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Thinning effects on forest productivity and site characteristics in stands of *Pinus sylvestris* in the Czech Republic

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Abstract

A clear-cutting system with soil preparation before replanting is usual for Scots pine stands in many European countries. Additionally, thinning regimes are applied during the rotation. Thus, forest floor is recreated in each rotation and can be influenced by thinning regime. The present study aimed to determine possible effects of thinning on production (evaluated by basal area) and forest-floor status (evaluated by dry mass, carbon and nitrogen content) in pine stands. We used data from four experiments established in 1962 in 25- to 45-year-old pine stands. In 2008, we analysed forest-floor characteristics under the observed stands. The results from basal area evaluation showed different development in treatments on all experiments during and at the end of observation. We observed substantial, but statistically non-significant, differences between treatments in quantity of dry mass (and of carbon and nitrogen) accumulated in humus horizons under Scots pine stands more than 40 years after first thinning.
Key words: thinning; forest floor; carbon; nitrogen; Scots pine.

Resumen

Efectos de las claras en la productividad forestal y características del sitio en rodales de *Pinus sylvestris* en la República Checa

En muchos países europeos es habitual un sistema de tala rasa con preparación del suelo antes de la plantación para pino silvestre. Además, se aplican regímenes de claras durante la rotación. Por lo tanto, el suelo forestal se recrea en cada rotación y puede ser influenciado por el régimen de claras. El presente estudio tuvo como objetivo determinar los posibles efectos de las claras en la producción (evaluada por el área basal) y el estado del suelo forestal (evaluado por peso seco, contenido de carbono y nitrógeno) en los rodales de pino. Se utilizaron datos de cuatro experimentos, iniciado en 1962 en rodales de 25 a 45 años de edad. En 2008, se analizaron las características de suelo forestal de los rodales. Los resultados de la evaluación de área basal mostraron un crecimiento diferente entre los tratamientos en todos los experimentos durante y al final del periodo de observación. Se han observado diferencias importantes, pero estadísticamente no significativas, entre tratamientos en la cantidad de masa seca (y de carbono y nitrógeno) en el horizonte de humus acumulado en los rodales de pino silvestre durante más de 40 años después de la primera entresaca.
Palabras clave: clara; suelo forestal; carbono; nitrógeno; Pino sivestre.

Introduction

In Central Europe, Scots pine (*Pinus sylvestris* L.) monocultures are usually managed by a clear-cutting system with relatively intensive soil preparation before planting. The forest floor —an important part of a forest ecosystem— is thus recreated in each rotation, and this process can be relatively long. It is known that the maintenance of forest soil fertility is largely dependent on this periodic return of plant material, its decomposition, and the release of elements which are important in forest tree nutrition (Piene and Van Cleve, 1978).

Comparison with afforestation on former agricultural land is relevant. For example, Rosenqvist *et al.* (2010) reported that 60 to 90 years of forest development resulted in accumulation of a thick (6-8 cm) O layer with carbon contents comparable to those of soils in this region with a longer forest history.

From the sustainable management point of view, some studies (*e.g.* Johnson, 1992) have found that the stocks of both N and C in soil decreased after intensive scarification. On the other hand, Nordborg *et al.* (2006)

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reported that their results did not support the hypothesis that losses of C and N from the ecosystem or soil increase after deep (50 cm) soil cultivation. In spite of the fact that published findings differ, intensive soil preparation before planting is a relatively strong intervention in a forest ecosystem, and especially in relation to nutrient cycling. In context of sustainable forests management, there is a real question as to whether this system impacts on the productive capacity of the sites.

During the rotation, thinning regimes are applied in the pine stands. Historically, the main reason for thinning is to influence wood production. Especially in soils with low nutrient stocks, however, stands should be thinned also to increase the transmittance of light, subsequent decomposition activity of the microflora, and ultimately the turnover of nutrients (Augusto *et al.*, 2002). Thinning's effects on litter decomposition beneath pine stands have been reported several times (*e.g.* Berg and Ekbohm, 1993; Pausas, 1997; Lorenz *et al.*, 2004; Blanco *et al.*, 2006; Hilli *et al.*, 2008), but long-term studies based on precisely known history of an entire stand are not so frequent.

The purpose of this study was to determine the effect of management (thinning) on production characteristics and site conditions status in Scots pine stands at sites typical for pine forests both in the Czech Republic and in Central Europe generally. Concretely, we observed the effect of thinning on stand basal area and quantities of dry mass, carbon and nitrogen in humus horizons under Scots pine stands.

