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Estimations of Total Ecosystem Biomass and Carbon Storage for Fir (*Abies nordmanniana* S. subsp. *bornmülleriana* (Mattf.)) Forests (Western Black Sea Region)

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Abstract

With increasing CO_2 in the atmosphere, there is an urgent need of reliable estimates of biomass and carbon pools, especially in Turkey where there is a serious lack of data. Information on amount of carbon biomass resulting from direct field measurements is crucial in this context, to know how forest ecosystems will affect the carbon cycle and also to validate the measurements. Biomass data were collected over the different vegetation types and land uses of pure fir forests in the Western Black Sea region in Turkey. Using site-specific allometric equation, we estimated biomass and carbon pools. We used GIS technology to develop a carbon biomass map of our study area. We estimated aboveground carbon, root carbon, and soil organic carbon down to 30 cm depth.

This study will provide estimates of biomass and carbon pools from pure fir forests in the Western Black Sea region as well as an appropriate methodology to estimate based on ecosystem carbon storage components.

Key words: Ecosystem base, living tree biomass, carbon, soil and root

Introduction

Forest biomass contains approximately 80% of all aboveground terrestrial carbon (C) and 40% of belowground C (Dixon et al., 1994; Goodale et al., 2002). Therefore, forests are considered an important sink for atmospheric carbon dioxide (CO_2) and provide a great potential for temporarily storing atmospheric CO_2 in terrestrial ecosystems. Enhancing C sequestration by increasing forested land area has been suggested as an effective measure to mitigate elevated atmospheric carbon dioxide (CO_2) concentrations and hence contribute towards the prevention of global warming (Watson 2000, IPCC 2001). In recent decades, changes in land-use including deforestation has resulted in an increased cover area of forests at different stages of their development. Thus, knowledge about the development of both above- and belowground biomass over the entire life cycle of a forest is required for accurate quantification of biomass and C pools on regional and national scale (Vogt, 1991; Kurz et al., 1996; Brown, 2002). Generally, regional and national biomass and C stock estimates for aboveground biomass as well as for individual tree components are derived from plot-level forest inventory data by applying allometric biomass equations and biomass expansion factors (BEF's) (Jenkins et al., 2001, Brown 2002, Goodale et al., 2002).

The greatest potential for aboveground biomass and C storage in forest ecosystems is usually found within the tree biomass components (stem, branches, and foliage). Biomass of understorey and ground vegetation as well as of dead standing tree and woody debris may also provide a considerable contribution (e.g. Whittaker & Woodwell, 1968; Long & Turner, 1975). Thus, neglecting these secondary biomass and C pools may lead to a significant underestimation of total C storage. Apart from aboveground vegetation, belowground tree root biomass, forest floor, and mineral soil provide large C pools (Johnson et al., 2003, Oliver et al., 2004). However, there has been some disagreement in literature about whether or not an increase in soil C may be achieved through forest plantations. Furthermore, due to the immense effort required in obtaining a precise estimate of tree root biomass, C storage in tree roots is often neglected or estimated from standard root to shoot ratios (Kurz et al., 1996; Cairns et al., 1997). Yet, root biomass may contribute a significant amount to ecosystem biomass. It is therefore imperative to include roots in forest biomass and C pool estimates.

Furthermore, the allocation of biomass and C storage among tree C pools changes over the lifespan of a forest stand (Satoo & Madgwick, 1982). Therefore, applying standard ratios to determine various biomass components that focus on few components only (e.g. inventory of merchantable stem wood) may lead to considerable errors in estimates of total ecosystem biomass and C storage.

Abies nordmanniana S. subsp. *bornmülleriana* (Mattf.) is considered one of the most important tree species in Turkey, due to its valuable wood and ecological function. Allometric biomass and carbon equations including only aboveground tree biomass have been developed for a few tree species in Turkey, i.e. alder, beech, Scots pine, and oak, but there is no study on total ecosystem biomass and carbon storage.

Therefore, there is a considerable lack of information about biomass and C pools in Turkey especially Western Black Sea region. The aim of this study was to quantify the total ecosystem biomass and carbon storage capacity for fir natural stands. Results of this study, especially those from destructive sampling of belowground roots, will help to fill a gap in the forest biomass estimation related literature.

