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The amount of carbon in the undergrowth biomass of main types of forests stands in Poland

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Abstract

The sequestration of carbon in biomass of herb and moss layers of forest ecosystems is relatively less studied, than analogical processes in trees biomass and soil organic mass. The paper presents mean values of carbon concentration and mean amounts of dry mass of plant material in the herb and moss layer of phytocoenoses formed under canopy of stands of main forest-forming species of trees in Poland. The parameters were studied for beech, birch, oak, alder, pine, fir and spruce forest stands, for most of the particular age classes. The studied plots were contained in following plant associations and communities: *Ribo nigri-Alnetum, Fraxino-Alnetum, Galio odorati-Fagetum, Luzulo luzuloidis-Fagetum, Molinio caeruleae-Quercetum roboris, Calamagrostio-Quercetum petraeae, Abietetum polonicum, Abieti-Piceetum montanum*, *Calamagrostio villosae-Piceetum,* as well as anthropogenic communities: *Betula pendula* comm. on *Leucobryo-Pinetum* habitat, *Larix decidua* comm. on *Tilio-Carpinetum* habitat, *Pinus sylvestris* comm. on *Tilio-Carpinetum* habitat, *Picea abies* comm. on *Luzulo pilosae-Fagetum* habitat (in lowland) and *Picea abies* comm. on *Luzulo luzuloidis-Fagetum* habitat (in lower mountain localities). The relatively highest carbon amount was observed in oak forests, pine forests and in older age classes of lowland beech forest, where the carbon concentration in dry mass reaches from 60 to 81%. The lowest concentrations were determined for lowland spruce forests, highland fir forests and for alder forests. The carbon concentration reached in these types of ecosystems from 39 to 41%.

Key words

carbon sequestration, understory biomass, forest vegetation

Introduction

Carbon sequestration in forests phytocoenoses is a dynamic process. The biomass of plants, other living organisms and litter gradually accumulates carbon during long time of growth and keeps it enclosed in-situ until eventual harvesting or natural disturbance. Thus, forests perform an extremely important role in the global carbon cycle (Johnson and Sharpe 1983; Turner et al.1995; Zeller and Nikolov 2000; Linder et al. 2002; Nikolov and Zeller 2003).

The binding of atmospheric carbon by forest ecosystems is an important factor in the global carbon balance and has been studied on a local, regional, national

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or continental level (Karjalainen 1996; Nabuurs et al. 1997; Shepashenko et al. 1998; Apps et al. 1999; Bhatti et al. 2002; Karjalainen et al. 2002, 2003; Kurbanov and Post 2002; Cannell 2003). The overall carbon balance of forest ecosystems in Poland was made by Galiński (1995). However, the problem of carbon accumulated by undergrowth vegetation is treated marginally in existing literature. Little interest in this component probably stems from the fact that herbaceous plants, mosses and lichens accumulate very small part of the total mass of carbon contained in forest ecosystems. According to Pussinen et al. (1997), more than 50% of the total weight of carbon is accumulated by trees, about one third – by the organic matter in the soil and about 10% by forest litter. The share of carbon accumulated in the herbs and moss layer is estimated at approximately 1–2% (Pussinen et al. 1997). However, these estimates were based on model simulation. In real ecosystems biomass of herb and moss layer, and thus the carbon concentration per unit area can vary widely as a result of forest dynamics and disturbances caused by forestry operations or natural catastrophes. In extreme cases – in highly degraded forests, under sparse canopy of trees, undergrowth biomass can reach amounts many times larger than average biomass of undergrowth in certain types of habitats. For this reason, omitting the herbs and moss biomass in estimations of total mass of carbon accumulated by the forest ecosystem can cause major inaccuracies (Muukkonen 2006).

The content of basic chemical components, including carbon, in the undergrowth of selected types of forests in north-eastern Poland were studied in the past by the group of Polish authors. These works concern especially: wet pine forest *Vaccinio myrtilli-Pinetum*, and subcontinental pine forest *Peucedano-Pinetum* (Banaszuk 1996; Banaszuk and Matowicka 1996), swamp alder forests *Carici elongatae-Alnetum* (Czerwiński and Pracz 1995a; Pasternak-Kuśmierska and Kotowska 1995; Pasternak-Kuśmierska and Traczyk 1995b), subcontinental oak-hornbeam forest *Tilio-Carpinetum* (Czerwiński and Pracz 1995b; Pasternak-Kuśmierska and Traczyk 1995a), boreal spruce forest *Sphagno girgensohnii-Piceetum* (Czerwiński and Pracz 1995c; Kotowska 1995) and bog forest *Vaccinio uliginosi-Pinetum* (Czerwiński and Pracz 1995d; Dyguś and Traczyk 1995). These studies have been realized in phytocoenoses representing the optimal phase of development of a forest, so allow comparison only among optimally developed stages of studied communities.

