Forest carbon stock in Left-bank Forest-Steppe of Ukraine according to intensive forest monitoring data

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The issues of carbon stock and dynamic in different carbon pools in forest stands of Left-bank Forest-steppe of Ukraine are considered. The aim of the study was to evaluate carbon stocks and their changes in main pools: trees biomass and mortmass. Data of two repeated observations on 19 permanent intensive forest monitoring plots in Kharkiv and Sumy regions were used. Conversion method was used.

Study of increment and mortality dynamics at monitoring plots showed, that two processes impact carbon balance: biotic damage which leads to trees dieback, and partial removal of dead wood from stands.

Oak stands have, on average, higher carbon stock in trees biomass and mortmass (102.9 t C ha⁻¹) than the pine stands (98.7 t C ha⁻¹), which is associated with a higher representation of mature and overmature oak stands. While comparison by age classes showed that pine stands, in general, have higher values of C in trees biomass, due to higher productivity. The increase in carbon stocks with age is observed.

The annual change of C stock in trees biomass is the highest in younger stands, and it decreases with age; while in mortmass it increases. Mature and overmature oak stands have negative trees biomass and positive dead wood growth.

At age 81-100 years oak forest stands have higher carbon storage capacity than pine (total carbon stock in main pools (biomass, mortmass, litter and soils (30-cm layer)) is 191.7 t C ha⁻¹ for oak and 175.4 t C ha⁻¹ for pine stands). Trees biomass carbon prevails among other pools (50.3 % in oak forests, and 57.6% in pine), the next is soil carbon pool (45.9 and 29.0%, respectively).

National forest inventory will provide data for assessments of carbon stocks and dynamics in trees biomass and mortmass pools. However, forest soil monitoring is necessary to evaluate carbon pools in soils and litter.

Key words: trees biomass; dead wood; carbon pools; carbon stock changes; oak stands; pine stands; age classes.

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**Introduction.** Paris climate agreement (2015) has confirmed the important value of forests as the main carbon sink.

Forests in terms of agroforestry, forest management, reforestation have been suggested as one of the most appropriate land management systems for mitigating atmospheric CO₂ through the photosynthesis process (Alemu, 2014). Forest ecosystems also contribute to store more than 80% of all terrestrial aboveground C and more than 70% of all Soil Organic Carbon (Alemu, 2014). The terrestrial carbon reservoir is actually a collection of carbon pools with a wide range of net primary production rates, respiration rates and carbon turnover times. Detailed information on carbon stored in dead wood and its relationships with different decay stages are required by national forest and carbon sink inventories to understand dead wood dynamics and the impact on microhabitats with a changing climate. These relationships are expected to vary with disturbance regime and forest type.

The issue of carbon balance research in forest ecosystems is receiving much attention today. Particularly important is the use of information technologies and mapping (Tokar, 2015; Wang et al., 2009).

Inventory of greenhouse gases in the forestry sub-sector can be performed by two methods: stock-difference and gain-loss (stock emission) (IPCC, 2014). In Ukraine, carbon stocks in forests are assessed by the second method (Buksha, Butrim, & Pasternak, 2008) on the base of stand wise forest inventory data since the national forest inventory is at the stage of development now. Comparison of forest stand wise inventory data is not possible due to the irregularity of their accounting, different methodological approaches to the compilation and the relatively low accuracy of the inventory of different components of forest ecosystems (Buksha, Butrim, & Pasternak, 2008).

Forest-steppe zone is a transition zone between forest and steppe, and it is vulnerable to expected climate change (Shvidenko, 2017).

In Ukraine complex studies of carbon stocks in forest ecosystems are fragmentary: one of the study areas are trees biomass and mortmass stocks evaluation, and conversion factors development on the ratios of trees biomass fractions (Lakida, Vasylyshyn, Lashenko, & Terentiev, 2011), estimation of carbon stocks in soils in Carpathians (Shpakivska & Maryskevych, 2009) and generally in Ukraine (Buksha, Raspopina, & Pasternak, 2012; Balyuk et al., 2017), several studies are devoted to the assessment of carbon stocks in forests based on stand wise forest inventory data (by using gain – loss method) (Shvidenko et al., 2014), several studies on sample plots (Alioshkina et al., 2011; Bilous et al., 2019). Studies are mainly carried out in the Forest zone of Ukraine (Polissya) (Bilous et al., 2017; Lakyda et al., 2018), while for the Forest-Steppe zone there are just a few of them (Yarotsky, Pasternak, & Nazarenko, 2019b; Bilous et al., 2019). The features of C dynamics were not studied in detail.

