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Analysis of biomass in young Scots pine stands as a basis for sustainable forest management in Czech lowlands

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Abstract

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Scots pine covers large areas on sandy soils in lowlands of the Czech Republic. These sites can be threatened by non-sustainable biomass removal after clear-cutting. Totally 14 young pine stands at 14–26 years of age were analysed. Particular biomass components were separated, weighed and analysed to investigate their biomass and nutrient contents such as N, P, K, Ca and Mg. Results showed that leaving slash (needles and branches) plus belowground biomass (stumps and coarse roots) on the site represents 51% of calcium, 62% of magnesium, 74% of nitrogen, 67% of phosphorus and 72% of potassium. The total nutrient pools (without fine roots) were 171–377 $kg \cdot ha^{-1}$ for nitrogen, 34–72 $kg \cdot ha^{-1}$ for phosphorus, 74–172 $kg \cdot ha^{-1}$ for potassium, 82–180 $kg \cdot ha^{-1}$ for calcium and 19–42 $kg \cdot ha^{-1}$ for magnesium. Needles and live branches are the most important pools of nutrients and the extraction of these parts of biomass can negatively affect the nutrient balance of forest stands on nutrient-poor sites. Stumps with coarse and fine roots also represent a significant pool of nutrients which is left on the studied sites.

Keywords: nutrients; nutrient-poor sites; *Pinus sylvestris* L.; crown; stem; roots

Scots pine (*Pinus sylvestris* Linnaeus) is the second most important commercial conifer in the Czech Republic. Nowadays, this species covers 16.5% of the total CR forested area (Ministry of Agriculture of the Czech Republic 2016). Silviculture of Scots pine needs specific management approaches on nutrient-poor sandy and acid sites in Czech lowlands. Two such sites account for 13% of the total forested area.

Management of pine stands in lowlands is historically aimed at "age class" forestry with regeneration and thinning techniques based on long-term research results and practical experiences (Peřina 1960; Remiš 1973; Pirogowicz 1983; Pařez, Chroust 1988; Waldherr 1996; Huss 1999; Slodičák, Novák 2007).

Besides silvicultural effects on growth and stability of pine stands, water status and nutrient cycles (Chroust 1997; Sariyildiz 2008; Saarsalmi et al. 2010; Slodičák et al. 2011; Urban et al. 2015), growth of pine seedlings after the site preparation (Remeš et al. 2016) and amounts of biomass (Vanninen et al. 1996; Cienciala et al. 2006; Repola, Ulvcrona 2014; Fernandez-Lacruz et al. 2015; Urban et al. 2015; Bílek et al. 2016; Egnell 2016) in managed stands are in the research focus.

A new use of logging residues is applied in the Czech Republic and abroad (de Jong et al. 2017). They are piled after clear-cutting and used for energetic purposes so as to follow efforts to exploit renewable resources of power. This practice may affect the sustainable nutrient cycling in forests.

This practice forces us to keep sustainable nutrient cycling in forests. If the removal of nutrients were not balanced with nutrient input from the

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environment or fertilization, forest soils would be degraded (Šrámek et al. 2009).

Since the knowledge of the quantity and nutrient content of biomass in pine stands is still insufficient (mainly because of a wide spectrum of pine-dominated sites in the Czech Republic), we focused our study on above- and below-ground biomass in young pine stands. Results from an experimental area in Eastern Bohemia should be the basis for planning and decision making of forestry management (degree of biomass exploitation during the rotation, etc.).

The objective of the study focuses on biomass and nutrient content in particular components of Scots pine stands as a basis for optimization of forest ecosystem management at lower altitudes.

MATERIAL AND METHODS

Study site. Biomass investigations were carried out in Municipal Forests of the City of Hradec Králové (hereinafter referred to as the MFHK). The MFHK are dominated by Scots pine (58%). Annual precipitation ranges from 600 to 700 mm. Mean annual air temperature is 8°C. Scots pine is grown on soils that developed from Pleistocene alluvial sand. The nutrient-poor site is classified as *Pineto-Quercetum oligotrophicum* (*arenosum*). Fourteen plots with thinning experiment were founded in 2014. The age of experimental stands at the time of biomass sampling ranged from 14 to 26 years (Table 1). Diameter of all stems and height of ca. 30 representative trees per plot are measured annually in all experimental plots. Before sampling, only cleaning or slight thinning were done in experimental stands.

