QUANTITATIVE ASSESSMENT OF CARBON SEQUESTRATION BY FOREST ECOSYSTEMS

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Abstract. Transformation of natural forests into plantations or economic semicultural forests leads to a substantial reduction of carbon storage in the living trees biomass and dead aboveground biomass. The effect of forest management and use on organic carbon storage depends on many site-specific factors (e.g. stand type, the climate and edaphic conditions) and often prevails over the high spatial variability of organic carbon storage in forest soil. The classification of carbon storage in forests of the Czech Republic is performed within an independent complex practical amendment to the forest functional assessment method (Vyskot et al. 2003). Carbon sequestration in forest ecosystems is mainly affected by two functional groups viz the bio-production function and the edaphic-soil-protective function and affects these in reverse. Therefore, the position of carbon storage classification in the system of forest functions is accentuated and evaluated as a subcategory (‘subfunction’) of the production function, respecting the system of forest ecosystem functions. The subcategory of carbon sequestration is quantified based on two function-determining criteria (ecosystem parameters) – the data on the amount of carbon bound in the aboveground biomass and the amount of carbon bound in the soil environment.

Introduction

Forestry approach to integrated polyfunctional management accepts the philosophy of equal significance of all forest functions including timber production for the life of human population by adopting the term “all-society forest functions”. Forest ecosystems store about 1200 x 1015 g C, which corresponds to 52 % of the total terrestrial carbon stock (Adams et al. 1990 in Campioli et al. 2008). Forests are the largest terrestrial carbon sink, accumulating around 1—3 x 1015 gC annually (Malhi et al. 1999 in Campioli et al. 2008). Minor changes in the carbon cycle in forest ecosystems can have great impact on the concentration of atmospheric CO_2 and global climatic changes. For the carbon cycle, the allocation in plants during assimilation processes (e.g. respiration, biomass production) and in organs (e.g. leaves, roots, branches, trunk) is vital as it determines the storage of carbon in forest ecosystems (Campioli et al. 2008).
The impact of climatic changes on the sector of forestry is categorized into the following: 1) processes in forest ecosystems, 2) changes in biodiversity, 3) interaction of disturbances (extreme influences), and 4) socioeconomic changes. These categories represent the key relations between the climate changes, the structure and functions of forests and the relations between human beings and forests (McNulty and Aber 2001).

Transformations of natural forests into plantations or production semicultural forests lead to a substantial reduction of carbon stock in the living tree biomass and dead aboveground biomass. In dependence on the intensity of stand tending, rotation period, harvesting technologies, tree species composition, the climate and the site conditions, the average living and dead biomass of production forests only reaches 20—60 % in contrast to natural forests. The effect of forest management and usage on organic carbon storage in the soil depends on many site-specific factors (e.g. stand type, the climate and edaphic conditions) and often prevails over the high spatial variability of organic carbon stock in forest soil.
A large part of the dendromass in production forests is regularly removed from the ecosystem and each felling is associated with soil cover erosion and different degrees of openings in the canopy. This all is reflected in the accumulation and decomposition of the forest floor humus. The degree of forest stand violation in consequence of canopy opening and timber harvest and the volume of timber which is removed from the forest during one felling decrease in this order: clear cutting – shelterwood system – selection system – natural forest (see table 1.).

Table 1. Summary of carbon stock in individual parts of the forest ecosystem – beech stands according to the management system (Mund 2004).

	shelterwood system	selection system	natural
		$tC.ha^{-1}$	
living biomass of trees	154.5 (149-160)	175.8 (153.9-219.4)	238.1 (212.7-285.0)
aboveground dead wood	1.5	1.5 (0-2.5)	6.4 (3.1-9.3)
humus layer	3.7 (3.3-4.0)	4.1 (4.1-4.2)	3.0 (2.3-3.8)
soil carbon of organic origin up to 15 cm depth	40.5 (33.6-42.5)	39.4 (35.3-45.7)	52.5 (51.2-54.9)
soil carbon of organic origin over 15 cm depth	45.9 (36.2-55.5)	45.1 (29.3-61.7)	52.5 (38.8-67.3)
total content of carbon in soil	86.4	84.5	105.0
in total	246.1	265.9	352.5
"modified" soil carbon of organic origin up to15 cm depth	41.8 (40.3-43.2)	41.7 (34.4-47.6)	47.9 (45.1-51.0)

Material and methods

The methodology for all-society forest function evaluation within the ecosystem conception (Vyskot et al. 2003) is based on the assumption of equal significance of all functions of forest ecosystems. However, equal significance of separate functions does not mean their equal value. Their value is a subject of quantification.