In Russia, forest carbon stocks were assessed on the base of stand wise forest inventory data, and multiple forest studies and models (Zamolodchikov, 2011).

In the majority of European countries forest carbon storage is assessed on the base of national forest inventory/monitoring (Cienciala, 2010), and soil monitoring data (Manual on methods, 2016). Due to the planned implementation of National forest inventory in Ukraine, it is important to develop a methodology for evaluating carbon stocks on sites.

**Objects and methods.** The study object is forest stands of the Left-Bank Forest-Steppe of Ukraine. The study subject is carbon in forest stands.

The aim of the research is to evaluate carbon stocks in main pools of forest ecosystems and their dynamics using the conversation method in the Left-Bank Forest-Steppe of Ukraine on intensive forest monitoring plots.

The study includes the results of two consecutive surveys of 19 intensive forest monitoring plots located in oak and pine forest stands of the Forest-steppe zone in Kharkiv and Sumy regions (Tab. 1). Each plot is observed every 4 years. The survey data for 2012-2015 were included in the study as the first observation and repeated survey held after 4 years in 2016-2019 were the second one. The monitoring plots are represented by zonal types of forest type conditions according to Alekseev-Pogrebnyak (Ostapenko, & Tkach, 2002): D₁ – fresh fertile forest type condition (Quercus robur L. (English oak) stands), C₁ – fresh relatively fertile forest type condition, and B₁ – fresh relatively poor forest type condition (Pinus sylvestris L. (Scotch pine) stands). The age of studied forest stands varies from 44 to 144 years old. Oak stands are mainly grown on dark gray forest soils, rarely on chernozems, and light gray forest soils; pure pine stands – on sod-podzolic soils. One monitoring plot is located in a 74-year deciduous forest with a dominance of Tilia cordata Mill. (small-leaved lime).

There were two types of monitoring plots (Tab. 1): the first – circular with concentric circles, with area 0.1 ha (all plots with «long» numbers), the second – square-shaped (ICP test-phase) (three plots 1, 2, and 3) – with area 0.25 ha.

At the intensive monitoring plots, the indicators of the main components of forest ecosystems (tree stand, undergrowth, ground vegetation, soil, litter) were evaluated. For each tree with DBH ≥ 7 cm, its status (living, dead, fallen) was recorded, which made it possible to trace the dynamics of trees mortality, or removal from the forest stand. Heights were measured for model trees. Index of health condition and the presence of damage were estimated. The litterfall type and thickness were assessed. Soil type was determined. For dead logs with diameter ≥ 7 cm: species, size (diameter and length), decomposition stage (5 classes) and type of rot were evaluated. Dead logs of different tree species and decomposition stages were sampled to determine the base density. Field-map was used for field work and data management.
**Table 1**

