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Ten years of changes in hydrology and vegetation in montane mires of temperate zone in Central Europe (Šumava National Park)

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Abstract

Because of their extreme environment and vulnerability, mires are well able to reflect the ongoing climate change. Northern mires are presently being studied intensively from this point of view. But little is known about the effect of climate change on peatlands in temperate zone. Monitoring of mires in sensitive montane regions of continental Europe can provide valuable information in this regard. This article uses more than 10 years of data from our monitoring to show hydrological and vegetation changes in well-preserved mountain mires. Primary attention has been paid to mire hydrology, especially the water table and its fluctuations, and vegetation, as they are among the key drivers for carbon cycling and ecological processes in peatlands. The results presented reveal a decreasing mean water table level in the studied mires, particularly in ombrotrophic bogs where their distinct microtopographic features show different responses. Minerotrophic fens well supplied by upwelling groundwater present a more hydrologically stable picture. Changes in mire vegetation were also found, the most significant shifts recorded being among wet microtopographic features related to open bog expanses (sedge hollows, lawns). For example, the cover of *Warnstorfia fluitans* and sedges (mainly *Carex limosa*) was considerably reduced. In contrast, the vegetation of hummocks (representing the drier end of the moisture gradient) proved to be relatively stable, including the species composition of *Sphagnum* mosses.

Key words: montane mires, hydrology, climate change, vegetation

INTRODUCTION

Mires are remarkable relict ecosystems significantly enhancing the biodiversity of Central Europe. Additionally, they are able to store great quantities of water (MOORE 2002), making them important water-retaining ecosystems (BREEUWER et al. 2009). Consequently, they have an important role in landscape hydrology and local climate (PARISH et al. 2008). Mires also play an important role in carbon sequestration (GORHAM 1991). Mires are characterized by extreme environmental conditions (flooding, anoxic conditions, oligotrophy, acidity, temperature extremes, etc.) which are reflected in their specific ecological links and many specialized species (Rydin & Jeglum 2006, Mineava & Sirin 2012). But the close adaptation of mire species to a narrow range of extreme conditions can limit their ability to benefit or even survive in changed/degraded habitat. For example, key peat-forming plant species like *Sphagnum* mosses, which are well adapted to wet and nutrient poor conditions, are very sensitive to increasing temperature and drought stress (Jassey et al. 2019). Other well-adapted mire species are not able to withstand competitively stronger non-peatland species if extreme conditions (e.g. waterlogging or lack of nutrients) should become moderated. When water tables drop, a typical oligotrophic and wet-loving mire species that produces only a small amount of biomass can often be replaced by a common “dryland” species; such interlopers are more successful and produce much more biomass but, nonetheless, are weak in accumulating organic matter. Therefore, mire ecosystems rich in specialized organisms are generally sensitive to even small changes in environmental conditions (Rydin & Jeglum 2006, Essl et al. 2012). Such ecosystems are thus well able to indicate a variety of anthropogenic impacts, e.g. disturbed hydrology via drainage, landscape overheating, eutrophication or air pollution (e.g. Bragg & Tallis 2001, Joosten 2015, Garcia-Alix et al. 2016, Stivrins et al. 2017) and reflect many of the current trends associated with global climate change (Schultheis et al. 2010, Esll et al. 2012, Potvin et al. 2015, Lamentowicz et al. 2016).

Various climate models for Europe predict considerable increases in climate extremes, especially temperature fluctuations, droughts and heavy precipitation events. As a result of that, decreased water availability in summers and changed precipitation patterns (Kyselý & Beranová 2009) with more frequent extreme rain events are expected (Kovats et al. 2014). Mires as strongly water-dependent ecosystems are potentially threatened by these trends particularly due to the frequent dry periods and increasing temperatures (Laiho & Vassander 2003, Breeuwer et al. 2009).

Most recent studies dealing with the impact of climate change on mires have been focused on boreal regions. They have revealed that northern peatlands are particularly sensitive to small perturbations in climate and can be significantly transformed by the changing climate (Malmer et al. 2005, Johansson et al. 2006, White et al. 2008, Laughlin et al. 2014). Results from northern bogs in Europe and North America suggest that climate change can shift the species composition in bogs (e.g. White et al. 2008). Lowered water levels affect plant community composition (Potvin et al. 2015), different plant functional groups (*Sphagnum* mosses, ericaceous shrubs and sedges; Weltzin et al. 2000), and the co-occurrence between vascular plants and peat mosses (Breeuver et al. 2009). Changed competitive links among different *Sphagnum* species, induced by water deficit or increased temperature, have also been recorded (e.g. Robroek et al. 2007, Breeuver et al. 2008). Because the plant community is one of the primary drivers of carbon cycling in mires, all these changes can considerably affect complex ecological processes, including decomposition, peat formation and carbon sequestration (Moore et al. 2002, White et al. 2008, Potvin et al. 2014).

In the temperate regions of central Europe, less attention has been devoted to an assessment of the potential impact of climate change on mires (Wieder & Yavitt 1994, Schultheis et al. 2010, Slowinska et al. 2013, García-Alix et al. 2017). Long-term monitoring of undisturbed mires, which is necessary for valuable information about trends, has also been scarce (Grünig 2005, Petras 2014, Poschlod et al. 2014). In central Europe, ombrotrophic mires are rather small island habitats, occurring in mountains or regions with specific hydrogeological conditions. They are embedded in the basic matrix of temperate ecosystems and influenced by a diverse set of anthropogenic impacts. Most of the mires have been considerably disturbed by peat exploitation, drainage, forestry or agriculture. The ongoing climate change further multiplies these human impacts (Joosten & Clarke 2002), in particular, due to the higher frequency and intensity of dry periods and changed distribution of precipitation. Long-term monitoring of the remaining intact peatlands and their response to climate change in temperate regions is therefore very important. A better understanding of how peatlands respond to increased temperatures and droughts in a continental climate could be helpful in setting a strategy for their future protection or restoration (Lamentowicz et al. 2016).

Mires in the Bohemian Forest started to be more intensively studied from the 1990s onwards, the large military area and border zones being then opened for the public (e.g. Spitzer et al. 1999, Soukupová et al. 2001, Svobodová et al. 2002, Hojdová et al. 2005, Horn & Bastl 2008, Kučerová 2009, Urbanová et al. 2010, 2012, Jaroš et al. 2014). Long-term monitoring that has been recording hydrological, hydrochemical, microclimatic and vegetation data from mires has been carried out by the Šumava National Park (ŠNP) authority since 2005 (Bufková et al. 2011). However, a more simplified monitoring design which included only water table measurements had already been started at some sites since 1996. The mire monitoring implemented by the ŠNP authority was primarily focused on the evaluation of restoration measures in drained mires. However, a long-term data set from control undisturbed sites has also provided a lot of information about the trends in natural mires, for example, with regard to ongoing climate change. A couple of years ago, within the framework of the Interreg project No. 26 “Silva Gabreta Monitoring – Implementation of cross-border monitoring of biodiversity and water regime”, monitoring was extended to the Bavarian Forest National Park (BFNP, Germany) and a transboundary design for common mire monitoring was started (Křenová & Seifert 2018). At the same time, the monitoring design was improved and the revealed gaps in the dataset were covered within the ŠNP. Monitored habitats and the gradient of abiotic variables (altitude and water sources) were then completed. The transboundary set of monitored sites and variables is giving valuable information about the mires disturbed by humankind and their further development after restoration. In addition, the monitoring of control sites provides unique transboundary data on the status and developmental trends in these natural mires.

The main aim of this article is to present hydrological and vegetation changes in well-preserved mountain mires based on more than ten years of data from the monitoring already completed. The main attention has been paid to the position and fluctuation of the water table, particularly in the context of changing temperature conditions and more frequent droughts in a mountain area. The role of key plant functional groups and microtopographic features in bogs and their changes during the study period have also been stressed.

The following questions have been addressed:

1) Are there significant changes in water table levels in long-term monitored mires during the last decade?
2) Are there differences in water table levels between ombrotrophic and minerotrophic mires?
3) Is there a shift to a higher abundance of more dry-tolerant species in mire vegetation?

To better understand the hydrological and vegetation changes, trends in local climatic conditions (i.e. data from a regional meteorological station, Churáňov, and several microclimate stations) were analysed and used to interpret our monitoring results.

METHODS

Study area

In the Bohemian Forest, the low mountain range straddling the border referred to as Šumava (in Czech) and the Böhmerwald (in German), abundant mire complexes (6000 ha in total) cover about 15% of the region (SOUKUPOVÁ 1996). In some areas, the proportion of mires reaches up to 26% (on the mountain plateau) or even 70% in river valleys (BUFKOVÁ & PRACH 2006). Mires here are situated near the southern boundary of peatlands in the northern hemisphere (GORE 1983), on the transition between an oceanic and continental climate (NEKOVÁŘ 1969). In this mountain landscape, mires have developed as remarkable habitat islands in a temperate forest zone (SPITZER 1994), where elements of the Nordic tundra and taiga have blended with central European species. The various mire types range from the dome-shaped ombrotrophic raised bogs that are fully dependant on rainfall, to the minerotrophic woody or treeless fens fed mainly by groundwater. Woody mires and bog forests are the most abundant mires in the area. Open sedge fens are rather small and can be either of natural (poor fens or transitional mires developed on springs) or of secondary origin (moderately-rich fens resulting from deforestation and traditional agriculture land). The most valuable mires in the area have been included within the core zones of the Bavarian Forest National Park (BFNP, Germany) and Šumava National Park (ŠNP, Czech Republic), or protected as nature reserves in the surrounding landscape (CHYTIL et al. 1999). On the Czech site most of the mires have been declared within the Ramsar Site "Šumavská rašeliniště" in 1990.

The study was conducted in the ŠNP (Fig.1) and our monitored sites were located along an altitude gradient from the central upland area (about 1200 m a.s.l.) to the Křemelná river basin in the upland periphery (800 m a.s.l.) (Table 1). Five well-preserved natural mires Blatenská slať, Šárecká slať, Nad Roklanským potokem, Malý Bor and Velký Bor were selected to study the three main mire types (mire typology according to CHARMAN 2002): (i) ombrotrophic raised bogs; (ii) poor fens; and (iii) moderately-rich fens. Some sites encompass multiple mire types. Water table data from the spruce mire surrounding the ombrotrophic bog Blatenská slať have also been included in this study.