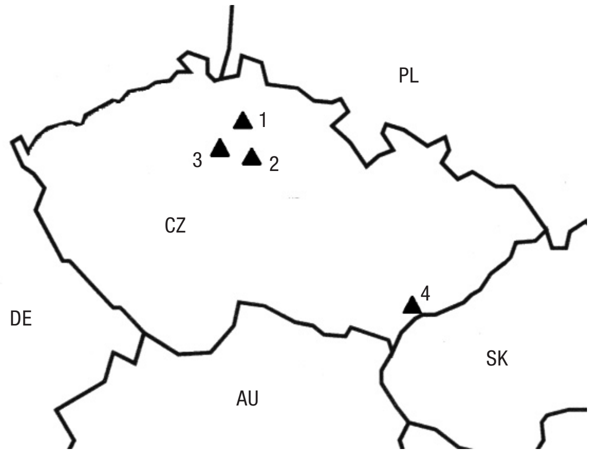

Figure 1. Location of the experiments in the Czech Republic (1: Boleslav. 2: Kersko. 3: Melnik. 4 : Straznice).

Material and methods

We used data from four experimental sites established in 1962 in 25- to 45-year-old pine stands (Fig. 1, Table 1). The thinning experiments were established in order to find the effect of thinning on production and stability of pine stands. According to data from the Czech Hydrometeorological Institute, during the pe-

Table 1. List of experimental sites with basic dendrometric characteristics (before thinning) at the start of experiments in 1962

Variables	Experimental sites							
	Boleslav		Kersko		Melnik		Straznice	
	C	T	C	T	C	T	C	T
Age (years)	26		34		45		33	
dg (cm)	9.1	8.8	14.3	13.8	13.5	13.5	11.9	11.8
G (m^2 ha^{-1})	26.7	25.7	35.8	37.8	33.7	34.6	37.6	38.3
N (trees ha^{-1})	4,092	4,244	2,232	2,532	2,356	2,432	3,384	3,528
h_{dom} (m)	11.9	12.6	17.2	17.6	17.1	17.6	13.5	13.9
Co-ordinates in the WGS 1984 system	50° 30' 15" 14° 53' 16"		50° 08' 40" 14° 55' 38"		50° 13' 34" 14° 44' 20"		48° 56' 40" 17° 12' 16"	
Forest type according to Viewegh *et al.* (2003)	(*Querceto*)-*Pinetum oligotrophicum*		(*Carpineto*)-*Quercetum mesotrophicum*		*Pineto-Quercetum oligotrophicum* (*arenosum*)		*Pineto-Quercetum oligotrophicum* (*arenosum*)	
Elevation (m)	280		185		192		207	

C: control plot. T: thinned plot. dg: diameter at breast height. G: basal area. N: number of trees. h_{dom}: top height (height of 200 thickest trees per hectare).

riod 1961-2000, mean annual precipitation was approximately 500 mm and mean annual temperature ranged from 8.6 to 9.0°C for all the investigated sites.

Stands had been planted with initial densities of 6,000-10,000 trees per hectare and intensive soil preparation (stump extraction and ploughing) used before planting.

All experimental sites consist of two comparative plots (each with an area of 0.25 ha, *i.e.* 50 × 50 m) with and without thinning, separated by isolation strip with minimal width 50 m. Within the experimental sites, treatments are not replicated. Unthinned plots are designated as «Control». Positive selection from above was used in the thinned plots, designated as «Thinned».

The experiments are surveyed as a rule in five-year periods at the end of vegetation-season and all trees are measured by callipers in mm over bark (diameter at breast height) and group of sample trees (according to current diameter distribution) are measured by altimeter Blume-Leiss (total height).

Thinning with positive selection from above was conducted in accordance with the principles of Schädelin (1942). In young stands before the first experimental thinning, 500-1,500 future crop trees per hectare, *i.e.* the centers of stand «cells» were selected and released by removing one or two of the most vigorous competitors. Every future crop tree with the best stem and crown form should be surrounded by several alternates. The crop tree (as a rule from higher tree classes) and alternates comprise a so-called stand cell. Thinning focused on releasing growing space for future crop trees' crowns and creating suitable growing conditions so that high quality increment was created on superior individuals. Dead, ill or damaged trees were removed except where they supported the selected future crop trees. After the culmination of height growth, approximately 500 of the best crop trees (per hectare) were selected and their crowns were kept free by removal of adjacent individuals. First thinning began in 1962.

Control plots were used for investigation of natural mortality in a stands and for comparison with investigated thinning variants. All stand characteristics are measured in the same way as on comparative plots with thinning, but intentional silvicultural treatments are omitted. Only dead, broken or uprooted trees are removed.

In autumn 2008, forest-floor humus horizons L, litter; F, fermentation, and H, humus (according to Green *et al.,* 1993) were sampled quantitatively and qualitatively on identical comparative plots. We used steel frames (25 × 25 cm) to define sampling area at six replications in each plot (C, Control, and T, Thinned). All samples were dried, first in open air, then in a laboratory oven at 80°C, and subsequently weighed to determine dry mass. Totally 48 samples of dry mass were analysed (6 samples × 2 treatments × 4 experimental sites).