| Plot ID | Region | Species composition* | Age, years | Forest site conditions | Site index | Density of stocking | M, m³·ha⁻¹ |
|---------|--------|----------------------|------------|-----------------------|------------|--------------------|-----------|
| 32491   | 1      | 9Querob 1Poptre+Tilcor | 52         | D₂                   | Ia         | 0.73               | 269       |
| 42906   | 2      | 9Querob 1Ulmlga+Acepla,Robpse | 84         | D₂                   | I         | 0.59               | 255       |
| 44262   | 2      | 8Tilcor 1Poptre1Fraexc+Acepla | 74         | D₂                   | I         | 0.59               | 259       |
| 2263079 | 1      | 10Pinsyl             | 97         | B₂                   | I         | 0.70               | 425       |
| 36324   | 1      | 7Querob 2Tilcor 1Acecam+Acepla | 124        | D₂                   | I         | 0.79               | 408       |
| 41544   | 2      | 4Querob 4Acepla1Fraexc1Tilcor | 144        | D₂                   | II        | 0.73               | 319       |
| 631309  | 1      | 10Pinsyl             | 44         | B₂                   | Ia         | 0.68               | 318       |
| 32473   | 1      | 8Querob 1Tilcor 1Acecam | 88         | D₂                   | II        | 0.93               | 339       |
| 32485   | 1      | 10Pinsyl             | 68         | B₂                   | Ia         | 0.68               | 413       |
| 32496   | 1      | 10Querob+Tilcor, Acecam | 103        | D₂                   | II        | 0.68               | 290       |
| 33734   | 1      | 3 Querob 3 Tilcor 2 Acepla2 Acecam +Ulmlga | 98         | D₂                   | II        | 0.83               | 286       |
| 33751   | 1      | 5 Querob 3 Fraexc 2 Tilcor + Acepla, Ulmlga | 88         | D₂                   | II        | 0.95               | 402       |
| 33754   | 1      | 5 Querob 2 Fraexc 2Tilcor 1Acepla | 103        | D₂                   | I         | 0.90               | 379       |
| 33760   | 1      | 10Pinsyl             | 63         | B₂                   | Ia         | 0.85               | 453       |
| 33761   | 1      | 9 Querob 1Fraexc   | 73         | C₂                   | I         | 0.55               | 200       |
| 33771   | 1      | 6 Querob 3Tilcor 1 Acecam + Acecam, Ulmlga | 84         | D₂                   | I         | 0.86               | 351       |
| 1       | 1      | 9 Querob 1Tilcor + Fraexc, Acecam, Acepla | 92         | D₂                   | I         | 0.74               | 335       |
| 2       | 1      | 6 Querob 3Fraexc 1Tilcor +Acecam, Acepla | 132        | D₂                   | II        | 0.82               | 368       |
| 3       | 1      | 7Querob 2Fraexc 1Acecam+Acecam,Tilcor, Ulmlga | 122        | D₂                   | II        | 0.75               | 301       |

Notes: 1. Kharkiv region, 2. Sumy region; * Querob – *Quercus robur*, Pinsyl – *Pinus sylvestris*, Fraexc – *Fraxinus excelsior*, Tilcor – *Tilia cordata*, Acepla – *Acer platanoides*, Acecam – *Acer campestris*, Ulmgla – *Ulmus glabra*, Robpse – *Robinia pseudoacacia*. B₂ – fresh relatively poor forest type conditions; C₂ – fresh relatively fertile forest type conditions; D₂ – fresh fertile forest type conditions (classes by Alekseev-Pogrebnyak).

According to IPCC (2014), there are main carbon pools in forest ecosystems: biomass (aboveground and underground biomass), dead organic matter (dead wood and litter) and soil organic matter. In our study, carbon stock calculations and dynamics were performed for trees biomass of forest stands, and dead wood (dead trees and dead logs) on the base of values of total stocks (volume), using conversion method of calculations. Growing stock and dead wood volume were converted into mass (using the base density for tree species and decay stages and species for dead wood) (Bilous et al., 2019; Cosmoa, Gasparinia, Palettoa, & Nocettib, 2013; IPCC, 2014) and the carbon stock (formulas (1)-(3)) (Buksha, Butrim, & Pasternak, 2008). The fraction of branches was considered without fractions of leaves and needles (Lakida, Vasylyshyn, Lashenko, & Terentiev, 2011). For deciduous mixes stands calculations were performed for individual trees, while for pine monocultures – for the total growing stock.

Carbon stock in trees biomass was estimated according to the formula:

\[ C_{trees} = \sum M_{si} \cdot BEF_{si} \cdot Di \cdot 0.5, \]  

where \( C_{trees} \) – total carbon stock in live trees biomass pool (tonnes C ha⁻¹); \( M_{si} \) – total stem volume of \( i \) tree species; \( BEF_{si} \) – conversion coefficient for calculation of stem biomass into total biomass taking into account branches, for \( i \) – tree species; \( Di \) – basic density of timber of \( i \) – tree species; \( 0.5 \) – conversion coefficient used for calculation of dry organic mass into carbon mass (carbon content of absolutely dry matter) (IPCC, 2014).

Carbon stocks in dead wood pool (dead trees and dead logs) were calculated according to the data on the basic density of dead wood by decomposition stages and tree species.

\[ C_{deadtrees} = \sum M_{dti} \cdot Di \cdot 0.5; \]  

\[ C_{deadlogs} = \sum M_{d} \cdot Dj \cdot 0.5; \]  

where \( M_{dti} \) – total stem volume of dead trees of \( i \) tree; \( Di \) – basic density of timber of \( i \) – tree species; \( M_{d} \) – total volume of dead logs; \( Dj \) – basic density of timber of \( i \) – tree species of \( j \) – decomposition stage.

