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IMPACT OF SOIL DRAINAGE TO THE RADIAL STEM GROWTH OF NORWAY SPRUCE (*PICEA ABIES* L. KARST.) IN PEATLAND FORESTS

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Peatland Norway spruce (*Picea abies* L. Karst.) forests represent very valuable ecosystems with considerable importance for nature conservation. However, a lot of peatland forests have been drained or used for opencast mining of peat. Since dendrochronological and dendroecological studies on trees growing on peatlands in Europe are not many, this study aimed to reconstruct the impact of drainage to the growth of trees in forest stands older than 100 years in the moment of drainage. Dendrochronological analysis was performed on two 0.25-ha square sampling plots (50*50 m) in two pre-selected stands (control site vs. drained site) with similar natural conditions and age. The mean-value functions of the ring indices, comparing the drained site with the control site, in the period after 1940 revealed very similar radial-growth trends. After the year 1992, when one site was substantially drained, the radial-growth trends not showed any significant change. Likewise, the result of the independent two sample t-test for the period after 1992 has not revealed any substantial statistically important difference in the mean index between the control site and the drained site.

Keywords: *Norway spruce; dendrochronology; tree-ring width; peatland; soil drainage; nature conservation*

1. Introduction

In Central Europe's mountainous region, peatland Norway spruce (*Picea abies* L. Karst.) forests represent very valuable ecosystems with considerable importance for nature conservation. In spite of their location in the area of severe climatic conditions at upper climatic tree distribution limit, some of these forests have been significantly influenced with human use with aim to increase their timber production. A lot of peatland forests have been drained or used for opencast mining of peat.

Drainage as a mean of improving tree growth has been used extensively with positive results namely in Fennoscandinavia (Paavilainen, Päivänen, 1995), thus much of the international knowledge about improved forest growth on peatlands after drainage is based on results from the Nordic countries and Russia (Gustavsen *et al.,* 1998). Drainage aerates part of the peat, resulting in a faster decomposition rate, which enables increased nutrient mineralization, which favour the tree growth (Moilanen *et al.,* 2012). Likewise, drainage might increase stand stability and stimulate radial stem growth, since water-logging in the soils cause worsened anchoring of trees due to higher occurrence of root decay and low cohesion between the soil particles and root surface (Rottmann, 1989).

However, at the same time, forest drainage has negative effect on original ecosystems. Drainage lowers the water table, increase soil temperature (Lieffers, Rothwell, 1987), change water quality and increase pH soil values (Prévost *et al.*, 1999). Increased frequency and quantity of runoff peaks increases erosion and suspended sediment transport from treated areas (Marttila, Klove, 2010; Marttila *et al.*, 2010). Hydrological study on effect of drainage suggested that the highest peak flows could be increased by drainage in cases of intensive rainstorms in catchments with already high (close to the soil surface) groundwater level (Iritz *et al.*, 1994).

Wetlands are known to be very sensitive to disturbance and the environmental impacts of management practices on wetlands must be considered before forest drainage becomes widespread (Prévost *et al.*, 1999). In order to preserve these unique ecosystems, many of the remaining peatlands are protected on the national level or as NATURA 2000 site (ecological network of protected areas in the territory of the European Union).

The area of the Ore Mountains (the Krusne hory Mountains), in the western Czech Republic, thanks to its favourable morphology and climatic conditions, offers several valuable peat complexes surrounded with wet mountain spruce forests dominated by Norway spruce with a number of critically threatened species of plants and animals. The downward trend of pollutants since the nineties enabled a significant improvement of growth conditions for original tree species and ecosystems.

Dendrochronological and dendroecological studies on trees growing on peatlands in Europe are not many (Badorek *et al.*, 2011; Cedro, Lamentowicz, 2008, 2011; Hokka *et al.*, 2012).

The area of the National Natural Reserve Božídarské rašeliniště peat bog includes peatland forest stands of various ages and therefore enables to study natural growth dynamics and effects of human impacts represented mostly by drainage of these stands changing its hydrological conditions.

The goal of this study was to analyze the growth development of peatland Norway spruce forests in this area in order to acquire better understanding of its dynamics and history. The specific objective was to test the null hypothesis: in forest stands older than 100 years in the moment of drainage, mean tree-ring indices of the control-site and the drained-site are equal. The assumption was that the soil drainage is expected to stimulate stem growth, including larger radial increment.

