation since 9 years that organic matter accumulation is between 0.1 and 0.5 mm early. Considering the above, the changes could result from the increase in surface moisture level in these habitats, which supported the retention of leaf biomass or the surface layers could have been enriched in studied mountain fen soils with organic matter washed out from habitats situated at higher levels due to minor surface erosion.

The C_{org}/N_{tot} ratio is used as good indicator for the mineralization process of organic matter. The low values of C/N ratio (< 20) indicate that organic matter mineralization process of these soils is very advanced. Glina et al. (2016) also observed the low values of C/N ratio (< 20) for fen peatland with weak aggregate structure (peaty-muck). Schrautzer et al. (2013) conducting studies on degraded fen soils before restoration processes also obtained values of C/N quotient lower than 20.

The groundwater level increased in the studied mountain fen soils was reflected in pH values. The reason might be with the inflow of water containing base ions, which neutralized acidic products of organic matter decomposition (Nicia et al. 2009). Increasing the content in the sorption complex Ca^{2+}, Mg^{2+}, and K^{+} was reflected in the increase in the TEB, CEC, and BS and the reduction of H_h in the mountain fens "Za Szałasem" and "Pod Dolnym Płajem." The inflow of these ions to the top soil layers of restored habitats occurred as a result of restoration processes. Similar dependencies connected with the influence of mineral soil components on the pH values and sorption properties of the mountain fen soils were described by Nicia and Bejger (2012) and in the lowland organic soils by Bieniek and Łachacz (2012).

In peatlands with natural organic matter accumulation, their transformation leads to formation of a heterogeneous system containing humic substances. Properties of these substances depend on the origin and degree of peat decomposition (Szajdak et al. 2007). The drainage of peatlands causes significant changes of biotic and abiotic properties of their soils, which lead to the degradation of the organic matter fractions (Szajdak and Szatyłowicz 2010). The lower organic matter proportion of drained peatlands as a consequence the degradation degree of peat soils was observed also by Benavides (2014).

Based on the value of C_{HA}/C_{FA} ratio, humification degree of soil organic matter is determined (e.g., Bejger et al. 2010; Kaverin et al. 2016). Low (< 1) C_{HA}/C_{FA} for studied mountain fen soils is typical for peats which soils from the organic matter accumulation phase entered in the decay phase.

5 Conclusions

The mountain fens under *Caltho-Alnetum* community in Babiogórski National Park, Poland, responded to the restoration processes. The groundwater level increased in the mountain fens under *Caltho-Alnetum* community influenced on the selected chemical soil properties, while the statistically significant changes were dependent on soil degradation degree. The low degraded habitat was characterized by a short response time on the active protection procedures. Too quickly increasing the groundwater level in more degraded habitats located on the slopes could cause soil erosion processes of these habitats.

The results suggest that 3-year restoration processes are not enough to observe significant changes in the quantity and quality of humic substance fractions, that is why the mountain fens under *Caltho-Alnetum* community need continuation of the restoration processes.

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