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The Silva Gabreta Project – transboundary cooperation in monitoring of biodiversity and water regime

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Abstract
The Bohemian Forest represents the most extensive continuous forest landscape in central Europe. Two neighbouring national parks (NP), the Bavarian Forest NP in Germany and the Šumava NP in Czechia, protecting the most valuable part of this area have been recognized as an important site for monitoring of effect of climate change on central European biodiversity and ecosystem structure. For long time, a hydrological monitoring program in the Große Ohe headwater catchment and complex monitoring of glacial lakes recently recovering from acidification were flagships of long-term transboundary research in the Bohemian Forest. Recently published results of biodiversity research in the Bavarian Forest NP and experiences with monitoring of mires in the Šumava NP supported a necessity of multidisciplinary and transboundary research. To improve the cooperation of both national parks, optimize methodologies, and coordinate research activities in the region a new Interreg project No. 26 "Silva Gabreta Monitoring – Implementation of transboundary monitoring of biodiversity and water regime" was jointly prepared. The aims and monitoring methodologies of three main project activities are presented in this paper: (i) monitoring of forest biodiversity, (ii) monitoring of mires, and (iii) monitoring of aquatic ecosystems. In addition, we briefly present several supplementary project activities and tasks, such as modelling of mesoclimatic conditions, monitoring of effect of deicing salt, project conference and common database. As well as sampling design, methods and strategies, and brief overview of the preliminary results are mentioned.

Key words: monitoring, biodiversity, water regime, mires, transboundary cooperation, forest management

Introduction

Recent trends in ecology emphasize both the dynamics and nonequilibrium nature of ecological systems (Shiel & Burslem 2003). Past decades have shown that large-scale natural disturbances, such as windthrows, fires, or insect outbreaks, can significantly moderate spatial and temporal processes in European forests, and even in central Europe (Niklasson et al. 2010). Increasing frequency of disturbance events have stimulated research focusing on effects of disturbance and post-disturbance forest management on biodiversity of central European mountain ecosystems.

Most recent studies have focused on the causes and consequences of natural disturbances in European temperate forests (e.g. Müller et al. 2008, 2010, Bässler & Müller 2010, Fischer & Fischer 2012, Svoboda et al. 2012) significantly contributing to our understanding of natural forest ecosystem dynamics. Numerous authors reported that traditional post-disturbance management and removal of large quantities of biological legacies (e.g. salvage cuttings) could have negative impacts on many species too (e.g. Thorn et al. 2017, Lindenmayer et al. 2017). Cavity-nesting birds and mammals, invertebrates, fungi and other taxa depending on dead wood, mosses and lichens closely associated with fallen logs are threatened with salvage logging (Hagan & Grove 1999, Martin & Eadie 1999, Nilsson et al. 2001). Research on this topic has been conducted also in the Bavarian Forest NP (BFNP) within the Biodiversity and Climate Change Project (BIOKLIM; Müller et al. 2007, 2008, 2010, Moning & Müller 2009, Bässler et al. 2010, Raabe et al. 2010).

The BIOKLIM Project was established in the BFNP in 2006 to contribute to the knowledge of expected effects of climate change on these low mountain range forest ecosystems (Bässler et al. 2008). Its fundamental objective was to quantify the dependency of various taxa on the environmental drivers affecting their local distribution. The project results confirmed that, together with the altitude, also large-scale disturbances (both windstorms and bark-beetle outbreaks) are the important drivers of biodiversity for many taxa (Bässler et al. 2010, Moning & Müller 2008, Müller et al. 2008, 2010, Raabe et al. 2010, Röder et al. 2010). The unique BIOKLIM research project focused only on biodiversity of forest ecosystems, the dominant habitat of the Bohemian Forest. The mires, however, the second most important habitat in this area, were not included notwithstanding that central European peat bogs, which originated during the Late Glacial and early Holocene, are supposed to be stable ecosystems that became hot spots of unique biological diversity, especially in mountainous areas (Spitzer & Danks 2006). Scattered distribution of these island-like habitats resulted from the changes in biota during the Pleistocene climatic oscillations (Tallis 1991). The mires as well as montane spruce forests are examples of the habitats occurring far south of their main boreal biome distributions (Dierssen & Dierssen 2001). They recently survive in the coldest, and usually the most remote, parts of central European mountains. The vulnerability of these habitat islands to climatic changes has got an increasing concern, but sensitivity of their communities to disturbances is less understood (Weltzin et al. 2000). Little is known whether mires and waterlogged forests (spruce mires) can serve as biodiversity refugia or sources of colonisers for the surrounding disturbed forest habitats. Together with mires, also catchments of mountain streams and glacial lakes were recognized as very important model ecosystems for research of the effects of natural disturbances and climate changes in central European forest ecosystems (Oulehle et al. 2013, 2018, Vrba et al. 2014, Beudert & Gietl 2015, Beudert et al. 2015, 2018, Kopáček et al. 2017). Long-term data were used as an important data source in many of these papers.

For long time, a hydrological monitoring program in the Große Ohe headwater catchment in the BFNP (Beudert & Gietl 2015) and complex monitoring of Czech and Bavarian glacial lakes recently recovering from acidification (Vrba et al. 2015, 2016) were flagships of long-term transboundary research in the Bohemian Forest (Heurich et al. 2010). Recently published valuable results of a hydrological monitoring program in the Große Ohe headwater catchment (Beudert et al. 2015, 2018) and glacial lakes research (e.g. Kopáček et al. 2017, 2018a,b, Vrba et al. 2014, 2016, Oulehle et al. 2018) have shown importance of long-term monitoring and transboundary cooperation. Results of biodiversity research in the BFNP (Bässler et al. 2015) and experiences with monitoring of mires in the Šumava National Park (ŠNP; Bufková et al. 2010) also supported a necessity of multidisciplinary and transboundary research delivering a detailed description of local biodiversity and environmental conditions in either "traditional" or "new" habitats established due to disturbance impacts. To improve the cooperation of the BFNP and ŠNP, optimize methodologies, and coordinate research activities, common Czech Republic–Bavaria Interreg project called "Silva Gabreta– monitoring of mountain ecosystems" (project No. 368) has started in January 2015 (Křenová & Seifert 2015). The outcomes of this project enabled the implementation the proposed monitoring activities within a following three-year project. The Interreg V project No. 26 "Silva Gabreta Monitoring – Implementation of transboundary monitoring of biodiversity and water regime" was jointly prepared and later successfully granted by the Cross-border cooperation programme Czech Republic–Bavaria Free State ETC goal 2014–2020. Together with BFNP, as a leading partner, also three Czech partners, the ŠNP, the Masaryk University in Brno and the Czech Agriculture University in Prague, as well as the Senckenberg Institute from Germany have been involved in this three-year project started in April 2016.

