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The Biomonitoring project – monitoring of forest ecosystems in non-intervention areas of the Šumava National Park[†]

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Abstract
The Šumava National Park is the largest national park in the Czech Republic. It belongs to one of the most valuable terrestrial Natura 2000 sites in central Europe, where large areas are covered by mountain spruce forests. These forest ecosystems are areas of special conservation value. Nowadays, 23% of the Šumava NP area is left without human interventions and this area offers a unique opportunity to study natural forest structure and dynamics. Data about stand structure (live and dead trees, snags, stumps, lying dead wood, and tree regeneration) and plot characteristics (slope, soil, microsite cover, vegetation) are collected within the Biomonitoring project, which has been started already in 2008. Results of the project show successful regeneration of mountain forests after natural disturbances. More than 90 % of inventory plots showed the regeneration densities >100 seedlings.ha^{-1}. We found, that there are enough young trees to guarantee the next generation of forests. The project also confirmed that the lying dead wood is an important microsite for natural regeneration of trees, especially for the Norway spruce (*Picea abies*), a dominant species of the spruce mountain forest.

Key words: Bohemian Forest, forest inventory, dead wood, natural regeneration, Norway spruce

Introduction

Two national parks, the Bavarian Forest National Park (Bavarian Forest NP, Germany) and the Šumava National Park (Šumava NP, Czech Republic) were established in the Bohemian Forest in 1970 and 1991, respectively. These two parks protect together 22,670 ha of mountain spruce forests, one of the largest complexes in central Europe. The Šumava NP and the Bavarian Forest NP are also significant part of the Natura 2000 network, which was established to protect the most endangered habitats and species in Europe, as defined in both the Habitats Directive (1992) and Birds Directive (1979). This area is a unique mosaic of natural and secondary habitats of exceptional natural value of European-wide significance. Each type of habitat hosts numerous rare and protected plant and animal species. Nineteen habitats are protected in the Site of Community Importance Šumava (SCI Šumava) that protects

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Table 1. Habitats that are subjects of protection in the SCI Šumava with their total area; priority habitats are marked by asterisks. Codes of forest habitats investigated in the Biomonitoring project are in bold; different proportions of these habitats occur in the non-intervention areas of the Šumava NP.

Code	Habitats of Annex I of Habitat Directives	Area (ha)	Biotop units for mapping (see CHYTRÝ et al. 2001)
3130	Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*	32.7	M2.2 – Annual vegetation on wet sands M3 – Vegetation of perennial amphibious herbs V6 – *Isöetes* vegetation
3150	Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation	39.2	V1 – Macrophyte vegetation of naturally eutrophic and mesotrophic still waters
3260	Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation	86.8	V4A – Macrophyte vegetation of water streams with currently present aquatic macrophytes
4030	European dry heaths	133.0	T8.2B – Secondary submontane and montane heaths without *Juniperus communis*
5130	*Juniperus communis* formations on heaths or calcareous grasslands	15.0	T8.2A – Secondary submontane and montane heaths with *Juniperus communis*
6230*	Species-rich *Nardus* grasslands, on siliceous substrates in mountain areas (and submountain areas, in Continental Europe)	1414.0	T2.1 – Subalpine *Nardus* meadows T2.3B – Submontane or montane *Nardus* meadows without *Juniperus communis*
6410	M*olinia* meadows on calcareous, peaty or clayey-siltladen soils (*Molinion caeruleae*)	484.0	T1.9 – Intermittently wet *Molinia* meadows
6430	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	1187.2	A4.2 – Subalpine tall-forb vegetation A4.3 – Subalpine tall-fern vegetation T1.6 – Wet *Filipendula* grasslands
6510	Lowland hay meadows (*Alopecurus pratensis*, *Sanguisorba officinalis*)	3698.7	T1.1 – Mesic *Arrhenatherum* meadows
6520	Mountain hay meadows	5230.9	T1.2 Montane *Trisetum* meadows
7110*	**Active raised bogs**	386.1	R3.1 – Open rised bogs R3.3 – Bog hollows
7140	**Transition mires and quaking bogs**	1422.8	R2.2 – Acidic moss-rich fens R2.3 – Transition mires
8220	Siliceous rocky slopes with chasmophytic vegetation	236.9	S1.2 – Chasmophytic vegetation of siliceous cliffs and boulder screes A6B – Acidophilous vegetation of alpine cliffs
9110	***Luzulo-Fagetum* beech forests**	27397.3	L5.4 – Acidophilous beech forests
9130	***Asperulo-Fagetum* beech forests**	3188.7	L5.1 – Herb-rich beech forests
9180*	***Tilio-Acerion* forests of slopes, screes and ravines**	346.8	L4 - Ravine forests
91D0*	**Bog woodland**	3822.2	L9.2A – Bog spruce forests L10.1 – Birch mire forests L10.2 – Pine mire forests with *Vaccinium* L10.4 - *Pinus rotundata* bog forests R3.2 – Raised bogs with *Pinus mugo*
91E0*	**Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*)**	1283.7	L2.1 – Montane grey alder galleries L2.2 Ash-alder alluvial forest
9410	**Acidophilous *Picea* forests of the montane to alpine levels (*Vaccinio-Piceetea*)**	21315.0	L9.1 – Montane *Calamagrostis* spruce forests L9.2B – Waterlogged spruce forests L9.3 – Montane *Anthyrium* spruce forests