Blatenská slať (BOG1) and Šárecká slať (BOG2)

Both sites are located on the central plateau of the Bohemian Forest and represent ombrotrophic raised bogs surrounded by spruce mires. BOG1 is situated in the upper part of the central plateau (1250 m a.s.l.), while BOG2 lies at a lower position at 1050 m a.s.l. Both ombrotrophic bogs are typical mountain high-raised bogs developed on a sloping surface through paludification (on ancient springs). The bogs are characterised by an open bog expanse, several bog pools and well-developed surface hummock-hollow microtopography (for descriptions, see next section). The shrub margins are formed of *Pinus × pseudopumilio*. The matrix of spruce forests around both bogs is in a "break-up" phase (since 1999 for BOG1 and 2010 for BOG2) due to the expansion of bark beetle. Both mire complexes moderately slope to the east.

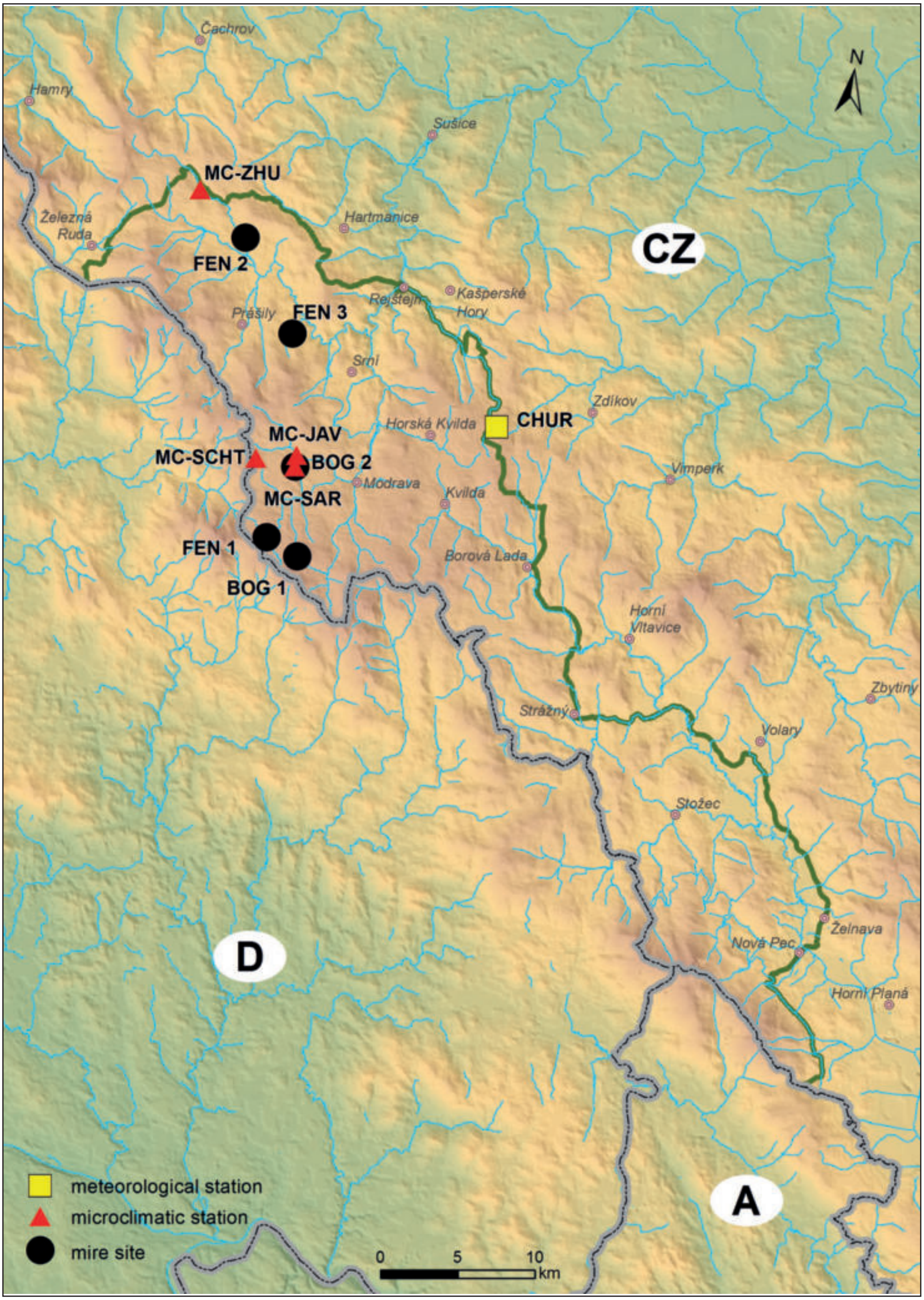


Fig 1. Location of monitored mire sites and meteorological stations (for abbreviations see Table 3–4).

Table 1. Basic characteristics of mire sites analysed in this paper.

Site	**Blatenská slať**	**Šarecká slať**	**Nad Roklanským potokem**	**Malý Bor**	**Velký Bor**
Code	BOG1	BOG2	FEN 1	FEN 2	FEN 3
Mire type	ombrotrophic: raised bog and spruce mire	ombrotrophic: raised bog	minerotrophic: poor fen	minerotrophic: poor fen and moderately rich fen	minerotrophic: moderately rich fen
Coordinates	48.97625N, 13.45687E	49.02778N, 13.44300E	48.98445N, 13.42755E	49.15559N, 13.36882E	49.10443N, 13.42324E
Total site area (ha)	10.7	18.3	1	1.6	0.4
Altitude (m a.s.l.)	1250	1020	1190	840	880
Position	central upland	central upland	central upland	upland periphery	upland periphery
Microclimate stations	MC-SCHT	MC-SAR (precip. from MC-JAV)	MC-SCHT	MC-ZHU	MC-ZHU
Total number of water table boreholes and vegation plots	18	6	6	3	1
Data set of water table boreholes	2005–2018	2011–2018	2009–2018	2009–2018	2009–2018
Data set of vegetation data	2005, 2010, 2018	2005, 2010, 2018	2005, 2018	2005, 2016	2005, 2018

Nad Roklanským potokem (FEN1)

A minerotrophic transitional mire situated in the upper part of the central plateau (i.e. a summit upland position). It represents a typical spring mire developed on a sloping surface and well supplied with upwelling groundwater. A spring is still detectable in the central part of the mire. The sloping mire surface is layered into three platforms, with a complex surface microtopography encompassing prolonged hollows and sedge or cotton grass lawns. The vegetation has the character of a poor fen with predominant sedge lawns. The high coverage of peat mosses (80–90%) with predominantly *Sphagnum fallax* and *S. flexuosum* is typical for the whole mire. *Drosera anglica*, a critically endangered species, is relatively abundant in flarks. In the middle of this site, there is a small spring with upwelling groundwater and different vegetation (Tables 2 and 4). The lower lagg margin is bounded adjacent to the bank of a small stream and is naturally eroded. The open mire is surrounded by spruce mires that have been in a "break-up" phase since 1999.

Malý Bor (FEN2) and Velký Bor (FEN3)

Two minerotrophic mires developed on two different moderate slopes in the Křemelná river basin. Both are well supplied by upwelling groundwater, with a small capillary stream naturally draining FEN2. The FEN2 complex consists of both poor and moderately-rich fens, while FEN3 represents a moderately rich-fen exclusively. Surface microtopography is less developed and rather uniform at both these sites; it is formed mainly by sedge lawns. In the surroundings, there is a mosaic of woody fens, wet meadows and waterlogged spruce forests.

The studied sites are part of the comprehensive monitoring of mires which started in the Bohemian Forest region in 2005 (Bufková et al. 2011) and since 2016 has been continued in a transboundary design (see Appendix 1; Křenová & Seifert 2018).

Microtopographic features

Hydrological and vegetation changes were monitored in certain distinct microtopographic features (term microsites can be also used as synonym) (Table 2) in order to cover the different moisture conditions in mires. These distinct features have different positions along a moisture gradient from waterlogged to drier sites. They are thus occupied by various plant species that reflect their different hydrological conditions (Charman 2002) and the changes in water availability. The main microtopographic features were identified in 2005 and classified according to Sjörs (1948) and Rydin et al. (2006). The final terminology was modified according to the local situation. These features generally represent the diverse microtopography where particular plant communities are growing mainly due to the varying distance to the water table (Moen 2002, Potvin et al. 2014).

In our study area, microtopographic features in ombrotrophic bogs are formed within a hummock-hollow system and include hollows (depressed and waterlogged), lawns (intermediate) and hummocks (elevated and relatively dry) (Fig. 2). Fens are more unified and are usually composed of only lawns with a scarcity of hollow or hummock features.

Based on the different abiotic conditions and vegetation, the following microtopographic features were determined in the monitored mires (sensu Rydin et al. 2006; modified to local conditions):

Sedge hollows: Shallow and waterlogged surface depressions with vegetation formed mainly by graminoids (only *Cyperaceae*) and *Sphagnum* mosses. Dominating graminoids in herb layer of these bog hollows, hereinafter so-called "carelimo hollows", are *Carex limosa* and *Scheuchzeria palustris*. Moss layer is formed mainly by *Sphagnum majus* or *Warnstorfia fluitans*. This feature is common in still active and well patterned sloping bogs. Similar features with dominating *Carex paupercula* and frequent *Eriophorum angustifolium*, hereinafter so-called "carepaup hollows", were recorded in poor fens.

Mud-bottom hollows: A group of hollows without vegetation or with only liverwort *Gymnocolea inflata* growing on bottom. They were recorded mainly from patterned sloping bogs. Vascular plants are missing. These small and narrow depressions can temporarily dry out during summer.

Table 2. Characteristics of monitored microtopography features.

