

# Carbon Stock in Forest Stands of Ukrainian Eastern Forest-Steppe: Forest Monitoring Data <sup>†</sup>

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**Abstract:** In Ukraine, carbon stocks in forests are assessed by the gain-loss method since the national forest inventory is under development now. For the evaluation of main pools of oak and pine forest stands, typical for the Forest-steppe of Ukraine, the stock-difference method was used for the data of repeated observations on 18 intensive forest monitoring plots. The average carbon stock in the phytomass was  $94.1 \pm 19.8$  tC·ha<sup>-1</sup> and  $93.4 \pm 12.8$  tC·ha<sup>-1</sup>, while in the deadwood, it was  $8.8 \pm 7.3$  tC·ha<sup>-1</sup> and  $5.3 \pm 4.3$  tC·ha<sup>-1</sup> for oak and pine forest stands, respectively. In terms of age classes, pine stands, due to their higher productivity, in general, had a higher carbon (C) stock in phytomass compared to oak. C stock changes in trees phytomass were the highest in younger stands, and they decreased with age, while in deadwood, they increased. At age 81–100 years, oak forest stands had higher carbon storage capacity than pine (total stock in main pools (phytomass, mortmass, and soils (30-cm layer)) was 191.7 tC·ha<sup>-1</sup> for oak and 175.4 tC·ha<sup>-1</sup> for pine stands). Trees phytomass carbon prevailed among other pools (50.3% in oak forests and 57.6% in pine).

**Keywords:** carbon pools; phytomass; dead wood; carbon stock changes; oak stands; pine stands; age classes

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## 1. Introduction

In many countries, for greenhouse gases (GHG) emissions estimates, especially carbon, in the forest sub-sector, national forest inventory (sample-based) (NFI) data are used [1]. In Ukraine, the NFI system is under development now, so the source of data for GHG reporting is the data of stand-wise forest inventory [2,3]. The methodology to calculate carbon stocks and test on forest monitoring plots is important for the development of NFI in Ukraine.

## 2. Materials and Methods

The study was held in the Eastern part of Ukraine (Kharkiv and Sumy regions), in the ecological zone of temperate forests (Forest-steppe zone) [4]. The data were collected at 18 intensive forest monitoring plots with the fixed area at two consequent observations in a 4-year interval. These monitoring plots are located at Scots pine (4 plots) (*Pinus sylvestris* L.) and English oak (14 plots) (*Quercus robur* L.) forest stands, which are typical Forest-steppe zones in the eastern part of Ukraine. Studied oak stands are represented mainly by natural coppice stands with an admixture of other deciduous species (*Fraxinus excelsior* L., *Acer platanoides* L., *Tilia cordata* Mill., etc.) on dark gray forest soils. Pine stands are artificial monodominant Scots pine forests on sandy sod-podsolic soils. The age of these stands varied from 44 to 144 years old; the average age of pine stands was 68 years, while that of oak was 99 years.

All trees with diameter at breast height DBH  $\geq 12$  cm (living and dead) on these monitoring plots were mapped, measured, and their sanitary condition was estimated. The litterfall type and thickness, as well as soil type, were determined. All dead logs with a diameter of  $\geq 7$  cm and stumps with a diameter of  $> 14$  cm were measured; their decomposition stage was evaluated.

Carbon (C) stock was evaluated for two observations at trees phytomass and deadwood mortmass (dead trees, dead logs, and stumps) by Intergovernmental Panel on Climate Change (IPCC) formulas [1], taking into account the basic wood density of trees species [5] and decomposition stage of deadwood [6,7]. For the estimation of carbon dynamics on studied monitoring plots by carbon pools, the stock-difference method was used [1].

Data were analyzed for pine and oak forest stands, in general and by 20-year age classes, as age influences the process of tree growth and carbon accumulation [8]. For the comprehensive evaluation of main carbon pools at plots level, the additional data on average soil carbon in 30-cm soil level and litter carbon stocks from [9] for the region of study (Forest-steppe) and types of forest stands were used.