The main aim of this paper is to introduce the jointly prepared project No. 26 "Silva Gabreta Monitoring – Implementation of transboundary monitoring of biodiversity and water regime" that included three main project activities: (i) monitoring of forest biodiversity, (ii) monitoring of mires, and (iii) monitoring of aquatic ecosystems; and several supplementary activities, for example modelling of mesoclimatic conditions and monitoring of effect of deicing salt.

Study area, monitoring design and methods

The Bohemian Forest represents the most extensive continuous forest landscape in central Europe. Valuable near natural habitats of mountain old-growth forests, mires, secondary grasslands, glacial lakes, and streams in the trilateral border region of the Czech Republic, Bavaria, and Upper Austria host unique and diverse plant and animal communities. Therefore, this area is an important part of the Natura 2000 network, established to protect the most endangered habitats and species in Europe, as defined in the Habitats Directive (1992) and Birds Directive (1979). The centre of this area is protected as the Bavarian Forest National Park (BFNP, 242 km^2) and the Šumava National Park (ŠNP, 680 km^2) with the Šumava Protected Landscape Area (Šumava PLA, 1000 km^2) serving as their buffer zone (Fig. 1). Local ecosystems have been affected by acid depositions in the past decades (Vrba et al. 2003, Šantrůčková et al. 2007) as well as by ongoing climate changes. Indeed, an annual mean temperature has increased in the Bohemian Forest during the past half a century by more than 1°C (Kettle et al. 2003, Turek et al. 2014).

The forests, mainly mountain spruce and mixed forests, cover more than 85 % of this territory. Large areas of these forests have been subjected to significant natural disturbances in a few last decades (Müller et al. 2008, Fischer & Fischer 2012, Svoboda et al. 2012). As a result, the Bohemian Forest is characterized by the diverse mosaic of old-growth forests, windthrow areas, forests impacted by bark beetle, and areas influenced by traditional forestry in the past. Furthermore, the mires are the most valuable and the most sensitive habitats of the Bohemian Forest (Schreiber 1924, Spitzer & Bufková 2008). Their vegetation types range from the typical ombrotrophic dome-shaped raised bogs to minerotrophic forested or treeless fens, which are often surrounded by spruce mire or birch forest on peaty soils (Rösch 2000, Svobodová et al. 2002, Konvalinková & Prach 2002, Bastl et al. 2008, Bufková et al. 2010). More than 70% of mires and spruce mires in this transboundary region have been influenced by drainage for forest and agriculture management, and peat extraction in the past (Bufková et al. 2010). Since 1999, a comprehensive "Mire Restoration Program" improving the hydrology regime in disturbed mires has been implemented in the ŠNP (Bufková et al. 2010, Bufková 2012). Restoration measures have been implemented also in the BFNP (Jehl 1994, Strunz 1994, Englmaier 2009). In the ŠNP, selected drained and intact mires have been monitored since 2004 aiming to characterize the degradation changes induced by the hydrology disturbation and evaluate the success of restoration (Bufková et al. 2010). In the BFNP, no detail monitoring of mires has been commenced until now.