habitat types, animal and plant species defined in the Habitats Directive. Eight of the habitats are forest habitats and significant proportions of many of them occur in non-intervention areas of the Šumava NP. Because the main focus of the directive is on maintaining and/or restoring a favourable conservation status for habitat types & species of community interest, the Biomonitoring project delivers very important information about the current status of the Natura 2000 habitats occurring in the Šumava NP.

The habitat 9410 (Acidophilous *Picea* forests of the montane to alpine levels (*Vaccinio-Piceetea*)) is the largest one (Table 1) and the significant part of this habitat occurs in the non-intervention areas, where the Biomonitoring project is conducted. As many other mountain spruce forests in Europe (Fischer et al. 2002, Grodzki et al. 2003, Kulakowski & Bebi 2004, Holeksa et al. 2007, Svoboda & Pouska 2008, Svoboda et al. 2010), also the spruce forests in the Šumava NP have been affected by natural disturbances (windstorms and bark beetle outbreaks) during the last two decades and it escalated discussions about the appropriate management of the forests. Since the very beginning of the Šumava NP decisions about its management have been bogged down in never-ending discussions about whether bark beetle infestations should be controlled or a "non-intervention" policy adopted. An increasing number of mountain spruce forests, growing in nature reserves and core zones of national parks worldwide, are managed as non-intervention areas, in which natural disturbances are accepted as an integral part of their development (Turner et al. 1997, Demetry 1998, Reice 2001, Franklin et al. 2007).

Sufficient natural regeneration is a key factor for the natural reconstruction of these forests. The monitoring results confirming successful regeneration of forests in non-intervention areas are crucial for negotiations about the National Park management with politicians, local representatives, and NP visitors. The Bavarian Forest NP, one of the best known booster of non-intervention management in the national parks, started a large-scale and long-term investigation of mountain forests' natural regeneration in a non-intervention ('natural') zone of the Bavarian Forest NP in 1991 (Heurich et al. 2010). Repeated investigations have already found a high degree of natural regeneration with good diversity and spatial distribution. Successful recovery of mountain forests in the Bavarian Forest NP after windstorm and bark beetle outbreaks has been confirmed (Heurich 2009). Various scientific results (i.e., Gromtsev 2002, Fischer & Fischer 2009, Jonášová et al. 2010) show that natural recovery of coniferous forests after wind, bark beetle, or other natural disturbances is important and can be more successful compared to artificial planting of trees but results of the local monitoring are necessary.