Microtopography feature	**Abbreviation**	**Relief**	**Wetness**	**Herb dominants**	**Moss dominants**	**Mire type**
Sedge hollow	carelimo hollows	depression	waterlogged	*Carex limosa*	*Sphagnum majus, Drepanocladus fluitans*	Raised bogs
Sedge hollow	carepaup hollows	depression	waterlogged	*Carex paupercula, Eriophorum angustifolium*		Poor fens
Mud-bottom hollow	mud bottom hollows	depression	alternately waterlogged		*Gymnocolea inflata*	Raised bogs
Graminoid lawn	trichcaes lawns	flat	wet	*Trichophorum caespitosum*	*Gymnocolea inflata, Warnstorfia fluitans*	Raised bogs
Graminoid lawn	carerost lawns	flat	waterlogged / wet	*Carex rostrata*	*Sphagnum fallax*	Poor fens
Graminoid lawn	carenigr lawns	flat	wet	*Carex nigra, Carex echinata*	*Sphagnum flexuosum*	Moderately rich fens
Graminoid lawn	eriovagi lawns	flat	wet	*Eriophorum vaginatum*	*Sphagnum fallax, S. magellanicum*	Poor fens; Raised bogs
Low hummock	low hummocks	elevated	drier	*Vaccinium uliginosum*	*Sphagnum russowii*	Raised bogs
High hummock	high hummocks	elevated	drier	*Andromeda polifolia*	*Sphagnum rubellum, S. fuscum*	Raised bogs
Spring	senerivu spring	flat	waterlogged	*Senecio rivularis, Deschampsia caespitosa*	*Sphagnum squarrosum*	Poor fens

Graminoid lawns: Flat and wet or very wet microtopographic features. Graminoids dominate the herb layer. Lawns dominated by *Trichophorum caespitosum*, hereinafter so-called “trichcaes lawns”, are typical for still active and patterned sloping bogs. Their moss layer is often strongly reduced and the liverwort *Gymnocolea inflata* is a typical species of these lawns. Sedge lawns in poor fens, hereinafter so-called “carerost lawns”, are mainly formed by *Carex rostrata*. The other type of lawns, hereinafter so-called “eriovagi lawns”, is dominated by *Eriophorum vaginatum*. Moss layer in poor fen lawns is well developed with prevailing *Sphagnum* species (mostly *Sphagnum fallax* or *S. flexuosum*). Lawns in moderately-rich fens, hereinafter so-called “carenigr lawns”, are commonly represented by a combination of sedges (*Carex nigra*, *C. echinata*, *C. panicea*), *Eriophorum angustifolium* and diverse meadow species like *Potentilla erecta*, *Lychnis flos cuculi* or *Senecio rivularis*. The moss layer consists of peat mosses (50–60%) together with brown mosses. Microtopographic features like hollows or hummocks are commonly missing in the moderately-rich fens and vegetation cover is only formed by lawns.

Low hummocks: Elevated and rather dry features characterized by dwarf ericaceous shrubs dominated by *Vaccinium uliginosum*. They represent the most common microtopographic feature in ombrotrophic bogs. Low hummock topography sections in bogs in the upland area can be covered by shrubs of *Pinus* × *pseudopumilio* which represent later successional stages on drier bog sites. Two main types of shrub formations on bogs were recognized: (i) isolated polycormons of prostrate *Pinus* × *pseudopumilo* growing in the open bog expanse, hereinafter so-called "pinupseu shrubs centr"; and (ii) tall shrubs of the same species on a bog margin, hereinafter so-called "pinupseu shrubs margin".

High hummocks: Relatively massive and firm elevated features that are developed scarcely on well patterned raised bogs in the upland area. *Sphagnum* mosses (*Sphagnum russowii* or *S. rubellum*) create most of the plant biomass. Herb layer is reduced: the more common species are only the ericoids *Andromeda polifolia* or *Oxycoccus palustris*. *Vaccinium uliginosum* is missing or has only low cover.

Another typical microtopographic feature on active raised bogs in the upland area are **bog pools** with permanent standing water. They were not included in our study.

Additionally, small **springs**, hereinafter so-called "senerivu spring", are well developed in some poor fens and characterized by upwelling groundwater. Meadow species, predominantly herbs (e.g. *Senecio rivularis*, *Willemetia stipitata*, *Stellaria alsine*, *Viola*

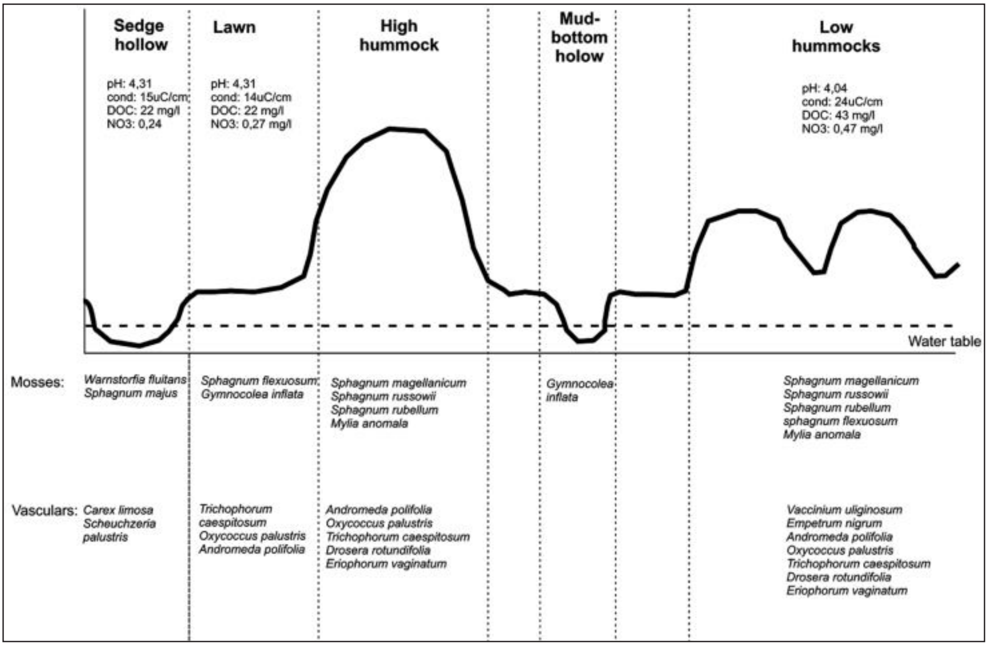


Fig. 2. Scheme of microtopography features on bogs analysed in the study.

palustris, *Deschampsia caespitosa* or *Caltha palustris*), grow only in these small spring patches (only several square metres large) inside of mires. The spring occurring only in FEN1 was included in our monitoring scheme.

Data collection and sampling

Data on the microclimate, water table fluctuation and vegetation composition were recorded between 2005 and 2018.

Data from the regional meteorological station Churáňov (CHUR) are the most usually used to describe the climate conditions in the region of the Šumava NP. However, the station is located on Churáňov hill (1122 m a.s.l., Fig. 1), on the upland's periphery. Records from this station thus inaccurately describe the microclimate conditions in the central upland and inverse valleys, which are the most abundant in mires and where our study sites are located. To improve this situation, we installed four microclimate stations MC–SCHT, MC–SAR, MC-JAV and MC–ZHU in the mires and compared their records from the decade 2009–2018 with the data from the Churáňov station recorded in 1961–2018. The stations monitored the summit and valley positions on both the upland area and its periphery, respectively (Fig. 1, Table 3). Microclimate data, i.e. air temperature and air moisture at levels 0.3 m and 1.2 m above the soil surface, were recorded at ten minute intervals via an automatic climate station (type M4016–G; FIEDLER AMS sro) (Fig. 3b). The microclimate stations MC–ZHU and MC–SCHT also recorded precipitation. Precipitation data relevant for the station MC–SAR were obtained from station MC–JAV which is located in the same valley position at a distance of no more than 1 km. Precipitation data at stations MC–ZHU, MC–SCHT, MC–JAV were collected using a standardized rain gauge (type SR03; FIEDLER AMS s.r.o). This unheated rain gauge allows data collection only from non-freezing periods and therefore only precipitation data from April/May to November were used in our analysis. Winter precipitation data were available only from the heated rain gauge used in the Churáňov station.

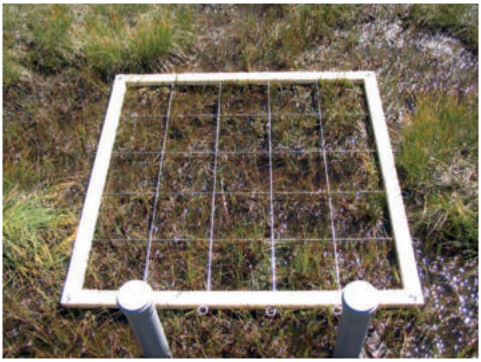


Fig. 3a. Plastic boreholes (code B9) installed for recording of water table position and adjacent vegetation plot in hollow (carelimo hollow) in ombrotrophic bog Blatenská slať (BOG1).

Fig. 3b. Microclimate station MC-SAR installed in BOG2 (Šárecká slať).

Table 3. Basic characteristics of meteorological stations used in study.

Meteostation	Code	Data set	Altitude (m a.s.l.)	Position	Habitat	Location
Churáňov	MC-CHUR	1961–2018	1119	Summit	Forest meadow	Upland periphery
Schachtenfilz	MC-SCHT	2009–2018	1140	Summit	Bog	Central upland
Šárecká slať	MC-SAR	2009–2018	1025	Inversion valley	Bog	Central upland
Javoří Pila	MC-JAV	2009–2018	1020	Inversion valley	Wet grassland	Central upland
Zhůří	MC-ZHU	2009–2018	920	Inversion valley	Fen	Upland periphery

Table 4. Number of water table boreholes and vegetation plots located in various microtopographic-vegetation features.

Microtopographic feature	Microtopographic-vegetation feature (microhabitat)	Blatenská slať	Šarecká slať	Nad Roklanským potokem	Malý Bor	Velký Bor
		BOG1	BOG2	FEN 1	FEN 2	FEN 3
Sedge hollow	carelimo hollow	3				
Mud-bottom hollow	mud-bottom hollow	3				
Graminoid lawn	trichcaes lawn	3	3			
Low hummock	low hummock	3	3			
High hummock	high hummock	3				
Low hummock	pinupseu shrub centr	2				
Low hummock	pinupseu shrub margin	1				
Graminoid lawn	eriovagi lawn			1		
Graminoid lawn	carerost lawn			2	2	
Sedge hollow	carepaup hollow			1		
Spring	senerivu spring			1		
Graminoid lawn	carenigr lawn			1	1	1
Total number of water table boreholes and vegetation plots		**18**	**6**	**6**	**3**	**1**

Climatic data from MC–SCHT are relevant for the mire sites located in the upland summit area (BOG1, FEN1), data from MC–SAR (temperature) and MC–JAV (precipitation) for the mire site in the upland valley (BOG2), and data from MC–ZHU for the sites located in the upland periphery valley (FEN2, FEN3; Table 1).

A set of 36 boreholes for measuring the water table and permanent plots (1×1 m) for monitoring the vegetation (Fig. 3a) covered the variety of all basic types of microhabitats related to specific bog or fen microtopographic features in our study sites (Table 4).

The water table was measured manually at 14 day intervals over the year from spring thaw to autumn frost (usually from the beginning of May to the end of November). The base of the boreholes was fixed on the mire surface by a plastic ring used as a reference surface value for water table measurements.

The cover of all vascular plants and bryophytes in permanent plots was estimated visually and species composition was recorded in percentage cover. Vegetation data were collected between July and September in 2005, 2010 and 2018 (once per year). Nomenclature of vascular plant species and mosses follows KUBÁT et al. (2002) and KUČERA et al. (2012), respectively.