The aim of this paper is to present more detailed values of biomass per unit area and carbon concentration in in the undergrowth of different types of forest stands commonly occurring in Poland.

Material and methods

The study was a part of a larger project aiming at determining the accumulation of carbon in forest stands of main forest tree species in Poland. Therefore, test areas used in this study were selected on the basis of the dendrological criteria, in a way allowing to study single-species stands having parameters most often occurring in forests in Poland. Due to such criteria, only a part of studied phytocoenoses could be classified as well-developed patches of phytosociological forest associations, and mainly for these types of communities, which were characterized by canopy formed by only one tree species. Such situation occurred in cases of beech, fir, pine on poor habitats, and oak stands. For other species, the areas represented either distorted form of a particular plant community (e.g. areas with pines on fertile sites representing distorted patches of *Tilio-Carpinetum*), or artificial communities on the habitat of a variety of forest (e.g. birch stands on habitats of pine). In the case of alder stands the study plots were situated in two different types of forest – ash and alder riparian forest *Fraxino-Alnetum* and swamp alder forest *Ribo nigri-Alnetum*, which represented communities with significantly different habitat conditions and species composition.

The location and description of studied areas is presented in Table 1 and Figure 1.

In order to estimate the carbon content of a specific portion of forest undergrowth two parameters are needed: the concentration of carbon in plants and the mass of the plants per unit area.

The concentration of carbon was studied on samples collected in plots designated under the single-species tree stands in different 20-year age classes, up to the age over 80 years. For each tree stand, six 1.0 × 0.5 m plots were chosen. The plots were selected in a way to capture all physiognomic types of floor vegetation present on the test area. For each plot, the percentage cover

Table 1. Data on location and habitat conditions of studied areas

Species	Forest district	Type of plant community
Beech *Fagus sylvatica* (mountain habitats)	Świeradów	*Luzulo luzuloidis-Fagetum*
	Szklarska Poręba	
	Śnieżka	
Beech *Fagus sylvatica* (lowland habitats)	Gryfino	*Galio odorati-Fagetum*
Birch *Betula pendula*	Wronki	Birch community on *Leucobryo-Pinetum* habitat
Oak *Quercus petraea* (poor habitat)	Zielonka	*Calamagrostio-Quercetum petraeae*
Oak *Quercus petraea* (rich habitat)	Piaski	*Molinio caeruleae-Quercetum roboris*
Fir *Abies alba*	Zagnańsk	*Abietetum polonicum*
Larch *Larix decidua*	Rogów	Larch community on *Tilio-Carpinetum* habitat
Black alder *Alnus glutinosa*	Syców	*Fraxino-Alnetum*
	Antonin	
	Siemianice	*Ribo nigri-Alnetum*
Scots pine *Pinus sylvestris* (rich habitat)	Rogów	Pine community on *Tilio-Carpinetum* habitat
Scots pine *Pinus sylvestris* (poor habitat)	Niedźwiady	*Leucobryo-Pinetum*
Spruce *Picea abies* (submountain habitat)	Świeradów	*Abieti-Piceetum montanum*
Spruce *Picea abies* (lower mountain habitat)	Śnieżka	*Abieti-Piceetum montanum*
Spruce *Picea abies* (upper mountain habitat)	Szklarska Poręba	*Calamagrostio villosae-Piceetum*
Spruce *Picea abies* (lowland habitat)	Kartuzy	*Luzulo pilosae-Fagetum*

of plant stems and leaves was noted. All the above- and belowground parts of plants in undergrowth were collected. The root systems were carefully dug out up to the depth of 50 cm. After transportation to the laboratory, the samples were dried to a constant weight at 65°C temperature, weighted and pulverized in the Mikro-Feinmühle-Culatti MFC grinder (IKA®-Labortechnik Staufen, Janke & Kunkel GmbH & Co KG, Germany). The concentration of carbon in the biomass was measured using the Elemental Combustion System analyzer (model ECS CHNS-O 4010; Costech Instruments, Italy/USA) in the Institute of Dendrology of Polish Academy of Sciences in Kórnik.

