4. ЛІСОВА ТАКСАЦІЯ ТА ЛІСОВПОРЯДКУВАННЯ

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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 CO_2 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 (by using gain – loos 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): D_2 – fresh fertile forest type condition (*Quercus robur* L. (English oak) stands), C_2 – fresh relatively fertile forest type condition, and $\hat{B}_2$ – 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.

Taxation characteristics of forest stands at intensive monitoring plots (2016-2019)

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 1Ulmgla+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 1Acepla+ Acecam	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 +Ulmgla	98	D₂	II	0.83	286
33751	1	5 Querob 3 Fraexc 2 Tilcor + Acepla, Ulmgla	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 Acepla + Acecam, Ulmgla	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 1Acepla+Acecam,Tilcor, Ulmgla	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:

$$C_{trees} = \Sigma Ms_i \cdot BEF_{si \cdot Di} \cdot 0.5, \qquad (1)$$

where C_{trees} – total carbon stock in live trees biomass pool (tonnes C ha⁻¹); Ms_i – 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.

$$C_{deadtrees} = \Sigma Mdt_i \cdot Di \cdot 0.5; \qquad (2)$$

where $C_{deadtrees}$ – carbon stocks in dead trees (tonnes C ha⁻¹); Mdt_i – total stem volume of dead trees of i tree; Di – basic density of timber of i – tree species.

$$C_{deadlogs} = Md \cdot Di_j \cdot 0.5; \qquad (3)$$

where $C_{deadlogs}$ – carbon stocks in dead logs (tonnes C ha⁻¹); Md – total volume of dead logs; Di_j – 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:

$$\Delta C = \sum \frac{C_{t2} - C_{t1}}{(t_2 - t_1)} \qquad (4);$$

where ΔC – annual changes of carbon stocks in pool i, tonnes C ha^{-1} year^{-1};

C_{t1} – total carbon stock in pool i at year t_1, tonnes C ha^{-1};

C_{t2} – 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.

$$Z = (M_2 - M_1 + Dw_2 - Dw_1)/(t_2 - t_1), \qquad (5);$$

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

M_1 – growing stock in year t_1, m^3, M_2 – growing stock in year t_2, Dw_2 – dead wood volume in year t_2, Dw_1 – dead wood volume in year t_1.

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

$$\Delta DW = (Dw_2 - Dw_1)/(t_2 - t_1), \qquad (6);$$

where ΔDW 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.

Table 2

Mortality and increment at monitoring plots

| Plot ID | Age class | Observed | | Reference | | Class on DW dynamic | Spp DW |
		Stock change, m^3 ha^{-1} year^{-1}	ΔDW stock m^3 ha^{-1}	Increment m^3 ha^{-1} year^{-1}	ΔDW stock m^3 ha^{-1}		
				Oak			
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	3.9	1.5	R	Maple
33734	81-100	5.1	-0.3	3.0	1.0	R	Maple
42906	81-100	3.2	0.0	4.3	1.2	0	0
33751	81-100	6.3	-0.3	3.9	1.5	R	Ash

Continuation of table 2

1	2	3	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
Pine							
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
Other deciduous							
44262	61-80	3.6	2.8	5.0	1.3	↑	Aspen

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 yeas) (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

Trees biomass and mortmass at monitoring plots for two observations (dry weight, tonnes ha⁻¹)

Plot ID	Trees biomass		Dead trees		Deadlogs		Total dead wood	
	1*	2	1	2	1	2	1	2
1	2	3	4	5	6	7	8	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
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	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

Continuation of table 3

1	2	3	4	5	6	7	8	9
41544	174.3	178.4	8.4	10.2	47.0	45.1	55.4	55.3
36324	192.5	208.0	0.0	0.0	22.0	23.2	22	23.2
2	251.8	222.8	10.2	5.1	17.6	25.9	27.8	31
3	221.7	171.8	0.0	1.5	2.9	14.5	2.9	16
Avg Oak	**186.8**	**188.3**	**4.0**	**7.4**	**9.0**	**10.1**	**13**	**17.5**
SD	**39.2**	**39.7**	**4.1**	**7.0**	**12.8**	**12.8**	**15.7**	**15.1**
631309	120.4	143.7	0.1	0.5	1.7	1.4	1.8	1.9
32485	184.0	191.7	1.2	2.2	0.1	1.5	1.3	3.7
33760	194.6	209.3	2.3	12.7	0.0	0.5	2.3	13.2
2263079	209.5	202.2	2.3	22.7	0.0	0.9	2.3	23.6
Avg Pine	**177.1**	**186.7**	**1.5**	**9.5**	**0.5**	**1.1**	**2**	**10.6**
SD	**34.0**	**25.6**	**0.9**	**8.9**	**0.7**	**0.4**	**0.5**	**10.0**
44262	151.8	154.1	1.2	6.1	0.4	1.4	1.6	7.5

* 1 – I observation (in 2012-2015), 2 – II observation (in 2016-2019); SD – standard deviation.

