CARBON POOLS IN MOUNTAIN NORWAY SPRUCE ECOSYSTEM IN THE BOHEMIAN FOREST (CZECH REPUBLIC)

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Human activity have influenced in many ways the state and function of forest ecosystems. There are many studies focusing on the growth, biomass and carbon stocks of forest ecosystem under different environmental conditions. The very current issue is a possible impact of altered growth of the trees, induced by nitrogen deposition, on carbon accounting. However, there are not so many studies dealing with methodological aspects of carbon stocks assessment or carbon stocks in other parts of forest ecosystem (e.g., ground vegetation).

In this paper we present a detailed analysis of carbon content in different parts of tree biomass (*Picea abies*). We have sampled aboveground and underground biomass (roots, bole, bark, foliage, and branches) of six trees in two watersheds (Plešné (PL) and Čertovo (CT) Lakes) in the Bohemian Forest (the Czech Republic) and analysed them for carbon concentrations. In addition, four of these analysed for carbon concentrations in the tree rings, sectioned by decades.

In the second part of the study we present analysis of carbon concentration in ground vegetation in the mountain spruce stands of the PL and CT watersheds. We have sampled the main species of ground vegetation (*Calamagrostis villosa, Vaccinium myrtillus, Avenella flexulosa, Luzula sylvatica, Athyrium alpestre*), estimated their biomass, and determined the carbon concentrations.

Keywords: *carbon, biomass, trees, ground vegetation, Picea abies, Calamagrostis villosa, Vaccinium myrtillus, Avenella flexulosa, Luzula sylvatica, Athyrium alpestre*

1. Introduction

The chemistry and element fluxes of the mountain lakes in the Bohemian Forest are intensively studies for long time. Many interesting results were already published, but there are still some questions there were not fully answered. Significant differences in the element concentrations and fluxes between the Plešné and Čertovo Lake were found in spite of the similarity between these two lakes (KOPÁČEK *et al.* 2001). To understand and explain these processes, detailed studies on lake and stream chemistry, atmospheric deposition, soil pools and biochemistry were carried out in recent years. However important components of the biogeochemical cycle were not yet studied.

The aim of this paper is to report the results of investigation on tree and ground vegetation biomass and carbon pools of the trees and ground vegetation in two spruce forests in the watersheds of Plešné and Čertovo Lake in Bohemian Forest. This investigation is a part of the integrated study on the Bohemian Forest watershed-lake ecosystems (Nutrient cycling in the nitrogen-saturated mountain forest ecosystem: History, present, and future of water, soil, and Norway spruce forest status). In this study we provide data on (1) biomass of individual tree componet (folige, wood and bark of branches, stem wood and bark, roots and (2) carbon concentrations and carbon pools of these tree components (3) biomass of different species of ground vegetation (4) carbon concentrations and carbon pools of ground vegetation

2. Methodology

2.1. Study sites

The research was carried out in the watersheds of Plešné (PL) and Čertovo (CT) lakes. PL Lake is situated in the Bohemian Forest National Park (BF NP), while CT Lake in the Bohemian Forest Protected Landscape Area (BF PLA). Basic information describing lakes, their watersheds and forest stands provide KOPÁČEK *et al*. (2002a, 2002b).

2.2. Sampling procedure and analysis of the trees

Both lakes, their watersheds with forest stands are located in strictly protected areas. Therefore we were not allowed to cut down or dig any trees. We were allowed to use for our sampling procedure only naturally uprooted trees. During the spring 2003 we have searched the forest stands in the watersheds of the both lakes and chosen three suitable recently uprooted trees in each watershed.

For each tree, the following parameters were measured: girth at breast height, total height, and length of live crown. The basic biometrical data of individual trees are shown in table 1. The stem of the tree was divided into 10 sections. For each of the sections, girth in the beginning, middle and end of the section were measured. From middle part of each section, and in case of first section also from DBH height, stem disks were taken and brought to the laboratory. The measurements of each stem section were used to calculate the stem volume of each tree.

The live crown of each tree was divided into 5 sections with the length corresponding to 1/5 of the total live crown length. Branches of each section were separated from the stem and weighed together with needles in the field. The number of branches in each section was counted. A representative sub-sample from each crown section was taken, weighed in the field and brought to the laboratory.