Annual changes of carbon stocks in carbon pools were calculated according to IPCC formula (2014) at site level, as the difference of two estimates:
where $\Delta C$ – annual changes of carbon stocks in pool $i$, tonnes C ha$^{-1}$ year$^{-1}$;

$C_{t_1}^i$ – total carbon stock in pool $i$ at year $t_1$, tonnes C ha$^{-1}$;

$C_{t_2}^i$ – total carbon stock in pool $i$ at year $t_2$, tonnes C ha$^{-1}$.

The growth and mortality in the studied monitoring plots were estimated. To estimate the growth, the annual changes in the growing stock of forest stands were calculated taking into account changes in dead wood stocks.

$$Z = (M_{t_2} - M_{t_1} + D_{w_{t_2}} - D_{w_{t_1}})/(t_2 - t_1),$$

where $Z$ – current annual increment, m$^3$ha$^{-1}$ year$^{-1}$;

$M_{t_1}$ – growing stock in year $t_1$, m$^3$;

$M_{t_2}$ – growing stock in year $t_2$, m$^3$;

$D_{w_{t_2}}$ – dead wood volume in year $t_2$;

$D_{w_{t_1}}$ – dead wood volume in year $t_1$.

To estimate the mortality changes in dead wood stocks were evaluated.

$$\Delta DW = (D_{w_{t_2}} - D_{w_{t_1}})/(t_2 - t_1),$$

where $\Delta DW$ is an annual change of total dead wood volume.

The analysis of the obtained values was performed by comparison with the data on the current growth and mortality according to the yield tables (Forest taxation guide book, 2013) for the main tree species and age classes in terms of an actual density of stocking. In case of negative balance of dead wood stock, it was concluded that some of the dead wood was removed from the studied stands.

For a comprehensive generalized assessment of all carbon pools in oak and pine forests, we used our data on carbon pools in biomass and mortmass (at forest stand aged 81-100 years) and data of (Buksha, Raspopina, & Pasternak, 2012) for litter and soils with adaptation for plots: for all oak stands in $D_2$ soil C stock in the 30-cm layer is 88.0 tonnes C ha$^{-1}$, in $B_2$ (sod-podzolic sandy soils) – 50.9 tonnes C ha$^{-1}$. These values are in the range of data published by (Balyuk et al., 2017) for the same soil types. Litter carbon pool was also calculated from (Buksha, Raspopina, & Pasternak, 2012): for oak stands – 2.78 tonnes C ha$^{-1}$, for pine stands – 11.6 tonnes C ha$^{-1}$. Changes in stocks in litter pools and soil have not been evaluated.

The results of the assessments were summarized by age classes and stand groups by the main tree species: oak, pine and other deciduous since in this case, the accuracy of productivity estimates is higher (Pregitzer & Euskirchen, 2004). The results are presented as an arithmetic mean values and standard deviations. The comparison of mean values was performed using the T-test.

**Results and discussion.** Significant trees dieback in the inter-survey period occurred in almost all plots (Tab. 2). The annual mortality rate exceeded the reference level (Forest inventory handbook, 2013) at half of the observed stands, at the rest sites this variable could not be compared with reference level due to the partial removal of dead wood from stands (sanitary cuttings and/or dead logs removal by the local population).

Between surveys at 6 oak forest stands (32473, 33734, 33771, 33754, 41544, 3), there was significant mortality of Norway maple and field maple ($Acer$ platanoides L. and $A$. campestre L.) caused by Verticillium wilt (Meshkova & Davydenko, 2016), at 5 plots there was oak dieback (at almost all age classes) exceeding the reference level, at two plots – pathological dieback of Common ash ($Fraxinus$ excelsior L.). In pine stands, trees mortality was registered in three plots, in two of them, the level of mortality exceeded the reference level, in two plots the dead wood was removed. The largest level of dieback was recorded at plot 2263079 due to the impact of clear-cut at the neighbor forest site several trees were damaged and microclimatic conditions on the studied plot changed. In the soft-leaved deciduous forest stand the pathological dieback of aspen ($Populus$ tremula L.) was observed.