Data analyses

Air temperature and precipitation analyses were based on monthly mean values. Data from stations MC–ZHU, MC–SCHT, MC–JAV were pre-elaborated (removal of incorrect data caused by a technical fault on the sensors) using software MOST (www.fiedler.company). For the meteorological station Churáňov (CHUR), data elaborated by the Czech Hydrometeorological Institute were used. Data gaps were filled in by the Czech Hydrometeorological Institute using standard methods (ratio method combining data from nearby stations, HYNDMAN 2010). Analyses were performed in MS Excel. The dependence of the groundwater table in particular microtopographic features on the sampling year was tested and visualized using linear models (GLM) (MCCULLAGH & NELDER 1989) implemented in R version 2.13.2 (R CORE TEAM 2011). Box-and-Whisker-Plots were used for the graphical presentations of variability of the groundwater table within the vegetation season.

RESULTS

Temperature and precipitation

Long-term data from the meteorological station Churáňov confirmed the observed regional trends in raising air temperatures. Monthly mean temperatures collected at this station for the last five-year period (2014–2018) are, except for autumn, more than 2°C higher than the corresponding long-term averages for the reference period 1961–1990 (Table 5). Ten-year data from the microclimatic stations have revealed growing air temperatures in the Bohemian Forest. Comparison of monthly mean values between the two five-year periods (2009–2013 and 2014–2018) showed considerable higher winter and summer air temperatures in the period 2014–2018 (Table 5). For the winter months (December, January, February), an increase in monthly mean air temperature by more than 2°C was recorded in the microclimatic stations in both the upland area and its periphery (MC–SCHT, MC–SAR and MC–ZHU). For the summer season (June, July, August), an increase in monthly mean air temperature by more than 1°C was recorded at the summit position in the upland area (MC–SCHT). Increases of summer air temperatures in the valley locations, both on the upland area (MC–SAR) and its periphery (MC–ZHU) were less pronounced. More detailed information showing monthly temperature fluctuations between months can be seen in Fig. 4.

Ten-year data from all microclimatic stations also showed a decline in total summer precipitation during 2014–2018 compared to the previous five-year period (Table 5). The biggest difference was found in the summit upland area (MC–SCHT), where there was 200 mm less rain in the summer. The other microclimatic stations and Churáňov station recorded a summer precipitation deficit of about 100 mm compared to the previous five-year period. The same trend was observed by precipitation totals for the entire growing season, with the largest deficit at the two upland stations (MC–SCHT, MC–SAR). By contrast, slightly higher spring precipitation was recorded for the last five-year period at all stations.

Data on winter precipitation were available only for Churáňov. In contrast to the air temperature, comparison of precipitation data from the last two five-year periods at the Churáňov station with long-term averages (for the reference period 1961–1990) did not show a clear trend. Spring precipitation recorded during both five-year periods was only slightly lower compared to the reference period 1961–1990. Summer precipitation was higher in 2009–2013 than the long-term average.

More detailed information showing monthly precipitation fluctuations between months can be found in Fig. 4.

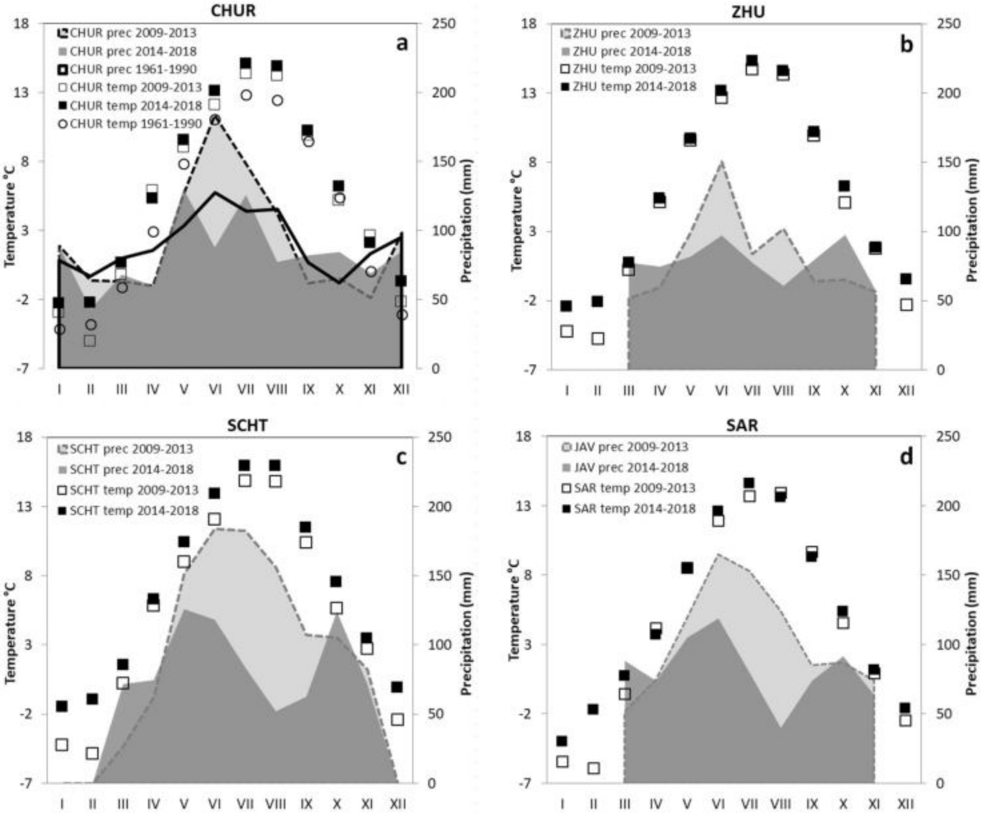


Fig. 4. Monthly mean values of air temperatures and precipitations measured in three microclimate stations and meteorological station Churáňov during two five-year periods (2009–2013, 2014–2018) and reference period 1961–1990.

Table 5. Mean seasonal temperatures and precipitations recorded in three microclimate stations located in mires and in meteorological station Churáňov (CHUR) for two five-year periods (2009–2013, 2014–2018) and reference period 1961–1990 (CHUR only). Data are based on the monthly mean values per distinct seasons: winter (December–February), spring (March–May), summer (June–August), autumn (September–November), growing season (April–August) and vegetation dormancy (September–March).

Station	**CHUR**			**MC-ZHU**		**MC-SCHT**		**MC-SAR**	
Location	PERIPHERY			PERIPHERY		UPLAND		UPLAND	
Position	summit			valley		summit		valley	
Period	1961–1990	2009–2013	2014–2018	2009–2013	2014–2018	2009–2013	2014–2018	2009–2013	2014–2018
Mean month temperature (°C)									
Winter	–3.6	–3.4	–1.7	–3.8	–1.7	–3.9	–0.8	–4.6	–2.4
Spring	3.2	4.9	5.2	5.0	5.3	5.0	5.8	4.4	4.3
Summer	12.1	13.6	14.4	13.9	14.3	13.9	15.3	13.1	13.6
Autumn	5.0	5.9	6.2	5.6	6.1	6.2	7.5	5.0	5.3
Growing season	9.4	11.1	11.6	11.3	11.6	11.3	12.6	10.1	10.6
Vegetation dormancy	0.4	1.0	2.0	0.8	2.0	1.1	3.1	0.1	1.3
Mean of total precipitations per season (mm)	**CHUR**			**MC-ZHU**		**MC-SCHT**		**MC-JAV**	
Winter	241	251	217	*	*	*	*	*	*
Spring	269	250	259	202	234	240	273	245	267
Summer	357	445	291	336	236	523	254	442	238
Autumn	223	179	236	185	235	295	258	247	229
Growing season	546	631	482	495	392	736	454	636	417
Vegetation dormancy	544	494	521	*	*	*	*	*	*

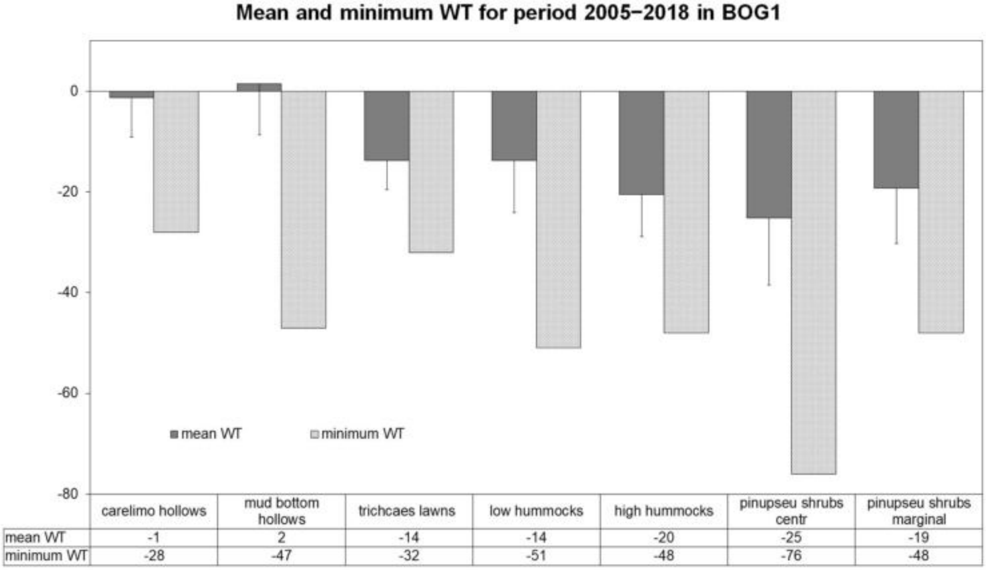
Data on winter precipitation were available only for Churáňov. In contrast to the air temperature, comparison of precipitation data from the last two five-year periods at the Churáňov station with long-term averages (for the reference period 1961–1990) did not show a clear trend. Spring precipitation recorded during both five-year periods was only slightly lower compared to the reference period 1961–1990. Summer precipitation was higher in 2009–2013 than the long-term average.

More detailed information showing monthly precipitation fluctuations between months can be found in Fig. 4.