Table 1. Basic characteristics and biometric data of the sample trees.

Lake	Tree no.	Height (m)	DBH (cm)	Crown length (m)	DBH age
CT	1	20.5	35.3	12.8	138
CT	2	30.9	53.2	18.7	177
CT	3	38.7	63.7	27.7	171
PL	4	25.5	50.9	11.3	134
PL	5	20.5	36.9	6.0	129
PL	6	14.1	28.0	6.8	84

The bare root system of the tree was cleaned from soil and approximately one-quarter sub-sample was taken to the laboratory. The data on root biomass were later verified using biometric equation.

In the laboratory, bark from the stem disks was separated. Thickness of the bark samples at four random points was measured and average bark thickness in each stem section was than calculated. The volume and dry matter (oven dried at 105 °C) of the bark samples and stem disks were determined. The measurements were used to calculate the bulk density of the stem bark and wood sample in each stem section. The bulk density for bark and wood samples and bark and wood section volume were used to compute dry matter for wood and bark in each section and than for whole tree.

For the crown sub samples, foliage was separated from live branches in the laboratory and oven dried at 105 °C. The data on foliage biomass were later verified using biometric equations. The branches sub samples in each crown section were divided into five diameter categories (0.0 – 0.5; 0.5 – 1.0; 1.0 – 2.0; 2.0 – 3.0; > 3.0 cm). Dry matter (oven dried at

105 °C) for each category of the crown section was analysed. For each diameter category of branches (except category 0.0 – 0.5 cm) across all trees and crown sections, ten samples were randomly taken and share of the branch wood and bark was analysed. The ratio between field fresh weights and dry matter of the section crown sub-sample was used to calculate dry matter of the branches of trees crown sections. The fine branches (0.0 – 0.5 cm) were analysed separately. Share of foliage, fine branches, branch wood and bark of trees crown sections were than used to calculate this share for each crown section and than for the whole tree.
Root sub samples were sprayed with water to remove soil remnants. Sub-sample of each tree was divided into five diameter categories (0.0 – 1.0; 1.0 – 3.0; 3.0 – 7.0; > 7.0 cm, stump). The volume and dry matter (oven dried at 105 °C) of each category were determined. These values were used to calculate root system dry matter of each tree according to diameter classes.

2.3. Sampling procedure and analysis of the ground vegetation

The biomass of the ground vegetation was measured using combination of vegetation cover survey and biomass sampling. Wooden frame (0.5 × 0.5 m) was used to sample aboveground biomass of vegetation. Underground biomass of vegetation was sampled using steel corer. Vegetation cover survey was performed in watersheds of both lakes. Cover of individual species was used to distinguish between significant plant species and plant species that were not sampled. As a cut off value was used cover less than 1%. Biomass of plant species with cover higher than 1% was than sampled in both watersheds. The cover of the following plant species was higher than 1% in watershed of the both lakes: *Calamagrostis villosa, Luzula sylvatica, Avenella flexulosa, Vaccinium myrtillus, Athyrium alpestre.* We have analysed 40 samples in the watershed of PL Lake and 50 samples in the watershed of CT Lake. Number of the samples for individual plant species was depended on relative abundance of plant species in each watershed. The samples were randomly placed across both watersheds to cover variability in site and stand conditions.
The samples of aboveground biomass were brought to the laboratory and oven dried at 105 °C. The samples of underground biomass were cleaned using running water on set on meshes of different site. The roots of ground vegetation were separated and oven dried at 105 °C.

2.4. Chemical analysis of the tree and ground vegetation biomass

Stem wood, stem bark, foliage, branch wood, branch bark and root were analysed for the total content of the carbon. For the stem wood, 5 samples taken across the whole length (section 1, 3, 5, 7, 9) of tree stem were analysed. For the stem bark, the sampling procedure was the same. Because of using uprooted trees for sampling, the foliage samples for chemical analyses were taken from surrounding live trees during autumn of the same year. Living trees of the same social status and biometrical data (DBH, height, crown length) were chosen. Needles samples were taken from the lower, middle and upper part of the crown of these trees and first year needles and mixture of the remaining needles were analysed. Similarly, fine branches (0.0 – 0.5 cm), branch wood and bark samples (categories 1.0 – 2.0 and > 3 cm) were taken from the lower, middle and upper part of the crown, but from the six sample trees. Root samples were taken for each tree for the following diameter classes (0.0 – 1.0; 1.0 – 3.0; 3.0 – 7.0; > 7.0 cm).
The aboveground and underground biomass of the different species of ground vegetation was analysed for the total content of the carbon.