Additionally in horizons F and H, we measured the concentration of oxidizable carbon (C_{ox}) from composite samples (three per treatment) using spectrophotometric determination of organic carbon in soil via oxidation by a chromosulphuric mixture and colorimetric analysis (Walinga *et al.,* 1992). Nitrogen content was determined from composite samples (three per treatment) after mineralization by mineral acids and analysed using the Kjeldahl procedure. Totally 24 samples of dry mass were analysed (3 composite samples × 2 treatments × 4 experimental sites).

Two-tailed paired t test (Unistat, 2000) was used to test for differences between treatments in the case of dry mass in horizon L, F, H and L + F + H and amount of nitrogen and carbon in horizons F and H. In order to avoid pseudoreplication, mean of the samples for each experimental unit (particular plot) was used. None of the variables were transformed.

Relationship between basal area and dry mass stored in forest-floor was showed by calculation of ratios (Control/Thinned) of periodic mean basal area (G10, last ten years; G20, last twenty years; G30, last thirty years; G40, last forty years) and ratios (Control/Thinned) of amount of dry mass in humus horizon in 2008. This relationship was calculated only for horizon H, because of the highest differences between treatments in dry mass stored in this horizon in all experimental sites.

Results

Growth

During the investigation extending over more than 40 years, the basal areas of the Control and Thinned plots exhibited different trends (Fig. 2, Table 2). Experiments started at stand ages of 26 (Boleslav), 34 (Kersko), 45 (Melnik) and 33 (Straznice) years. The initial basal areas were 26-27, 36-38, 34 and 38 m^2 ha^{-1} for the Boleslav, Kersko, Melnik and Straznice series, respectively.

After the third experimental thinning (ten years from the start of experiments), the basal area of the Control

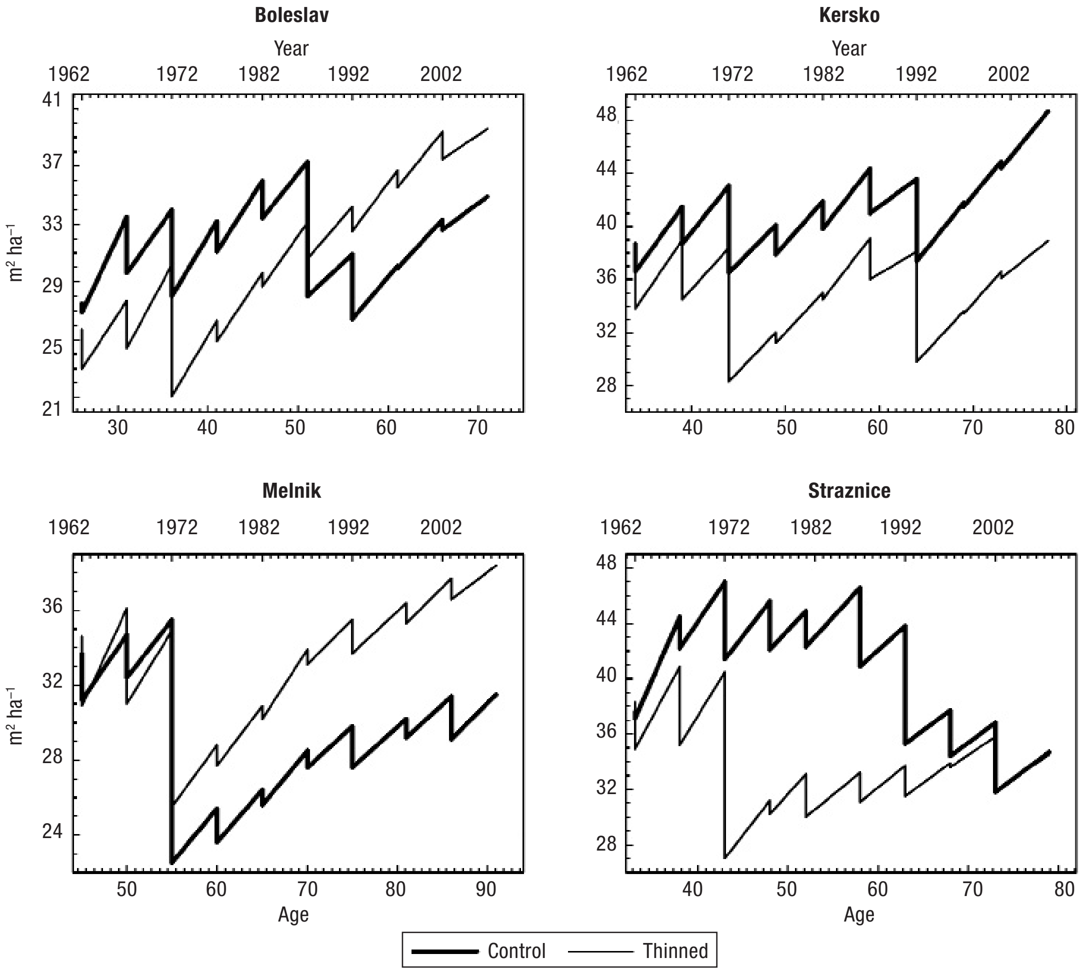

Figure 2. Basal area development on experimental sites in pine stands (Control: salvage cutting only. Thinned: positive selection from above).

and Thinned plots began to differ substantially. Essentially, we found two types of basal area development within the observed experimental sites.