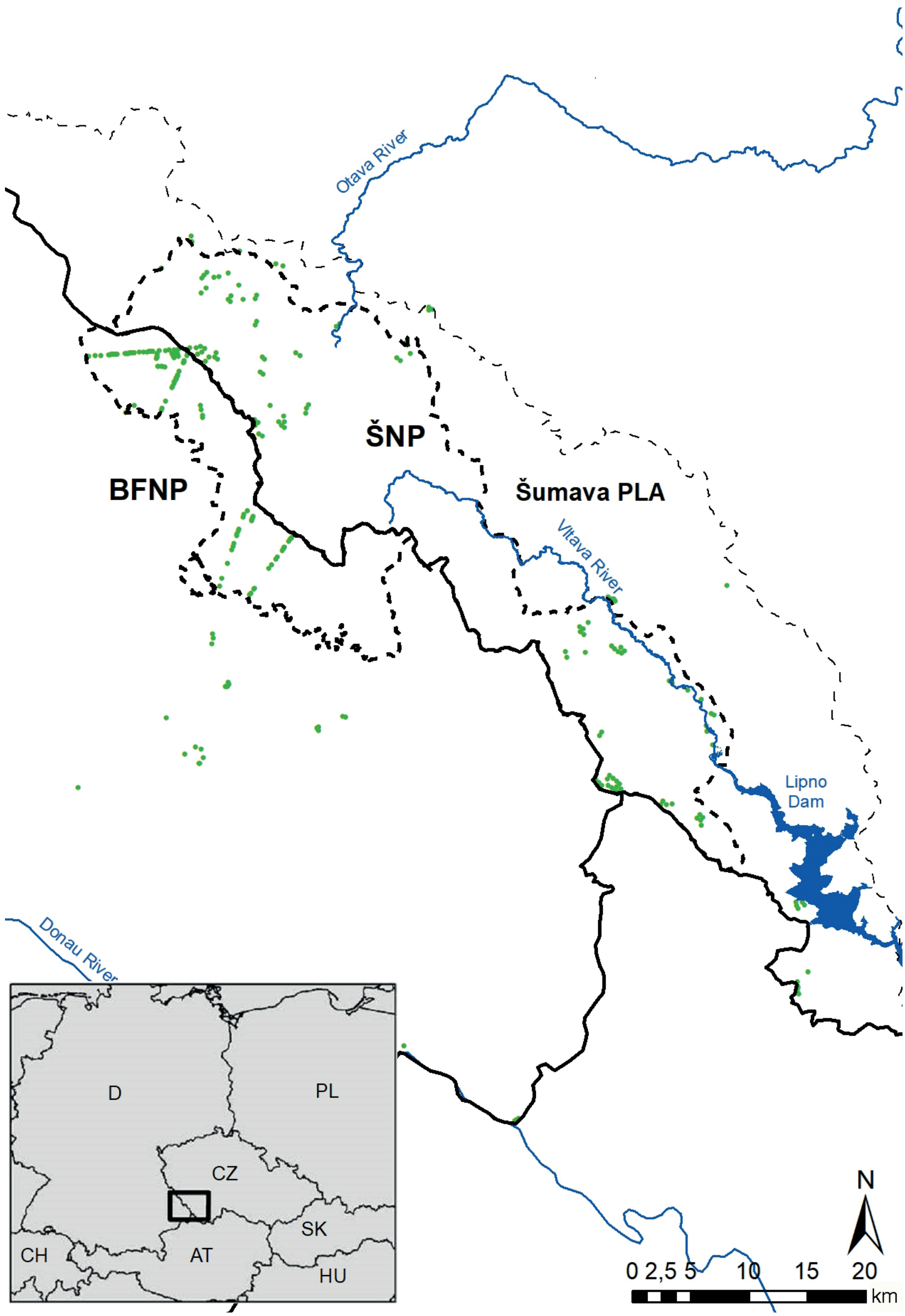

Fig. 1. Map of 157 and 120 plots (green points) in Bavaria and Czechia, respectively, where monitoring of forest biodiversity was conducted in the Interreg project No. 26 "Silva Gabreta Monitoring – Implementation of transboundary monitoring of biodiversity and water regime". Dashed lines are borders of the Bavarian Forest National Park (BFNP), Šumava National Park (ŠNP) and Šumava Protected Landscape Area (Šumava PLA).

Unlike the newly initiated monitoring of mires in the BFNP, hydrological monitoring of the Grosse Ohe catchment has a very long and successful history. The Große Ohe headwater catchment is 19.1 km² in size and its altitudinal range is from 770 m to 1453 m a.s.l. (Großer Rachel Mt.). It is 98% forested, with spruce (70%) and European beech being the dominant species (Beudert & Gietl 2015). The Große Ohe headwater catchment monitoring programme started in 1977 and the main aim of the program was to document and investigate the changes in water cycling during, and due to, the transition from commercial to near-natural forest under the strict protection and non-intervention policy (Beudert & Gietl 2015, Beudert et al. 2018). These objectives required truly long-term observation of physical-chemical parameters and of biotic components of ecosystems showing environmental changes: meteorological parameters and pollutants in ambient air (SO_2, NO_x and O_3), water and element cycles in beech and spruce stands and at the catchment level, vitality and growth of single trees, forest stands and understorey vegetation, and recovery of brown trout.

No stream catchment monitoring has been conducted in the Czech part of the region, but long-term monitoring of glacial lakes, including their catchments, has also delivered very important knowledge about ecosystem changes. The Bohemian Forest has been among the most acidified lake districts in the world (Kopáček et al. 2015, Vrba et al. 2015). Historical data (available since 1871) and regular monitoring (since 1984) on both water chemistry and aquatic biota provide a valuable background for the long-term ecological research of the catchment–lake ecosystems that currently focuses on (i) chemical reversal and biological recovery of the lakes, (ii) acidification effects on in-lake nutrient cycling, (iii) climatic effects on water chemistry, and (iv) catchment processes, including soil biogeochemistry and acidification impacts on vegetation (mountain spruce forests). Recently published papers (e.g. Vrba et al. 2014, 2016, Kopáček et al. 2015, 2017, 2018a,b, Seedre et al. 2015, Oulehle et al. 2018) well documented successful recovery of these glacial lakes ecosystems from acidification both on hydrochemical and biological levels. Long-term monitoring of glacial lakes and hydrological monitoring of the Große Ohe headwater catchment deliver unique knowledge; however, only little has been known about hydrobiology of streams and other aquatic ecosystems in the Bohemian Forest until now.

It was obvious that in the time of climatic changes, including increasing frequency of natural disturbances, more intensive and better coordinated common monitoring of biodiversity changes and water regime are crucial for responsible management of protected areas in transboundary region. More details on the monitoring of forest biodiversity, mires, and aquatic ecosystems follow bellow.

Monitoring of forest biodiversity

The Bohemian Forest provides a wide elevation gradient from ca. 300 to 1456 m a.s.l. (Grosser Arber Mt.) and a mosaic of forests of different structure and age resulted from different forestry management (managed/unmanaged) and natural disturbances (forest dieback caused by bark-beetle infestation and/or wind storms) in the past. The biodiversity data from a set of study sites distributed in different forest types (old-grown forests, windblown sites, post bark beetle sites etc.) along the elevational gradient enable us to evaluate the impacts of natural disturbances and climate changes on species and functional diversity and composition of biotic communities.

The monitoring aims to describe the biodiversity of 17 groups of flora and fauna along the gradients of elevation and forest structure using jointly developed design based on the BIOKLIM project (Bässler et al. 2015). The obtained data are fully comparable with the initial BIOKLIM data collected in the BFNP in 2006 (Friess et al. 2018) and the study area has recently been extended to the ŠNP.

Table 1. Taxonomic groups, size of their study area, and sampling methods used for monitoring of biodiversity in the Interreg project No. 26 "Silva Gabreta Monitoring – Implementation of transboundary monitoring of biodiversity and water regime".