Table 1. Mensurational characteristics of the plots in 2015 before thinning

Plot	Age (yr)	No. of trees per hectare	Mean diameter (cm)	Mean height (m)	Basal area ($m^2 \cdot ha^{-1}$)
211	14	5,650	7.6	8.4	25.3
212	14	5,200	7.7	8.1	24.5
221	14	5,500	7.6	8.7	25.2
222	14	5,000	8.3	9.2	27.4
231	18	3,050	11.1	12.9	29.7
232	18	2,200	11.6	12.6	30.0
241	18	4,350	8.9	9.6	26.8
242	18	4,400	8.3	9.4	23.8
311	25	2,511	12.5	14.7	30.7
312	25	2,400	12.3	14.3	28.6
321	26	1,833	14.7	16.4	31.3
322	26	1,178	16.1	16.3	23.9
331	26	2,289	13.2	14.8	31.3
332	26	2,344	12.7	13.9	29.5

Biomass sampling and measuring. Six sample trees were taken from protection boundaries of the experimental plots. DBH of the sampled trees ranged from 4 to 19 cm. Particular biomass components: stem, branches (living and dead) and needles were separated. Stem diameter (over bark) of 1m sections was measured with a calliper. Three samples per stem were taken and bark was separated from wood. Fresh weight of biomass components was measured in the stand using a portable weighing apparatus. Needles, bark and wood samples were weighed again after drying at 80°C. After drying, nutrient contents of the samples were analysed in a laboratory.

Totally 26 pine stumps were excavated using an excavator. The stumps were weighed (to the nearest 0.5 kg) in a fresh state and in a dry state again. A stump cross-section diameter was also measured (to the nearest 1 mm). A wood sample per stump was taken for nutrient analysis. Coarse roots were cut from stumps and divided by their diameters to fractions: < 1.0, 1.1–5.0, 5.1–10 and > 10 cm.

Additionally, fine roots were sampled using an earth auger (8.3 cm in diameter) in nine experimental plots. Five sampling points were placed diagonally within each plot. Forest floor humus layers and mineral soil were removed from the sample core representing the 20-cm profile of the soil. Fine roots were separated into three fractions: < 1, 1–2 and > 2 mm. After drying, the fine roots were analysed in a laboratory.

Coarse and fine roots were separated because of expected different nutrient content and samples of particular diameter classes were analysed separately.

Nutrient analysis. Contents of nitrogen, phosphorus, potassium, calcium and magnesium in particular samples were analysed in a laboratory. Nitrogen content was measured by Kjeldahl methods and phosphorus content with a spectrophotometer (Macháček, Malát 1982). Potassium content was measured with an absorption spectrophotometer (Novozamsky et al. 1983). Calcium and magnesium content was measured by atomic absorption after lanthanum addition (Ramakrishna et al. 1966). Composite samples per particular trees were used for determination of nutrient contents in branches and needles. Totally 6 samples of needles, 6 samples of branches (wood over bark), 18 samples of stem wood, 18 samples of stem bark, 9 samples of stump wood, 2 samples of stump bark, 29 samples of coarse roots and 27 samples of fine roots were analysed.