2. Materials and methods

2.1. Study Area

The study was conducted in the area of the National Natural Reserve Božídarské rašeliniště peat bog in the Ore Mountains (the Krusne hory Mountains), in the western Czech Republic (Fig. 1).

For the study, based on forest management maps and aerial photographs, two stands with similar ecological conditions and age structure were selected to meet the requirements for a site homogeneity, which largely determines the quality of the chronology (Cook and Kairiukstis, 1990). Based on forest management plan, both stands are approximately 130 years old and in accordance with the Czech ecosystem classification (Plíva and Průša, 1969) classified as a Raised Bog Spruce, with an origin of slope raised bog (Dohnal, 1965) and a forest site type *Sphagno-Piceetum* (Chytrý *et al.*, 2001). The stands are situated on a slightly sloping terrain, trees grow on wet peat soil, irrigated only by atmospheric precipitations. Norway spruce dominates both stands and is rarely accompanied by *Pinus x pseudopumilio, Betula pubescent and Sorbus aucuparia,* some parts are sparsely forested. In herbal vegetation prevails *Sphagnum sp, Vaccinium myrtilus* and *Eriophorum vaginatum*. The average temperature is around 4°C, average annual rainfall of 1150 mm, 110 days long vegetation period with night frosts during whole year (Český hydrometeorologický ústav *et al.*, 2007).

The control site (50°24'39.0''N 12°53'40.3''E), situated on a slight north-facing slope (5°), 993 m a.s.l., is located directly in the National Natural Reserve Božídarské rašeliniště peat bog and based on available forest management plans and observation on the field, it was not drained during last 50 years, likely never during the existence of the actual trees. On the other hand, the affected site (50°25'08.7''N 12°53'31.4''E), on a slight south-facing slope (2°), 980 m a.s.l., is located outside the border of the National Natural Reserve. In the year 1992, the water regime of the drained site was substantially altered due to construction of numerous drainage ditches with aim to improve tree growth.

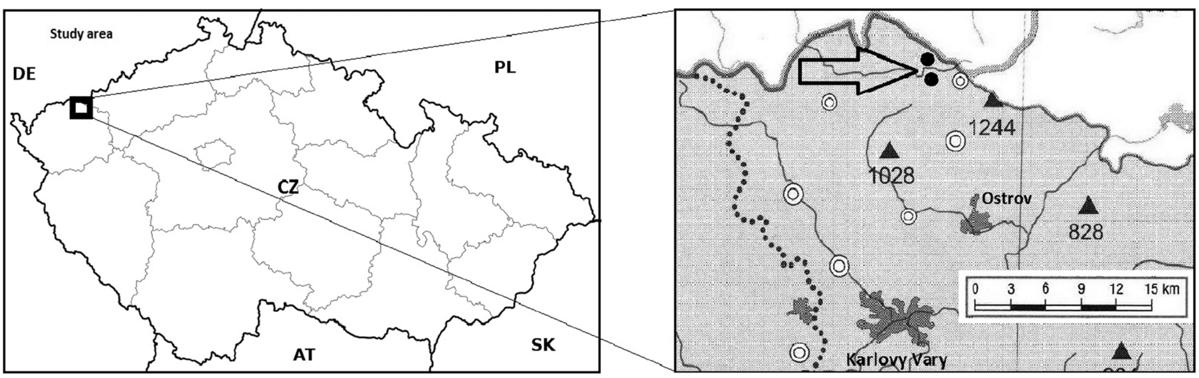

Fig. 1. Location of the study area

Table 1. Basic features of the control and drained site from their forest management plans (LHProjekt 2012)

Stand	Stand age	Mean DBH [cm]	Mean height [m]	Mean stem volume [m³]	Number of trees per ha
Control site	128	23	15	0,28	485
Drained site	115	26	19	0,45	517