Taxonomic group	**Study area**			**Sampling**
	0.02 ha	0.1 ha	1 ha	
Aculeata	x			Malaise trap
Arachnida	x			pitfall trap
Aves			x	grid mapping
Chiroptera		x		sound mapping
Cicadina	x			Malaise trap
Coleoptera	x			Malaise, flight interception and pitfall trap
Collembola	x			pitfall trap
Formicidae	x			pitfall and flight interception trap
Fungi		x		mapping
Heteroptera	x			Malaise, flight interception and pitfall trap
Lepidoptera		x		light traps
Lichen	x			mapping
Mammalia	x			camera traps
Mollusca	x			hand collecting
Bryophyta	x			mapping
Neuroptera	x			Malaise traps
Opiliones	x			pitfall traps
Symphyta	x			Malaise traps
Syrphidae	x			Malaise traps
Tracheophyta	x			mapping

In the BFNP, an optimized set of 157 study sites (121 in the national park and 36 in the surrounding area) were selected for the transboundary monitoring network. Thirty-six sites outside the national park were included to extend the elevation gradient to the Danube valley, i.e. from 1420 to 287 m a.s.l. (Fig. 1; for more details, see Friess et al. 2018). The study sites were distributed in elevational transects covering complete forest structural gradient including old-growth forests, areas impacted by bark beetle, and areas influenced by traditional forestry in the past.

In the Czech Republic, the forest biodiversity monitoring was conducted at 120 study sites (95 sites in the ŠNP and 25 sites in the Šumava PLA) selected from the set of the Biomonitoring project plots studied to evaluate long term changes in forest structure in non-intervention zones of the ŠNP (Čížková et al. 2011). Twenty-five sites located in nature reservations in the Šumava PLA were included to extend the elevation gradient. The study sites were grouped in two groups (Fig. 1). The first group of sites situated in the western part of the ŠNP represented the elevational gradient from the north foothill of the Bohemian Forest (the lowest elevation of 605 m a.s.l. in the Otava River valley) over the high-mountain plateau to the highest area on the border with Germany (Plesná Mt., 1332 m a.s.l.). The second group of plots was situated in the southern part of the ŠNP ranging from the Lipno reservoir (the lowest elevation of 688 m a.s.l. in the Jasánky Nature Reserve) to the main border range (Trojmezná Mt., 1340 m a.s.l.). The additional set of 30 sites was located in naturally treeless areas (mountain plains, mire meadows, *Nardus* meadows, and heathlands – all Natura 2000 habitats) in the ŠNP.

Unified protocols were used for monitoring of all taxonomic groups in both national parks. Sampling of vegetation (flowering plants, ferns, mosses and lichens), fungi, birds, snails, beetles, bugs, spiders and other insects (see Table 1 for the list of studied groups) were conducted at all study sites (for more details, also see Friess et al. 2018). Field work was conducted in seasons 2016 and 2017 and determination and data analysis continued in 2018 and 2019. The same methodology for monitoring of biodiversity in forests and natural tree-less areas in the ŠNP were used.

Four types of insect traps (Malaise, flight interception, pitfall, and light traps) were used to collect invertebrates and the following taxa from insect traps were determined: Arachnida, Opiliones, Cicadina, Collembola, Syrphidae, Heteroptera, Coleoptera, Diptera, Aculeata, Symphyta. All 157 sites in Bavaria and 150 sites in Czechia (120 forest sites and 30 tree-less sites) were equipped with flight interception and pitfall traps. Additionally, a high-informative subset of 52 sites in the BFNP or 50 forest sites in the ŠNP were selected and stratified for altitude and forest structure. The high-informative sites were continuously (from May to September) equipped with Malaise traps and once per month with light traps, which helped to record moths in night surveys. Light traps were placed at a height about 2 m, in relative open spots and used in nights without rain or strong wind.

In addition, batcorders (www.ecoobs.com) were established in these high-informative plots in the BFNP. Bat calls were recorded from May to September 2016 in all night surveys (approximately 1 hour prior sunset to 1 hour past sunrise) using automated recording devices. The batcorders were placed on wooden poles at a height of 2.5 meters above ground with the microphone facing 30° upwards in order to prevent water from accumulating at the tip of the microphone. At each site a relatively open spot was chosen for the location of the pole in order to reduce sound attenuation by dense vegetation. Survey nights with temperatures below 0°C and with a high rainfall probability were avoided as bat activity is usually reduced under these conditions (Grindal et al. 1992).

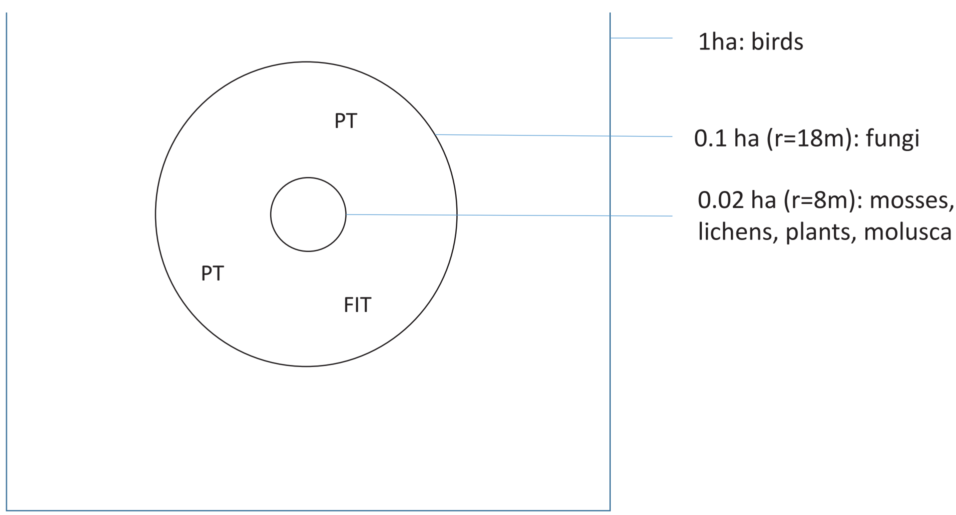

Fig. 2. Study plot diagram. Monitoring of different taxonomic groups was carried out at the plots of different size (see Table 1). One flight interception trap (FIT) and two pitfall traps (PT) were installed in all plots; Malaise traps, light traps, batcoders, and camera traps were used at a high-informative subset of 52 plots in the Bavarian Forest NP and 50 plots in the Šumava NP and PLA.