Allometric equations. Relations between independent variable (DBH) and dependent variables:

Table 2. Regression parameters (a, b) and their standard errors (SE) of allometric equations $y = a \times x^b$

Dependent variable	Independent variable	a	b	SE	
				a	b
Stem volume (m^3)	DBH	6.20E-05	2.82E+00	1.65E-05	9.32E-02
Stem mass (kg)		0.025	3.11821	0.01095	0.15284
Needle mass (kg)		0.005288	2.842911	0.006912	0.457362
Branch mass (kg)		0.002517	3.400664	0.004833	0.668532
Stump mass (kg)	D0	0.01628	2.594991	0.009775	0.180587
N in stumps (g)		0.033748	2.311495	0.007786	0.06427
P in stumps (g)		0.008828	2.366918	0.002281	0.071893
K in stumps (g)		0.012309	2.414096	0.002241	0.050628
Ca in stumps (g)		0.019878	2.305395	0.006634	0.09298
Mg in stumps (g)		0.004044	2.401382	0.001165	0.080099

D0 – stump cross-section diameter

stem volume and mass, needle mass, branch mass were derived from an allometric equation (Eq. 1):

$$y = a \times \mathrm{DBH}^b \quad (1)$$

where:
a, b – regression parameters.

An allometric equation (Eq. 2) was used to calculate the relationship between stump cross-section diameter (D0) and stump weight:

$$y = a \times \mathrm{D0}^b \quad (2)$$

The allometric equation was also used to assess the relationship between stump diameters (D0) and DBHs (based on 100 trees) for the purposes when only DBHs are known. Allometric equations were used for the calculation of total nutrient contents in stumps as well (Table 2). Calculations were performed in R statistical language (Version 3.0.3., 2013).

RESULTS

Biomass components

Densities of 14–26-years-old Scots pine stands were from 1,178 to 5,650 trees per hectare. Basal area ranged from 24.5 to 31.3 $m^2 \cdot ha^{-1}$ and stand mean height varied between 8.1 and 16.4 m (Table 1). The total fresh biomass ranged between 157 and 350 $t \cdot ha^{-1}$. The heaviest part of aboveground biomass was a stem component ranging from 85 to 216 $t \cdot ha^{-1}$; it accounted for 55–62% of the total mass. Branches and needles weighed 16–48 $t \cdot ha^{-1}$ and 10–21 $t \cdot ha^{-1}$ (Table 3) representing 10–14%

Table 3. Biomass (fresh mass) characteristics of the plots in 2015 before thinning

Plot	Stem volume ($m^3 \cdot ha^{-1}$)	Mass ($t \cdot ha^{-1}$)				
		stem[1]	needle	branches[1]	stump[2]	above-ground
211	108	86	10	16	39	112
212	106	85	10	16	38	111
221	108	86	10	16	38	112
222	128	105	12	20	43	137
231	170	152	16	31	50	199
232	178	161	17	33	52	211
241	130	109	12	21	43	142
242	111	92	10	18	37	120
311	190	175	18	37	54	230
312	176	162	17	34	50	213
321	222	216	21	48	59	285
322	182	182	18	41	46	241
331	203	190	19	41	56	250
332	185	170	18	36	52	224

[1]over bark, [2]with coarse and fine roots

and 6% of the total mass, respectively. Stumps with coarse and fine roots represented 38–59 t·ha^{-1} of biomass. The mean weight of fine roots was 6.5 t·ha^{-1}, but with great variability both within and among plots. Weights of all biomass components increased with the stand age.

Nutrient concentrations

Scots pine needles were the highest in nutrients such as nitrogen (1.41%), phosphorus (0.14%), potassium (0.46%) and magnesium (0.07%). The highest concentration of calcium was found in the bark of stem (0.44%). Wood components were the lowest in all nutrients except for dead branches being lowest in phosphorus (0.03%) and potassium (0.03%). Live branches were significantly higher in nutrients (except calcium) compared to dead ones (Table 4). In case of fine roots, high concentration of nitrogen (0.48–0.97%) and very low concentration (0.01–0.02%) of calcium and magnesium were found (Table 5).

