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DEADWOOD STOCK IN A LINDEN-PINE-OAK FOREST OF SLOBOZHANSKYI NATIONAL NATURE PARK

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ABSTRACT

Deadwood is one of the principal components of forest ecosystems. It completes numerous nature conservation and ecological functions. The work aimed to assess the reserves of woody detritus in the mixed forest of Slobozhanskyi National Nature Park (NNP) of natural origin. The research was carried out in an 86-year-old forest on fresh and fertile soils. Dead wood fractions, tree species, components, and classes of destruction were assessed on fixed area sample plot. The volume of woody detritus (WD) in the forest ecosystem is 21.8 $m^3 \cdot ha^{-1}$. It consists of fallen dead trunks and dead branches, which make up 75.7% of the total WD. Standng dead trunks (snags) account for the remaining 24.3%. The main part of the volume of dead wood formed by three tree species: *Tilia cordata* Mill., *Pinus sylvestris* L. and *Quercus robur* L. The share of these species together was 78.0%. The WD belonged from the I to V class of destruction. At the same time, the WD of the II class of decomposition was 52.5% had an advantage. The volume of snags was 5.3 $m^3 \cdot ha^{-1}$. In terms of species composition, *Q. robur*, *Acer platanoides* L., *T. cordata*, and *P. sylvestris* had a significant advantage. In the total volume of snags, the wood of the I class of destruction significantly prevailed at 67.9%, and the woody volume of the II class was 32.1%. Logs had a reserve of 16.5 $m^3 \cdot ha^{-1}$. The species composition dominated by wood detritus of *T. cordata* (35.8%), slightly fewer detritus of *P. sylvestris* (31.5%), and *Betula pendula* Roth. (22.4%). The fallen dead wood were represented by five classes of destruction. The biggest variety of fallen dead wood by classes of destruction was characteristic of *T. cordata*. A low amount of detritus are associated with a short period of strict protection of the studied forest ecosystem.

Key words: woody detritus, deadwood, forest ecosystem, biodiversity.

INTRODUCTION

The deadwood (DW) or woody detritus is a relevant component of forest ecosystems and performs many environmental and ecological functions (Harmon et al., 1986; Bujoczek, 2021; Kapusta et al., 2021). Coarse woody detritus (CWD) includes dry standing dead trees (snags) and fallen trees (logs) and fragments of fallen trees (trunks),

branches and their parts, and coarse tree roots. DW is a substrate and habitat for some species among lichens (Harmon et al., 1986; Blni et al., 2017), mosses (Harmon et al., 1986; Kropik et al., 2021), fungi (Yang et al., 2021; Baldrian et al., 2016) invertebrates (Chumak 2016; Parisia et al., 2021; Andringa et al., 2019), small birds and mammals (Harmon et al., 1986; Bölöni et al., 2017). According to scientists, approximately 25% of forest biodiversity species depend on decomposing DW (Stokland et al., 2004; Schuck et al., 2004). Therefore, DW is a relevant indicator of the biodiversity of forest ecosystems (Schuck et al., 2004). Dead wood plays the principal role in the biological cycle of substances, and energy, carbon deposition and is a source of nutrients (Harmon et al., 1986; Yarotskiy et al., 2019). Evaluation of DW as a component of the forest biomass is an unsolved problem in the context of the study of the biological productivity of forests (Yarotskiy et al., 2019; Volodymyrenko et al., 2016).

Slobozhanskyi NNP belongs to the important protected areas of the Forest Steppe in the Left Bank of Dnieper, Ukraine. Its total area is 5244 hectares (UKRNDIEP, 2015). It is the natural center of the Slobozhansk-Halytskyi ecological corridor within the framework of the ecological network of Ukraine (UKRNDIEP, 2015) and the centers of phytodiversity conservation in Ukraine and Europe (Bezrodnova et al., 2017).

Large areas of the NNP are dominated by pine or oak forest stands of artificial origin. Preserved plant groups of mixed oak-pine and pine-oak forests of natural origin grow on small areas within the NNP. However, the vast majority of the park is dominated by pine or oak forest stands of artificial origin.

Such group as centers of floristic diversity have significant phytosozological value. Several species from the rare part of the flora of the Slobozhanskyi National Park (both regionally rare and those protected at the national and European levels) are found within these types of forest. In particular species as: *Allium ursinum*, *Iris furcata* M. Bieb., *Iris pineticola* Klokov, *Fritillaria ruthenica* Wikstr., *Pulsatilla pratensis* (L.) Mill. s.l., *Tulipa quercetorum* Klokov & Zoz, *Dracocephalum ruyschiana* L., *Platanthera bifolia* (L.) Rich., *Neottia nidus-avis* (L.) Rich., *Epipactis helleborine* (L.) Crantz (Bezrodnova et al., 2020).