(1) Two experimental sites (Straznice and Kersko) showed continual substantially higher basal area on the Control plots. These differences continued to the end of the study on both sites with the exception that on the Straznice site the basal area of the Control and Thinned plots showed only small differences at the final, 10th year of observation. At the end of observation the basal areas on the Kersko site were 49 and 39 m^2 ha^{-1} on Control and Thinned plots, respectively. On the Straznice site, the basal areas were 35 m^2 ha^{-1} for both Control and Thinned treatments.

(2) Two experimental sites (Boleslav and Melnik) exhibited a change of basal area development during the period of observation. Thinned treatments displayed a higher basal area after the third (Melnik) and sixth (Boleslav) thinnings due to severe salvage cutting (snow damage) on the Control plots. These differences continued to the end of the observation period for both sites. At the end of observation, the basal areas on the Melnik site were 31 and 38 m^2 ha^{-1} and on the Boleslav site 35 and 40 m^2 ha^{-1} on Control and Thinned plots, respectively.

Dry mass of humus layers

Stored dry mass (*i.e.* needles, twigs, cones and mosses) were in a range of 6.1-10.2 Mg ha^{-1} in the humus horizon L (Table 3). Differences between treatments were statistically non-significant (p-value 0.75). The highest difference within individual site was observed in the case of the Kersko site, where we found about 28% greater dry mass in this horizon on Thinned plots

Table 2. Development of basic dendrometric characteristics (main stand, *i.e.* after thinning) during the period of observation 1962-2007

Year	Variables	Boleslav C	Boleslav T	Kersko C	Kersko T	Melnik C	Melnik T	Straznice C	Straznice T
1962	Age (years)	26	26	34	34	45	45	33	33
	dg (cm)	9.4	8.9	15.0	14.6	13.8	13.6	12.0	11.8
	G (m^2 ha^{-1})	26.1	23.0	32.5	33.8	31.2	30.9	37.1	34.9
	N (trees ha^{-1})	3,760	3,720	1,852	2,020	2,088	2,112	3,264	3,192
	h_{dom} (m)	11.9	12.6	17.2	17.6	17.1	17.6	13.5	13.9
1967	Age (years)	31	31	39	39	50	50	38	38
	dg (cm)	11.4	10.6	16.6	16.3	15.3	15.7	13.7	13.2
	G (m^2 ha^{-1})	28.9	24.4	30.7	34.5	32.4	31.0	42.2	35.2
	N (trees ha^{-1})	2,856	2,748	1,424	1,652	1,760	1,608	2,844	2,568
	h_{dom} (m)	15.8	15.3	20.4	20.6	18.7	19.5	16.0	16.9
1972	Age (years)	36	36	43	43	55	55	43	43
	dg (cm)	13.8	14.0	19.4	19.2	17.1	18.3	15.6	16.3
	G (m^2 ha^{-1})	28.0	21.1	27.1	28.3	22.5	25.5	41.4	27.0
	N (trees ha^{-1})	1,868	1,368	916	976	984	968	2,168	1,292
	h_{dom} (m)	17.2	17.9	21.8	22.4	19.9	20.6	18.4	18.9
1982	Age (years)	46	46	53	53	65	65	53	53
	dg (cm)	17.9	18.6	22.8	22.1	19.8	21.4	18.2	19.5
	G (m^2 ha^{-1})	33.2	28.7	31.5	34.5	25.6	30.2	42.3	30.0
	N (trees ha^{-1})	1,320	1,064	768	900	832	840	1,624	1,008
	h_{dom} (m)	21.8	21.2	25.0	25.2	23.1	23.5	21.7	22.3
1992	Age (years)	56	56	63	63	75	75	63	63
	dg (cm)	22.2	22.8	26.9	25.7	22.9	24.7	22.0	22.9
	G (m^2 ha^{-1})	26.4	32.5	30.5	29.8	27.6	33.7	35.3	31.5
	N (trees ha^{-1})	684	800	536	576	668	704	936	764
	h_{dom} (m)	24.1	24.0	27.9	28.2	25.6	26.6	24.3	24.7
2002	Age (years)	66	66	73	73	85	85	73	73
	dg (cm)	25.7	26.5	30.0	28.6	25.4	27.0	24.9	25.6
	G (m^2 ha^{-1})	32.6	37.5	37.3	36.1	29.1	36.6	31.9	31.9
	N (trees ha^{-1})	644	680	528	564	576	640	656	620
	h_{dom} (m)	27.2	26.7	29.7	29.9	26.6	27.4	25.0	25.2
2007	Age (years)	71	71	78	78	90	90	78	78
	dg (cm)	26.3	27.2	31.2	29.6	26.4	27.6	25.9	26.6
	G (m^2 ha^{-1})	34.9	39.6	40.2	38.9	31.5	38.4	34.7	34.5
	N (trees ha^{-1})	644	680	528	564	576	640	656	620
	h_{dom} (m)	28.3	28.1	30.1	30.1	27.4	28.1	25.3	25.5