The value of the potential function ability is represented by the real potential of all-society forest functions (hereinafter 'RPff'). By the real potential of forest functions we mean the exactly quantified and classified functional ability of forests in the optimum possible ecosystem conditions.

The value of the current functional efficiency is represented by the real effect of all-society forest functions (hereinafter 'REff'), i.e. quantified functional effects of forests in the current ecosystem conditions. REff is formulated as a reduced value of RPff, expressed in % of RPff. It is determined by the reduction of RPff by function-reducing criteria of age, stocking and health condition. Both RPff and REff are expressed for groups of all-society forest functions, namely bioproduction function, ecological–stabilizing function, hydrological–water-management function, edaphic–soil-protective function, social-recreation function and health-promoting function.

The RPff values are classified in 0—6 degrees of value, where 0 is functionally unsuitable RPff, and 6 means extraordinary RPff (Vyskot et al. 2003). The sum of the value degrees of RPff of individual all-society forest functions shows the total real all-society potential ∑RPff, which is further diversified into classes (∑RPff I—VI). Class I contains very low total all-society real potential, class VI - extraordinary.

RPff values for the forests of the Czech Republic are available in tables for specific stand types (ST) within functional management groups (FMG). A FMG is a group of functionally related forest type groups (FTG). ST is a simplified expression of the tree-species composition of the forest stand, which consists of a capital letter showing the code of a tree-species representation (or a group of tree-species) and a numerical code for the tree-species.

The classification of carbon storage in forests of the Czech Republic is performed within an independent complex practical amendment to the forest functional evaluation method (Vyskot et al. 2003). The principle of the solution is based on the ecosystem approach to the performance of forest functions. Forest functions are the total production of quantified all-society effects of forest ecosystems. Quantification of forest functions is based on the characteristics and features of forest ecosystems which enter the methodical procedure in the form of determination criteria, and their values are used to calculate the real potential of forest functions. The current condition of a forest stand affects its current functional effects. Carbon sequestration in forest ecosystems is mainly affected by two function groups: the bioproduction function and the edaphic–soil-protective function, and these are in reverse affected by carbon sequestration. Other relations are observed to the health-promoting function and the hydrological–water-management function. However, at the current level of knowledge no complete sets of data are available for these functions within the conditions of Czech forests. Therefore, the position of carbon storage classification in the system of forest functions is evaluated as a subcategory ('subfunction') of the production function, respecting the system of forest ecosystem functions.

The subcategory of carbon sequestration is quantified based on two function determination criteria (ecosystem parameters) – the data on the amount of carbon bound in the aboveground biomass and the amount of carbon bound in the soil environment. The evaluated unit is a stand type (tree-species composition) within a management group. The amount of carbon in the aboveground biomass is converted using specific conversion formulas (Cienciala et al. 2006) for the main species of the CR (spruce, pine, oak, beech). The amount of carbon in the aboveground biomass is evaluated for mass of large timber. To derive this to the total mass (large timber + small timber), it is necessary to use other expansion factors (Cienciala et al. 2006). The data on the amount of carbon bound in the soil profile have been gained from the output data of PS 4 and 5 of CzechCarbo project (Macků 2006).

Results and disscussion

To define the amount of carbon as a function determination criterion (ecosystem parameter) the following steps have been taken:

1. Analysis of the amplitude of the amount of carbon bound in the soil up to 30 cm of soil environment (Macků 2006) for the conditions of the CR (see table 2.).
2. Conversion of the amplitude of the amount of carbon bound in the aboveground biomass using CBEF – conversion biomass factor (Cienciala et al. 2006).
3. Differentiation of the amplitude values of the above-mentioned criteria into function value degrees based on function intervals (see table 3.—4.).
4. Quatification of the amount of carbon by individual forest types for management group of stands (see examples in table 5.).

Within the further procedure to quantify the all-society function of "carbon sequestration" by forest ecosystems, the weights of the determination criteria were established in dependence on the total ability of a forest ecosystem to hold carbon and the definition of individual determination criteria with their units was specified.