Nutrient pools

Development of nutrient pools is driven by both nutrient concentrations and amounts of particular biomass components. Nutrient pools are increasing with tree's dimensions and biomass which are reflecting the age. Needles show the greatest nitrogen pool ranging from 56 to 118 kg·ha^{-1} (Table 6). Stem wood and branches become more important pools with increasing stand age for all nutrients (Tables 7 and 8). The belowground component (stump with coarse roots) was an important pool for phosphorus ranging between 12 and 16 kg·ha^{-1} (Table 9). Additionally, more 4.6 kg·ha^{-1} of phosphorus were stored in fine roots (Table 5). Pools of all components are higher in calcium compared to the needle pool. Stem bark is less important for all nutrients except calcium (Table 10). The total nutrient pools

Table 4. Nutrient concentration in particular components of dry biomass

	N	P	K	Ca	Mg
			(%)		
Dead branches	0.28	0.03	0.03	0.23	0.04
Live branches	0.51	0.09	0.29	0.17	0.06
Wood of stem	0.10	0.03	0.05	0.07	0.02
Bark of stem	0.30	0.05	0.10	0.44	0.04
Needles	1.41	0.14	0.46	0.24	0.07
Wood of stump	0.14	0.04	0.08	0.09	0.02
Bark of stump	0.25	0.05	0.08	0.15	0.03

Table 5. Nutrient concentrations and nutrient contents in fine roots

Diameter (mm)	N	P	K	Ca	Mg
		Concentration (%)			
< 1	0.97	0.09	0.11	0.01	0.02
1–2	0.72	0.07	0.10	0.01	0.02
> 1	0.48	0.06	0.08	0.02	0.02
		Content (kg·ha^{-1})			
< 1	22.1	2.1	2.5	0.2	0.4
1–2	7.8	0.8	1.1	0.1	0.2
> 1	14.9	1.7	2.6	0.6	0.8
Total	44.8	4.6	6.2	1.0	1.4

Table 6. Nutrient contents in pine needles

Plot	N	P	K	Ca	Mg
			(kg·ha^{-1})		
211	56	6	18	9	3
212	56	6	18	9	3
221	56	6	18	9	3
222	67	7	22	11	3
231	90	9	29	15	5
232	96	10	31	16	5
241	67	7	22	11	3
242	56	6	18	9	3
311	101	10	33	17	5
312	96	10	31	16	5
321	118	12	39	20	6
322	101	10	33	17	5
331	107	11	35	18	6
332	101	10	33	17	5

Table 7. Nutrient contents in pine branches

Plot	N	P	K	Ca	Mg
			(kg·ha^{-1})		
211	35	6	18	13	4
212	35	6	18	13	4
221	35	6	18	13	4
222	43	8	23	16	5
231	67	12	36	23	7
232	71	13	39	25	8
241	45	8	24	16	5
242	39	7	21	14	4
311	80	14	43	28	9
312	73	13	40	25	8
321	104	18	57	35	11
322	88	16	49	30	10
331	88	16	48	30	10
332	78	14	42	27	8

Table 8. Nutrient contents in pine wood of stems

Plot	N	P	K	Ca	Mg
	(kg·ha⁻¹)				
211	30	8	16	22	6
212	30	8	16	22	5
221	30	8	16	22	6
222	37	10	20	27	7
231	54	15	29	39	10
232	57	16	31	41	10
241	38	11	21	28	7
242	32	9	18	24	6
311	62	17	33	45	11
312	57	16	31	42	10
321	76	21	41	56	14
322	64	18	35	47	12
331	67	19	36	49	12
332	60	17	32	44	11

Table 9. Nutrient contents in pine stumps with coarse roots

Plot	N	P	K	Ca	Mg
	(kg·ha⁻¹)				
211	41	12	19	24	6
212	39	12	18	23	6
221	40	12	19	24	6
222	44	13	21	26	7
231	48	15	23	28	7
232	49	15	24	28	8
241	43	13	20	25	6
242	38	12	18	22	6
311	50	15	25	29	8
312	47	14	23	27	7
321	52	16	26	30	8
322	41	13	20	23	6
331	52	16	25	30	8
332	49	15	24	28	7

Table 10. Nutrient contents in pine bark of stems

Plot	N	P	K	Ca	Mg
	(kg·ha⁻¹)				
211	11	2	4	15	1
212	11	2	4	15	1
221	11	2	4	15	1
222	13	2	4	19	2
231	19	3	6	27	2
232	20	3	7	29	3
241	14	2	5	19	2
242	11	2	4	16	1
311	22	4	7	31	3
312	20	4	7	29	3
321	27	5	9	39	3
322	23	4	8	33	3
331	24	4	8	34	3
332	21	4	7	30	3