2.2. Data Sampling

Dendrochronological analysis was performed at the turn of June–July 2012 on two 0.25-ha square sampling plots (50*50 m). The plots were located randomly before going into the field by using GPS coordinates using aerial photographs and actual forest management plans. The each 0.25-ha plot was divided into 25 cells (10*10 m) for systematic sampling of the trees nearest to its centre. A total of 50 samples were collected (25 samples from each plot). The selected trees were cored with a Pressler increment borer at breast height (1,3 m), one core per tree, but the direction of coring was randomly changed to balance possible irregularity in its thickness growth (Šmelko, 1982). A diameter of each tree at breast high (DBH) was measured. Visibly damaged and suppressed trees were avoided to reduce the variability owing to competition (Cook, Kairiukstis, 1990). However, suppressed trees are very rare given the open structure of peatland forests with trees growing at their upper climatic distribution limit. The cores were put in the straw and labelled.

2.3. Data analysis

In the laboratory, the increment cores were extracted from the straws, attached to the wooden holder and numbered. In total 47 undamaged cores (25 from the control site and 22 from the affected site) were prepared for measurement and visual analysis using the sanding method (the surface of cores was sanded with a rotary-sanding tool using a grit size 280) (Cook and Kairiukstis, 1990). The visual analysis was made by identifying narrow marker years (Yamaguchi, 1991), since narrow rings are more important because these rings often record limiting environmental factors (Speer, 2010). Annual ring widths were measured to the nearest 0,01 mm and cross-dated with image analysis using software WinDENDRO 2009b (RIC and Inc.) 2009). Virtual skeleton plots and graphical comparisons against a mean chronology were used to cross-date images of increment cores (Maxwell *et al*., 2011). The quality of data was verified with COFECHA software (Holmes, 1983), which provides a statistical match between segments of each core and the master chronology that is made of the measurement that are entered into a program (Speer, 2010). The data analysis and statistics was performed using software package STATISTICA 10 (StatSoft 2010). At first, the age trends from the raw chronologies were removed to obtain a raw of stationary tree-ring indices by dividing each measured ring width by its expected value (Fritts, 1976). The expected value was calculated using the Korf´s increment function (Korf, 1939). Then, the index series, separately of each sampling plot, were averaged together to form two mean-value functions of the ring indices. We used the independent two sample t-test to verify the null hypothesis that the mean tree-ring indices of the control-site and the drained-site in the period 1985–2011 are equal. Moreover, in order to smooth out possible short-term fluctuations in our two time series in this period we used 5-year and 10-year moving average to highlight possible longer-term trend of the tree-ring indices.

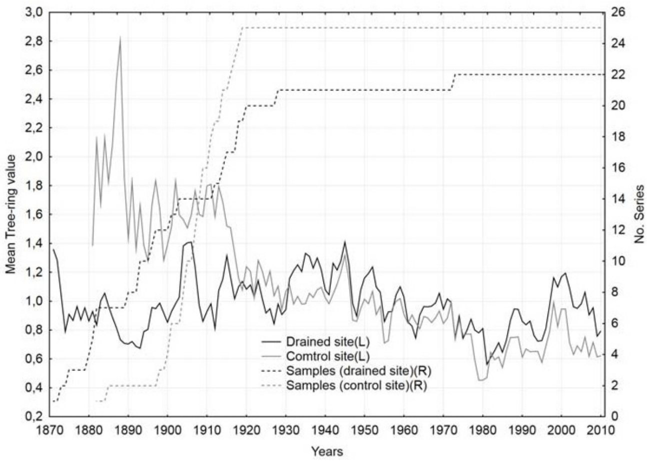

Fig. 2 (a). Chronological development (drained vs. control site) of the mean tree-ring widths and sample size (number of tree-ring series)

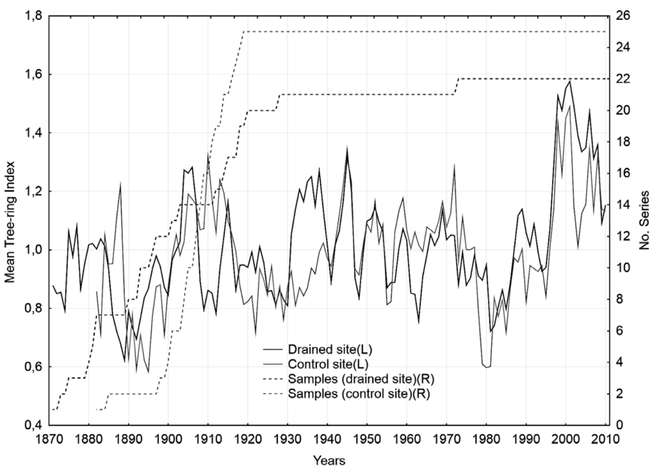

Fig. 2 (b). Chronological development (drained vs. control site) of the mean tree-ring index and sample size (number of tree-ring series)