Table 2. Function determination criterion – Total content of oxidizable forms of carbon – COx in the forest floor humus and mineral horizon of forest soils up to 30 cm depth. Source: authors' archive.

function degree	function interval %	function criterion: total content of COx in the forest floor humus and mineral horizon (up to 30 cm) of forest soils ($t\ ha^{-1}$)	interaction criterion: aggregated typological units of the Forest Management Institute
0	< 11	< 17.57	0e, 0Luh, 0Jav, 1R, 2R, 3R, 4Luh, 7Luh, 7Jav, 8Luh, 9Y, 9g, 9G, 9Luh, 9Jav
1	11-30	17.57-49.50	4g, 2G, 1Jav, 1g, 4e, 1K, 4Jav, 0e
2	31-45	49.51-73.45	5g, 1G, 3Jav, 2g, 1Luh, 5K, 5Z, 5Jav, 2Luh, 3Z, 5e, 3g, 4Z, 2K, 0G, 0g, 1Z, 3K, 6Luh, 4K, 4K, 3Luh, 3G, 2Z, 0K
3	46-55	73.46-89.42	0Z, 7R, 8e, 2Jav, 6Z, 6K, 5Luh, 6g, 4G
4	56-70	89.43-113.38	9R, 7g, 9K, 4R, 7K, 0R, 6G, 6Jav, 8R, 7e, 5R, 7Z, 6R, 9e, 8G
5	71-90	113.39-143.73	5G, 2e, 8Z, 8Jav, 8K, 1e
6	> 90	> 143.73	7G

Table 3. Function determination criterion – Volume of carbon (C) stock in the aboveground biomass in 100 years for the main economic tree-species

function degree	function interval %	function criterion: RVB (AVB)		interaction criterion: volume of C stock in the aboveground biomass in 100 years m^3ha^{-1}			
		SM, BK	BO, DB	SM	BO	BK	DB
0	< 11	-9(16)	-9(12)	155	81	143	107
		9(18)	9(14)	187	101	166	131
1	11—30	8(20)	8(16)	219	122	191	156
2	31—45	7(22)	7(18)	250	145	216	185
		6(24)	6(20)	285	167	243	216
3	46—55	5(26)	5(22)	320	192	271	248
4	56—70	4(28)	4(24)	355	217	303	283
		3(30)	3(26)	393	242	338	320
5	71—90	2(32)	2(28)	433	267	374	358
6	> 90	1(34)	1(30)	474	293	4113	397
		+1(36)	+1(32)	516	319	453	439

SM – spruce, BO – pine, BK – beech, DB - oak. Conversion of large timber mass (in % of biomass), RVB – relative height yield class, AVB – absolute height yield class. Source: authors' archive.

stock in the aboveground biomass during the rotation period for the main economic tree-species. Conversion of large timber mass. Source: authors' archive.

Table 4. Function determination criterion - Volume of carbon

function degree	function interval %	function criterion: RVB (AVB)		interaction criterion: volume of C stock in the aboveground biomass in the rotation period			
		SM, BK	BO, DB	SM 100	BO 130	BK 160	DB 150
0	< 11	-9(16)	-9(12)	89	79	147	122
		9(18)	9(14)	106	101	174	146
1	11—30	8(20)	8(16)	125	123	214	177
2	31—45	7(22)	7(18)	143	147	244	203
		6(24)	6(20)	163	172	283	246
3	46—55	5(26)	5(22)	183	197	339	287
4	56—70	4(28)	4(24)	203	223	378	336
		3(30)	3(26)	224	250	433	391
5	71—90	2(32)	2(28)	247	276	500	451
6	> 90	1(34)	1(30)	270	303	548	484
		+1(36)	+1(32)	294	330	596	560

Table 5. Values of the potencial functional ability of carbon sequestration Fv (real potencial) of forest ecosystems - for chosen management group of forests 21 and 53 and forest stands in value clasification 0–6.

ST	C stock in in the aboveground biomass	COx stock in the forest floor humus and mineral horizon of forest soils	Fv
MGS 21			
C3	2	5	4
C5	4	5	5
D3	2	5	4
D5	3	5	4
C7e	2	5	4
C1	4	5	5
D1	4	5	5
D5P9x	3	5	4
M3P1	2	5	4
M3P5	2	5	4
MGS 53			
C1	2	2	2
D1	2	2	2
D1P3	3	2	3
M1P3	2	2	2
C3	4	3	4
M1Z3	2	2	2
D1P4	4	2	3
D1P6	3	2	3
D3	3	3	3
Z1Z3	3	2	3

Fv - Values of carbon sequestration function of forest ecosystems; 1 - 6 values - functional degree; MGS - management group of stands; ST - specific stand type (Vyskot et al. 2003)

Function determination criteria are involved in the establishment of the value of individual functions in different degrees – the weight of significance expressed by the coefficient of variation. The coefficient of variation is expressed in %.