Material and Methods

The data used in this study were collected from fir natural stands in Bostan Forest District of Kastamonu Forest Enterprise. Total area of the study area is 8,297.5 ha and forested area is 5,764 ha. Mean altitude and slope of this area are 1,750 m and 60%, respectively.

From the various age and site classes, 20 temporary sample plots were measured in 2012. Plot size is 600 sq.m. In each sample plot, diameter at breast height, stump diameter, bark thickness of all trees and the height of at least 30 trees that have different size were measured. In addition, 15 sample trees 65 to 186 years old were cut to determine the site index. The age, diameter at breast height and total height of these trees, are shown in Table 1.

Methods

Biomass and carbon data were obtained from felled trees collected in the year 2012. These biomass and carbon data were provided by 15 trees. Sample trees were selected from each diameter classes with an effort to equal allocation. For each diameter class, efforts were made to include every height classes.

Table 1. Summary Statistics of Sample Trees

Number of Tree	Age (Years)	Dbh (cm)	Total Height (m)
1	100	10.0	6.2
2	146	57.5	36.9
3	159	47.5	31.4
4	140	57.3	39.5
5	106	32.6	22.7
6	160	37.5	29.3
7	103	11.4	10.1
8	69	19.2	17.6
9	79	32.2	26.3
10	85	16.8	14.8
11	67	14.0	10.6
12	65	12.9	12.1
13	121	51.9	28.8
14	105	28.7	22.2
15	186	32.4	26.3

The aboveground portion of each sample tree was divided into components and the fresh weight of each component was measured. All 15 trees were felled and weighed. Once cut down, the trees were divided into trunk and crown, the latter being considered as starting from the first line branch. Then, each tree component was measured for raw weight. To determine dry weight, samples of different tree components were weighed in a laboratory before and after desiccation. In 20 sample plots all trees were measured. The parameters recorded were species name, dbh, total height and geographical coordinates x and y. In the sample plots, representative samples were collected, dried weighed and the root system extracted from the soil and its dry weight measured when it was possible. The Huber's formula was used to determine the volume of sample trees and the biomass stem wood samples were taken from different heights. The wood samples were oven-dried during

96 hours at 102 °C and weighed using an electronic balance.

The total above ground biomass was estimated using allometric biomass regression equation. The total biomass of a sample plot was obtained by multiplying the weighted biomass by the number trees. To estimate carbon content in tree biomass, we collected 4-5 core samples from each sample tree with an increment borer. Each core sample was oven-dried at 102 °C during 96 hours and samples were analyzed for C-concentration using a CHNS elemental analyzer (Costech, Italy).

In each of the 20 plots, soil samples were collected at depth layers of 0-10 cm, 10-30 cm, 30-50, 50-80 cm, and over 80 cm. To evaluate bulk density and soil carbon 3 soil samples were collected from each layer with a cylinder of 10 cm diameter and 10 cm length. The carbon content was analyzed at the Forest Yield Laboratory. Soil samples were oven-dried and analyzed for C-concentration using a CHNS elemental analyzer (Costech, Italy). The soil carbon (SC) pool in each layer was estimated using equation V in which %C is the weight percentage of carbon in this layer, p the bulk density of the soil in kg/cu.m. and V the volume of soil per hectare. To estimate belowground biomass of trees we used the roots directly measured in the field. The roots were separated into three groups (fine, small and coarse). The biomass of fine (0-2 mm), small (2-5 mm) and coarse (over 5 mm) roots were assessed by collecting four 30 cm depth, 6.4 cm diameter cores per plot. The roots were separated from the soil by soaking in water and then gently washing them over a series of sieves with mesh sizes of 2 and 5 mm. The roots were sorted into the diameter classes 0-2 mm (fine root), 2-5 mm (small root) and over 5 mm (coarse root) root classes. The roots from each size category were oven-dried at 65 °C for 24 hours and weighed. In each sample plots, ground vegetation (all seedling trees (height < 1.3 m), shrubs, herbs, and woody debris) was estimated by destructive harvesting placing 1 m x 1 m quadrats at the peak productive time in year 2012. Identification of species and an estimate of their cover-area were conducted for each species found within the plot. Biomass of each ground vegetation component was air dried and sub-samples were oven-dried at 65 □C for 72 h, in order to calculate dry biomass on an area basis. Litter was sampled with 25 cmx25 cm wooden quadrates in four different fields in each sample plot. All allometric regression equations were developed using SPSS 20 v.1 (SPSS, 2011). The independent variable was dbh.