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 it 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 it 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 C ha^{-1}, respectively, by observations. For the studied pine stands, these values are 88.6±3.8 and 93.4±12.6 t C ha^{-1}, respectively. The lowest carbon stock is observed in other deciduous stands (75.9 and 77.1 t C ha $^{-1}$), which is natural taking into account their lower productivity.

Table 4

Average carbon stocks at main C pools for two observations (t ha^{-1})

Age class	C trees biomass		C dead wood		C total	
	1	2	1	2	1	2
1	2	3	4	5	6	7
Oak stands						
41-60	80.1	91.1	0.5	5.0	80.6	96.0
61-80	68.1	60.2	10.9	11.9	79.0	72.1
81-100	90.0±17.1	96.5±23.0	3.8±4.0	4.4±4.0	93.8±18.1	100.9±23.7
101-120	99.7±25.1	98.5±17.4	1.4±1.0	8.6±6.8	101.1±26.1	107.1±24.1
>120	105.0±14.7	97.6±10.5	13.5±9.4	15.7±7.4	118.6±12.6	113.3±12.0
Avg Oak	93.4±19.6	94.1±19.8	6.5±7.6	8.8±7.3	99.9±21.4	102.9±21.7

1	2	3	4	5	6	7
Pine stands						
41-60	60.2	71.9	0.9	1.0	61.1	72.8
61-80	94.7±2.6	100.3±4.4	0.9±0.3	4.2±2.4	95.6±2.9	104.5±6.8
81-100	104.8	101.1	1.2	11.8	105.9	112.9
Avg Pine	88.6±17.0	93.4±12.8	1.0±0.2	5.3±4.3	89.5±17.1	98.7±16.1
Other deciduous stands						
74	75.9	77.1	0.8	3.8	76.7	80.8

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 (C_2) 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).

Table 5

Average changes in carbon stocks per year (t ha⁻¹year⁻¹)

Age class, years	ΔC trees biomass	ΔC dead wood	ΔC total	ΔC 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 (Ķēniņa, 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.

References

Alemu, B. (2014). The Role of Forest and Soil Carbon Sequestrations on Climate Change Mitigation. *Journal of Environment and Earth Science, 4* (13), 98-111. Retrieved from https://www.researchgate.net/publication/324844908_The_Role_of_Forest_and_Soil_Carbon_Sequestrations_on_Climate_Change_Mitigation

Alioshkina, U., Zhovtenko, A., Vyshenska, I., Rasevych, V., Gavrylov, S., & Tkachova, A. (2011). Carbon accumulation by forest ecosystems (by the example of «Foresters» reserve, Kyiv). *NaUKMA Research Papers.* «Biology and ecology». Vol. 119, 52-55 (in Ukrainian).

Balyuk, S., Medvedyev, V., Kucher, A., Solovey, V., Levin, A., & Kolmaz, Yu. (2017). Control over organic carbon of soil in the context of safety and climate fluctuation. *Bulletin of agrarian science, 95*

(9), 11-18. Retrieved from https://agrovisnyk.com/pdf/en_2017_09_02.pdf

Bilous, A., Matsala, M., Radchenko, V., Matiashuk, R., Boyko, S., & Bilous S. (2019). Coarse woody debris in mature oak stands of Ukraine: carbon stock and decomposition features. *Forestry Ideas, 25* (1), 196-219. Retrieved from http://oaji.net/articles/2020/6191-1577991276.pdf

Bilous, A., Myroniuk, V., Holiaka, D., Bilous, S., See, L., & Schepaschenko, D. (2017). Mapping growing stock volume and forest live biomass: a case study of the Polissya region of Ukraine. *Environmental Research Letters*, *12* (10). https://doi.org/10.1088/1748-9326/aa8352

Bilous, A. M., & Kotlyarevska, U. M. (2017). The biomass structure of alder plantations of Ukrainian Polissya. *Scientific bulletin of Ukrainian National Forestry University, 27* (9), 14-18. https://doi.org/10.15421/40270902 (in Ukrainian).

Buksha, I. F., Raspopina, S. P., & Pasternak, V. P. (2012). Carbon stock in soil and litter in forest monitoring plots. *Forestry & Forest melioration*, *120*, 106-112. Retrieved from http://forestry-forestmelioration.org.ua/index.php/journal/issue/view/13/120-pdf (in Ukrainian).