3. Results

The chronological development (drained vs. control site) of the mean tree-ring widths, the mean tree-ringindex and sample size (number of tree-ring series) on which the mean-value functions of the ring widths and indices were developed – Figure 2(a),(b), show in the period after 1940 very similar radial-growth trends. The variability of growth representing the period prior to 1940 can be attributed to reduced sample size (the period prior to 1910). Likewise, the different variability of age structure (drained vs. control site) indicates diverse regeneration conditions on individual stands – an undergrowth origin of the drained site vs. an open-growth origin of the control site. The data analysis revealed the time span of samples, average number of tree-rings and its variability (Table 2).

The impact of drainage is analysed in detail of the period 1985 – 2011 in Figure 3 (a), which shows the standartized mean tree-ring index (drained vs. control site) in this period. However, the radial-growth trends show in their development after the year 1992 very similar without an evident impact of drainage to the tree growth. Furthermore, we used the moving average to smooth out possible short-term fluctuations in our two time series in this period to highlight possible longer-term trend of the tree-ring indices, as shown in Figure 3 (b): 5-year moving average and in Figure 3 (c): 10-year moving average. Likewise, with use of moving averages, there is not a sign of significant change in the tree growth on the drained site vs. the control site.

Table 2. Statistical data of the control and drained site

Stand	Number of samples	Time span	Average number of tree-rings	Tree age-standard deviation	Tree age-coefficient of variation	Average DBH
Control site	25	130	108.0	8.3	0.08	24.34
Drained site	22	144	115.3	20.2	0.18	26.46

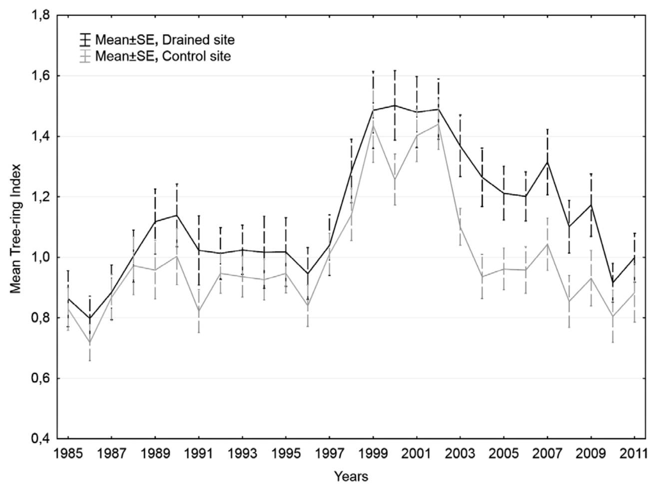

Fig. 3 (a). Standartized mean tree-ring index in detail of the period 1985–2011

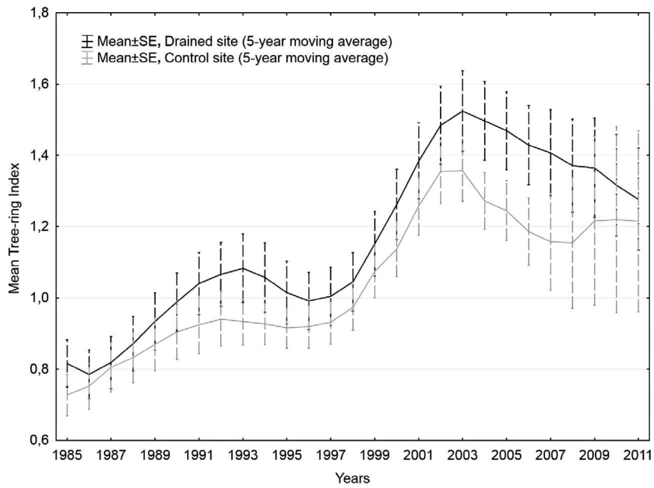

Fig. 3 (b). Standartized mean tree-ring index in detail of the period 1985–2011: 5-year moving average