Within the boundaries of the Volodymyriv nature conservation research department of the Slobozhanskyi NNP, studied forest stands of plantations are formed by *Quercus robur*, *Pinus sylvestris*, *Tilia cordata* with an admixture of *Acer platanoides*, and sometimes *Populus tremula* L. or *Betula pendula*. The total area is 45.3 hectares or only 1.7% of the area is covered by forest vegetation in the department (UKRNDIEP, 2015). A cenopopulations of plant species listed in the Red Book of Ukraine were found in these forest ecosystems (Bezrodnova et al., 2020).

Natural forests dominated by *Quercus robur* and, separately, those dominated by *Pinus sylvestris* have phytosociological value and are important object for the study of dead wood, in particular those that developed without significant human impact. In these forest ecosystems, the forest stand was formed by several tree species, contributes to the formation of a variety of dead wood components.

In Ukrainian scientific publications, WD is primarily studies as an significant component in the total biomass of forest. The detritus has been observed in the context of carbon deposition and forest productivity research (Volodymyrenko et al., 2016; Kotlyarevska, Bilous, 2017; Matsala, Bilous, 2017). In the oak forests of the Left Bank Forest Steppe of Ukraine, the average volume of DW and the average volume of snags and logs were studied by Yarotskiy V. et al. (2016). The volume of DW did not exceed 8% of the growing volume of the stand (Pasternak et al., 2017) and fallen dead wood as 6.5 $m^3 \cdot ha^{-1}$ in the pine forests of the Left Bank of Dnieper, Ukraine (Yarotskyi, 2016).

Scientists have also proven the importance of the species composition of WD forming habitats and substrates for several species dependent on it (Schuck et al., 2004). In this direction, research by Chumak (2016), Chernyavskyi (2014), and others, studied dead wood in the context of providing habitats (substrate) for living organisms in forest ecosystems.

The relationship between coarse woody debris (CWD) and biodiversity has not been comprehensively studied in the forests of the Forest Steppe in the Left Bank of Dnieper. Therefore, it is necessary to assess the reserves of dead wood in mixed forest stands of natural origin with fresh hygrotopes and relatively fertile soil.

MATERIAL AND METHODS

According to physical and geographical zoning, the territory of the Slobozhanskyi National Nature Park belongs to the East Poltava Upland Region, located in the Left Bank-Dnieper forest-steppe region, in a warm zone of insufficient moisture.

The climate of the National Nature Park belongs to the temperate-continental type. On average, 498-568 mm of rainfalls per year. The total amount of precipitation is approximately 65% (341 mm) in the warm period of the year

(April–October). An average of 184 mm (35%) of precipitation falls in the cold period of the year. The snow cover was formed at the end of November and the beginning of December. Maximum snow accumulation occurs at the end of February, and the height of the snow cover reaches 14–18 cm. The stable snow cover lasts for about 65–80 days. The NNP Slobozhanskyi is characterized by unstable winds in terms of direction and speed. However, southeast, southwest, and northwest winds predominate (UKRNDIEP, 2015). According to the forest typological zoning, the territory of the Slobozhanskyi NNP belongs to the Slobozhanskyi district of the region of fresh hygrotopes and the most fertile soils (Yarotskiy et al., 2016). Oak-pine forests (38%) are predominant in fresh humid areas on relatively poor soils, forests with maple and linden on rich fertile soils (31%), and mixed forests with linden, oak, and pine within fresh hygrotopes on relatively rich soils (16%) (UKRNDIEP, 2015).

In the grass layer of oak-pine and pine-oak forests, among representatives of grasses and sedges, and *Carex michelii* Host., *C. pilosa* Scop., *Melica picta* K. Koch, *Poa nemoralis* L., *Milium effusum* L. are easily found. *Aegopodium podagraria* L., *Convallaria majalis* L., *Glechoma hirsuta* Waldst. & Kit., *Lathyrus vernus* (L.) Bernh., *Mercurialis perennis* L., *Polygonatum odoratum* (Mill.) Druce and *Stellaria graminea* L. are most often present among the species of forest forbs.