The coefficient of variation of function determination criteria the content of oxidizable carbon forms – COx in the soil, and the mass of C stock in large timber during the rotation period was established as ratio 50 % : 50 %.

NOTE: The content of carbon in large timber mass can be expressed in several ways with the same information capacity because these are coefficients or values of wood density etc. which can be mutually converted:

- amount of carbon stock in large timber mass in the rotation period – $m^3\ ha^{-1}$ – converted from the volume of large timber/ha using coefficients and conversion formulas;
- weight of large timber stock in the rotation period – $t\ ha^{-1}$ – converted from the volume of large timber stock using the mean wood density for all tree-species 1530 kg m^{-3}= 1.530 t m^3 (Gandelová et al. 2004)
- weight of drymass in large timber stock in the rotation period – converted from the volume of large timber stock using basic density ρk (Gandelová et al. 2004)
- weight of carbon stock in large timber drymass in the rotation period – converted using the carbon content in drymass – 0.45 tC t^{-1} of drymass (Fott et al. 1998)

Conclusions

The ability of forest stands to bind carbon is an organic part of their ecosystem functions. In the system of forest function quantification it is a part of bioproduction. It is determined by two criteria: the volume of carbon stock in the aboveground biomass during the rotation period and the total content of oxidizable carbon forms COx in the forest floor humus and the mineral horizon of forest soils up to 30 cm depth. Using economic addition, the quantified amount of carbon bound in various types of forest stands can be converted to a financial expression. In this way, the above-mentioned procedure can be used for meeting international conventions in the field of global climate changes.

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References

Campioli M, Verbeeck, H., Lemeur, R., Samson, R., C allocation among fine roots, above- and belowground wood in a deciduous forest and its implication to ecosystem C cycling: a modelling analysis. Biogeosciences Discuss 5, 3781-3823, 2008.

Cienciala, E., Henžlík, V., Zatloukal, V., Assessment of carbon stock change in forests – adopting IPCC LULUCF Good Practice Guidance in the Czech Republic. Forestry Journal 52, pp. 17–28, ISSN 0323–1046, 2006.

Fott, P., Pretel, J., Neužil, V., Bláha, J., Inventarizace skleníkových plynů v České republice v roce 1998. ČHMÚ Praha, 61 pp, 1998.

Gandelová, L., Horáček, P., Šlezingerová, J., Nauka o dřevě. Mendel University in Brno. Brno, 184 pp. ISBN 80-7157-577-1, 2004.

Macků, J., Bilance uhlíku v nadložním humusu a svrchním minerálním horizontu. Manuscript. 2006.

McNulty, S.G., Aber, J.D., US National Climate Change Assessment on Forest Ecosystems: An Introduction. Bioscience 51, 720-722, 2001.

Mund, M., Carbon Pools of European Beech Forests (Fagus sylvatica) under different silvicultural management. Berichte des Forschungszentrums Waldökosysteme. Reihe A, Band 189, 256 pp. ISSN 0939-1347, 2004.

Schimel, D., Manning, M., (eds.) IPCC Meeting on Current Scientific Understanding of the Processes Affecting Terrestrial Carbon Stocks and Human Influences upon Them. Expert Meeting Report. IPCC WG I. Geneva, 37 pp, 2003.

Šlezingerová, J., Gandelová, L., Stavba dřeva. Mendel University in Brno. Brno, 179 pp. ISBN 80-7157-137-7, 1994.

Vyskot, I., et al. Quantification and Evaluation of Forest Functions on the Example of the Czech Republic. Ministry of Environment, 194 pp., ISBN 80-7212-265-7, 2003.

Vyskot, I., Schneider, J., Pokorný, R., Marek, M.V., Vázání uhlíku lesními ekosystémy a jeho místo v systému celospolečenských funkcí lesů. In: Marek MV et al.: Uhlík v ekosystémech České republiky v měnícím se klimatu. 1. Praha: Academia, pp. 187–206. ISBN 978-80-904351-1-7, 2011.