The Biomonitoring project delivers valuable information about the forest dynamics and natural regeneration not only in "politically-hot" mountain spruce forests but also in all other forest habitats occurring in non-intervention area. Nowadays, 23% of the Šumava NP in so-called non-intervention zones are left for spontaneous natural development. This area offers a unique opportunity to study the natural forest ecosystem dynamic. The Šumava NP Authority responded this challenge in 2008, when the large-scale inventory of mountain forest regeneration started (Čížková et al. 2011). The Biomonitoring project is the first project covering the whole non-intervention zone. Various tree characteristics are recorded in permanent plots with the main goal to describe species composition, spatial structure, and natural dynamics of mountain spruce forests. Methodologies of inventories in the Šumava NP and the Bavarian Forest NP are analogous, and allow comparing results from the bilateral national parks sharing the same forest ecosystem.

The main objectives of the Biomonitoring project are: (1) to collect well structured data about current state of forest ecosystem in non-intervention areas and (2) to create a network of permanent research plots for repeated measurements. The network of permanent research

Table 2. Natura 2000 habitat types and other natural habitats investigated within the Biomonitoring project. Priority habitats of the highest EU interest are marked by asterisks. The numbers of plots, which have been already measured during 2008–2014 or are planned for measuring in the next years, are listed. Distribution of permanent plots within different habitats is unbalanced; a proportion (%) of different habitats in the complete set of 1111 permanent plots is shown.

Natura 2000 habitats		**No. of plots**	**%**
7110*	Active raised bogs	24	2.2
7140	Transition mires and quaking bogs	10	0.9
9110	*Luzulo-Fagetum* beech forests	95	8.6
9130	*Asperulo-Fagetum* beech forests	22	2.0
9140	Medio-European subalpine beech woods	14	1.3
9180*	*Tilio-Acerion* forests of slopes, screes and ravines	8	0.7
91D0*	Bog woodlands	269	24.2
91E0*	Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*	11	1.0
9410	Acidophilous spruce forests	427	38.4
L.8.1	Boreo-continental pine forests	4	0.4
L1	Alder carrs	3	0.3
Other natural habitats		126	11.3
Habitats strongly affected by human activities		98	8.8
Total		**1111**	**100**

plots will be used for repeated investigations in the future. Each additional measurement increases the predicative value of our data. Permanent plots with detailed descriptions of the structure of the forest can be also used as study sites for various new projects.

The project improves our knowledge about mountain forest ecosystems, which can be used for setting of appropriate management practices in both non-intervention and intervention areas.

Materials and methods

Project duration

The pilot project testing methodology was conducted in 2008 (Čížková et al. 2011). Its results helped to improve the methodology. The updated, slightly modified, methodology has been used since 2009. The plots measured in 2008 have been re-investigated with this updated methodology; it means that all data are equal. The number of plots measured each year differs (Table 2) and 750 plots have been already measured till the end of 2014 (Fig. 1). The total number of permanent research plots depends on the size of non-intervention areas, the current sum of permanent plot is 1111 (Table 2).

Site

The forests cover 80% of the Šumava NP and various forest types, occurring in different parts of the mountains, reflect different local environmental conditions. Permanent plots of the Biomonitoring project are irregularly distributed within the Šumava NP in the non-intervention zones (Fig. 1) and all Natura 2000 habitats protected in the SCI Šumava are investigated within the Biomonitoring project (Table 2, 3).

Table 3. Number of the plots measured in the Biomonitoring project during 2008–2014.

Year	No. of plots
2008	130
2009	151
2010	155
2011	139
2012	119
2013	97
2014	89
Remains for the next years	361

Methods

A network of randomised points separated by 353.55 meters, formerly established as a network for the Forest Inventory in the Czech Republic (ÚHÚL 2007) and the Large-Scale Inventory of the Šumava NP Forests, was used to place the centres of permanent plots. Similar network is also used for the project Operational Forest Inventory, some of the plots overlap and can be used in both projects.

Field-Map technology (Černý 2010) was used to mark the plots in the field and collect the data. Permanent plots are circles with the size of 500 m^2 (12.62 m in diameter). Each plot is fixed by three independent ways for the next investigation. The plot centre is fixed by a merestone, GPS coordinates are recorded and one or two trees close to the research plots are marked by reflex spray. Coordinates of these trees are also recorded.