Buksha, I. F., Butrim, O. V., & Pasternak, V. P. (2008). *Inventory of greenhouse gases in the land use and forestry sectors*. Kharkiv: KhNAU (in Ukrainian).

Cienciala, E., Seufert, G., Blujdea, V., Grassi, G., & Exnerová, Z. (2010). Harmonized Methods for Assessing Carbon Sequestration in European Forests. Results of the Project «Study under EEC 2152/2003 Forest Focus regulation on developing harmonized methods for assessing carbon sequestration in European forests». JRC-IES Italy, EUR 24300 EN – 2010 Retrieved from https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/harmonized-methods-assessing-carbon-sequestration-european-forests

Cosmoa, L. Di, Gasparinia, P., Palettoa, A., & Nocettib, M. (2013). Deadwood basic density

V. Pasternak, T. Pyvovar, V. Yarotsky. Forest carbon stock in Left-bank Forest-Steppe of Ukraine according to intensive forest...

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values for national-level carbon stock estimates in Italy Forest. *Ecology and Management*, *295*, 51-58. https://doi.org/10.1016/j.foreco.2013.01.010

Filipchuk, A. N., Malysheva, N. V. Moiseev, V. V., & Strahov, V. V. (2016). Analytical overview of methodologies calculating missions and absorption of greenhouse gases by forests from the atmosphere. *Forestry information*, *3*, 36-85. Retrieved from http://lhi.vniilm.ru/PDF/2016/3/LHI_2016_03-04-Filipchuk.pdf (in Russian).

IPCC (2014). Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T. G. (eds). Published: IPCC, Switzerland. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/kpsg/index.html.

Jandl, R., Bauhus, J., Bolte, A., Schindlbacher, A. & Schüler, S. (2015). Effect of Climate-adapted forest management on carbon pools and greenhouse gas emissions. *Current forestry report 1*, 1-7. https://doi.org/10.1007/s40725-015-0006-8

Ķēniņa, L., Jaunslaviete, I., Liepa, L., Zute, D., & Jansons, Ā. (2019). Carbon pools in old-growth Scots pine stands in Hemiboreal Latvia. *Forests, 10* (10), 911. https://doi.org/10.3390/f10100911

Lakyda, P., Vasylyshyn, R., Lashenko, A., & Terentiev, A. (2011). *Standards of evaluation of components of aboveground trees biomass of trees of the main forest-forming species of Ukraine*. Kyiv: ECO-inform (in Ukrainian).

Lakyda, P., Bilous, A., Shvidenko, A., Myroniuk, V., Matsala, V., Vasylyshin, R. ... Lakyda, I. (2018). *Ecosystem services of Ukrainian forests: a case study for Polissya region*. Kyiv: National University of Life and Environmental Sciences of Ukraine.

Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. (2016). UNECE ICP Forests Programme Co-ordinating Centre (ed.). Thünen Institute of Forest Ecosystems, Eberswalde, Germany. Retrieved from http://www.icp-forests.net/page/icp-forests-manual

Meshkova, V., & Davydenko, K. (2016). Verticillium wilt on Norway maple (*Acer platanoides* L.) in the East of Ukraine. *Proceedings of the Forestry Academy of Sciences of Ukraine. 14*, 174-179. Retrieved from http://nbuv.gov.ua/UJRN/Nplanu_2016_14_27.

Ostapenko, B. F., & Tkach, V. P. (2002). *Forest typology: Tutorial*. Kharkiv: Kharkiv State Agrarian University (in Ukrainian).

Paris agreement. (2015). United Nations. 25 p. Retrieved from https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

Pregitzer, K. S., & Euskirchen, E. S. (2004). Carbon cycling and storage in world forests: biome patterns related to forest age. *Global Change Biology, 10*

(12), 2052-2077. https://doi.org/10.1111/j.1365-2486.2004.00866.x

Shpakivska, I. M. & Maryskevych, O. G. (2009). Estimation the reserves of organic carbon in the forest ecosystems of Eastern Beskydy. *Forestry & forest melioration, 115*, 176-180 (in Ukrainian).

Shvidenko, A. Z., Schepaschenko, D. G., Nilsson, S., & Buluy, Yu. I. (2008). *Tables and models of growth and productivity of forests of major forest forming species of Northern Eurasia (standard and reference materials)* (2nd ed.). Moscow: Russian Federal Forestry Agency (in Russian).