Just at one plot (42906) in oak and at one (631309) in pine stands there was no mortality during the study period.

| Plot ID | Age class | Stock change, m$^3$ ha$^{-1}$ year$^{-1}$ | ADW stock, m$^3$ | Increment, m$^3$ | ADW stock, m$^3$ | Class on DW | Spp DW |
|---------|-----------|----------------------------------------|-----------------|-----------------|-----------------|--------------|--------|
|         | 1         | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 32491   | 41-60     | 6.9 | 4.4 | 8.5 | 3.1 | ↑ | Oak |
| 33761   | 61-80     | -5.9 | 1.0 | 4.8 | 1.2 | ↓, R | Oak |
| 32473   | 81-100    | 3.8 | -0.1 | 3.0 | 1.0 | R | Maple |
| 33734   | 81-100    | 5.1 | -0.3 | 0.0 | 1.2 | 0 | 0 |
| 42906   | 81-100    | 3.2 | 0.0 | 4.3 | 1.5 | R | Ash |
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123 4 5 6 7 8
1 81-100 4.9 5.4 3.8 1.2 ↑ Oak
33771 81-100 5.7 -0.5 5.3 1.7 R Maple
32496 101-120 5.8 1.5 2.2 0.7 ↑ Oak
33754 101-120 -1.7 11.8 3.3 1.1 ↑ Maple, Ash
41544 >121 2.1 0.1 1.7 0.6 R Maple
36324 >121 5.0 0.9 2.0 0.6 ↑ 0
2 >121 -8.5 3.3 2.4 0.7 ↑ Oak
3 >121 -12.8 1.0 2.3 0.6 ↑ Maple
631309 41-60 12.4 -0.1 12.3 3.1 R Pine
32485 61-80 4.7 2.4 9.5 3.7 ↓ Pine
33760 61-80 11.2 5.8 11.5 4.9 ↑ Pine
2263079 81-100 7.3 11.4 8.6 3.2 ↑ Pine

Notes: Reference – Forest inventory handbook, 2013; ↓ – lower level of mortality compared to reference level, ↑ – higher level of mortality compared to reference level; R – removed dead wood.

The average annual increment of studied stands varies in a wide range. For oak stands the increment level lower than in reference data (Forest inventory handbook, 2013) is observed in younger (2 plots) and older (age class >120 years) (2 plots) stands, and 1 plot at age 81-100. That is typical for old-growth stands where the process of mortality prevails over growth. In younger oak stands (41-60 and 61-80 years) – it can be explained by the influence of high mortality level caused by diseases. Almost all other oak stands have increment level higher than in (Forest inventory handbook, 2013), mainly due to the growth of younger accompanying tree species. Among pine stands the increment was normal at two stands, and lower at another two plots.

Trees biomass stocks (Tab. 3) in the studied stands vary over a wide range from 120.4 to 251.8 t·ha⁻¹. The average value is 186.8±39.2 t·ha⁻¹ for oak stands and 177.1±34 t·ha⁻¹ for pine stands in the first survey cycle (during 2012-2015). For the second cycle (2016-2019), the range of values increased: from 120.0 to 287.8 t·ha⁻¹, the average for oak stands is 188,3±39.7 t·ha⁻¹, and for pine stands – 186,7±25.6 t·ha⁻¹.

Table 3

| Plot ID | Trees biomass | Dead trees | Deadlogs | Total dead wood |
|---------|---------------|------------|----------|----------------|
| 1 2 3 4 5 6 7 8 | 1* 2 1 2 1 2 1 2 | 9 9 |
| 32491 | 160.2 | 182.1 | 0.9 | 8.5 | 0.0 | 1.4 | 0.9 | 9.9 |
| 33761 | 136.1 | 120.3 | 5.7 | 11.8 | 16.1 | 12.0 | 21.8 | 23.8 |
| 32473 | 180.0 | 186.8 | 1.5 | 0.9 | 0.4 | 0.7 | 1.9 | 1.6 |
| 33734 | 147.1 | 156.8 | 5.8 | 5.8 | 1.0 | 0.8 | 6.8 | 6.6 |
| 42906 | 138.8 | 144.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 33751 | 244.3 | 287.8 | 1.7 | 2.9 | 4.7 | 2.2 | 6.4 | 5.1 |
| 1 | 188.7 | 192.3 | 4.9 | 15.6 | 1.1 | 0.9 | 6.0 | 16.5 |
| 33771 | 180.7 | 190.5 | 13.4 | 13.0 | 11.1 | 9.4 | 24.5 | 22.4 |
| 32496 | 149.2 | 162.3 | 0.4 | 3.5 | 0.5 | 0.1 | 0.9 | 3.6 |
| 33754 | 249.5 | 231.8 | 3.2 | 25.3 | 1.6 | 5.3 | 4.8 | 30.6 |