Water table

Microsite heterogeneity

In the studied sites we found different water table fluctuations in different microsite surface features. Microsite heterogeneity was found more complex in the ombrotrophic bogs than in the fens and the longest set of water table data (recorded in BOG1 since 2005) was used to demonstrate this heterogeneity. In BOG1, mean water table ranged between +2 cm and –25 cm; however, the minimum water table was recorded at –76 cm (Fig. 5). The highest mean water table was recorded in the mud-bottom hollows occupied by the liverwort *Gymnocolea inflata*. On the other hand, the lowest mean water table and deepest drop in water table position was found under the low polycormons of pine shrubs (*Pinus* × *pseudopumilio*) growing in the bog expanse. Sedge hollows (carelimo hollows) and mud-bottom hollows showed similar mean water table values of 1 cm below and 2 cm above the surface, respectively. However, the water table minimum was highly pronounced in the mud-bottom hollows, where it reached almost half a metre under the surface (Fig. 5). Two hummock types differing in their vegetation also differed in the position of their water table and its fluctuation. The mean water table



	carelimo hollows	mud bottom hollows	trichcaes lawns	low hummocks	high hummocks	pinupseu shrubs centr	pinupseu shrubs marginal
mean WT	-1	2	-14	-14	-20	-25	-19
minimum WT	-28	-47	-32	-51	-48	-76	-48

Fig. 5. Mean and minimum water table recorded manually in BOG1 (Blatenská slať) between 2005 and 2018. Carelimo hollows – hollows with *Carex limosa* in bogs; mud bottom hollows – hollows without vascular plants in bogs; trichcaes lawns – lawns with *Trichophorum caespitosum* in bogs; low hummocks – hummocks with *Vaccinium uliginosum* in bogs; high hummocks – hummocks with *Andromeda polifolia* in bogs; pinupseu shrubs centr – prostrate polycormons of *Pinus* × *pseudopumilio* in bog expanse; pinupseu shrubs marginal – tall shrubs of *Pinus* × *pseudopumilio* in bog margin.

below high hummocks formed by predominant mosses and only sparse vascular plants was significantly lower, but much more stable, than that below low hummocks covered by *Vaccinium* dwarf shrubs.

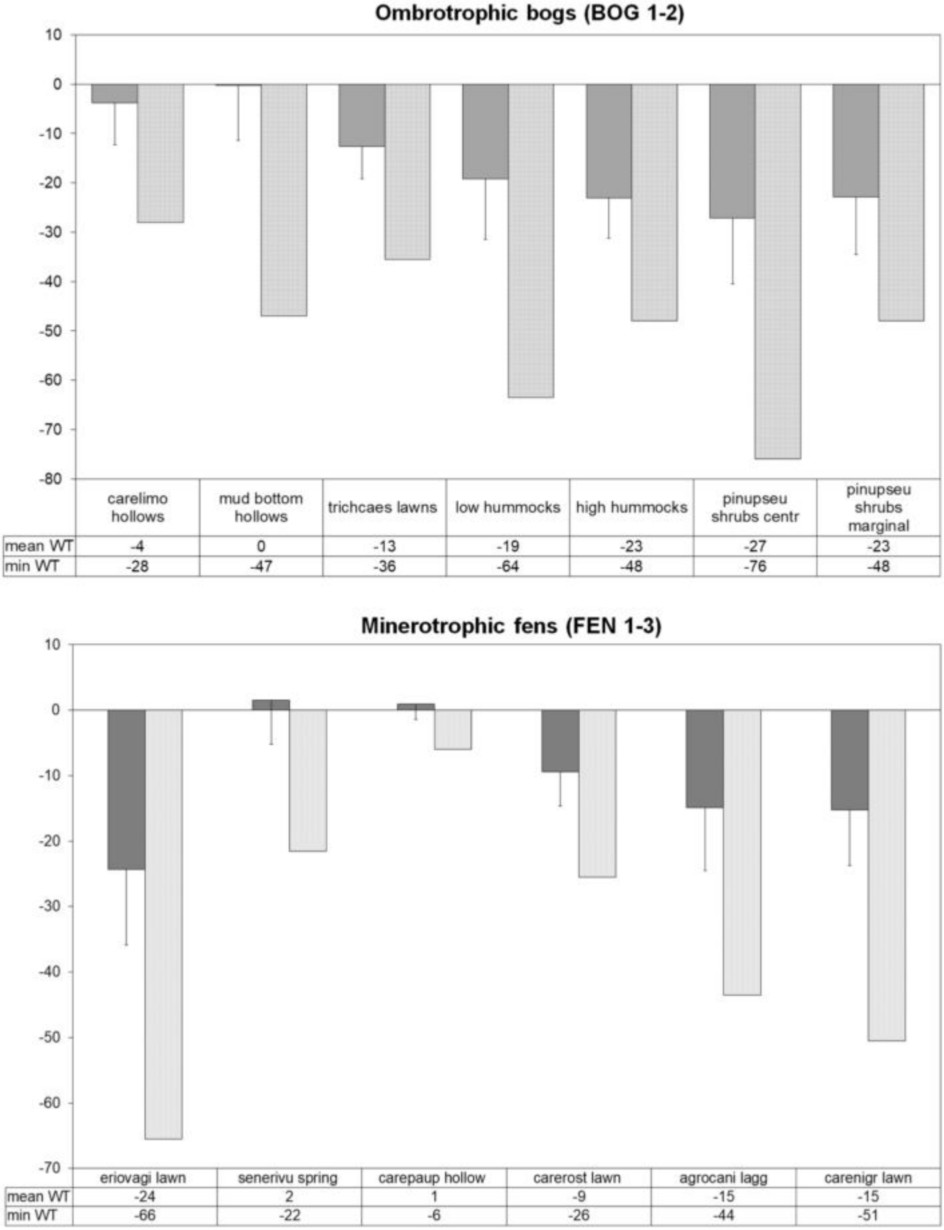
Microsite heterogeneity in minerotrophic mires, formed mainly by graminoid lawns, was generally less diverse. Water table data that was available for all monitored mire sites from the same period (2011–2018) were used for the comparison of ombrotrophic and minerotrophic sites. These data showed that the mean water table in fens was generally maintained at a higher position than in ombrotrophic sites (Fig. 6a,b). The most wet microtopographic features were recorded in poor fens. The highest mean water table (1–2 cm above the surface) was recorded in sedge hollows (carepaupe hollows) and the spring section of poor fens. In carerost lawns, a predominant feature in poor fens, the water table rarely dropped below 10 cm under the surface (Fig. 6b). Only those parts of the fen with a thick peat layer (more than 1 m) covered by eriovagi lawn showed both a mean and minimum water table similar to the situation in ombrotrophic bogs. The mean water table in moderately-rich fens (mostly uniform in microtopographic features), formed mainly by carenigr lawns, was only about 15 cm under the surface. However, the position of the water table was found here to be relatively unstable with the minimum values more than 50 cm below the surface.

Inter-annual changes

The inter-annual variability of the mean water table, recorded during more than a10 year period, also revealed differences between ombro- and minerotrophic mires and among the distinguished microtopographic features. At the ombrotrophic bog Blatenská slať (BOG1), we found a significant decrease of the water table in the following types of microsites and vegetation (Fig. 7): carelimo hollows (p = 0.008); high hummocks (p = 0.006); low hummocks (p = 0.003); and shrubs of *Pinus* × *pseudopumilio* (p = 0.017). A significant decline of the water table (p = 0.002) was also recorded for minerotrophic woody mires represented by the spruce mire *Sphagno-Piceetum* surrounding the Blatenská slať bog. A decrease of the water table in the mud-bottom hollows with *Gymnocolea inflata* was close to a statistical level of significance (p = 0.069) and no-significant changes were found under the trichcaes lawns (p = 0.165).

In the treeless minerotrophic fens supplied by underground water, the observed year-on-year changes in the water table were only moderate and statistically non-significant for almost all microtopographic and vegetation features (Fig. 8). In eriovagi lawns, growing in the parts of poor fens with the deeper peat layers that likely represent a transition to ombrotrophic conditions, the inter-annual changes were more visible and close to statistical significance (p = 0.070). A visible water dropdown beneath all microtopographic features, including those occurring in fens, mirrored the extreme dry and warm conditions in 2015. But only in fens did the mean water table return to a near normal situation during the following years (2016–2018).

Comparison of the mean and minimum water tables between the two studied periods (2009–2013 and 2015–2018) showed generally lower values for the latter period, especially in bogs, and under lawns with *Eriophorum vaginatum* in poor fens, and in richer fens covered by lawns of *Carex nigra* (Table 6).



	carelimo hollows	mud bottom hollows	trichcaes lawns	low hummocks	high hummocks	pinupseu shrubs centr	pinupseu shrubs marginal
mean WT	-4	0	-13	-19	-23	-27	-23
min WT	-28	-47	-36	-64	-48	-76	-48

	eriovagi lawn	senerivu spring	carepaup hollow	carerost lawn	agrocani lagg	carenigr lawn
mean WT	-24	2	1	-9	-15	-15
min WT	-66	-22	-6	-26	-44	-51

Fig. 6. Mean and minimum water table recorded in ombrotrophic raised bogs (BOG 1, BOG2) and minerotrophic fens (FEN 1–3) between 2011 and 2018. Eriovagi lawn – lawns with *Eriophorum vaginatum*; senerivu spring – springs with *Senecio rivularis*; carepaup hollows – hollows with *Carex paupercula*; carerost lawns – lawns with *Carex rostrata*; agrocani lagg – lagg of poor fen with *Agrostis canina*; carenigr lawn – fens with *Carex nigra*. For abbreviations of features in ombrotrophic bog see Fig. 5. For number of boreholes per each type see Table 4.