A study of CWD stocks was conducted in a natural forest stand on fresh hygrotopic and relatively fertile soils. The experimental site was located in the eastern part of the Volodymyrivske nature protection research department (quarter 90 according to the 2010 forest inventory documentation) (coordinates 50.055442° N, 35.260061° E) within the strictly protected zone (UKRNDIEP, 2015) (see Fig. 1).

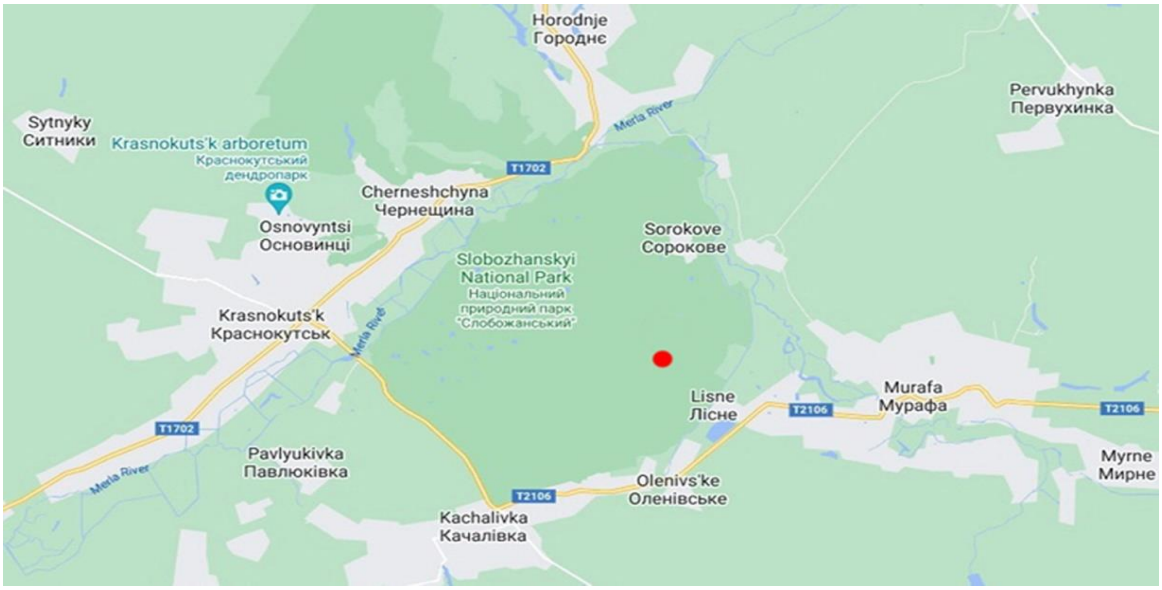

Figure 1. Map with the location of the study plot.

The age of the *Pinus sylvestris* and *Quercus robur* in the studied forest is 86 years. The forest has a natural origin and developed without human intervention in the last 10 years. Prior to the transfer of this forest tract to Slobozhanskyi NNP, forestry measures were carried out in this area, including selective sanitary felling and the removal of fallen dead wood.

The composition of dead wood volume was studied through a full census of woody detritus (WD) (Woldendorp et al., 2004) on a fixed area sample plot (Harmon, Sexton, 1996) measuring 0.50 hectares (a rectangle), which was established on the experimental area in 2020 according to standardized requirements (Forest Inventory Sample Plots: Establishing Method, 2006). The method developed by A. Bilous (Bilous, 2014) used to classify fractions and components of dead wood. Standing dead trees were generally inventoried using the same methodology as living trees (Rondeux & Sanchez, 2009). All whole or broken dead trees with a diameter of 6.0 cm and more at height of 1.3 m were included and accounted for at standing dead wood fraction. All components of standing dead wood diameter and height measured according to generally accepted methods in forest mensuration. The diameter and dry height were measured for all components according to the methods generally accepted in forest taxation. For dead, broken trees up to 5 m of height the diameter of the trunk at average height was measured. The fraction of lying

dead wood included and accounted for the following components: fallen trees (trunks), fragments of fallen trees (trunks), and branches (fragments of branches) with a median diameter of 6 cm or more, which were counted within the sample plot. Median diameter and length were measured for all lying DW components. Tree species were determined based on morphological characteristics for all parts of dead wood. Dry standing trees and logs are divided by I-V decomposition classes according to the methodology (Bilous, 2014). The volume of whole dead trees (trunks) was determined according to assortment tables (Kashpor et al., 2013). The volume of all components of logs was determined by Huber's formula:

$$V = \frac{\pi}{4} d_{0,5l}^2 l \quad (1) \qquad (1)$$

V – the volume of the trunk (trunk fragment) or coarse branch.
$d_{0,5l}$ – the diameter of the trunk (its fragment) or a coarse branch in the middle of the length;
l – the length of the trunk (its fragment) or a coarse branch;
π – constant (3,1415926…).