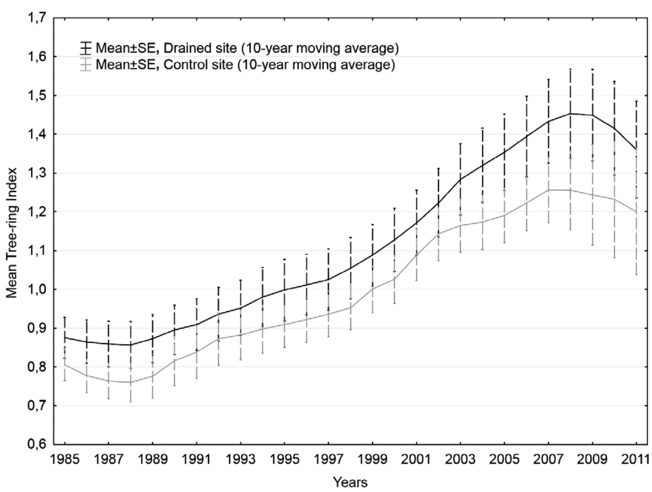

Fig. 3 (c). Standartized mean tree-ring index in detail of the period 1985–2011: 10-year moving average

Table 3. Results of independent two sample t-test in detail of the period 1985–2011 (t – value, p – value, df = 45)

T-test control site vs.drained site 1985 – 2011						
Years	Individual		5-year moving average		10-year moving average	
	t-value	p	t-value	p	t-value	p
1985	0.295	0.769	0.997	0.324	0.884	0.381
1986	0.827	0.413	0.357	0.723	1.137	0.262
1987	0.141	0.888	0.128	0.898	1.211	0.232
1988	0.251	0.803	0.374	0.710	1.240	0.221
1989	1.111	0.272	0.588	0.560	1.188	0.241
1990	0.980	0.332	0.755	0.454	0.938	0.353
1991	1.894	0.065	0.978	0.333	0.766	0.448
1992	0.622	0.537	1.082	0.285	0.701	0.487
1993	1.177	0.245	1.316	0.195	0.953	0.346
1994	0.531	0.598	1.185	0.242	0.984	0.330
1995	-0.203	0.840	0.972	0.336	0.952	0.346
1996	0.929	0.358	0.734	0.467	0.976	0.334
1997	0.533	0.597	0.716	0.478	1.024	0.311
1998	1.133	0.263	0.702	0.486	1.157	0.253
1999	0.499	0.620	0.663	0.511	1.056	0.297
2000	1.531	0.133	1.004	0.321	1.114	0.271
2001	0.634	0.530	0.935	0.355	0.939	0.352
2002	0.609	0.546	0.928	0.359	0.920	0.363
2003	2.387	0.021	1.203	0.235	1.068	0.291
2004	2.369	0.022	1.686	0.099	1.296	0.202
2005	1.176	0.246	1.648	0.106	1.455	0.153
2006	0.854	0.398	1.667	0.102	1.489	0.144
2007	0.350	0.728	1.358	0.181	1.403	0.167
2008	0.537	0.594	0.938	0.353	1.259	0.214
2009	0.095	0.925	0.521	0.605	1.058	0.296
2010	-0.162	0.872	0.313	0.756	0.815	0.419
2011	0.098	0.922	0.206	0.838	0.728	0.471

The result of the independent two sample t-test for the period of 1985–2011 has not revealed any substantial statistically important difference in the mean index between the control site and drained site (Table 3).

4. Discussion

Our results not revealed any statistically important difference in tree growth between the unaffected control site and drained site after the year 1992. In naturally forested peatlands and wetlands, tree growth is generally dependent on hydrological variations because the high water table level significantly limits tree growth (Macdonald, Yin, 1999). Thus, drainage of peatlands for forestry purposes aims at removing the restrictive role of naturally high water table levels on tree growth (Hokka *et al*., 2012). Alteration of the hydrological regime causes lowered groundwater levels, shifts between evapotranspiration and evaporation and gradual changes, such as an expanded root zone, increased interception, etc. (Iritz *et al*., 1994). In one study of tenth-year growth and yield improvements of black spruce in a forested Ontario peatland, the Wally Creek area, a response to drainage took about five to seven years (McLaren, Jeglum, 1998). Even though hydrological conditions of our drained site had been significantly altered, this fact did not enhanced tree growth in following 7-years period compared to the control site.