Each plot is divided into two concentric circles, 7 m and 12.62 m in diameter. Positions of trees with diameter breast height (DBH) >30 cm are measured in a whole plot. More detail investigation, including all trees with DBH>7 cm, is conducted in a small inner plot having 7 m in diameter. Natural regeneration (individuals with DBH<69 mm) is recorded in a whole plot and a more detail investigation is conducted in a small regeneration plot, a circle 3 m in diameter. A centre of this circle is located 7 m north from the centre of the research plot (Fig. 2).

The methodology of the Biomonitoring was agreed in 2009 (NPŠ 2009), data on each plot are clustered in seven sections: (1) plot characteristics; (2) living trees (DBH>30 cm, or >7 cm); (3) dead trees; (4) snags and stumps; (5) lying dead wood; (6) tree regeneration (seedlings >10 cm high, DBH<7 cm); (7) phytocoenological relevé and proportion of microsites important for tree species regeneration (Table 4). Also soil characteristics are recorded.

Results and project benefits

Currently we have got data from 750 research plots. All Natura 2000 forest habitats protected in the Šumava SCI have been already investigated but the distribution of permanent plots is unbalanced (Table 3). The highest number of measured plots is situated in natural spruce forests (habitat 9410, *Vaccinio-Piceetea* forests) and in bog woodlands (91E0*), a priority habitat. Also beech forests (9110, *Luzulo-Fagetum*, and 9130, *Asperulo-Fagetum*) and raised bogs (7110*), another priority habitat, were investigated often. Only few plots were situated in a broad leaves forest (9180* *Tilio-Acerion* forests of slopes, screes and ravine), alluvian forests (91E0*), and transition mires (7140), habitats which are not very com-