The volume of standing broken trees (trunks) is determined according to Huber's formula (1). Processing of field data and their analysis was carried out using MS Excel software.

RESULTS

The forest stand formed by *Q. robur* and *P. sylvestris* L., *T. cordata*, *Acer platanoides*, *B. pendula*, and *Acer campestre* L. in the studied area have been presented.
On the investigated plot, the projective cover of *S. graminea* was 10%. Coverage indicators from 2% to 7% were in such species as *Geranium robertianum* L. (7%), *Geum urbanum* L., *Chelidonium majus* L. (3%), *Urtica dioica* L. (3%), *Alliaria petiolata* (M. Bieb.) Cavara & Grande (2%), *Mycelis muralis* (L.) Dumort. (2%). In some places, *Fallopia convolvulus* (L.) A. Löve, *Galeopsis bifida* Boenn., *Lamium maculatum* (L.) L. recreate a significant role in the formation of grass cover of the surveyed forest type. The total projective coverage of the grass layer in the studied area was 20%.
The total projective coverage of the shrub layer was 30%. The structure of the shrubs was determined by *Corylus avellana* L. and *Ulmus glabra* Huds., *Frangula alnus* Mill. Their projective coverage was 10.7%, and 5%, respectively. *A. platanoides* and *Acer tataricum* L. were also detected. Their projective cover was 5% and 3%, respectively. This layer also included such shrubs as *Sambucus racemosa* L. (3%) and *Euonymus verrucosa* Scop. (4%), *Crataegus curvisepala* Lindm. (1%).
The results of the study of dead wood volume by fractions and tree species presented in Table 1.

Table 1. The volume of CDW in the linden-pine-oak forest

№	Tree species	The volume of dead wood by fractions, $m^3 \cdot ha^{-1}$		
		Snags	Logs	In total
1	*Quercus robur*	3.8	1.3	5.1
2	*Tilia cordata*	0.4	5.9	6.3
3	*Pinus sylvestris*	0.4	5.2	5.6
4	*Betula pendula*	0.0	3.7	3.7
5	*Acer platanoides*	0.7	0.4	1.1
Total		5.3	16.5	21.8

Dead wood in the researched forest stand was formed as a result of the death of trees of five species. It was formed by two fractions: standing and fallen dead wood (Fig. 2a, 2b, 2c, 2d).
Snags in the studied area has a reserve of 5.3 $m^3 \cdot ha^{-1}$, formed by whole and broken dead trees. In terms of species composition, *Q. robur* has a significant advantage (71.8%). *A. platanoides* (13.2%), *T. cordata* (7.2%) and *P. sylvestris* (7.2%) have much smaller shares. In the total volume of standing dead wood, the detritus of the first class

of destruction (3.6 $m^3 \cdot ha^{-1}$, 67.9%) is significantly predominant, compared to the second class (1.7 $m^3 \cdot ha^{-1}$, 32.1%). The standing deadwood of most tree species is represented by both classes of destruction, and *P. sylvestris* – class II. Logs has a reserve of 16.5 $m^3 \cdot ha^{-1}$ was formed as a result of the death of trees of five tree species. It consists of whole fallen trees (trunks), fragments of trunks and rough branches (fragments of branches). Wood detritus of *Tilia cordata* predominates (5.9 $m^3 \cdot ha^{-1}$, 35.8%), slightly fewer detritus of *P. sylvestris* (5.2 $m^3 \cdot ha^{-1}$, 31.5%) and *B. pendula* (3.7 $m^3 \cdot ha^{-1}$, 22.4%), and the detritus fractions of *Q. robur* (1.2 $m^3 \cdot ha^{-1}$, 7.9%) and *A. platanoides* (0.4 $m^3 \cdot ha^{-1}$, 2.4%) are minor. The median diameter of the wood detritus components of *T. cordata* is 6.0–23.0 cm, *P. sylvestris* – 6.8–26.2 cm, *B. pendula* – 7.5–39.0 cm, *Q. robur* – 6.0–26.2 cm, *A. platanoides* – within 6.0–12.5 cm.

a b

c d

Figure 2 (a, b, c, d). Deadwood in the linden-pine-oak forest of the Slobozhanskyi National Nature Park.