### 3. Results

The average carbon stock in trees phytomass was  $94.1 \pm 19.8$  tC·ha<sup>-1</sup> at the studied oak stands and  $93.4 \pm 12.8$  tC·ha<sup>-1</sup> at pine stands (Table 1). In all types of stands, the phytomass C stocks increased with age; just at one plot at the oak stand (age 61–80 years), it decreased due to the mortality of significant trees caused by biotic damage. The average deadwood C stocks at the studied oak stands were  $8.8 \pm 7.3$  tC·ha<sup>-1</sup>, while in the pine stands were  $5.3 \pm 4.3$  tC·ha<sup>-1</sup>.

**Table 1.** Carbon stocks (t ha<sup>-1</sup>) and dynamics (t ha<sup>-1</sup>·year<sup>-1</sup>) in phytomass and mortmass of the studied oak and pine stands.

Forest Type and Age Class	C Stock in Trees Phytomass	C Stock in Deadwood Mortmass	Average C Change in Trees Phytomass	Average C Change in Deadwood Mortmass
Oak 41–60 years	91.1	5.0	2.7	1.1
Oak 61–80 years	60.2	11.9	−2.0	0.3
Oak 81–100 years	96.5 $\pm$ 23.0	4.4 $\pm$ 4.0	1.6	0.1
Oak 101–120 years	98.5 $\pm$ 17.4	8.6 $\pm$ 6.8	−0.3	1.8
Oak > 120 years	97.6 $\pm$ 10.5	15.7 $\pm$ 7.4	−1.9	0.5
Average Oak	94.1 $\pm$ 19.8	8.8 $\pm$ 7.3	0.2	0.6
Pine 41–60	71.9	1.0	2.9	0
Pine 61–80	100.3 $\pm$ 4.4	4.2 $\pm$ 2.4	1.4	0.8
Pine 81–100	101.1	11.8	−0.9	2.7
Average Pine	93.4 $\pm$ 12.8	5.3 $\pm$ 4.3	1.2	1.1

Data showed (see Table 1) that both pine and oak stands at age 41–60 years had the highest C change due to their intensive growth. The oldest stands had negative trees phytomass C change and positive deadwood C change due to slow growth and increased mortality.

According to the combined calculation at studied forest stands obtained on the basis of our observations on C stock in stands and deadwood and data from [9] on C stock in soils and litter at age class 81–100 in oak forest, the total carbon stock in main carbon pools was 191.7 t C ha<sup>-1</sup> (phytomass–96.5, mortmass–4.4, soil–88.0, litter–2.8 t C ha<sup>-1</sup>) and at pine stands was 175.4 t C ha<sup>-1</sup> (phytomass–101.1, mortmass–11.8, soil–50.9, litter–11.6 t C ha<sup>-1</sup>).

### 4. Discussion

Results showed that the average carbon stocks in trees phytomass and mortmass of the studied oak stands were higher than in pine stands, which was associated with a difference in age structure (oak stands were older than pine stands). Our results were lower

than the average values calculated for modal oak and pine stands (104 and 101.3 t C ha<sup>-1</sup>, respectively) for the Forest-steppe zone of Ukraine at the same age, according to [2]. For these calculations, the gain-loss method was used.

The results showed that deadwood C stock at oak stands was higher than in pine stands due to higher mortality rates and longer decomposition period of the oak deadwood.

So, our data proved that, in general, at age 81–100 years, oak stands have higher carbon storage capacity than pine stands. Among other pools, trees phytomass plays the most significant role in C sequestration (50.3% and 57.6% of total carbon stock in oak and pine stands, respectively); the second important pool is forest soil (45.9 and 29.0%, oak and pine stands, respectively), while the deadwood and litter pool are the smallest (3.8% and 13.3%, oak and pine stands, respectively).

However, these results are preliminary and just show general trends and illustrate the methods used. Of course, implementation of NFI and soil monitoring at the country level will allow obtaining more detailed estimates in these carbon pools values for different forest types and age groups, and just after two repeated NFI observations, it will be possible to obtain modern data on carbon budget in the forests of Ukraine.

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