One important limiting factor might be the age of a forest stand at the time of drainage. Some older studies carried out in the former USSR by Piawczenko, Sabo, 1962 (Socha, 2012) indicated, that Norway spruce may still respond to drainage at ages over 100 years. In the study of growth of black spruce, a response occurred primarily in trees that were young to middle-aged at the time of drainage (MacDonald, Yin, 1999). In case of Scots pine, it was found that the asymptote for height growth is a function of stand age and the timing of drainage (Hokka, Ojansuu, 2004). Based on one study focused on a long-term effect of wetland drainage on the productivity of Scots pine in Poland, the effect of drainage depended primarily on the age of the stand at the time of drainage; a positive growth response (i.e., an increase in height) was observed in stands that were younger than 45–50 years at the time of drainage; stands older than 50 years at the time of drainage were assumed to be unaffected (Socha, 2012). In our study, the affected site was drained in the year 1992, at the time when the average age of the stand, based on the collected samples, reached 105–110 years. This average age is in line with the age stated in related forest management plan, which indicates the average age of 110 years. The result of our study has not revealed the ability of Norway spruce to respond to drainage at ages over 100 years.

Another important limiting factor might be the fact, that the response of trees to drainage is influenced with a capability of a tree to utilize deeper soil layers with its root system (Schweingruber, 2007). From the comparison of Norway spruces growing on the well-drained and poorly drained sites resulted, that the root systems were two times shallower in poorly drained sites than in well-drained ones and the horizontal development of root biomass was detrimental to roots penetrating vertically (root systems in these sites were broader by one-third units than those in well-drained sites) (Konôpka, 2002). Likewise, trees grown on wet sites need larger root systems for oxygen and nutrient uptake (Tobin *et al*., 2007) and have larger belowground biomass expressed on stem diameter at waterlogged than well-drained soils (Konôpka *et al*., 2010). Thus, drainage of soil is assumed to stimulate stem increment owing to increased ration for carbohydrates allocation between stem and root system. However, the weak reaction of threes to soil drainage in our study could be limited with the fact, that in the average age of 105–110 years, trees were not already able to adapt their root systems to modified water table level.

At both sites, there is evident a significant growth reduction between the years 1970 – 1980 as well as the following recovery of growth and the rapid increase of the mean radial increment, which might be attributed to the increase and following significant reduction of SO_2 emission and climate change. A recent study of silver fir (*Abies alba* Mill.) in Southern Germany provided clear evidence that SO_2-immissions play a key role in such decline and that tree growth corresponds with the regional and temporal pattern of SO_2 pollution (Elling *et al*., 2009). In another study in Harz Mountains in Germany, SO_2 pollution caused reduced tree-ring width in Norway spruce (*Picea abies* L. Karst.) and a rapid recovery of stem growth after the reduction of SO_2 emission (Hauck *et al*., 2012). The recent climate-growth relationships of silver fir (*Abies alba* Mill.) was investigated in the Western Carpathians in Slovakia as well (Bošeľa *et al*., 2014). The results of this study provide clear evidence of significant increase of silver fir's radial increment over the entire Western Carpathian area since 1970 – 1980 and the assumption that the most probable factors behind the rapid recovery of tree radial increment were reductions in emissions of NO_3 and SO_2, alongside a significant increase in mean June, July and April temperatures.

The data analysis in our study further indicated, that trees situated on the drained site have obviously a higher average annual radial increment during their existence. Due to the fact, that even very small differences in the site condition influence growth (Schweingruber, 2007), we can attribute this variance to a slightly different terrain conditions and stand exposure: while the control site has the northern exposure, the drained site benefits from its southern exposure. Moreover, the area of the drained site was historically under stronger anthropogenic influence, hence we estimate other interventions in its hydrological conditions somewhere around 1930, in spite of exact historical records are not available. Thus, the drained site might benefit over a long period from lower water table level. Generally, it is possible to assume that young to middle-aged trees respond better to drainage and build a deeper root system, which is an advantage in the period of drought like in the year 2003 (Meteorological Station Fichtelberg, Deutscher Wetterdienst), when the recent differences between the mean tree-ring width started.