Total content of carbon was analysed by the C, N analyser unit. The Laboratory of the Hydrobiological Institute, AS CR, performed all the analyses.

3. Results and discussion

3.1. Tree biomass

Diameters and heights of the sample trees range from 28.0 to 63.7 cm and from 14.1 to 38.7 m. The age of sample trees range from 84 to 177 years. For detailed characteristic of sample trees and sites see Table 1.

Total tree biomass, aboveground and underground biomass, tree component dry matter (DM) is shown in Table 2. Because of some restrictions during sampling procedure, the foliage biomass and root biomass were verified using biometric equations and allometric ratios. This approach was also used in work presented by KOVÁŘOVÁ and VACEK (2003). The measurements of foliage biomass were underestimated probably due to time period between fall of the trees and sampling procedure. The verified average value on foliage biomass (Table 2) was therefore used while calculating total tree biomass. The measurements of root biomass were overestimated probably due to difficulties during sampling procedure. The root plate of the windfallen tree was only partially uncovered and sampling of one-quarter root system was rather difficult. The verified average value on root biomass (Table 2) was therefore used while calculating total tree biomass.

Table 2. Total tree biomass, total aboveground and underground biomass, and tree component dry matter of sample trees.

Tree component dry matter (kg)	Tree no./lake					
	1/CT	2/CT	3/CT	4/PL	5/PL	6/PL
Dry matter of stem wood (kg)	411.6	1 180.3	1 906.6	967.6	414.9	154.4
Dry matter of stem bark (kg)	35.3	113.3	134.0	88.4	34.5	17.3
Dry matter of foliage (kg)	14.9	49.3	77.7	15.3	16.2	7.4
Verified dry matter of foliage[1] (kg)	40.9	90.1	154.2	60.2	21.2	20.1
Dry matter of branch wood (kg)	41.9	119.8	189.8	43.9	23.2	5.3
Dry matter of branch bark (kg)	12.7	40.3	50.8	13.1	7.3	2.0
Dry matter of fine branches (kg)	8.6	30.7	57.0	9.6	8.2	4.4
Total branch biomass (wood and bark) (kg)	63.2	190.8	297.5	66.6	38.7	11.7
Dry matter of roots (kg)	176.0	391.7	984.7	296.1	216.6	62.8
Verified dry matter of roots[1] (kg)	97.3	278.0	440.0	208.8	89.9	35.9
Total stem biomass	446.9	1 293.6	2 040.6	1056.0	449.4	171.7
Total branch and foliage biomass[2] (kg)	104.1	280.9	451.7	126.8	59.9	31.8
Total root system biomass[2] (kg)	97.3	278.0	440.0	208.8	89.9	35.9
Total aboveground biomass[2] (kg)	551.0	1 574.5	2492.3	1182.8	509.3	203.5
Total underground biomass[2] (kg)	97.3	278.0	440.0	208.8	89.9	35.9
Total tree biomass[2] (kg)	648.3	1 852.4	2932.3	1 391.6	599.2	239.4

[1] Verified values of foliage and roots biomass were calculated using biometric equation (foliage) and biomass – roots ratio (roots); [2] Verified values of foliage and roots dry matter were used to calculate final values of tree component dry matter and tree biomass.

Total biomass of the sample trees range from 239.4 kg (tree no. 6) to 2932.3 kg (tree no. 3) (Table 2). Biomass value variation between the sample trees is the consequence of the tree biometric data (height and DBG) and age differences. Share of tree DM components from total tree biomass is shown in Table 3. Our results confirm the well-known fact that stem DM creates the biggest portion of the whole tree biomass, while the root biomass and branch – foliage biomass creates relatively similar portion of the tree biomass (CHRISTIAN *et al.* 2004). Share of the stem wood and bark ranges from the 63.5 to 69.5%, and from the 4.6 to 7.2%

respectively. Share of the foliage and fine branches ranges from the 4.3 to 8.4%, and from the 0.7 to 1.9% respectively. Share of the branch wood and bark ranges from the 2.2 to 6.5%, and from the 0.8 to 2.2% respectively (Table 3).