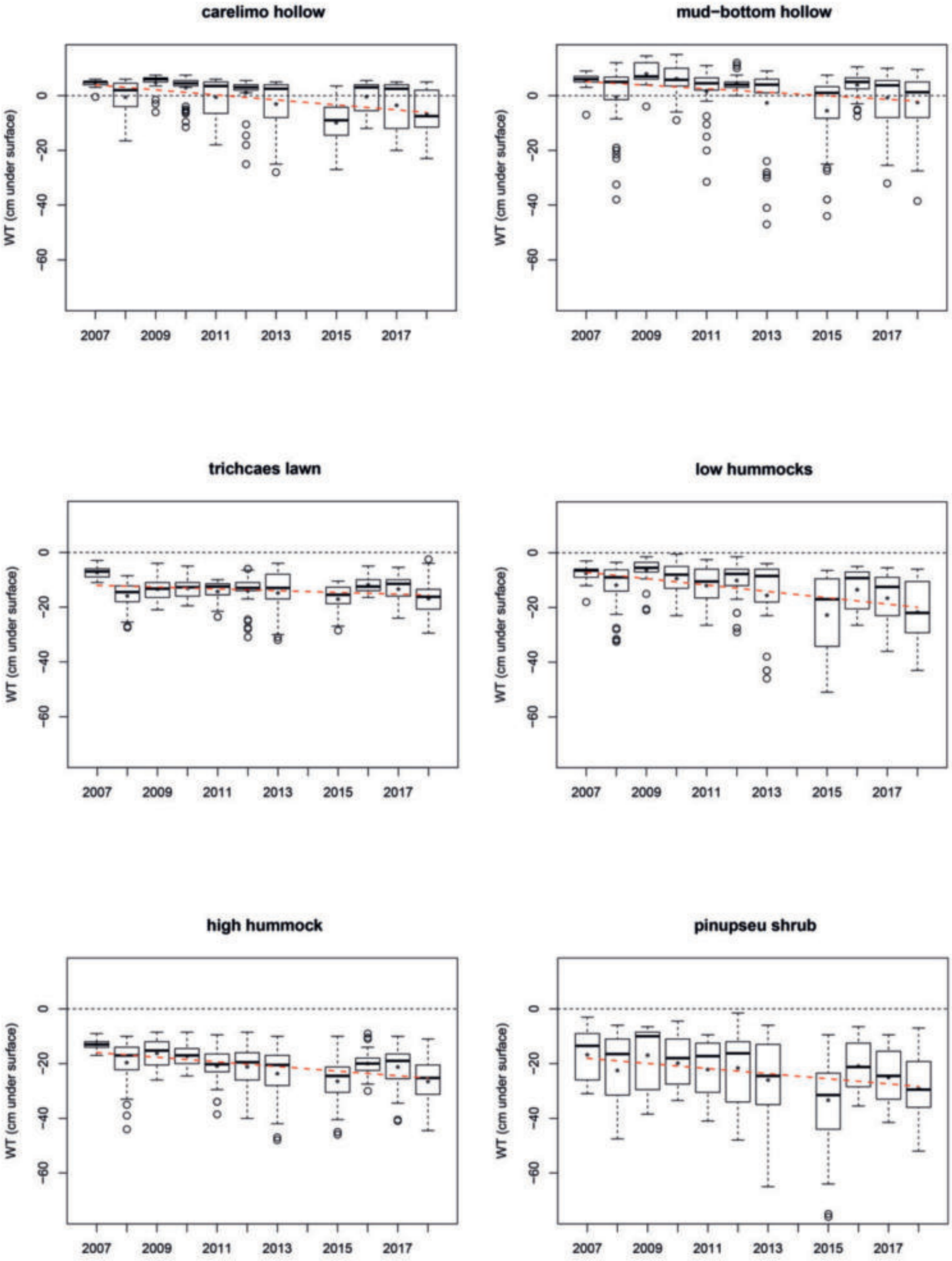


Fig. 7. The inter-annual variability in position of mean water table in BOG1 during the years 2007–2018. For abbreviations of features see Fig. 5.

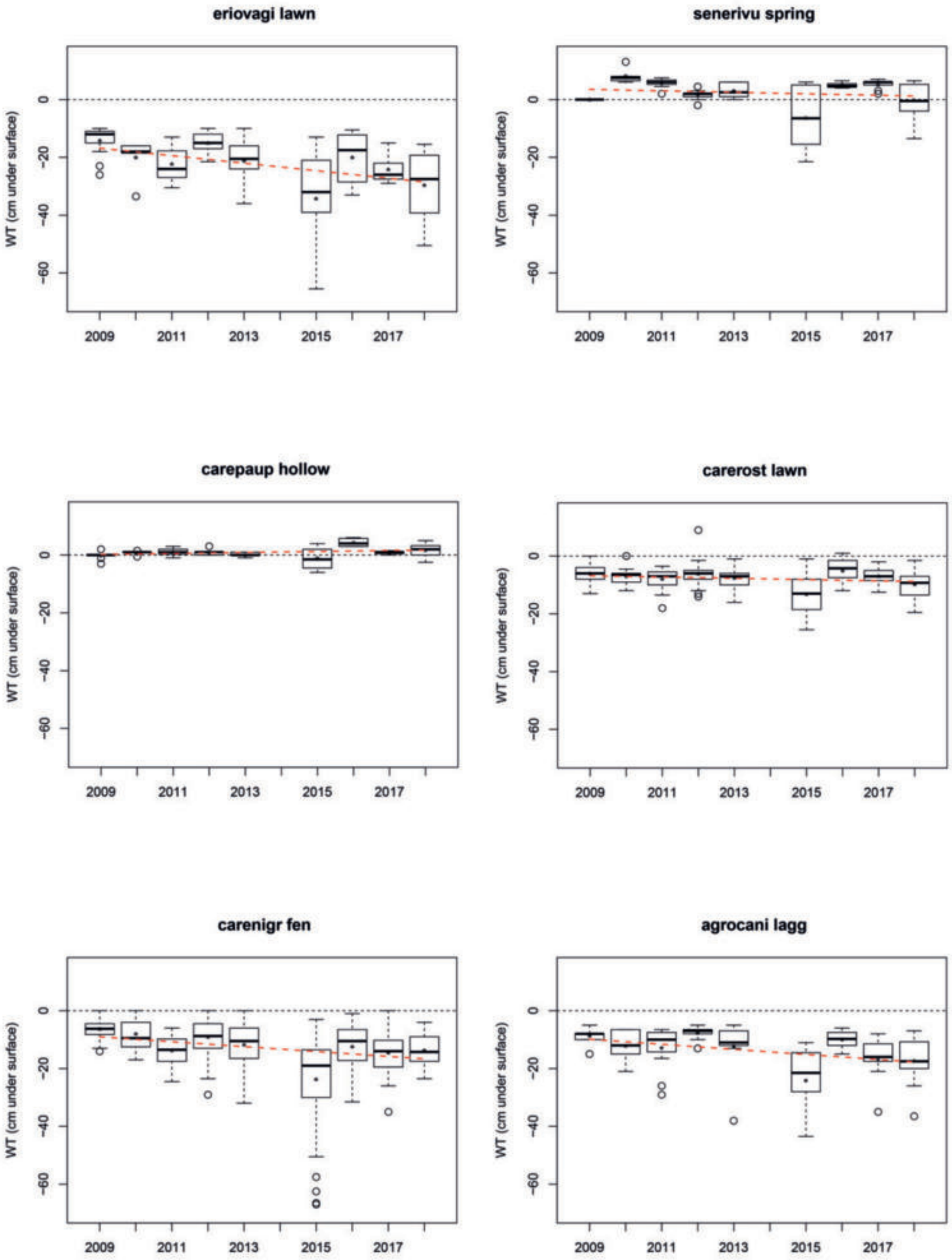


Fig. 8. The inter-annual variability in position of mean water table in minerotrophic fens (FEN 1–3) during the years 2009–2018. For abbreviations of features in fens see Fig. 6.

Table 6. Mean and minimum water table recorded beneath microtopography features in ombrotrophic bogs and fens during two five-year periods (2009–2013, 2014–2018).

Mire site	**BOG1**				**BOG2**			
Period	2009–2013		2015–2018		2011–2013		2015–2018	
Microtopographic-vegetation feature	Mean WT	Min WT	Mean WT	Min WT	Mean WT	Min WT	Mean WT	Min WT
carelimo hollow	1	–13	–6	–17				
mud-bottom hollow	4	–10	–2	–21				
trichcaes lawn	–13	–23	–15	–23	–7	–22	–11	–27
low hummocks	–11	–28	–19	–36	–11	–44	–21	–52
high hummocks	–19	–32	–24	–34				
pine shrubs central	–23	–37	–28	–46				
pine shrubs marginal	–16	–34	–26	–43				

	FEN 1				**FEN 2**				**FEN 3**			
Period	2009–2013		2015–2018		2009–2013		2015–2018		2009–2013		2015–2018	
Microtopographic-vegetation feature	Mean WT	Min WT	Mean WT	Min WT	Mean WT	Min WT	Mean WT	Min WT	Min WT	Min WT	Min WT	Min WT
eriovagi lawn	–18	–30	–28	–45	-	-	-	-	-	-	-	-
senerivu spring	3	1	0	–7	-	-	-	-	-	-	-	-
carepaup hollow	0	–1	1	–1	-	-	-	-	-	-	-	-
carerost lawn	–7	–12	–10	–16	–7	–14	–8	–14	-	-	-	-
carenigr lawn	–11	–23	–18	–33	–10	–17	–13	–19	–10	–17	–21	–35

Vegetation

Sedge hollows

In the ombrotrophic bog BOG1, we found considerable changes in the vegetation of the carelimo hollows during the period 2005–2018 (Fig. 9a). These changes were characterized mainly by a declined cover of moss *Warnstorfia fluitans* from 44% in 2005 to 8% in 2018. As the generally low proportion of *Sphagnum majus* was only slightly reduced, *Warnstorfia fluitans* was mainly responsible for the total reduction of the moss layer in these hollows (Fig. 10a). In addition to this, a considerable decrease of *Carex limosa* from 29% in 2005 to 7% in 2018 was recorded with the highest change already occurring between 2005 and 2010 (Fig. 9a). The low proportion of *Scheuchzeria palustris* (below 5%) remained almost the same throughout the whole survey period. A slightly increasing *Trichophorum caespitosum* cover was responsible for the increasing proportion of herb layer after 2010 (Fig. 10a). In addition to changes in the cover of individual species, a general increase in the total number of species was recorded in sedge hollows. This shift was driven mainly by species adapted to drier conditions or the later successional stages, such as *Oxycoccus palustris*, *Andromeda polifolia*, and *Trichophorum caespitosum*.

Graminoid lawns

In the ombrotrophic bog BOG1, we also found a considerable decrease of *Warnstorfia fluitans* cover in the trichcaes lawns (Fig. 9b). The cover of moss species declining from 68% in 2005 to only 5% in 2018, with the highest change after 2010. However, in this case, the strong reduction of *Warnstorfia fluitans* was compensated by the increasing cover of *Sphagnum majus* and the liverwort *Gymnocolea inflata*, from 0% to 55% and from 3% to 30%, respectively. Thus, in trichcaes lawns, the total cover of the moss layer remained almost the same (80–90%), (Fig. 10b). In addition, the number of species increased, particularly between the years 2005–2010.