C: control plot. T: thinned plot. dg: diameter at breast height. G: basal area. N: number of trees. h_{dom}: top height (height of 200 thickest trees per hectare).

compared to Control plots, mainly due to higher quantities of mosses under the Thinned plot.

In the F horizon, we found 13.9-31.9 Mg ha^{-1} of dry mass. Differences between Control and Thinned treatments were statistically non-significant (p-value 0.72).

The greatest quantity of dry mass was found in the H horizon: 31.3-117.0 Mg ha^{-1}. In comparing Control and Thinned treatments, we found substantially lower dry mass stored in this horizon under Thinned stands in two sites, Straznice (about 54%) and Kersko (about 44%). On the other hand, the amount of dry mass in horizon H was higher (by about 6%) in Thinned plots compared to Control plots in the Boleslav and Melnik sites. That is one reason why the differences were statistically non-significant (p-value 0.31).

Table 3. Amount of dry mass (DM), oxidizable carbon (C_{ox}) and total nitrogen (N_{tot}) in the horizons under control unthinned (C) and thinned (T) pine stands

Horizon	Variables		Boleslav C	Boleslav T	Boleslav %*	Kersko C	Kersko T	Kersko %*	Melnik C	Melnik T	Melnik %*	Straznice C	Straznice T	Straznice %*
L	DM	Mean	8.9	9.8	110	6.1	7.8	128	9.1	8.6	95	10.2	9.1	89
p = 0.75	(Mg ha^{-1})	SD	3.4	2.8		0.8	1.0		2.2	2.3		4.2	4.3	
F	DM	Mean	31.9	27.3	86	13.9	16.5	119	16.3	22.8	140	19.1	18.3	96
p = 0.72	(Mg ha^{-1})	SD	8.8	7.1		4.5	1.0		7.9	8.3		2.6	1.9	
	Cox	Mean	12.8	12.7	99	5.1	6.2	122	3.6	6.5	181	6.2	6.3	102
p = 0.24	(Mg ha^{-1})	SD	7.6	3.8		2.7	1.4		1.0	0.8		1.8	1.1	
	Ntot	Mean	502.5	503.8	100	234.2	289.5	124	202.9	294.2	145	316.6	281.9	89
p = 0.39	(kg ha^{-1})	SD	176.0	160.9		90.0	14.4		57.3	41.5		21.6	48.2	
H	DM	Mean	61.7	65.7	106	102.9	45.4	44	110.1	117.0	106	57.8	31.3	54
p = 0.31	(Mg ha^{-1})	SD	14.3	20.4		21.4	5.2		14.0	13.2		18.9	11.9	
	Cox	Mean	19.2	17.1	89	24.0	12.0	50	22.6	28.2	125	8.4	3.4	40
p = 0.42	(Mg ha^{-1})	SD	5.4	7.8		3.8	4.0		6.5	6.9		5.2	0.9	
	Ntot	Mean	894.6	712.8	80	1,346.8	732.6	54	941.0	1,264.5	134	586.9	256.9	44
p = 0.38	(kg ha^{-1})	SD	30.4	254.4		251.6	66.4		87.8	303.9		144.8	67.2	
LFH	DM	Mean	102.5	102.8	100	123.0	69.7	57	135.5	148.4	110	87.1	58.6	67
p = 0.33	(Mg ha^{-1})	SD	15.7	22.4		20.3	4.7		23.3	23.2		22.3	14.8	

SD: standard deviation. p: probability value from paired t-test. * Ratio between values in thinned plot compared to control plot (100%).

Altogether, horizons L + F + H contained 58.6-148.4 Mg ha^{-1} of dry mass. Differences between treatments were substantial only in the cases of the Straznice and Kersko sites, *i.e.* where the differences were substantial in horizon H as well.

Content of carbon and nitrogen in humus layers

Different dry mass values in the humus layers resulted in a similar picture for accumulated oxidizable carbon (C_{ox}) (Table 3). In horizon F, from 3.6 (Control plot at Melnik) to 12.8 (Control plot at Boleslav) Mg ha^{-1} of C_{ox} was stored. A higher amount about 22 and 81% of C_{ox} in Thinned plots compared to Control plots was found at Kersko and Melnik, respectively. On the other hand, only small differences (1-2%) between Control and Thinned plots were found in this horizon at Boleslav (12.8 and 12.7 Mg ha^{-1}) and Straznice (6.2 and 6.3 Mg ha^{-1}).