Notes: Reference – Forest inventory handbook, 2013; ↓ – lower level of mortality compared to reference level, ↑ – higher level of mortality compared to reference level; R – removed dead wood.
Continuation of table 3

| Age class | C trees biomass | C dead wood | C total |
|-----------|----------------|-------------|---------|
| 1-2       | 174.3          | 47.0        | 55.4    |
| 3-4       | 192.5          | 22.0        | 25.9    |
| 5-6       | 251.8          | 17.6        | 27.8    |
|           | 221.7          | 2.9         | 16.0    |
| Avg Oak   | 186.8          | 7.4         | 10.1    |

Dead wood at studied stands is represented both by dead trees and dead logs, at oak stands prevail dead logs, and at pine stands – dead trees. Dead wood in oak stands is predominantly formed by English oak, while other species as Norway maple and field maple, elm, common ash, linden are less represented. This is explained not only by the dominance of the oak in the composition of the stands but also by its significant decline compared to other species and a longer decomposition time (Yarotsky, Pasternak, Nazarenko, 2019a). In pure pine stands dead wood is formed only by pine.

During the four-year period between observations, changes in trees biomass and mortmass stocks occurred as a result of natural growth processes, as well as the dieback and removal of dead wood from the stands. Carbon stocks and its accumulation in forest ecosystems depend on productivity, species composition, and age structure, as well as on forest management regime and disturbances (biotic damage and anthropogenic) (Jandl, Bauhus, Bolte, Schindlbacher, Schüler, 2015). Generalized data on the total carbon accumulation in tree biomass (Tab. 4) and mortmass showed that the oak stands have, on average a higher carbon stock in these two pools than the pine stands, which is associated with a higher representation of mature and overmature oak stands. The average C in the trees biomass of oak stands is 93.4±10.3 and 94.1±10.5 t ha\(^{-1}\), respectively, by observations. For the studied pine stands, these values are 88.6±3.8 and 93.4±12.6 t ha\(^{-1}\), respectively. The lowest carbon stock is observed in other deciduous stands (75.9 and 77.1 t ha\(^{-1}\)), which is natural taking into account their lower productivity.

Table 4

| Age class | C trees biomass | C dead wood | C total |
|-----------|----------------|-------------|---------|
| 41-60     | 80.1           | 5.0         | 85.6    |
| 61-80     | 68.1           | 10.9        | 79.0    |
| 81-100    | 90.0±17.1      | 3.8±4.0     | 93.8±18.1|
| 101-120   | 99.7±25.1      | 1.4±1.0     | 101.1±26.1|
| >120      | 105.0±14.7     | 13.5±9.4    | 118.6±12.6|
| Avg Oak   | 93.4±19.6      | 6.5±7.6     | 99.9±21.4|

* 1 – I observation (in 2012-2015), 2 – II observation (in 2016-2019); SD – standard deviation.
The estimated values for oak and pine stands are lower than average values for modal oak (104 t C·ha⁻¹) and pine stands (101.3 t C·ha⁻¹) for the forest-steppe at the same age ranges according to «Tables and models of growth...» (Shvidenko, Schepaschenko, Nilsson, & Buluy, 2008).

Generally, forest carbon pools vary with stand age, so our data were generalized by age classes. Unfortunately, the monitoring plots didn’t represent all age classes range and for some age classes, there was just one plot. However, comparison of total carbon stocks at trees biomass by age classes presented in both types of stands, shows that pine stands, in general, have higher values (in age classes 61-80 and 81-100), which is associated with higher pine productivity. In the age class 41-60, the situation is opposite. Both in oak and pine stands, the increase in carbon stocks with age is observed. The exclusion is plot 33761 in the age group 61-80, which is located in an oak stand in poorer conditions (C₂) with a lower density of stocking, and a significant mortality of trees.

In general, mortmass carbon stocks in oak stands is higher than in pine stands both in absolute and relative terms: in oak stands, it makes 6.5±7.6 and 18.8±7.3 t C·ha⁻¹ or 7.0% and 9.3% of trees biomass pool for each survey, respectively, while in pine stands only 1.0±0.2 and 5.3±4.3 t C·ha⁻¹, or 1.1% and 5.7% respectively. Generally, the mortmass pool is characterized by C stock higher variability compared to trees biomass.