Results

The total tree density was 873 trees ha^{-1}. The soil carbon (SC) percent was low in the bottom soil layer (50-80 cm) (Table 1).

Table 1. Stand structure and soil characteristics of fir natural stands in Bostan Forest District

Altitude (m)	1,750
Area of forest	5,764
Total tree density (trees/ha)	873
Soil bulk density (gr/cm^3)	0.600
Soil carbon (%)	3.82 ± 0.77

Highly significant ($p<0.001$) allometric biomass and carbon equations were obtained (Table 2).

Table 2. Allometric relationship between the biomass and carbon of tree components and diameter at breast height for *Abies nordmanniana* S. subsp. *bornmülleriana* (Mattf.)

Tree component		Model	Intercept	b1	b2	R^2
Bole	Biomass	Quadratic	107.197	-13.702	0.665	0.815
Branch		Power	0.003	3.052		0.739
Needle		S	5.676	-52.915		0.594
Bark		Quadratic	23.162	-1.556	0.038	0.469
Bole	Carbon	Quadratic	51.648	-6.414	0.303	0.804
Branch		S	5.311	-55.244		0.691
Needle		Power	0.033	1.764		0.552
Bark		Quadratic	9.974	-0.634	0.016	0.456

The total tree biomass for *Abies nordmanniana* S. subsp. *bornmülleriana* (Mattf.) was 445 kg (from 24.8 kg to 1,476 kg). The total tree carbon storage of natural fir stand was 145.6 t/ha (from 71.4 t/ha to 299.2 t/ha). The bole carbon storage of it was 117.1 t/ha. The branch, needle and bark carbon storage of fir stand were 12.8 t/ha, 9.8 t/ha and 6.0 t/ha, respectively.

The carbon content of a fir tree bole ranged from 43.9% to 46.0%. For the other biomass components' (branch, needle and bark) the C contents were 46.6%, 56.1% and 38%, respectively.

Carbon content of litter for natural fir stands ranged from 26.2% to 50.6%. Litter carbon storage was 5.93 t/ha. Shrub herb biomass carbon storage ranged from 69 kg/ha to 1,016 kg/ha.

Fine root biomass ranged from 1,684.5 kg/ha to 9,214.1 kg/ha. Small and coarse roots biomass were 4,097 kg/ha and 11,762 kg/ha on average. Fine, small and coarse roots carbon storages ranged from 485 kg/ha to 3,566 kg/ha, 392 kg/ha to 2,673 kg/ha and 1,049 kg/ha to 6,428 kg/ha, respectively. Total root biomass and carbon storage were 39,628 kg/ha and 9,365 kg/ha.

Conclusions

The total ecosystem biomass carbon storage of natural fir (*Abies nordmanniana* S. subsp. *bornmülleriana* (Mattf.)) stands in Western Black Sea region was 314.1 t/ha on average (Table 3).

The forests will play an important role in mitigating the increase of CO_2 concentration in the atmosphere if new stands are established and mature forests can be better protected.

There are five pools in forest ecosystems: living trees, deadwood, understory vegetation, litter floor, and soil. In this research, we estimated the carbon sequestration in all pools. However, carbon flux in living trees and soil are responsible for the largest carbon storage among five forest carbon pools, which could account for 87% of total carbon storage in forest ecosystems.

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Table 3. Total ecosystem carbon pools in natural fir stands in the western Black Sea region

Ecosystem Carbon Pools	Minimum	Maximum	Mean
Bole	47.20	261.50	117.10
Branch	2.78	18.10	12.80
Needle	5.30	19.60	9.80
Bark	3.80	10.50	6.00
Litter	2.36	14.09	6.00
Shrub	0.07	0.43	0.16
Soil	46.64	255.20	155.60
Fine roots	0.49	3.57	1.62
Small roots	0.32	2.67	1.64
Coarse roots	1.10	6.4	2.95

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