In horizon H, we found from 256.9 (Thinned plot at Straznice) to 1,346.8 (Control plot at Kersko) kg ha^{-1} of N_{tot}..

The amount of nitrogen (N_{tot}) in observed humus horizons displayed trends similar to those for the carbon results (Table 3). Higher amounts of N_{tot} about 24 and 45% in Thinned compared to Control plots were found at Kersko and Melnik in horizon F. On the other hand, this horizon under the Thinned plot showed the same (100%) or lower (89%) amounts of N_{tot} compared to Control plot at Boleslav and Straznice.

In horizon H, we found from 256.9 (Thinned plot at Straznice) to 1,346.8 (Control plot at Kersko) kg ha^{-1} of N_{tot}. A lower amount of N_{tot} in Thinned plots compared to Control plots 44, 54 and 80% was found at Straznice, Kersko and Boleslav, respectively. As in the case of carbon, horizon H under the Thinned plot showed a greater amount of N_{tot} (about 34% compared to Control plot) at Melnik.

Relationship between growth and status of humus layers

As it was mentioned above, relationship between stand basal area and dry mass in forest-floor was showed by calculation of ratios (Control/Thinned) of periodic mean basal area (G10, last ten years; G20, last twenty years; G30, last thirty years; G40, last forty years) and ratios (Control/Thinned) of amount of dry mass in

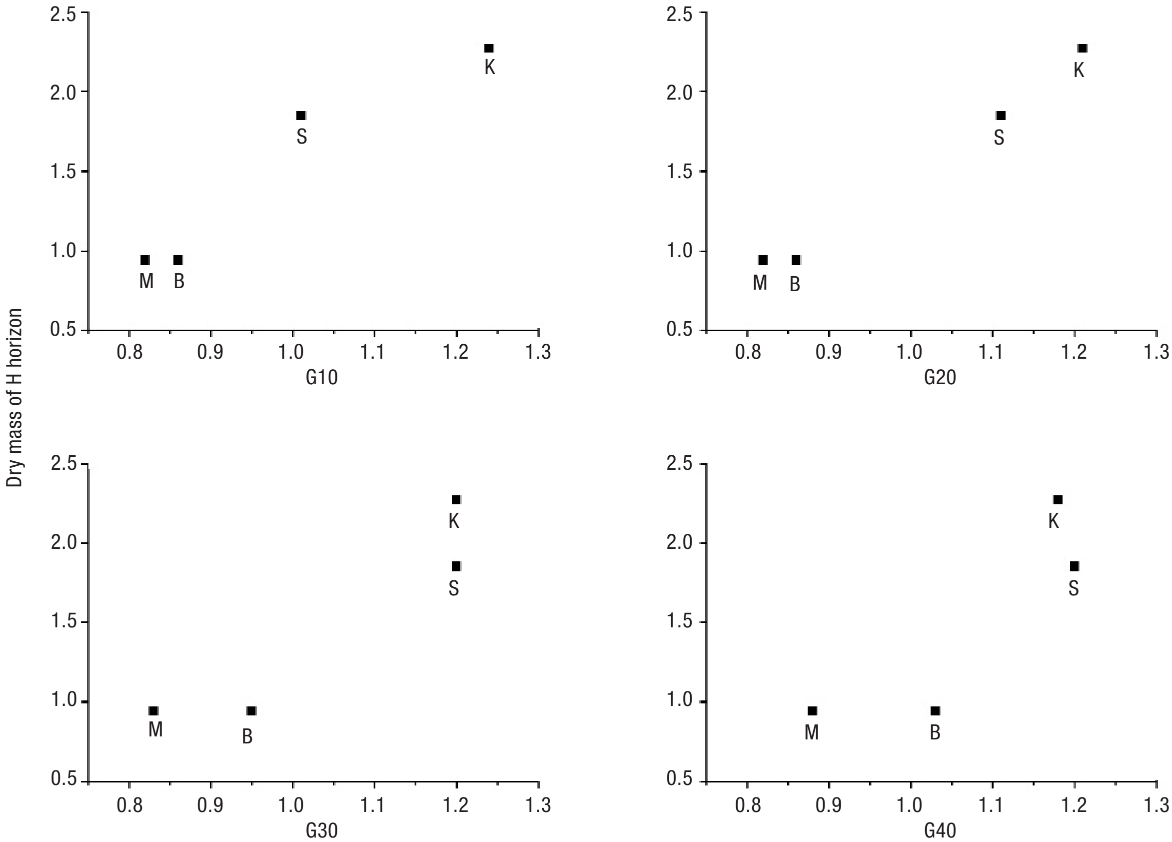

Figure 3. Relationship between ratios (control/thinned) of periodic mean basal area (G10: last ten years. G20: last twenty years. G30: last thirty years. G40: last forty years) and ratios (control/thinned) of amount of dry mass in horizon H in 2008. Experimental sites: B, Boleslav; K, Kersko; M, Melnik; S, Straznice.

humus horizon H (which showed the highest differences between treatments in all experimental sites) observed in 2008 (Fig. 3).