The data on average annual carbon change in the studied forest stands showed (Tab. 5) that the youngest oak stands have the highest level of the total C change (mainly due to higher trees biomass increment), while mature and overmature oak stands have negative trees biomass growth and positive dead wood growth. In such forests, the net ecosystem productivity is low due to the slow growth and rather large volumes of dead wood (Taylor, Seedre, Brassard, & Chen, 2014).

For pine stands the similar features are observed: the change of C stock in trees biomass is the highest in younger stands, and it decreases with age; in mortmass changes is the opposite situation: increasing with age is observed (see Tab 5).

Combination of our data for oak and pine stands at age class 81-100 (the latest observation) with data from (Buksha, Raspopina, & Pasternak, 2012) on carbon stock in litter and soils (30-cm layer) showed (Tab 6), that oak forest stands have higher carbon storage capacity, than pine stands (total carbon stock in main pools of the oak forest is 191.7 t C·ha⁻¹ and in pine stands – 175.4 t C·ha⁻¹). The share of trees biomass carbon pool is the highest among other pools (50.3 % in oak forests, and 57.6% in pine forests), the next is soil carbon pool (45.9 and 29.0%, respectively).

| Age class, years | ∆C trees biomass | ∆C dead wood | ∆C total, %* |
|------------------|------------------|--------------|--------------|
| Oak stands       |                  |              |              |
| 41-60            | 2.7              | 1.1          | 3.9          | 4.8          |
| 61-80            | -2.0             | 0.3          | -1.7         | -2.18        |
| 81-100           | 1.6              | 0.1          | 1.8          | 1.9          |
| 101-120          | -0.3             | 1.8          | 1.5          | 1.5          |
| >120             | -1.9             | 0.5          | -1.3         | -1.1         |
| AVG Oak          | 0.2              | 0.6          | 0.8          | 0.8          |
| Pine stands      |                  |              |              |
| 41-60            | 2.9              | 0.0          | 2.9          | 4.8          |
| 61-80            | 1.4              | 0.8          | 2.2          | 2.3          |
| 81-100           | -0.9             | 2.7          | 1.8          | 1.7          |
| AVG Pine         | 1.2              | 1.1          | 2.3          | 2.6          |
| Other deciduous  |                  |              |              |
| 74               | 0.3              | 0.7          | 1.0          | 1.3          |

* Calculated as per cent of changes of C total (observation 1)

Our data (see Tab 6) is comparable to the results of (Shpakivska & Maryskevych, 2009) on carbon pools in Carpathians in spite of different climatic zone and forest composition: the percentage of the C stock in trees biomass in average is 54.2%, and in soils – 41.4%. Similar proportions of carbon pools were described by (Kēnina, Jaunslaviete, Liepa, Zute, & Jansons, 2019) for old-growth unmanaged Scots pine stands in Latvia: trees biomass – 59%, mineral soils – 31%.
Table 6

Total C stock in oak and pine stands by main pools (at age class 81-100 years)

| Stands | Main C pools | Total |
|--------|--------------|-------|
|        | Trees biomass | Mortmass | Litter* | Soil* |       |
|        | Absolute values, t C ha⁻¹ |       |
| Oak    | 96.5         | 4.4     | 2.78    | 88    | 191.7 |
| Pine   | 101.1        | 11.8    | 11.6    | 50.9  | 175.4 |
|        | Percentage, % |       |
| Oak    | 50.3         | 2.3     | 1.5     | 45.9  | 100   |
| Pine   | 57.6         | 6.7     | 6.6     | 29.0  | 100   |

* data from (Buksha et al, 2012)

Our results are preliminary, as soil and litter data are from literature, and studied stands don’t represent all age classes and productivity classes. Introduction of NFI and soil monitoring in Ukraine will allow obtaining in particular precise data of forest carbon stocks and their dynamics.

Conclusions. In the forest-steppe zone of Ukraine tree biomass and mineral soils are the main carbon pools. The total carbon stock in main pools of oak and pine forests at age class 81-100 is 191.7 t C·ha⁻¹ and 175.4 t C·ha⁻¹, respectively. Two processes influence the carbon balance in studied stands: biotic damage which leads to tree dieback, and partial removal of dead wood from stands.