For each studied forest stand the mean and standard deviation of carbon concentration was calculated based on values from six plots. Additionally, on the basis of data concerning of percentage cover of analyzed plant layer in particular plots, the amount of dry mass of collected plants in one percent of cover for each particular plots were calculated, and mean values of such parameter for particular types and ages of forest stands were also computed. Having this data, one can easily calculate the amount of carbon on any given plot, multiplicating presented index by area of the plot and mean percent coverage of undergrowth on the plot.

The calculations were performed using Microsoft Excell 2007 with the standard statistical plugin.

Figure 1. Location of forest districts with selected study areas overlaid on the map of Poland

Results and discussion

The results of the study, containing mean values of carbon amount in dry mass of herb and moss layer in certain types of forest-stands in particular age classes are shown in Table 2.

Table 2. The concentration of carbon in the dry mass of plants from herb and moss layer in phytocoenoses under main forest-forming species of trees in Poland

Species of tree Plant association Forest type	Age class	Carbon concentration [% dry mass]		Dry mass of plants per 1 m^2 and 1% of plant cover [g]	
		Mean	Std. dev	Mean	Std. dev
1	2	3	4	5	6
Beech *Fagus sylvatica* (lowland habitats) *Galio odorati-Fagetum* Broadleaf forest	I	51.85	24.127	1.1999	1.1045
	II	40.06	0.883	2.4737	2.2299
	III	71.57	32.248	0.7401	0.4053
	IV	60.67	31.252	1.4098	1.7751
	V	60.51	31.379	0.7201	0.2919
	VI	72.43	31.300	1.7477	2.1518
Beech *Fagus sylvatica* (mountain habitats) *Luzulo luzuloidis-Fagetum* Mixed broadleaf forest	I	45.02	1.378	1.5344	1.2816
	II	44.75	2.437	2.6750	3.2484
	III	46.14	1.198	1.7682	2.5252
	IV	41.73	2.985	1.9175	1.6187
	V	45.44	0.677	2.3184	1.8881
	VI	44.04	0.739	2.6325	2.1612
Birch *Betula pendula* comm. on *Leucobryo-Pinetum* habitat Coniferous forest	I	45.30	0.785	3.7056	1.5406
	II	44.22	1.880	1.4923	0.6970
	III	43.98	1.549	3.0309	1.8894
	IV	45.87	0.959	3.9485	1.4891
	V	44.28	2.482	1.3056	1.0077
Oak *Quercus petraea* (poor habitat) *Calamagrostio-Quercetum petraeae* Mixed broadleaf forest	I	64.18	28.554	1.5539	1.2560
	II	63.01	29.444	1.4146	1.2368
	III	71.38	32.451	0.6362	0.4074
	IV	61.81	33.944	2.1280	0.7476
	V	81.51	33.765	1.9841	0.0294
	VI	62.78	29.632	1.6349	1.1516
Oak *Quercus petraea* (rich habitat) *Molinio caeruleae-Quercetum roboris* Wet mixed broadleaf forest	I	63.92	32.135	1.9684	1.6732
	II	56.55	29.653	1.4768	0.9372
	III	62.85	29.561	1.0091	0.2266
	IV	44.80	0.572	3.8367	1.4911
	V	55.24	25.601	1.4519	0.5565
	VI	63.89	28.753	3.1400	1.6797
Fir *Abies alba* *Abietetum polonicum* Mixed coniferous forest – highland type	I	44.16	2.400	0.4007	0.3942
	II	43.30	2.466	1.1970	0.9799
	III	40.35	4.518	0.8709	0.7264
	IV	43.15	2.267	2.2040	2.3230
	V	43.87	2.480	0.7899	0.3576
	VI	42.85	0.758	2.1289	2.2268
Larch *Larix decidua* comm. on *Querco-Pinetum*, (I–II) and *Tilio-Carpinetum* habitats Mixed coniferous forest Mixed broadleaf forest	I–II	42.55	0.799	3.3199	1.7693
	III	43.14	1.546	4.9628	7.1961
	IV	44.93	1.419	2.5964	1.2001
	V	46.12	1.303	4.0142	5.7627
	VI	44.85	0.474	1.7002	1.8063
Black alder *Alnus glutinosa* *Fraxino-Alnetum* Riparian alder-ash forest	I	42.97	1.067	1.4145	1.2026
	II	41.76	1.986	1.6451	1.1924
	III	39.93	2.147	2.0604	1.2660
	IV–V	no data	no data	no data	no data
Black alder *Alnus glutinosa* *Ribo nigri-Alnetum* Swamp alder forest	I–III	no data	no data	no data	no data
	IV	42.74	0.953	1.7863	0.4684
	V	42.79	0.625	1.7765	0.9805
Scots pine *Pinus sylvestris* (poor habitat) *Leucobryo-Pinetum* Coniferous forest	I	71.89	31.890	2.0095	1.2991
	II	72.71	30.994	2.4879	0.1615
	III	72.40	31.333	2.2306	0.4432
	IV	63.39	29.134	1.7726	0.6527
	V	72.84	30.843	1.7181	0.8584
	VI	72.41	31.323	2.5061	0.8275