(without fine roots) were 171–377 kg·ha^{-1} for nitrogen, 34–72 kg·ha^{-1} for phosphorus, 74–172 kg·ha^{-1} for potassium, 82–180 kg·ha^{-1} for calcium and 19–42 kg·ha^{-1} for magnesium. Moreover, fine roots represented per hectare 44.8 kg·ha^{-1} for nitrogen, 4.6 kg·ha^{-1} for phosphorus, 6.2 kg·ha^{-1} for potassium, 1.0 kg·ha^{-1} for calcium and 1.4 kg·ha^{-1} for magnesium.

DISCUSSION

Aboveground biomass increases over time since 14- to 26-years-old studied stands showed 111 to 285 t·ha^{-1}. Bílek et al. (2016) reported 154 and 271 t·ha^{-1} in 100- and 128-years-old Scots pines. Our standing biomass is, however, a fresh-weight value containing ca. 40% of water.

Nitrogen, phosphorus, potassium and magnesium showed the highest concentrations in pine needles; bark stem was higher in calcium compared to the other biomass parts. Needle nitrogen pool was the greatest in all samples. Needle phosphorus pool was low due to the relatively small amount of needle biomass and 10 times lower concentration of phosphorus in needles compared to nitrogen. Needle mass (10–21 t·ha^{-1}) was ca. 10 times lower compared to stem mass (85–216 t·ha^{-1}) in our study. It represents, however, a greater source of nitrogen due to decomposition of organic matter compared to fine and coarse woody debris (Prescott 2002). Woody logging residues can also release the nutrients; the decomposition, however takes more time. There are also some species-specific processes. It seems that birch stumps can release nitrogen and phosphorus (Palviainen et al. 2004) and carbon (Palviainen et al. 2010a) faster compared to pine stumps after clear-cutting. Hellsten et al. (2013) found birch stumps higher in nitrogen, phosphorus, potassium, calcium, magnesium and sodium compared to pine. Palviainen et al. (2010b), however, found that birch stumps lost more than 2/3 of the initial content of phosphorus and magnesium over 40 years after felling, while pine stumps were phosphorus and magnesium sinks containing more (sometimes doubled) P and Mg compared to initial contents. Increasing nutrient contents are attributable to decomposing organisms and/or organisms benefitting from the site rich in dead wood.

Overbark stem is the most frequently removed from the site after thinning. This removal would represent 26% of nitrogen, 33% of phosphorus, 28% of potassium, 49% of calcium and 38% of magnesium that were stored in total Scots pine biomass in MFHK. Obvious is a great amount of calcium. Similarly Bílek et al. (2016) confirmed pine needles high in calcium (stem bark is the highest in our study).

We are inclined to agree with Bílek et al. (2016), who did not recommend the extraction of Scots pine aboveground biomass from thinning. Also Knust et al. (2016) and Węgiel et al. (2017) pointed out a nutrient loss resulting from whole-tree harvesting. Egnell and Ulvcrona (2015) found reduced growth after whole-tree thinning in Scots pine. Another study from Sweden (de Jong et al. 2017) suggests an optimum extraction of 28% of stumps and 14% slash available for final cutting; if their scenarios included also thinning extraction, forest production would decrease (de Jong et al. 2017). Despite this, the authors also considered harvesting of 50% of slash and 20% of stumps as a possible approach.

CONCLUSIONS

Leaving slash (needles and branches) plus belowground (stumps and coarse roots) biomass on the site represents 51% of calcium, 62% of magnesium, 74% of nitrogen, 67% of phosphorus and 72% of potassium. Needles and live branches are the most important pools of nutrients and the extraction of these parts of biomass can negatively affect the nutrient balance of forest stands on nutrient-poor sites. Stumps with coarse roots also represent a significant pool of nutrients which is left on the studied sites. Since the investigated stands are to be managed till the rotation age, it can be concluded that no biomass removal is supposed from pre-commercial thinning.

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