Table 3. Share of tree dry matter component from total tree biomass and basic statistics (mean value, standard deviation a coefficient of variation).

Share of tree dry matter component from total tree biomass (%)	Tree no./lake						Mean	Std. Dev.	CV (%)
	1/CT	2/CT	3/CT	4/PL	5/PL	6/PL			
Dry matter of stem wood	63.5	63.7	65.0	69.5	69.2	64.5	65.9	2.7	4.2
Dry matter of stem bark	5.4	6.1	4.6	6.4	5.8	7.2	5.9	0.9	15.1
Dry matter of foliage[1]	6.3	4.9	5.3	4.3	3.5	8.4	5.4	1.7	31.5
Dry matter of branch wood	6.5	6.5	6.5	3.2	3.9	2.2	4.8	1.9	40.4
Dry matter of branch bark	2.0	2.2	1.7	0.9	1.2	0.8	1.5	0.6	37.6
Dry matter of fine branches	1.3	1.7	1.9	0.7	1.4	1.8	1.5	0.5	30.7
Total branch biomass	9.7	10.3	10.1	4.8	6.5	4.9	7.7	2.6	34.3
Dry matter of roots[1]	15.0	15.0	15.0	15.0	15.0	15.0	15.0		
Total stem biomass	68.9	69.8	69.6	75.9	75.0	71.7	71.8	3.0	4.1
Total branch and foliage biomass[2]	16.1	15.2	15.4	9.1	10.0	13.3	13.2	3.0	22.5
Total root system biomass[2]	15.0	15.0	15.0	15.0	15.0	15.0	15.0		
Total aboveground biomass[2]	85.0	85.0	85.0	85.0	85.0	85.0	85.0		
Total underground biomass[2]	15.0	15.0	15.0	15.0	15.0	15.0	15.0		
Total tree biomass[2]	100.0	100.0	100.0	100.0	100.0	100.0	100.0		

[1] Verified values of foliage and roots biomass were calculated using biometric equation (foliage) and biomass – roots ratio (roots); [2] Verified values of foliage and roots dry matter were used to calculate final values of tree component dry matter and tree biomass.

While for the some values of the tree DM components the coefficient of variation (CV) is low, for other component mean value is rather high (Table 3). The CV value for stem wood DM mean value is 4.2%, for stem bark is 15.1%, and for whole stem is 4.1% (Table 3). Higher CV value for stem bark is probably due to age differences between sample trees. Younger trees have higher portion of stem bark to stem wood compared to older trees (CHRISTIAN *et al.* 2004). Tree no. 6 has the highest portion of stem bark. The CV value for total branch DM mean value is 34.3%, for branch wood is 40.4%, for branch bark is 37.6, and for fine branches is 30.7% (Table 3). There is no clear explanation for rather high CV values for branch biomass. The CV value for foliage DM mean value is 31.5%. The highest foliage portion was found for the tree no 6. Higher value of CV for foliage is probably due to age differences between the individual trees. Younger trees have higher portion of foliage DM to tree biomass compared to older trees (CHRISTIAN *et al.* 2004).

3.2. Carbon concentration in tree components and total carbon pools in the tree biomass

Results on carbon concentration in different components (foliage, fine branches, branch bark and wood, stem bark, stem wood and roots) of individual sample trees are given in Table 4. Results on mean carbon concentration and coefficient of variation of mean concentration are also given in Table 4.

Concentration of C in different tree component was rather similar. The highest concentrations of C were found in fine branches (44.7 $mol.kg^{-1}$) and fine roots (44.1 $mol.kg^{-1}$) (Table 4). The lowest concentrations of C were found in stem wood (41.8 $mol.kg^{-1}$) and stem wood (41.9 $mol.kg^{-1}$). The coefficient of variation of mean value ranged from 0.9 to 3.5%.

Results on total carbon pools of the sample trees, carbon pools in the tree component of individual trees are given in Table 4.