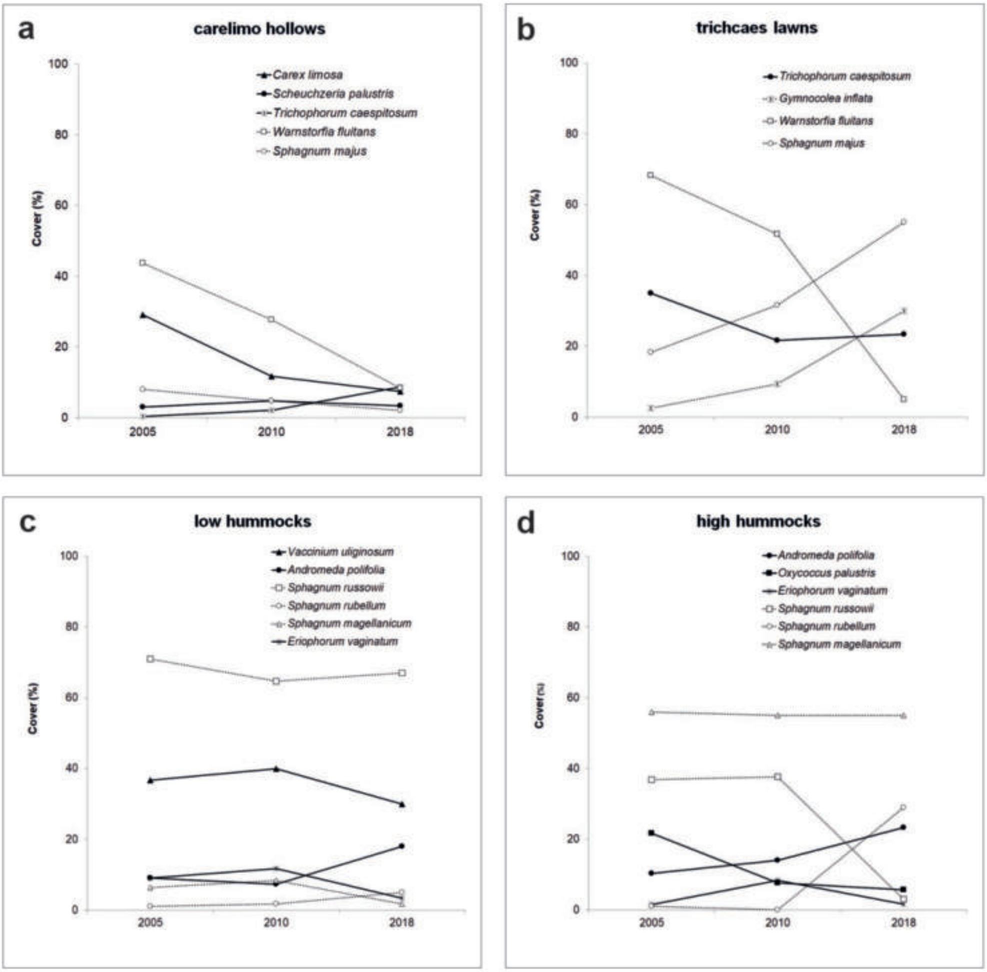


Fig. 9. Changes in cover of selected species in analysed permanent plots in ombrotrophic BOG1 between the years 2005 and 2018.

Low and high hummocks

Compared to sedge hollows and graminoid lawns, the vegetation composition in hummocks seems to be more stable (Fig 9c,d). Only the cover of *Andromeda polifolia* increased both in the low and high hummocks since 2010. In the high hummocks, the total herb layer decreased from 55% to 37% between 2010–2018 (Fig. 10c,d), mainly due to the decreasing cover of *Oxycoccus palustris* and *Eriophorum vaginatum*. No significant changes in total number of species were recorded. A moderate rise in species number in the high hummocks was especially reflected in changes in the moss layer. However, exchanges in the proportions of two *Sphagnum* species (*Sphagnum russowii* and *S. rubellum*) was probably caused by incorrect determination of the *Sphagnum* species in 2005–2010.

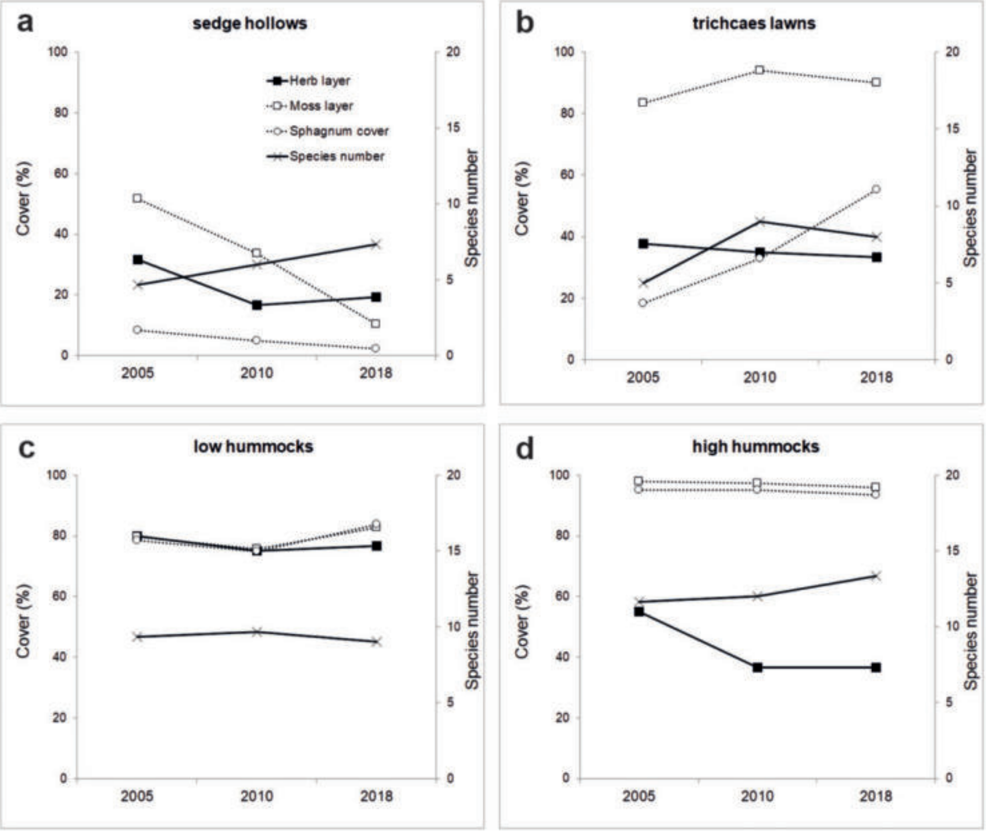


Fig. 10. Changes in main vegetation parameters in analysed permanent plots in ombrotrophic BOG1 between the years 2005 and 2018.

Table 7. Phytocoenological relevés of analysed permanent plots from the site Blatenská slat (BOG1). Vegetation data collected in 2006, 2010 and 2018. Cover of distinct species is given as a percentage.

Code of permanent plot	B1	B1	B1	B7	B7	B7	B9	B9	B9	B4	B4	B4	B11	B11	B11	B2	B2	B2	B6	B6	B6
Year	2005	2010	2018	2005	2010	2018	2005	2010	2018	2005	2010	2018	2005	2010	2018	2005	2010	2018	2005	2010	2018
Species number	5	8	12	5	5	4	4	5	6	1	2	3	1	5	2	7	10	9	4	9	6
E3:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E2:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E1:	40	20	20	35	20	20	20	10	18	0	1	1	0	0.1	4	35	35	30	40	50	45
E0:	20	16	6	80	30	5	55	55	20	45	45	0.5	60	80	0	95	98	95	75	84	90
Carex limosa	35	15	15	35	15	2	17	5	5	.			.			.			.		
Scheuchzeria palustris	5	5	2	1	4	3	3	5	5	.			.			.	0.01	0.1	.	0.1	0.1
Trichophorum caespitosum	.	1	3	1	4	15	.	1	8	.	1	1	.	0.1	2	30	20	30	40	30	20
Carex pauciflora	.			.			.			.			.			.			.		
Drosera rotundifolia	.			.			.			.			.			0.1	0.1		.	0.01	
Oxycoccus palustris	.	0.1	0.1	.			.		0.01	.			.			5	5	3	3	20	25
Andromeda polifolia	.	0.01	0.5	.			.		0.01	.		0.5	.	0.01	2	0.02	0.5	0.1	.		
Eriophorum vaginatum	.			.			.			.			.			.	10	0.01	.	2	
Vaccinium uliginosum	.		3	.			.			.			.			.			.		
Empetrum nigrum	.		0.01	.			.			.			.			.			.		
Pinus x pseudopumilio	.		0.1	.			.			.			.			.			.	1	
Sphagnum majus	20	11	6	2	1		2	2		.			.	20		15	20	70	15	15	60
Wanstorfia fluitans	.			78	30	5	53	53	20	.			.	0.5		80	70	10	65	65	2
Gymnocolea inflata	4	4	0.1	.			.			45	45	0.5	60	60		5	4	10	.	4	30
Sphagnum flexuosum	1	1	0.1	.			.			.			.			.	.	.	.	.	.
Calypogeia sphagnicola	.			.			.			.			.			.			.		
Sphagnum magelanicum	.		1	.			.			.			.			.			.		
Sphagnum russowii	.			.			.			.			.			.	4	1	.		
Sphagnum rubellum	.			.			.			.			.			.			.		
Mylia anomala	.			.			.			.			.			.			.		
Sphagnum tenellum	.			.			.			.			.			.			.		
Straminergon stramineum	.			.			.			.			.			.			.		
Cephalozia conivens																					
Nardia scalaris	.			.			.			.			.			.			.		
Sphagnum angustifolium	.			.			.			.			.			.			.		
Sphagnum fuscum																					

Table 7. Continued.

Code of permanent plot	B10	B10	B10	B3	B3	B3	B5	B5	B5	B8	B8	B8	B12	B12	B12	B13	B13	B13	B14	B14	B14
Year	2005	2010	2018	2005	2010	2018	2005	2010	2018	2005	2010	2018	2005	2010	2018	2005	2010	2018	2005	2010	2018
Species number	4	8	9	12	11	12	11	13	14	12	12	14	9	10	9	9	10	9	10	9	9
E3:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E2:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E1:	38	20	25	40	30	30	60	40	35	65	40	45	80	75	75	85	75	75	75	75	80
E0:	80	100	85	97	96	97	100	99	92	97	97	99	60	52	70	80	80	80	99	95	98
Carex limosa	.			.			.			.			.			.			.		
Scheuchzeria palustris	.		0.1	0.02	0.01	0.01	0.01	0.01		.	0.1	0.1	.			.			.		
Trichophorum caespitosum	35	15	20	10	5	4	25	10	15	30	10	15	15	10	15	35	20	15	20	5	10
Carex pauciflora	.	0.01	1	.		0.01	.			.			.			.			.		
Drosera rotundifolia	.			8	3	0.5	8	2	0.1	.	0.01		.			.			.		
Oxycoccus palustris	5	2	4	10	5	4	30	8	5	25	10	8	0.02	5	0.1	0.01	0.01		0.05	1	0.1
Andromeda polifolia	.	1	1	10	15	30	6	12	15	15	15	25	2	2	4	10	10	10	15	10	40
Eriophorum vaginatum	.	5	0.1	2	5	1	1	15	2	0.1	5	2	20	15	3	4	15	5	3	5	2
Vaccinium uliginosum	.			.			.			.			35	25	30	25	35	40	50	60	20
Empetrum nigrum	.			.			.			.			15	20	30	.			.		0.1
Pinus x pseudopumilio	.			.			.			.			.			.		5	.		
Sphagnum majus	25	60	35	.		0.1	.	1		0.5	0.5	0.1	.			.			.		
Wanstorfia fluitans	60	20	3	1	0.1		4	3	0.1	0.5	0.5	0.01	.			.			.		
Gymnocolea inflata	.	20	50	0.2	0.2		.		0.1	2	2	2	1	1		.			0.5	0.5	
Sphagnum flexuosum	.	.	.	.		1	1	5	3	0.5		5	.		5	.	0.1	18	0.5	0.5	5
Calypogeia sphagnicola	.			.			.	0.1		0.1	0.1		.			.			.		
Sphagnum magelanicum	.			95	95	85	73	70	80	.			.			19	25	5	0.1		
Sphagnum russowii	.			0.5	0.1	5	20	20	3	90	93	1	57	50	40	60	50	60	96	94	3
Sphagnum rubellum	.			.			.		2	3		85	.		25	3	5		.		90
Mylia anomala	.			0.1	1	4	.		0.1	1	1	4	2	2		0.5	0.5	3	2	2	
Sphagnum tenellum	.			.			.			.			.			.			.		
Straminergon stramineum	.			.			.		0.1	.		0.1	.			.			.		
Cephalozia conivens														0.1							
Nardia scalaris	.			0.2			.			.			.			.			.		
Sphagnum angustifolium	.			.			2	1		.			.			.			.		
Sphagnum fuscum									5			5									