Results showed the trend between ratios of periodic mean basal area and ratios of dry-mass amount in horizon H. The higher ratio of basal area, the higher ratio of dry-mass. This trend is more obvious in the case of periodic mean basal area for last twenty years (G20). For the ratios of periodic mean basal area G10, G30 and G40, this trend is not so evident.

Discussion

Our results from basal area evaluation showed different development in treatments on all sites during and at the end of observation. Basal areas were higher on Control plots during the main part of observation (Straznice and Kersko sites) or basal areas on Control plots decreased by salvage cut and were lower compared to those for Thinned plots (Boleslav and Melnik sites). In addition, the two last-mentioned sites showed different ratios between basal area values of Control and Thinned plots. Whilst the Thinned plot at Melnik showed higher basal area compared to the Control plot since the third revision, the basal area of the Thinned plot at Boleslav was higher compared to that for the Control after the sixth revision (*i.e.* in the second half of the observation period).

A certain ambiguity in findings can be explained by relatively late first thinning in the observed pine stands. For example, Pirogowicz (1983) and Huss (1983) had reported that intensive thinning in 50-year-old and older pine stands did not result in higher diameter increment. Accordingly, Juodvalkis *et al.* (2005) published that significant increase in volume increment is achievable with thinning only of young forest stands, *e.g.* pine, birch and ash 10-20 years old or oak, aspen and spruce 10-30 years old.

Although the experimental stands grow on relatively poor sites (especially at Melnik and Straznice), total basal area achieved from 70% (Control plot at Melnik) to 114% (Control plot at Kersko) of values for the best site index of Czech growth tables (Cerny *et al.*, 1996). According to these tables, pine stands located in the best site index +1(32) should have basal area of 42.1 and 43.5 m^2 ha^{-1} at ages 70 and 90 years, respectively.

Litter (L) horizons contained from 6.1 (Control at Kersko) to 10.2 (Control at Straznice) Mg of dry mass per hectare. We can compare this amount only with the published litterfall observations, because litterfall was not measured directly in our stands. Generally, annual litterfall is in a range of 2-4 Mg per hectare in Scots pine stands 60 to 90 years old (Viro, 1955; Perina and Vintrova, 1958; Hoffmann and Krauss, 1988; Pausas 1997; Augusto *et al.*, 2002). Thus, we can calculate that L horizons contain approximately 2-5 years of litterfall under the analysed pine stands and, consequently, the current L horizon was created only in the last few years. However, the composition of its individual parts (needles, twigs, cones, mosses) plays an important role in this horizon. This variation had probably resulted in non-significant differences (the highest were in relation to mosses content at Kersko) in the amount of dry mass in this horizon.

Altogether, the combined L + F horizons contained from 20.0 (Control at Kersko) to 40.8 (Control at Boleslav) Mg ha^{-1} of dry mass. We can compare these data with the 32.5 Mg ha^{-1} published by Komlenović (1997) or 25 Mg ha^{-1} reported by Podrázský (1995), although the pine stands investigated in those studies were only 30 years old.

Generally, our study found an effect of thinning on the amount of dry mass in the H horizon in the case of two sites (Straznice and Kersko), which showed long-term differences between Control (with higher basal area – see above for more details) and Thinned plots. Opening of the canopy (and consequently a decrease in basal area) resulted in reduction of dry mass in the H horizon at the end of the observation period.

This partly corresponds with findings of Sariyildiz (2008), who had shown that tree canopy can significantly alter litter decomposition rates of Scots pine. On the other hand, Will *et al.* (1983) had found that tree canopy density had little or no effect on litter decomposition rate or loss of nutrients. But their study was conducted during four years in a younger stand (14 years old) of *Pinus radiata* D. Don in Australia.

Total amount of dry mass in the L + F + H horizons reached from 87.1 to 135.5 Mg ha^{-1} on the Control plots. This amount is generally higher compared to earlier published findings. Forest-floor biomass per hectare ranged from 18 and 28 Mg (Kavvadias *et al.*, 2001) in a 25-year-old stand of *Pinus pinaster* Aiton and one 40 years old of *Pinus nigra* Arn., respectively, to 33 and 43 Mg (Gower and Son, 1992) in 28-year-old *Pinus Strobus* L. and *Pinus resinosa* Soland. stands, respectively. For Scots pine, forest-floor has been reported to be 60 Mg ha^{-1} in a 33-year-old stand (Podrázský 1995) or 46 and 71 Mg ha^{-1} in 49- and 63-year-old stands, respectively (Muys 1995).