Table 2. Environmental parameters of biodiversity monitoring plots and types of their measurement.

Variables	Definition	Measurement
General information		
Geographic coordinates	coordinates according to WGS84 and ETRS	GIS model
Altitude	elevation in meters a.s.l.	
Exposition	degree	
Slope	degree	
Radiation	potential sum in the growing season (kWh/m^2)	
Climate parameters		
Temperature	annual mean temperature	GIS model
Precipitation	annual mean precipitation	
Radiation	annual mean radiation	
LiDAR data	penetration rates in different heights	airborne Laserscanner
Forest structure		
Breast height diameter	tree diameter in 1.3 m height	measurement
Tree height	in meter	measurement
Tree vitality	living or dead	estimation
Length of deadwood	in meter	measurement
Type of deadwood	standing or lying	estimation
E_{total}: total canopy cover	sample area shaded by horizontal projection of tree layer separated for occurring tree species in %	estimation
E_{3H}: high tree layer (>15 m) cover and height	% or meter	estimation
E_{3L}: lower tree layer (<15 m) cover and height	% or meter	estimation
E_2:shrub layer cover and height	% or meter	estimation
E_{1H}: herb layer cover and height	% or meter	estimation
E_{1G}: grass layer cover and height	% or meter	estimation
E_0: crypto layer cover and height	% or meter	estimation
Stone cover	%	estimation
Deadwood cover	%	estimation
Litter cover	%	estimation
Open water area cover	%	estimation
Soil		
Soil type	physical description	estimation
Moisture index	calculated	calculation
pH	for humus layer and mineral layer	lab analysis
Exchangeable nutrient elements	H, Al, Ca, Fe, K, Mg, Mn, Na	lab analysis
Cation exchange capacity		lab analysis
Base saturation		lab analysis
C/N ratio		lab analysis

Monitoring of different taxonomic groups was performed on plots of different sizes at each site (Fig. 3). Molluscs were recorded by hand collecting at suitable substrates (leaf litter, under stones, at dead wood etc.) in a single survey at 0.02-ha plots. In the field mainly macroscopic determination was conducted, partly microscopic determination was necessary with section in the lab.

All mosses, lichens (at 0.02-ha plots) and fungi (at 0.1-ha plots) species on available substrates were recorded and the available substrate types up to a height of 2 m were listed. Tree species, level of decomposition and diameter, as well as length for dead wood were measured too. If several substrates of one type were available, one per each type was recorded. If available substrates in the plot were very similar, usually three ones per each type were recorded. Partly microscopic determination was necessary with section in lab too. Vascular plants were recorded in a single survey at 0.02-ha plots in May–September. Vernal geophytes are negligible in this area due to the short growing season and the absence of rich soils. The survey was focused on the vascular understorey vegetation (including ferns) up to 1 m in height, which was estimated visually in percentage cover or on a modified scale by Londo (1976). Species and their cover were estimated in all vegetation layers. Also the type and coverage of overlay was noted.

Birds were recorded at 1-ha plots by means of quantitative grid mapping (cf. Bibby et al. 2000, Moning & Müller 2008) at all plots. All acoustic and visual detectable breeding birds were recorded. Bird calls listening started with one minute at the edge of each plot to detect also birds that are sensitive to disturbances. Then listening went on in the plot centre for eight minutes. In the end, listening were finished with one minute at the other edge to distinguish between birds inside and outside the plot and thus to correct error detections from the centre. For each individual the specific behaviour was noted (simple detection by sighting or calling, territorial-indicating or breed-indicating young birds or food-carrying old birds). Due to phenological differences in occurrence bird mapping was repeated five times, i.e. in the end of March, in the middle of April, in the beginning and the end of Mai and in the beginning of June (Müller 2005, Moning & Müller 2008). Mapping was conducted from sun rise till 11 a.m. under good weather conditions, i.e. hardly wind, no rain, preferably sun (Moning & Müller 2008; Müller 2005). To minimize process-depended errors each plot was mapped to different hours in the morning and at least ones from each of three mapping persons. Additionally, camera traps were installed in high-informative plots to record vertebrates passing or occurring there.

Furthermore, different environmental parameters were recorded and soil samples were taken and analysed (Table 2). Forest structure was investigated at biodiversity study sites both in the BFNP (Hilmers et al. 2018) and in the ŠNP and Šumava PLA, where the methodology of the Biomonitoring project was used (Zenáhlíková et al. 2015). In addition, a dendrochronology analysis was conducted to estimate the age of trees at the sites and a study of mesoclimatic conditions (Romportl et al. 2018) delivered useful background for interpretation of biodiversity monitoring.

Monitoring of mires

The transboundary monitoring of mires aims to evaluate the water level balance, hydrochemistry and vegetation in drained, restored, and near-natural mires of different elevation. The study has mainly focused on the evaluation of the effects of climate changes and applied conservation measurements, particularly water regime restoration, on water regime of mires. Within the project No. 26 "Silva Gabreta – Monitoring of biodiversity and water regime", long-term monitoring of mires was optimized in the ŠNP and newly established in the BFNP. Currently, altogether 12 mires in the ŠNP and Šumava PLA and 9 mires in Bavaria (6 in the

Fig. 3. Map of mires monitoring sites (blue points) where monitoring was conducted in the Interreg project No. 26 "Silva Gabreta Monitoring – Implementation of transboundary monitoring of biodiversity and water regime". Dashed lines are borders of the Bavarian Forest National Park (BFNP), Šumava National Park (ŠNP) and Šumava Protected Landscape Area (Šumava PLA).

Table 3. Monitoring design for jointly implemented monitoring of mires in the Šumava NP. C – control intact mire, R – restored mire; Alt – altitude (m a.s.l.), Wtb – water table in boreholes, Hch – Hydrochemistry, McA – microclimate air, McS – microclimate soil, Rof – run off, Pre – precipitation, Veg – vegetation monitored on permanent plots.