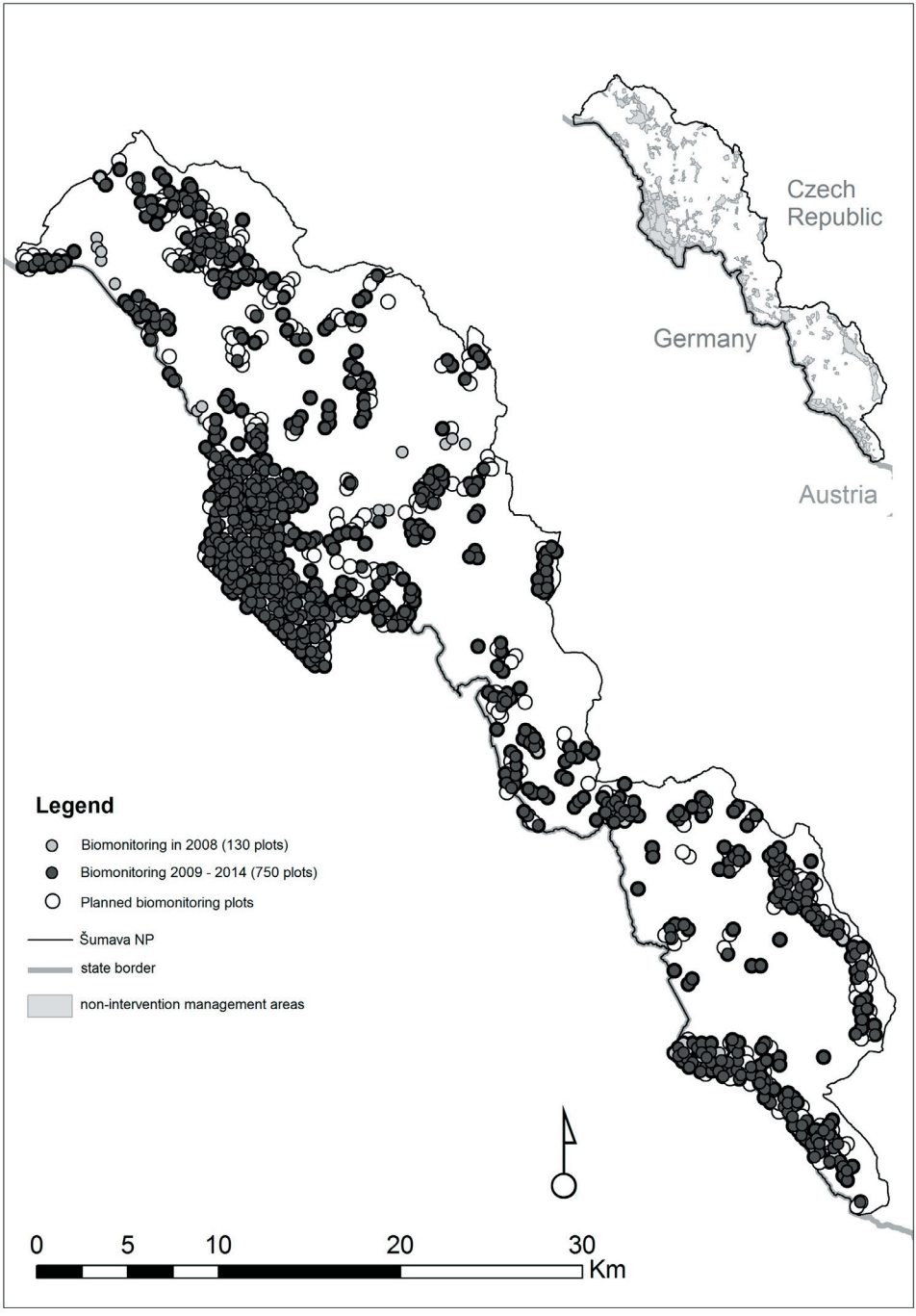

Fig. 1. Locations of the permanent research plots in non-intervention areas (insert) of the Šumava NP measured during 2008–2014 and those planned for future measuring.

Table 4. The plot characteristics and collected attributes.

Layer	Characteristics and monitored attributes
Plot	Basic plot characteristics: date, altitude, slope, aspect, terrain relief, canopy, past management.
Living trees	Position and description of living trees inside 2 concentric circles: tree species, diameter breast height (DBH), height, stem breaks, forks, stem damage, presence of fungi, evidence of bark beetle.
Dead trees	Position and description of standing dead trees inside 2 concentric circles: tree species, DBH, height, stem breaks, forks, presence of fungi.
Tree regeneration	Description of tree species regeneration: plants with height between 0.1 m and DBH 69 mm. Whole plot and small regeneration plot.
Snags and stumps	Position and description of stumps smaller than 1.3 m: tree species, diameter class, origin, stage of decay, presence of fungi, density of tree species regeneration.
Lying dead wood	Position and description of lying deadwood (with the minimal diameter of 70 mm and the minimal length of 1 m): tree species, length, middle diameter, origin, stage of decay, surface contact, vegetation cover, presence of fungi, density of tree species regeneration.
Site	Phytocoenological relevé and proportion of microsites important for tree species regeneration.

mon in the Šumava NP. Significantly represented are also areas identified as habitat heavily modified or created by man. These areas were previously influenced by man but nowadays are parts of non-intervention areas because of unification of fragmented zones.

The Biomonitoring project delivers important results about current state and characteristics of natural regeneration in forest habitats occurring in the Šumava NP. The dominant species is Norway spruce (*Picea abies*, 79%), also European beech (*Fagus sylvatica*, 10%) and rowan (*Sorbus aucuparia*, 4%) are more common.

Natural regeneration is sufficient for recovery of a new forest generation. We found seedlings density >100 ind.ha^{-1} in 93% of the investigated plots and density >500 ind.ha^{-1} in 84% of the investigated plots. Successful regeneration was confirmed even in the locations, which were strongly affected by large scale disturbances (windstorm in combination with bark beetle).This can be easily illustrated by results from the Modrava region, a central part of the Šumava NP. This area, which was strongly affected by several windstorms and large bark beetle outbreak in 1990s, is the oldest non-intervention area in the Šumava NP (since 1995). Average number of seedlings recorded in this area is 3 015 ind.ha^{-1} (SD = 3 971; median = 1 720 ind.ha^{-1}, range: 40–19 660 ind.ha^{-1}). Hence, there is no doubt about successful natural regeneration of this area.