Shvidenko, A., Buksha, I., Krakovska, S., & Lakyda, P. (2017). Vulnerability of Ukrainian forests to climate change. *Sustainability*, *9* (7), 1152. https://doi.org/10.3390/su9071152

Shvidenko, A., Lakyda, P., Schepaschenko, D., Vasylyshyn, R., & Marchuk, Yu. (2014). *Carbon, climate, and land-use in Ukraine: Forest sector: A monograph*. Korsun-Shevchenkivskyi: FOP Gavrishenko V. M. (in Ukrainian).

Strochynsʹkyy, A. A. & Kashpor, S. M. (Ed.) (2013). *Forest inventory handbook*. Korsun-Shevchenkivsky: publisher Maidachenko (in Ukrainian).

Taylor, A. R., Seedre, M., Brassard, B. W., & Chen, H. Y. H. (2014). Decline in net ecosystem productivity following canopy transition to late-succession forests. *Ecosystems*, *17*, 778-791. https://doi.org/10.1007/s10021-014-9759-3

Tokar, O. (2015). *Information technology for studying carbon sink in forest ecosystems*. (Thesis for Ph.D degree. Lviv Polytechnic National University, Lviv, Ukraine) (in Ukrainian).

Wang, G., Oyana T., Zhang, M., Adu-Prah, S., Zeng, S., Lin H., & Se J. (2009). Mapping and spatial uncertainty analysis of forest vegetation carbon by combining national forest inventory data and satellite images. *Forest Ecology and Management. 258* (7), 1275-1283. https://doi.org/10.1016/j.foreco.2009.06.056

Yarotskiy, V. Yu., Pasternak, V. P., & Nazarenko, V. V. (2019a). Deadwood in the oak forests of the Left Bank Forest steppe of Ukraine. *Folia Forestalia Polonica*, *Series A. Forestry. 61* (4), 247-254. https://doi.org/10.2478/ffp-2019-0024

Yarotskiy, V. Yu., Pasternak, V. P., & Nazarenko, V. V. (2019b). Phytomass and mortmass assessment in pine Forests of Left-bank Forest Steppe of Ukraine. *Silva Balcanica. 20* (2), 63-71. https://silvabalcanica.files.wordpress.com/2020/03/sb_202_2019_6.pdf

Zamolodchikov, D. (2011). Carbon stock assessment and forecasting systems in forest ecosystems. *Sustainable forest management. 4* (29), 15-22. Retrieved from https://wwf.ru/upload/iblock/fb8/04-_17_.pdf (In Russian).

Запаси вуглецю у лісах Лівобережного Лісостепу України за даними інтенсивного моніторингу

В. П. Пастернак[1], Т. С. Пивовар[2], В. Ю. Яроцький[3]

Розглядаються питання запасів і динаміки вуглецю в різних вуглецевих пулах лісових насаджень Лівобережного Лісостепу України. Метою дослідження було оцінити запаси вуглецю та їхні зміни в основних пулах – фітомасі та мортмасі 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 пулах фітомаси і мортмаси оцінено за допомогою конверсійного методу. Узагальнені значення запасів вуглецю в грунтах та підстилці за літературними даними включені до сумарної оцінки запасу вуглецю для дубових і соснових насаджень у віці 80-100 років. Дані представлено за класами віку.

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

Встановлено, що середній запас вуглецю © у фітомасі дубових лісів становить 94,1 ± 10,5 тС·га⁻¹; соснових – 93,4 ± 12,6 тС·га⁻¹, у мортмасі дубових – 8,8 ± 3,8 тС·га⁻¹; соснових – 5,3 ± 4,2 тС·га⁻¹. У середньому в усій вибірці дубові насадження нагромаджують сумарно більший запас вуглецю у фітомасі та мортмасі (102,9 тС·га⁻¹), ніж соснові (98,7 тС·га⁻¹), що пов'язано з більшою представленістю стиглих і перестійних дубових насаджень. Однак, порівняння значень за класами віку показало, що соснові насадження загалом мають більші значення С у фітомасі, що пов'язано з більшою продуктивністю соснових деревостанів. Відзначено збільшення запасів вуглецю з віком. Найменший запас вуглецю визначений в інших листяних насадженнях (77,1 т С га⁻¹).

Встановлено, що запас вуглецю у мортмасі у дубових лісах вищий, ніж у соснових, як в абсолютному, так і у відносному вираженні: у перших він становить 9,3% пулу фітомаси, тоді як у останніх – лише 5,7%.

У дубових і соснових лісах найбільшу річну зміну запасу С у фітомасі визначено у молодших насадженнях, і з віком цей показник зменшується, тоді як у мортмасі – збільшується. Стиглі і перестійні дубові насадження характеризуються негативним приростом фітомаси і позитивним – мортмаси.