5. Conclusions

The mean-value functions of the ring indices, comparing the affected site with the control site, showed in the period after 1940 very similar radial-growth trends. In the year 1992, the water regime of the drained site was substantially altered due to construction of numerous drainage ditches with aim to improve tree growth. However, the radial-growth trends show in their development after the year 1992 very similar radial-growth trends without an evident impact of drainage to the tree growth. In order to smooth out possible short-term fluctuations, we used 5-year and 10-year moving average to highlight possible longer--term trend of the tree-ring indices. Likewise, there is not a sign of significant change in the tree growth on the drained site vs. the control site. The result of the independent two sample t-test has not revealed any substantial statistically important difference in the mean index between the control site and drained site.

The obtained results are a source of further information in order to understand better the growth dynamics of peatland Norway spruce forests to be able to manage effectively its protection. At the same time, the study shows, that human intervention in such ecosystems should be beforehand carefully analyzed from different point of views, because not always bear expected results. In further study at the field the following effect to be analysed: the impact of drainage response in trees young to middle-aged at the time of drainage; the effects of soil drainage to tree stability and health status; influence of climate variables and air pollutants to the growth of trees.

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Souhrn

Rašelinné smrčiny představují velmi cenné ekosystémy se značným významem pro ochranu přírody. Protože není doposud k dispozici mnoho dendroekologických studií růstových charakteristik smrku ztepilého (*Picea abies* L. Karst.) na rašelinných stanovištích střední Evropy, byl v oblasti Krušných hor v západní části ČR (obr. 1) proveden dendrochronologický průzkum, porovnávající vliv odvodnění stanoviště ve věku porostu přesahujícím 100 let na radiální přírůst kmene smrku ztepilého. V oblasti NPR Božídarské rašeliniště byly odebrány vývrty ze čtvercových výzkumných ploch (50*50 m) z porostu odvodněného v roce 1992 ("drained site") a kontrolního stanoviště ("control site") – základní charakteristiky porostů uvádí tabulka 1. Z každé plochy bylo odebráno 25 vývrtů ve výšce 1,3 m, z každého stromu po 1 vývrtu a změřena výčetní tloušťka vzorníku. Nepoškozené vývrty byly změřeny a datovány v softwaru WinDENDRO 2009b (RIC and Inc.) 2009), kvalita dat ověřena v software COFECHA (Holmes, 1983). Statistická data odebraných vývrtů uvádí tabulka 2. Standartizace byla provedena za použití Korfovy přírůstové funkce (Korf, 1939) v software STATISTICA10 (StatSoft 2010). Byly vytvořeny řady průměrných šířek letokruhů a statisticky porovnány průměrné hodnoty letokruhových indexů. Vývoj časové řady průměrných šířek letokruhů (obr. 2 a) a letokruhových indexů (obr. 2 b) je po roce 1940 velmi podobný. Rozdílný trend přírůstů před rokem 1940 je značně ovlivněn sníženým počtem vzorků (viz obr. 2 a,b "No. Series"), zejména před rokem 1910. Vliv odvodnění je detailně analyzován za období 1985–2011 (obr. 3a) a porovnává vývoj průměrného letokruhového indexu (odvodněná vs. neodvodněná lokalita) v tomto období. Časová řada průměrných letokruhových indexů po roce 1992 má velmi obdobný trend, bez evidentního vlivu odvodnění na radiální přírůst. Použití 5-ti a 10-ti letých klouzavých průměrů k eliminaci krátkodobých výkyvů časové řady tento stejný trend ještě více zdůraznilo (obr. 3 b,c). Výsledky dvouvýběrového t-testu pro období 1985 – 2011 neodhalily podstatný statisticky významný rozdíl v hodnotách průměrného letokruhového indexu (tab. 3), což naznačuje velmi slabou odezvu radiálního přírůstu starších stromů na odvodnění stanoviště.