Type of mire	Site	Alt (m)	Measures						
			Wtb	Hch	McA	McS	Rof	Pre	Veg
Ombrotrophic mires									
High raised bog (C)	Blatenská slať	1250	18	x				1	18
High raised bog (C)	Šárecká slať	1020	6	x	1	1		1	6
High raised bog (R)	Schachtenfiz	1140	21	x	1	1	1	1	21
High raised bog (R)	Rybárny	1020	4	x					4
High raised bog (R)	Křemelná	930	8	x			1	1	8
High raised bog (R)	Novohuťské močály	1220	11						11
High raised bog (R)	Kamerální	1210	5						5
Minerotrophic mires									
Spruce mire (C)	Tetřevská	1110		x					
Transitional mire (C)	Malý Bor	900	3	x					3
Transitional mire (C)	Roklanský les	1190	9	x					9
Meadow mire (C)	Velký Bor	870	2	x					2
Spruce mire (R)	Schachtenfilz	1140	7	x					7
Spruce mire (R)	Rybárny	1020	5	x			1		5
Spruce mire (R)	Blatenská slať	1250	2	x	1	1			2
Spruce mire (R)	Filipohuťské polesí	1120		x					
Transitional mire (R)	Křemelná	930	6						6
Meadow mire (R)	Křemelná	930	12	x					12

Table 4. Monitoring design for jointly implemented monitoring of mires in the Bavarian Forest NP. C – control intact mire, R – restored mire; Alt – altitude (m a.s.l.), Wtb – water table in boreholes, Hch – Hydrochemistry, McA – microclimate air, McS – microclimate soil, Rof – run off, Pre – precipitation, Veg – vegetation monitored on permanent plots.

Type of mire	Site	Alt (m)	Measures						
			Wtb	Hch	McA	McS	Rof	Pre	Veg
Ombrotrophic mires									
High raised bog (C)	Grosser Filz am Spitzberg	1320	2	x	x	x		x	6
High raised bog (C)	Zwieselter Filz	1125	2	x					6
Valley raised bog (C)	Klosterfilz	745	2	x	x	x		x	6
Valley raised bog (C)	Todten Au	720	2	x					6
Valley raised bog (C)	Dorner Au	720	1	x					3
Valley raised bog (R)	Finsterauer Filz	1045	2	x	x	x		x	6
Valley raised bog (R)	Großer Filz at Riedlhütte	745	4	x					12
Minerotrophic mires									
Spruce mire (C)	Latschenfilz	1150	2	x	x	x		x	6
Spruce mire (C)	Filzwald bei Klingenbrunn Bahnhof	750	2	x	x	x		x	6
Transitional mire (C)	Grosser Filz am Spitzberg	1320	2	x					6
Transitional mire (C)	Klosterfilz	745	1	x					3
Transitional mire (C)	Dorner Au	720	1	x					3
Spruce mire (R)	Grosser Filz at Spitzberg	1320	3	x					9
Spruce mire (R)	Zwieselter Filz	1125	2	x	x	x		x	6
Spruce mire (R)	Todten Au	720	2	x					6

BFNP and 3 in the surrounding area) together form unified set of monitoring sites (Fig. 2). All main types of mires are included: ombrotrophic alluvial and montane raised bogs, and three minerotrophic mire types, spruce mires, transitional fens, and treeless fens. The study sites are at elevations between 870 to 1250 m a.s.l.

The mire habitats under the monitoring program are ombrotrophic bogs (*Leuco-Scheuchzerion palustris*, *Oxycocco-Ericion*, *Sphagnion medii*), waterlogged and mire spruce forests (*Mastigobryo-Piceetum*, *Sphagno-Piceetum*). Both restored sites (R, where water regime restoration measures were applied) and control sites (C, i.e. intact) were included in the monitoring design (Table 3). The following environmental parameters have been recorded at all study sites: water level, hydrochemistry, runoff, air moisture and temperature (0.3 m and 1.2 m above the soil surface), soil moisture and temperature (0.01 m, 0.03 m and 1.2 m below the soil surface), precipitation, surrounding stand structure, and vegetation mapping. Three new study sites have been added recently to the already existing monitoring design in the ŠNP to cover all types of mires occurring in the region. New automatic water-level recorders have been set at study sites measured only manually so far. Monitoring was newly implemented in the BFNP (Table 4) where no detail monitoring of mires has been done until present. Additionally, several palynology studies and peat surveys were conducted in the BFNP to detect historical impact on mires.

In the ŠNP, more than one hundred permanent plots with associated water wells were monitored to characterize microtopographic, vegetation, and drainage patterns of the different mire sites. Position of water table was measured manually in all boreholes at nearly fortnight intervals. Automatic gauging (at one-hour interval) by piezometers was used in selected boreholes. Water samples from boreholes, ditches, runoff profiles from drained sites and samples from streams were taken monthly for a detailed hydrochemical analysis, including content of main cations and anions (SO_4, NO_3, NH_4, PO_4, Ca, Mg, Al, Fe), pH, conductivity and DOC. Runoff from drained sites, as well as amount of precipitation were measured continually. Vegetation, both vascular plants and mosses, was mapped at the plots of 2×2 m annually. In the BFNP, vegetation was mapped at 90 permanent plots of 2×2 m annually and six micro climate stations continuously measuring air and soil moisture, air and soil temperature, and precipitation were installed in 2016. Automatic gauging (at 1-h intervals) by piezometers was applied in 30 boreholes from which water samples for hydrochemical analysis were collected monthly from April till September 2017.

Wetland vegetation along the restored streams was studied to describe the effects of restorations. Monitoring of vegetation started in 2011 in the Hučina floodplain, i.e. three years before its restoration (Bojková et al. 2015). In order to document the vegetation prior to the stream restoration, a map of the habitat types was made. With aim to follow vegetation changes after the stream restoration, permanent plots were established along three transects laid across the stream floodplains perpendicular to the stream. Transect 1 was laid in the upper part of the studied floodplain, transect 2 in the middle, and transect 3 in the lower part. Altogether 12 plots of 4×4 m were positioned in the central open part of each floodplain and 14 plots having 10×10 m were placed in the surrounding forested parts. Boreholes were installed at a border of each plot to a depth of 1 m. Each year, vegetation relevés were recorded at all plots in early summer and the water level was measured. The first results of vegetation monitoring along the Jedlový Potok are published in this issue (Čížková & Padrtová 2018).