Table 4 Carbon concentrations, mean carbon concentration and coefficient of variation of mean values in the tree components of all sample trees. For abbreviation of tree component, crown and stem section, diameter category and needle year see chapter "Sampling procedure"

Tree component	Crown / stem section	Needle year/ diameter (cm)	Tree no./lake						Mean concentration	Coefficient of variation
			1/CT	2/CT	3/CT	4/PL	5/PL	6/PL		
			mol.kg^{-1}						mol.kg^{-1}	%
Foliage	1	1 year old	42.90	42.13	42.92	43.08	42.55	43.09	42.8	0.8
F	1	older than 1 y.	43.53	42.57	43.07	42.86	43.46	43.12	43.1	0.8
F	3	1 year old	42.59	42.72	42.59	nd	42.51	42.21	42.5	0.4
F	3	older than 1 y.	43.20	43.46	43.21	42.81	43.24	43.21	43.2	0.4
F	5	1 year old	43.06	42.90	42.72	43.11	43.00	42.89	42.9	0.3
F	5	2 years old	42.90	43.29	42.98	42.96	43.32	43.00	43.1	0.4
F	5	older than 2 y.	43.12	43.63	42.65	43.07	43.67	43.29	43.2	0.8
Fine Branches	1	0.0 – 0.5	44.62	43.80	43.87	44.74	43.64	42.93	42.8	0.8
FB	3	0.0 – 0.5	44.61	44.53	43.28	44.86	44.06	43.86	44.2	1.2
FB	5	0.0 – 0.5	45.36	44.48	44.87	44.58	44.09	44.74	44.7	0.9
Branch Bark	1	1.0 – 2.0	43.50	42.09	42.20	41.76	41.14	41.74	42.1	1.7
BB	1	> 3.0	40.96	41.19	41.42	40.93	39.76	40.87	40.9	1.3
BB	3	1.0 – 2.0	42.59	43.93	40.63	43.76	41.96	42.14	42.5	2.7
BB	3	> 3.0	41.49	42.19	40.95	41.68	40.61	41.20	41.4	1.2
BB	5	1.0 – 2.0	43.91	44.06	44.14	44.46	42.65	43.15	43.7	1.4
BB	5	> 3.0	42.28	43.49	43.22	43.59	42.15	42.86	42.9	1.3
Branch Wood	1	1.0 – 2.0	42.64	42.55	42.47	42.64	41.80	41.72	42.3	0.9
BW	1	> 3.0	42.96	43.35	41.82	42.69	42.95	42.48	42.7	1.1
BW	3	1.0 – 2.0	42.58	42.31	42.26	41.96	41.63	42.50	42.2	0.8
BW	3	> 3.0	nd	43.41	42.27	42.93	42.42	43.22	45.3	1.2
BW	5	1.0 – 2.0	42.03	42.29	42.35	41.88	41.82	41.97	42.1	0.5
BW	5	> 3.0	43.00	42.31	42.56	42.19	41.34	42.31	42.3	1.2
Stem Bark	1		42.32	42.50	45.24	43.48	43.32	42.62	43.2	2.3
SB	3		42.74	42.62	42.13	43.45	41.99	42.31	42.5	1.1
SB	5		42.91	42.32	41.47	43.71	42.10	42.81	42.6	1.7
SB	7		46.25	42.58	41.47	42.78	42.18	43.33	43.1	3.5
SB	9		44.94	43.03	42.12	42.90	42.32	43.13	43.1	2.1
Stem Wood	1		41.40	41.33	41.82	42.10	43.16	42.29	42.0	1.5
SW	3		41.76	41.42	41.42	41.75	42.67	42.13	41.9	1.0
SW	5		41.76	41.51	41.25	41.74	42.37	42.42	41.8	1.0
SW	7		42.15	41.68	41.51	42.02	42.59	42.64	42.1	1.0
SW	9		41.96	41.66	41.77	41.83	42.63	42.70	42.1	1.0
Roots		0.0 – 1.0	44.23	44.37	44.19	43.99	44.13	43.67	44.1	0.5
R		1.0 – 3.0	43.07	42.61	41.26	43.63	42.85	44.05	42.9	2.1
R		3.0 – 3.7	42.18	42.61	41.98	42.58	43.47	42.47	42.5	1.1
R		> 7.0	41.98	42.92	40.31	41.87	43.95	42.75	42.3	2.7

3.3. Ground vegetation biomass

The first preliminary estimates of the ground vegetation aboveground biomass are shown in Table 5. The values of plants aboveground biomass ranged from 0.154 to 0.713 kg.m^{-2}. The highest values of biomass were found for plant cover of *Vaccinium myrtillus*. Plant cover of *Avenella flexulosa* showed on the other hand the lowest values of biomass from all analysed plant species. There were generally not big differences between biomass of plant cover of individual species in the watersheds of both lakes.