Discussion

The trend of rising air temperatures in the Bohemian Forest during the last three decades has already been recorded by several authors (Matějka 2014, Beudert et al. 2018, Bílá et al. 2018, Procházka et al. 2018). Matějka (2014) reported a mean annual temperature increase of 0.046°C per year in Churáňov between 1983 and 2011, with the most significant change in the distribution of precipitation over the year (dry/wet periods) and increase in average temperatures being between 1994 and 1995. According to his analysis, the months of April and June were revealed to have a significant reduction in mean precipitation totals between 1995 and 2011. On the other hand, he also emphasised a rise in episodic and extremely high precipitation and increased annual climate variability. Bílá et al. (2018) also analysed the meteorological data from Churáňov station as well as several other stations both in the mountains and adjacent foothill locations of the Bohemian Forest for the years 1961–2017. They revealed significant rises in temperature in the winter, spring and summer, particularly since the year 2000. They also reported a decline in precipitation and significant negative trends in snow cover since 2000.

Due to their quality and the long time series, the data from Churáňov station are of particular importance for the assessment of the climatic situation and trends in the Bohemian Forest (Vavruška 2002). However, Churáňov's situation is rather in the inner part of the mountains and therefore additional data from more exposed positions on the windward side of the mountains are of high value when evaluating the impacts of climate changes. A much higher increase of temperature in spring and a related acceleration of snow melt in the last five years has been reported, for example, by Procházka et al. (2018) for Březník station (near the border mountain ridge) compared to the data from Churáňov. This corresponds well with our results obtained from Schachtenfilz station (a summit position on the upland area), which also showed a much higher increase in temperatures since 2014, and not only in spring, but also in summer and autumn, compared to Churáňov. Winter temperatures recorded from all our stations have been higher after 2014. The increasing temperature and changes in distribution of precipitation, with more frequent spring and summer droughts, could lead to shifts in water tables in the mires, including large mid-summer declines in water table levels (Hilbert et al. 2000). Among others, this can have an adverse impact on the moisture-loving vegetation of mires, where key peat-forming species (particularly *Sphagnum* mosses) are adapted to extremely wet conditions. As these species are directly responsible for building the mire environment and play an important role in ecological links and processes, any disadvantage due to changing temperature or humidity conditions can lead to significant structural and functional changes in the mires. Interactions between mire species and the feedbacks through and from species may affect abiotic conditions and result in further vegetation changes in the long term (Heijmans et al. 2008). Furthermore, the rising temperature and lowering of the water table will support the aeration of peat layers and can change the type and intensity of microbial activities with subsequent effects on the mire environment and its processes.

In studied mires, we found that the mean water table on the ombrotrophic bog reflected the broken surface microtopography and distribution of distinct features along a moisture gradient from wet and the open bog expanse to more dry and the shrubby bog margin. Hollows, lawns and high hummocks in this pattern have mainly developed on the bog expanse while the low hummocks or their successional stages with *Pinus* shrubs have predominated towards the bog margin. Such a complex pattern had already been recorded on well-preserved and still-active peat bogs in the upland area of Bohemian Forest (SVOBODOVÁ & SOUKUPOVÁ 2000). The mean positions of the water table related to the distinct microtopographic features were consistent with the results of several short-term studies implemented in undisturbed mires in the area (KUČEROVÁ et al. 2009, VICHEROVÁ 2009, VLČEK et al. 2012). VICHEROVÁ 2009 also reported close correlations between water table decreases and the presence of shrub vegetation. That is coincident with our observations of the lowest water table having been recorded beneath prostrate *Pinus* shrubs on the generally wet and open bog expanse. The observed differences in the minimum water table can also reflect the different thickness of the acrotelm layer, which is at its thickest in those microhabitats typical of the drier parts of the moisture gradient (low hummocks and hummock vegetation with an already developed shrub and tree canopy). Another study from the same area but implemented on bogs affected by a long-term lack of water through drainage, also revealed relationships between both the mean and minimum water table and the distinct microtopographic structures (BUFKOVÁ et al. 2010). However, the water table was maintained at lower positions in those sites and the vegetation pattern was much simplified towards drier (and later) successional stages with prevailing low hummocks and shrubby vegetation. The wet-loving hollows had all but disappeared in those drained bogs.

The recorded year-on-year changes in water table levels below the studied microtopographic structures on our sites may suggest a possible connection with the observed increase in air temperature and the changed distribution pattern of precipitation in the mountain region. The question is: Why were these changes not the same for all the microhabitats analysed on the same site (BOG1)? One possible explanation could be the various feedbacks through vegetation and species composition, which can also affect the moisture conditions and water availability (BRIDGHAM et al. 1999, BREEUWER et al. 2008). The structure and properties of the peat layers, which are formed by dead plant remains, as well as the composition of the current vegetation that is forming the given microhabitat could explain these feedbacks. Some authors (e.g. HEIJMANS et al. 2008) have highlighted vegetation changes as one of the important indicators of the response of mire ecosystems to climate change. WELTZIN et al. (2001) expected that the response of peatlands to changing environmental conditions is dictated in part by their topographic heterogeneity which interacts with the hydrology, vegetation, nutrients and gas emissions. EPPINGA et al. (2010) also suggested that future climate change may affect mires by altering vegetation and microtopography patterns and their functions in a redistribution of both water and nutrients within the ecosystem. Such a proportional shift in the pattern of microtopographic features towards more drier types (see above), due to drier and warmer climate conditions, could be similar to that recorded in the drained mires (BUFKOVÁ et al. 2010).

The different hydrological response of ombrotrophic bogs and minerotrophic mires to temperature changes and insufficient water supply has been reported from Austrian peatlands by ESSL et al. (2012). They have stated that climatic changes can affect all types of mires, but ombrotrophic bogs supplied only with rainwater are the most vulnerable. This corresponds well to our finding that the inter-annual decline of the mean water table in two poor fens, which were still well saturated with groundwater, was less prominent than in the rain-fed ombrotrophic bogs. In these poor fens, the reduced water input from precipitation during the vegetation season, and increased water losses through evapotranspiration under raising air temperatures, were probably compensated, at least to some extent, by the upwelling groundwater. Exceptions were those parts of the poor fen with a weaker groundwater supply due to a deeper peat layer (more than 2 m), which represented rather a transitional stage to an ombrotrophic system.

Our studies have revealed some changes in bog vegetation which could be related to the measured inter-annual decrease in the water table and the observed air temperature and precipitations changes. It is well known that the current changing climate could initiate considerable shifts in bog vegetation with potential further impacts to ecological processes in mires (Weltzin et al. 2000, Schultheis et al. 2010, Kapfer et al. 2011, Potvin et al. 2015). Close interaction between different components of climate change (temperature, precipitation, CO_2, nitrogen deposition) and their impacts on mire vegetation were studied by Heijmans et al. (2008). Potvin et al. (2015), for example, have demonstrated the negative effects of a decreased water table on sedges. This corresponds well with our results, which showed the reduced cover of *Carex limosa* in sedge hollows as a likely response to the decline of the water table. On the other hand, other short-term studies have demonstrated increased sedge abundance after a lowering of the water table (Laine et al. 1995, Weltzin et al. 2000). Along with *Carex limosa*, a reduction of the moss *Warnstorfia fluitans* was found both in the hollows and trichcaes lawns of our studied bog. The declining trend in frequency of occurrence of this moss on Swedish peatlands has been also reported by Kapfer et al. 2011. An increase in the total number of species was observed both in the carelimo hollows and trichcaes lawns of the studied bog. Especially in hollows it was due to spreading of more dry-loving species like ericaceous dwarf shrubs (*Oxycoccus palustris*, *Andromeda polifolia*) or cottongrass *Eriophorum vaginatum*. Many authors have reported an increase of ericaceous shrub productivity and abundance as a result of the lowering of water table (Laiho et al. 2003, Breeuwer et al. 2009, Straková et al. 2010). Increases in ericaceous litter could even offset the higher rate of peat decomposition and further promote shrub growth and expansion. Potvin et al. (2015) have also shown that the positive response of shrubs to lower water tables was stronger in the absence of sedges.

CONCLUSION

We can conclude that data recorded from upland microclimate stations show a considerable increase in air temperature, even in the upland part of the Bohemian Forest. Summer and winter air temperatures have particularly increased since 2014. The studied ombrotrophic bogs and minerotrophic fens show a different response to the interannual changes in temperature and precipitation with regard to their water table levels. In the fens, the reduced water supply from precipitation and increased water loss through evapotranspiration could be compensated for by the available upwelling groundwater. Intact fens would thus appear to be less vulnerable to climate change.

On the other hand, a significant decrease of the water table over the last ten years was recorded in almost all the microtopographic features on ombrotrophic bogs, except for the lawns with *Trichophorum caespitosum*. Regarding vegetation changes, considerable reductions were recorded, especially in the cover of species less tolerant to dry conditions (e.g. *Carex limosa* and *Warnstorfia fluitans*). Larger changes in species composition were recorded in the wet microtopographic features (hollows and lawns), while other features with more dry-tolerant species remained more stable.

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