Monitoring of aquatic ecosystems

The monitoring consists of the following five studies focused on different aquatic ecosystems in the Bohemian Forest.

(i) A systematic long term monitoring aiming to evaluate the effects of natural disturbances and climate changes on biodiversity of streams started at seven catchments (Große Deffernik, Kolbersbach, Kleiner Regen, Große Ohe, Kleine Ohe, Sagwasser, and Reschbach) distributed throughout the BFNP. Altogether 51 sampling sites were located along the elevation gradient from 600 to 1100 m a.s.l. with sampling sections at each 100 elevational meters. From 700 to 900 m a.s.l., smaller side branches were added to sites at main streams as replicates to enable comparison of streams of similar size at all elevational steps. The results of the pilot study preceding the above-mentioned monitoring to evaluate macroinvertebrate diversity and community composition in lower sections of main streams draining the BFNP are presented in this issue (Bojková et al. 2018).

(ii) Monitoring of macroinvertebrate diversity in the core area of both national parks involved the detailed study of two model mountain catchments, upper Vydra in the ŠNP and Große Ohe in the BFNP. This monitoring aimed to explore main gradients in species data and factors governing species richness, abundance and composition of macroinvertebrate assemblages within both stream networks with a special focus on the effect of acidification. Species and environmental data were collected at 43 sites in the Vydra catchment and 49 sites in the Große Ohe catchment. Sites were distributed to cover all stream types and different forest structure within the catchments. Species and basic environmental data from the Große Ohe catchment are presented in this issue (Bojková et al. 2018).

(iii) Long-term monitoring of three restored streams, Hučina, Jedlový Potok and Žlebský Potok in the ŠNP. It was focused on the evaluation of the success of the restoration based on the data on the colonization of restored streams by benthic macroinvertebrates, development of their assemblages in relation to flow and substrate conditions, and comparison of environmental conditions and macroinvertebrate communities before and after the restoration. The results will be used for planning next stream restorations in the ŠNP in the future.

(iv) Common transboundary monitoring of bog pools was focused on the biodiversity of different aquatic invertebrates (zooplankton, benthic and free-swimming insects) and environmental drivers of their communities. Altogether 54 pools from 22 groups of pools or restored blocked ditches were investigated. Species and environmental data have been used to compare natural and artificially created bog pools, and to study relict and endangered aquatic species inhabiting raised bogs.

(v) Long term research of the glacial lakes provides crucial information on recovery of terrestrial and aquatic ecosystems from atmospheric acidification and the role of forest disturbances in water fluxes of nutrients and important elements in lake catchments. Within the Silva Gabreta project, a comparative study on pools and fluxes of major nutrients and ecologically important elements in the terrestrial and aquatic parts of both Plešné Lake and Čertovo Lake catchments has been conducted (Kopáček et al. 2018a,b). The aim of this study has been to estimate nutrient losses and leaching of toxic aluminium forms from forest soils and their effects on aquatic biota. Similar study has been commenced in Rachelsee.

Monitoring of streams (i.e. stream monitoring in the BFNP, and both in the Vydra and Große Ohe catchments) was conducted using standard methodology based on the AQEM protocol (AQEM Consortium 2002, Meier et al. 2006) to ensure compatibility of the data. Sampling of macroinvertebrates was based on a standard multi-habitat scheme designed for sampling of major mesohabitats proportionally according to their share within the sampling site (AQEM Consortium 2002). Each sample consisted of 20 plots of 0.25×0.25 m taken from all mesohabitat types with a share of at least 5% coverage at the sampling site. The 20 plots were distributed according to the share of mesohabitats. Kick-samples were sampled using a standard hand net with 0.5 mm mesh size. In the Bavarian streams, Phylib method (Schaumburg et al. 2012) was used for sampling of macrophytes, i.e. species cover was mapped. Diatoms together with other phytobenthos were sampled from the available substrate. Fish were sampled using electrofishing. Malaise traps were installed at 12 of 51 sites investigated in the BFNP in 2016 to sample adults of aquatic insects, especially Ephemeroptera, Plecoptera, and Trichoptera.

Different sampling methods were used for the monitoring of restored streams. At each sampling site, three mesohabitats, riffle, run and pool, were investigated. Macroinvertebrates were sampled semiquantitatively using a hand net with 0.25-mm mesh size. At each mesohabitat, altogether five approx. 0.25×0.25 m plots were sampled and merged into one sample characterising one mesohabitat. Prior to sampling of each plot, water depth and velocity were measured using a Flo-Mate flowmeter and water samples for chemical analysis were collected (Bojková et al. 2015). Altogether, seven sites were located in the restored parts of streams (three in Hučina, two in Žlebský Potok, and two in Jedlový Potok) and five sites were located at reference sites nearby (one site in a near-natural part of Hučina and Žlebský Potok above their restored stretches, one site in the Studená Vltava stream and in the Teplá Vltava stream, i.e. in the recipients downstream the restored stretches, and one site at the channelized Jedlový Potok above the restored stretch). For more details on the methodology of this study see Bojková et al. (2015). Pre-restoration data are available only for two streams, Jedlový Potok and Žlebský Potok.