The introduction of National forest inventory will provide primary data for state-level assessments of carbon stocks and dynamics in forest stands and dead wood pools. However, special large-scale studies, such as forest soil monitoring, are needed to evaluate carbon pools in soils and litter that play an important role in carbon cycling.

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Запаси вуглецю у лісах Лівобережного Лісостепу України за даними інтенсивного моніторингу

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Розглядаються питання запасів і динаміки вуглецю в різних вуглецевих пуллах лісових насаджень Лівобережного Лісостепу України. Метою дослідження було оцінити запаси вуглецю та їхні зміни в основних пуллах – фітотаомах та мортмасах на ділянках інтенсивного моніторингу лісів. Для дослідження використано дані двох повторних спостережень на 19-ти постійних ділянках інтенсивного моніторингу лісів у Харківській і Сумській областях. Запаси і динаміка вуглецю в пуллах фітотаоми і мортмаси оцінено за допомогою конверсійного методу. Узагальнені значення запасів вуглецю в грунтах та підстилці за літературними даними включено до сумарної оцінки запасу вуглецю для дубових і сососнових насаджень у віці 80–100 років. Дані представлено за класами віку.

Вивчення динаміки приросту та відпаду на ділянках моніторингу показало, що на баланс вуглецю впливають дві процеси: біотичні пошкодження, що призводять до всихання та відпаду дерев, і часткове відновлення мертової деревини з деревостанів.

Встановлено, що середній запас вуглецю у фітотаомах дубових лісів становить 94,1 ± 5,5 т/га⁻¹; соснових – 93,4 ± 12,6 т/га⁻¹, у мортмасах дубових – 8,8 ± 3,8 т/га⁻¹; сососнових – 5,3 ± 4,2 т/га⁻¹. У середньому у вісім біорічних пулвах насаджень негативно впливають на їхні прирости вуглецю у фітотаомах та мортмасах (102,9 т/га⁻¹), ніж сососнових (98,7 т/га⁻¹), що пов’язано з більшою представленістю стиглих і перестійних дубових насаджень. Однак, порівняння значень за класами віку показало, що соснові насадження загала мають більші значення у фітотаомах, що пов’язано з більшою продуктивністю сососнових деревостанів. Відзначено збільшення запасів вуглецю з віком. Найміцніші запаси вуглецю визначений в інших листяних насадженнях (77,1 т/га⁻¹).

Запасы углераода в лесах Левобережной Лесостепи Украины по данным интенсивного мониторинга

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Рассмотрены вопросы накопления и динамики углерода в разных углеродных пуллах лесных насаждений Левобережной Лесостепи Украины. Целью

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Установлено, що запас угерода в мортмасі в дубових лесах вище, чим в сосняках, як в абсолютному, так і в относительном вираженні: в
перших вони становлять 9,3% пулі фитомаси, в то
время как во вторых – тільки 5,7%.

В дубових і соснякових лесах найбільше годо-
вое відновлення запасу С в мортмасі відчущено в бо-
лее молодих насадженнях і зростом уменьша-
ється, в то время как в мортмассе – відновлюється.

Спільно і перестойні дубові насадження харак-
теризуються отримочним приростом фитомаси

і положительним – мортмассу.

Сочетание наших данных с литературными

данными о запасах угерода в пулак подстил-

ки і почвы (0-сантиметрового слою) показа-

ло, что в возрасте 81-100 лет дубове леса явля-

ються более ефективными накопителями угеро-

да, чем соснякове (обший запас угерода в четырех основных пулках составляет 191,7 т C га-1

для дубових лесов і 175,4 т С га-1 для сосняков).

Доля угерода в фитомасі преобладає серед

других пульт (50,3% в дубових лесах і 57,6% в

соснякових), за ней слідують почвенный пул угерода (45,9 і 29,0% відповідно).

Ввездені Национальної інвентаризації ле-
сов обезпечить первинними даними для оцен-
ки запасів угерода і його динаміки для пулі

фитомаси і мортмассы. Однак для оцінки

пульт почв і подстилки, які відіграють важну роль в

круговороті угерода в лесних екосистемах необ-

ходим моніторинг лесних почв.

Ключеві слова: фитомаса; мортмасса; угеродні пулі; відновлення запасів угерода; дубові насадження; соснякові насадження; класи возраста.