Поєднання наших даних із літературними про запаси вуглецю в пулах підстилки та грунту (30-сантиметровому шарі) свідчить, що у віці 81-100 років дубові ліси є більш ефективними нагромаджувачами вуглецю, ніж соснові (загальний запас вуглецю в чотирьох основних пулах становить 191,7 т С га⁻¹ для дубових лісів і 175,4 т С га⁻¹ для соснових). Частка вуглецю у фітомасі переважає серед інших пулів (50,3% у дубових лісах і 57,6% у соснових), за нею йде пул грунтів (45,9 і 29,0% відповідно).

Впровадження Національної інвентаризації лісів забезпечить первинними даними для оцінювання запасів вуглецю і його динаміки для пулів фітомаси та мортмаси. Однак, для оцінювання пулів грунтів і підстилки, які відіграють важливу роль у кругообігу вуглецю в лісових екосистемах, необхідний моніторинг лісових грунтів.

Ключові слова: фітомаса; мортмаса; вуглецеві пули; зміни запасів вуглецю; дубові насадження; соснові насадження; класи віку.

Запасы углерода в лесах Левобережной Лесостепи Украины по данным интенсивного мониторинга

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

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исследования было оценить запасы углерода и их изменение в основных пулах – фитомассе и мортмассе на участках интенсивного мониторинга лесов. Для исследования использованы данные двух повторных наблюдений на 19 постоянных участках интенсивного мониторинга лесов в Харьковской и Сумской областях. Запасы и динамика углерода в пулах фитомассы и мортмассы оценены при помощи конверсионного метода. Обобщенные значения запасов углерода в почвах и подстилках по литературным данным включены в суммарную оценку запаса углерода для дубовых и сосновых насаждений в возрасте 80-100 лет. Данные представлены по классам возраста.

Изучение динамики прироста и отпада на участках мониторинга показало, что на баланс углерода влияют два процесса: биотические повреждения, приводящие к усыханию и отпаду деревьев, и частичное удаление мертвой древесины из древостоев.

Установлено, что средний запас углерода © в фитомассе дубовых лесов составляет $94,1 \pm 10,5$ тС·га$^{-1}$; сосновых – $93,4 \pm 12,6$ тС·га$^{-1}$, в мортмассе дубовых – $8,8 \pm 3,8$ тС·га$^{-1}$; сосновых – $5,3 \pm 4,2$ тС·га$^{-1}$. В среднем по всей выборке дубовые насаждения накапливают суммарно больший запас углерода в фитомассе и мортмассе ($102,9$ тС·га$^{-1}$), чем сосновые ($98,7$ тС·га$^{-1}$), что связано с большей представленностью спелых и перестойных дубовых насаждений. Однако, сравнение значений по классам возраста показало, что сосновые насаждения в целом имеют более высокие значения С в фитомассе, что связано с более высокой продуктивностью сосны. Отмечено увеличение запасов углерода с возрастом. Наименьший запас углерода наблюдается в других лиственных насаждениях ($77,1$ тС·га$^{-1}$).

Установлено, что запас углерода в мортмассе в дубовых лесах выше, чем в сосновых, как в абсолютном, так и в относительном выражении: в первых он составляет 9,3% пула фитомассы, в то время как во вторых – только 5,7%.

В дубовых и сосновых лесах наибольшее годовое изменение запаса С в фитомассе отмечено в более молодых насаждениях и с возрастом уменьшается, в то время как в мортмассе – увеличивается. Спелые и перестойные дубовые насаждения характеризуются отрицательным приростом фитомассы и положительным – мортмассы.

Сочетание наших данных с литературными данными о запасах углерода в пулах подстилки и почвы (30-сантиметровом слое) показало, что в возрасте 81-100 лет дубовые леса являются более эффективными накопителями углерода, чем сосновые (общий запас углерода в четырех основных пулах составляет $191,7$ т С га$^{-1}$ для дубовых лесов и $175,4$ т С га$^{-1}$ для сосновых). Доля углерода в фитомассе преобладает среди других пулов (50,3% в дубовых лесах и 57,6% в сосновых), за ней следует почвенный пул углерода (45,9 и 29,0% соответственно).

Внедрение Национальной инвентаризации лесов обеспечит первичными данными для оценки запасов углерода и его динамики для пулов фитомассы и мортмассы. Однако для оценки пулов почв и подстилки, которые играют важную роль в круговороте углерода в лесных экосистемах необходим мониторинг лесных почв.

Ключевые слова: фитомасса; мортмасса; углеродные пулы; изменения запасов углерода; дубовые насаждения; сосновые насаждения; классы возраста.