The Biomonitoring project also confirmed the importance of dead wood for successful forest regeneration (Čížková et al. 2010). Coarse woody debris (CWD) covers just a small part of the forest floor (about 5%) but a role of this substrate for natural regeneration is irreplaceable. Both dead wood quantity and quality (level decomposition, structure, distribution in forest, etc.) are crucial for successful natural regeneration of mountain spruce forest.

We also found that the natural regeneration is limited by browsing. Ungulates, mostly the red deeers (*Cervus elaphus*) and the roe deers (*Capreolus capreolus),* can make significant

demages on young trees. More than 50% of rowans (*Sorbus aucuparia*), sycamores (*Acer pseudoplatanus*), and willows (*Salix* sp.) were browsed.

Preliminary results of the Biomonitoring project were presented at several conferences (Čížková 2010a-c) and also popularized in the Lesnická Práce journal (Čížková 2010d) and the Šumava journal (Čížková 2014). Except the results of the pilot project (Čížková et al. 2011, Zeppenfeld et al. 2015), all other data from this monitoring project remain unpublished up to date.

Since 2009, the Biomonitoring project is conducted also in the Šumava Protected Landscape Area. The plots are situated in strictly protected nature reserves, where remnants of primeval forests occur, and non-intervention areas protecting abounded seminatural or secondary habitats (for example old pastures, meadows, settlements) of different succession stages. The preliminary, not yet published, results show that natural ecosystems of high conservation value can appear in abounded secondary habitats, which were managed for decades and then left for natural development.

Conclusions

The Biomonitoring project brings detailed information about the state and development of forests in non-intervention areas. The project results improve our knowledge about the mountain forest ecology and help us to prepare the appropriate management plan for the Šumava National Park. A credit of this project is very high already now and its importance

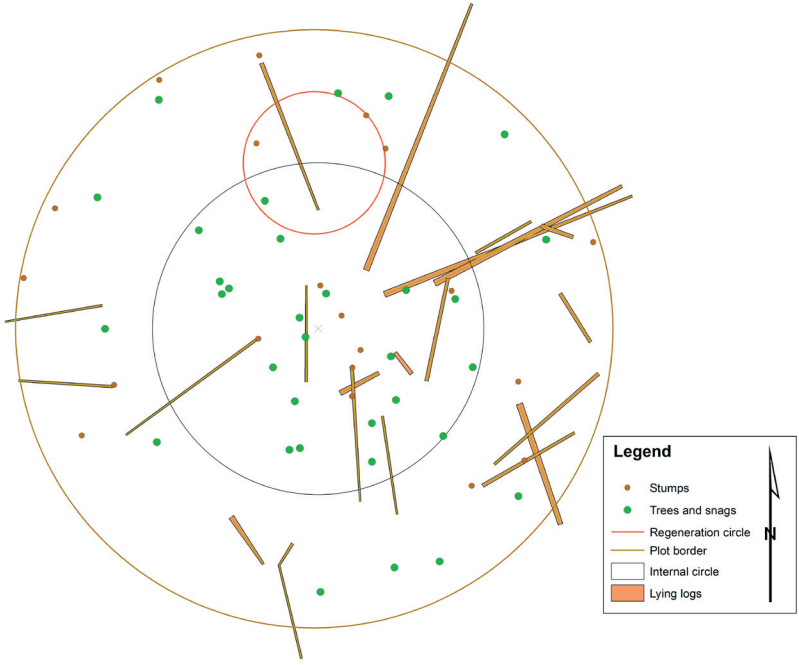

Fig. 2. An example of visualised results of the measured project plot.

will increase in the future, when we will have data from repeated investigations. Data, continuously collected by the Šumava NP employees, are comparable with data from the project Operational Forest Inventory, another project operated by the Šumava NP Authority. The plots of this project are situated in zones, where active forest management is applied, and data sets of both projects can be shared. The methodology of the Biomonitoring project is also comparable with the monitoring of natural regeneration in the Bavarian Forest NP. It means, that the adjacent national parks can share data and compare the results.

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