Table 5. Mean carbon concentration in aboveground and underground biomass of the ground vegetation plant species.

Plant Species	Plešné Lake		Čertovo Lake	
	Aboveground biomass	Underground biomass	Aboveground biomass	Underground biomass
	C (mol.kg^{-1})			
Calamagrostis villosa	38.91	42.21	39.99	41.85
Luzula sylvatica	40.01	44.18	39.26	41.95
Avenella flexulosa	40.06	42.86	40.26	43.42
Vaccinium myrtillus	42.51	42.19	42.36	43.84
Athyrium alpestre	40.81	42.88	39.67	43.21

3.4. Carbon concentration and total carbon pools in the ground vegetation biomass

Carbon concentrations in above and underground biomass of individual plant species are shown in Table 6. There were generally higher concentrations of C in underground biomass compared to aboveground biomass for all plant species. There was about 2% difference in C concentration in underground biomass of different plant species. The samples of *Vaccinium myrtillus* had the highest concentration of C in aboveground biomass of all analysed species. This was the case for the samples from both watersheds. The concentration of C in the samples of other plant species did not show any strong difference.

Table 6. Mean values of the aboveground biomass and cover of the ground vegetation plant species.

Plant Species	Plešné Lake		Čertovo Lake	
	Mean aboveground biomass	Plant species cover	Mean aboveground biomass	Plant species cover
	kg.m^{-2}	%	kg.m^{-2}	%
Calamagrostis villosa	0.198	5	0.154	65
Luzula sylvatica	0.226	5	0.278	2
Avenella flexulosa	0.160	5	0.088	10
Vaccinium myrtillus	0.713	80	0.561	10
Athyrium alpestre		2		4

4. Conclusion

We have analysed C concentrations and pools in the biomass of the six trees of *Pica abies* and samples of different species of ground vegetation in the watershed of PL and CT Lakes. In general, there were some differences between C concentrations in individual tree components. Fine branches and fine root had the highest C concentrations. Except *Vaccinium myrtillus* there were no differences in C concentration in aboveground biomass between individual plant species of ground vegetation. There were found generally higher concentration of C in underground biomass compared to aboveground biomass of plant cover.

References

1. KOPÁČEK, J., VESELÝ, J., STUCHLÍK, E., 2001: Sulphur and Nitrogen Fluxes and Budgets in the Bohemian Forest and Tatra Mountains during the Industrial Revolution (1850–2000). Hydrol. Earth System Sci. **5**(3): 391–405. – 2. KOPÁČEK, J., KAŇA, J., ŠANTRŮČKOVÁ, H., PORCAL, P., HEJZLAR, J., PICEK, T., ŠIMEK, M., VESELÝ, J., 2002a: Physical chemical, and biological characteristics of soils in watersheds of the Bohemian Forest lakes: I. Plešné Lake. Silva Gabreta. 8, p. 43–66. – 3. KOPÁČEK, J., KAŇA, J., ŠANTRŮČKOVÁ, H., PORCAL, P., HEJZLAR, J., PICEK, T., ŠIMEK, M., VESELÝ, J., 2002b: Physical chemical, and biological characteristics of soils in watersheds of the Bohemian Forest lakes: II. Čertovo and Černé Lakes. Silva Gabreta. 8, 97–94. – 4. KOVÁŘOVÁ, M., VACEK, S., 2003: Mountain Norway spruce forests: Needle supply and its nutrient content. Journal of Forest Science. 49, 327–332. – 5. WIRTH, CH., SCHUMACHER, J., SCHULZE E.D., 2004: Generic biomass functions for Norway spruce in Central Europe – a meta-analysis approach toward prediction and uncertainty estimation. Tree Physiology. 24, p. 121–139.