Bog pools were investigated using several sampling methods covering various aquatic organisms. Littoral benthic macroinvertebrates were sampled semiquantitatively by a standard hand net with 0.5 mm mesh size. Sampling effort was standardized by time, i.e. macroinvertebrates were sampled by sweeping by a net for five minutes. Free-swimming aquatic insects were collected by two light traps (one trap in littoral zone and the second one in open water zone). Moreover, two activity traps were set in littoral zone. All traps were exposed for 24 hours. Microinvertebrates (Rotifera, Cladocera and Copepoda) were sampled both qualitatively and quantitatively. Qualitative samples were taken by plankton net of 40 µm mesh size from four different part of each pool to cover its heterogeneity. Eight litres of quantitative samples were taken by a 2-l vessel and concentrated through a 40-µm mesh size. Littoral vegetation coverage was estimated. Depth and size of the pool, basic physical-chemical parameters (temperature, dissolved oxygen concentration, pH, and conductivity) were measured at each pool and samples for water chemistry (total phosphorus, total nitrogen) and chlorophyll *a* concentration were analysed in the laboratory.

Long-term research of glacial lakes includes various research activities with complex methodology. Overview of research activities and references on methodology are available in Vrba et al. (2015). Comparative study on pools and fluxes of major nutrients and elements included in the Silva Gabretaproject in the catchments of Plešné and Čertovo lakes included monthly sampling of precipitation and lake water samples and annual sampling of litter of spruce and deciduous trees. The following parameters were analysed in water samples: Cl^-, SO_4^{2-}, NO_3^-, F^-, H^+, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, DOC, all forms of P, total and organic N. Aluminium and iron were analysed only in samples of lake water. Dry matter and total amount of Ca, Mg, Na, K, Al, Fe, Mn, P, C, and N were analysed in tree litter samples. More details on sampling and analytical methods are available in Kopáček et al. (2018a,b).

Project outputs

The detailed field investigation of biodiversity of different ecosystems has provided important data for both basic species inventory and evaluation of ecological changes driven by natural and anthropogenic disturbances. Our multi-taxa biodiversity monitoring delivered a large set of species records supplemented by environmental data. Field work was mainly done in the 2016 and 2017 seasons and processing of samples and species' determination and data analysis have continued until 2019. The first scientific papers have been already published (e.g. Fries et al. 2018, Hilmers et al. 2018, in press, Vondrák & Malíček, in prep.) and several others are under preparation. The common monitoring of forests offers a unique opportunity to analyse structural and biological diversity across the border and study the Bohemian Forest as a one ecosystem. The gained knowledge stimulates convergence of management of the both NPs and support preparation of common nature conservation projects.

Both newly established monitoring of mires in the BFNP and improved monitoring of mires in the ŠNP have delivered unique data sets enabling an evaluation of the restoration success. The preliminary results confirmed the importance of restoration and suggested that hydrochemical changes were more expressed in spruce mires than in raised bogs. Continuation of mire monitoring and detailed statistical analyses of data are planned to evaluate long-term trends in local temperature, precipitation, and water level fluctuation in different types of mires, which could reveal possible effects of climate changes and/or current climatic extremes on functioning of mires. Current monitoring of benthic macroinvertebrates colonising three restored streams (Bojková et al. 2017) and vegetation in their floodplains (Čížková & Padrtová 2018) in the ŠNP has delivered scientific support for planning of new restoration projects. The newly established monitoring of streams in the BFNP aims to provide unique data on an altitudinal distribution of benthic macroinvertebrates and its relation to effects of acidification and/or forest disturbances. Preliminary results are presented in this issue by Bojková et al. (2018). Continuation of this monitoring will provide sufficient data for evaluation of the altitudinal shifts in species distribution induced by climate changes, i.e. complementary data to those from terrestrial forest monitoring (e.g. Bässler et al. 2008, 2010, Fries et al. 2018).

Beudert et al. (2018) evaluated long-term hydrological for the whole Bohemian Forest that clearly suggested some positive mitigation effects of natural disturbances in the NPs, which have offset current climate changes. The study on long-term trends in precipitation and runoff in the Modravský Potok catchment (Lamačová et al. 2018) similarly confirmed that bark beetle outbreaks and changes in forest structure did not affect runoff significantly. Higher runoffs were particularly correlated with higher precipitation, whereas the lower runoffs with lack of rain and snow, and similar trends are predicted also in future (Lamačová et al. 2018). Data from the long-term monitoring of both Plešné Lake and Čertovo Lake catchments enabled to prepare the balance studies on pools and fluxes of major nutrients (Kopáček et al. 2018a,b).

New data from monitoring of effect of deicing salt to ecosystems along the roads in protected areas confirmed our assumption that Na^+ and Cl^- ions increased in the streams crossed with the roads maintained by deicing salt (Zýval et al. 2018). Increasing concentrations of Na^+ and Cl^- ions were found also in soil samples collected along the roads maintained by deicing salt, both in BFNP (Křenová et al., in press) and ŠNP.

All the above-mentioned scientific contributions have provided the basis for developing suitable management strategies to maintain and enhance biodiversity and ecosystem services.

The main project outputs planned in the project proposal included: extensive set of environmental and species data, rich material from samples of various taxa prepared for continuing determination, and results of comparative studies form useful platform for meeting the following project outputs listed in the project proposal:

1) Implementation of the common monitoring design after the standardization of methodology.

2) Preparation of common biodiversity database for forest, mire and stream monitoring

data.
3) Review of the practicability of applied monitoring designs for a long-term continuation within a monitoring program.
4) Recommendations for a common management in the both NPs.
5) Common publication of the results and collaboration of Bavarian and Czech research teams.
Part of these results are published on this issue together with several short papers delivering new information about hydrology and biodiversity, improving the Silva Gabreta Monitoring project knowledge.

Conclusions

The Interreg project No. 26 "Silva Gabreta – Monitoring of biodiversity and water regime" has offered for the first time the possibility to implement a jointly prepared transboundary monitoring design. Except for the long-term cooperation in the glacial lake research, no real common monitoring activities of the both BFNP and ŠNP had existed in the Bohemian Forest region until this Silva Gabreta Monitoring project has been implemented. The practical implementation of the common planned monitoring design with standardized methods set the starting point for a long-term, unified monitoring program in both National Parks. The collected data, results and experiences serves for the elaboration of recommendations for a common national park management. Knowledge gained from a close-to-nature reference area can substantially contribute to the enhancement of biodiversity and ecosystem services in other man-influenced biotopes and find here application.

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