The effect of thinning on forest-floor (L + F + H) biomass was substantial in the case of two sites (Straznice and Kersko), *i.e.* we found greater amounts of dry mass on unthinned variants (Controls). These series showed higher basal area on Controls in the long term. We observed the opposite trend at Melnik, where the Thinned variant showed greater basal area for a long period and the amount of forest-floor dry mass was higher compared to the Control. A third type of result was observed for the Boleslav site, where the ratio of basal area between the Control and Thinned variants changed approximately halfway through the observation period and forest-floor dry mass reached practically the same values under the two variants.

Different development of stand basal area ratio between Control and Thinned variant in individual experimental sites was reflected on different ratio of dry-mass stored in horizon H. These trends were clear mainly in the case of sites Kersko and Straznice, where stand basal area was lower long-term in Thinned plot compared to Control plot. From this perspective, past 20 years before sampling of humus layers seem to be the most important period.

In the H horizon, where the most substantial differences between treatments were found in our study, from 3.4 to 28.2 Mg ha^{-1} of C_{ox} was stored. Comparison with published studies is rather complicated because different methods of carbon analysis (C_{ox} or C_{tot}) had been used. Furthermore, some of the results represent all horizons, *i.e.* complete forest floor (Kavvadias *et al.*, 2001). For Scots pine stands, various amounts of carbon (for whole forest floor) have been found in published studies: 20-38 Mg ha^{-1} (Heinsdorf 1997), 177 Mg ha^{-1} (Fischer *et al.*, 2002) and 0.5-2.5 Mg ha^{-1} (Kurbanov *et al.*, 2007). Although the carbon content of forest floor is relatively variable under pine stands (Tolunay, 2009), we found a higher amount of C_{ox} in Control plots compared to Thinned plots in the Straznice, Boleslav and Kersko sites. On the other hand, horizon

H under the Thinned plot showed a greater amount of C_{ox} in the Melnik site. This corresponds with the results from dry mass investigation in our study.

The amounts of nitrogen in the F + H horizon showed relatively large differences between treatments and sites, ranging from 539 kg ha^{-1} (Thinned plot in Straznice) to 1,580 kg ha^{-1} (Control plot in Kersko). Comparable amounts (90-1,700 kg ha^{-1}) had been found in another study (Heinsdorf ,1997), but that had been for complete forest floor. For horizons F + H, Kavvadias *et al*. (2001) reported about 573-633 kg ha^{-1} under a 25-year-old *Pinus pinaster* stand and about 392-746 kg ha^{-1} under a 40-year-old *Pinus nigra* stand.

We found substantially (for the Straznice and Kersko sites) lower amounts of nitrogen and carbon in horizon H under thinned stands compared to unthinned stands. By contrast, Piene and Van Cleve (1978) had observed (in a 70-year-old stand of *Picea glauca*) higher percentage weight loss of elements (significant in the case of magnesium) from organic matter in a rigorously thinned plot than in the control. Nitrogen was an exception in this instance.

We found similar results in the literature in relation to carbon. For example, Vranova *et al.* (2009) had reported that higher intensity of thinning decreased total carbon content and C/N in the Ae horizon under young Norway spruce stands. Also, Vesterdal *et al.* (1995) had found significant reduction in organic layer carbon due to heavy thinning of Norway spruce stands in Denmark. On the other hand, Nilsen and Strand (2008) had observed no significant effects on carbon and nitrogen storage in soil in connection with increasing thinning intensity in Norway spruce stands. They had concluded that, in consideration of variability occurring within soils, a time period of 32 years after thinning is probably too short to detect soil carbon and nitrogen differences due to thinning.

Conclusions

On the basis of the observations from four experimental sites with thinning (by positive selection from above) in pine stands in the Czech Republic we can conclude:

— The results from basal area evaluation showed different development in treatments on all experiments during and at the end of observation. Basal area was higher on Control plots during the main part of observation (two sites) or basal area on Control plots decreased by salvage cutting and it was lower compared to Thinned plots (two sites).

— Consequently, we observed substantial, but statistically non-significant, differences between treatments in the case of dry mass accumulated in humus horizons under Scots pine stands more than 40 years after the start of thinning.

— The results obtained indicate that the thinning regime (positive selection from above) resulted in different (lower) quantities of accumulated humus, and consequently of carbon and nitrogen, especially in the H horizon under treated pine stands. This effect was substantial in the stands without high salvage cutting.

— Thus, we conclude that intensive thinning can contribute to lower accumulation of dry mass under Scots pine stands. This effect has an important impact on the sustainable management of Scots pine stands, which are usually managed by a clear-cutting system with relatively intensive soil preparation before planting. As a result of this intensive site preparation, the forest floor must be recreated in each rotation.

For further investigation of the effect of thinning on forest productivity and site characteristics in pine stands, a more detailed investigation is necessary (especially a higher number of replications).

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