1	2	3	4	5	6
Scots pine *Pinus sylvestris* (rich habitat) comm. on *Tilio-Carpinetum* habitats Mixed broadleaf forest	I	56.13	25.089	1.1835	1.0817
	II	44.42	2.399	2.8305	3.7581
	III	47.21	1.177	3.3170	1.5253
	IV	64.62	31.529	2.5124	0.7948
	V	44.43	0.637	3.5354	2.2461
	VI	47.15	1.711	2.4509	0.4455
Spruce *Picea abies* (lowland habitat) comm. on *Luzulo pilosae-Fagetum* habitats Mixed broadleaf forest	I	39.19	4.121	0.6825	0.3220
	II	45.04	1.388	1.2854	1.1101
	III	43.34	0.622	1.0583	1.3387
	IV	44.52	1.586	1.6038	0.9500
	V	42.46	1.348	1.9966	1.9611
	VI	43.71	0.494	1.7706	1.1382
Spruce *Picea abies* (submountain habitat) comm. on *Luzulo luzuloidis-Fagetum* hab. Mixed broadleaf mountain forest	≤40 y.	46.46	0.865	2.5498	2.2730
	41–80 y.	44.44	1.421	0.8061	0.1235
	>80 y.o.	44.65	0.797	0.9823	0.4540
Spruce *Picea abies* (lower mountain habitat) *Abieti-Piceetum montanum* Mountain coniferous forest	≤40 y.	46.25	0.839	1.6161	0.5901
	41–80 y.	46.38	1.071	0.7290	0.5418
	>80 y.o.	45.88	0.798	1.2088	0.8023
Spruce *Picea abies* (upper mountain habitat) *Calamagrostio villosae-Piceetum* Alpine coniferous forest	≤40 y.	47.71	1.797	3.3552	1.5964
	41–80 y.	44.54	1.010	0.9864	0.2481
	>80 y.o.	45.95	0.596	2.0381	0.0489

The results of analyses show that the amount of carbon in herb and moss layer in different forest stands is very diversified. Obviously, such differences are the effects of variable soil and water conditions, and changing availability of light and other resources for understory plants, during growth and development of main tree canopy. The highest concentrations of carbon in understory biomass was observed in pine forest stands on coniferous forest habitats. It can be interpreted as the result of most dense cover of vascular plants and mosses in undergrowth due to strong light penetration under canopy of pine forest stands in higher age classes, and additionally – as an effect of dominance in the undergrowth shrubs with partially woody stems. The relatively high concentration of carbon was observed also in the undergrowth in lowland oak and beech tree stands whose herb layer is created partly by shrubs and partly by dense grass stems and leaves containing large amounts of sclerenchyma.

Discussing the role of undergrowth in capturing carbon from the atmosphere one must not forget the fact that most of aboveground parts of stems and significant part of root systems of plants die at the end of each vegetation period, and dead leaves and stems become litter and undergo a slow decomposition. This means that annually, a part of carbon accumulated by undergrowth is translocated into the soil, and thus into another "reservoir" of carbon in the forest ecosystem.

The study showed, that carbon concentration in understory is strongly diversified, due to age of forest stand and floristic composition, and the same – due to type of forest. Forests communities are especially highly diversified, creating numerous floristic variants, facies and degenerative forms, strongly differing in species composition, plant cover and spatial structure of the understory. In general, obtained results are similar to data presented in literature for similar types of ecosystems, that means for subcontinental pine forest *Peucedano-Pinetum* (Banaszuk 1996; Banaszuk and Matowicka 1996), and swamp alder forests *Carici elongatae-Alnetum* (Czerwiński and Pracz 1995a; Pasternak-Kuśmierska and Kotowska 1995; Pasternak-Kuśmierska and Traczyk 1995b).

A detailed study of biomass and carbon concentration of all these characters would require a huge number of trials and tests, it is therefore unlikely that in the near future such studies have been carried out. In the absence of precise details in estimating the concentration of carbon in forest undergrowth, the data provided in this paper can be a basis for more provisional estimation of carbon sequestration in herb and moss layers, on the basis of of forests in Poland.

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