There is a considerable moss cover on the fallen trunks of *T. cordata* and *B. pendula* of III–IV destruction classes. A fragmentary moss cover is also present on the dead wood of *Q. robur* and *A. platanoides*.
In the studied forest ecosystem, logs are represented by five classes of destruction from I to V (Fig. 3).

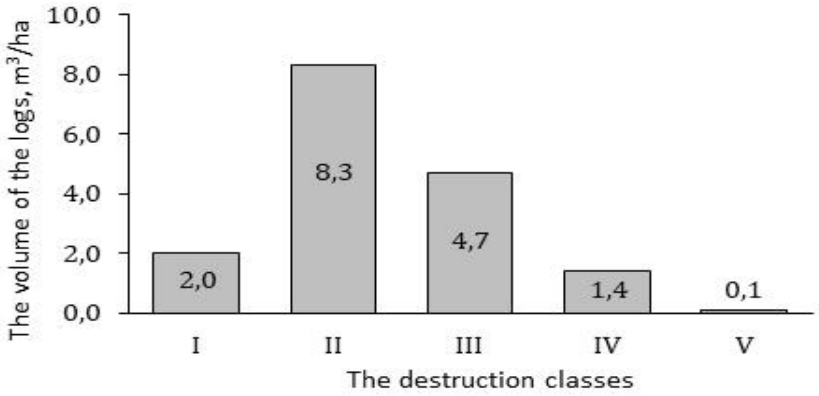

Figure 3. The volume of logs is divided by classes of destruction

The volume of the II destruction class prevails – 8.3 $m^3 \cdot ha^{-1}$ (50.3%), much less detritus of the III class is 4.7 $m^3 \cdot ha^{-1}$ (28.5%) and of the I class is 2.0 $m^3 \cdot ha^{-1}$ (12.1%). Volume and, accordingly, the shares of logs of other destruction classes are insignificant: IV class – 1.4 $m^3 \cdot ha^{-1}$ (8.5%), class V – 0.1 $m^3 \cdot ha^{-1}$ (0.6%).

Dead lying wood of most tree species is formed by detritus of two classes of destruction. So, in particular, lying dead wood of *Q. robur* is formed by III (54.7%) and II (45.3%) classes of destruction. Wood detritus of *P. sylvestris* was formed by II (81.7%) and III (18.3%) stages of decomposition. At the same time, *T. cordata* is characterized by the presence of four classes of destruction (I–IV), among which II (53.6%) and I (34.6%) prevail. Detritus of destruction class V is present only in the case of the *A. platanoides* (Fig. 4).

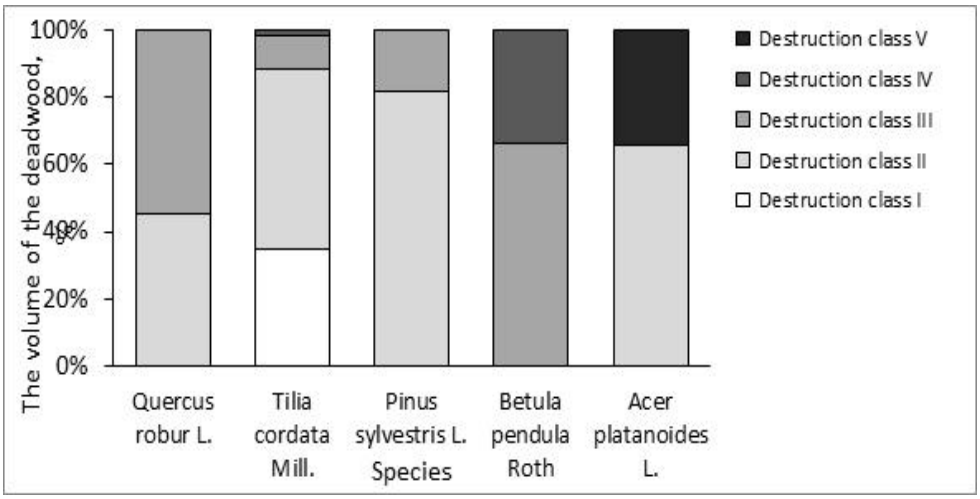

Figure 4. The volume of logs is divided by tree species and destruction classes.

The total volume of dead wood in the studied ecosystem is 21.8 $m^3 \cdot ha^{-1}$. It formed as a result of the death of trees of five species: *Q. robur*, *T. cordata*, *P. sylvestris*, *B. pendula* and *A. platanoides.* Logs prevails – at 75.7%, and the share of snags is 24.3%. The main part of the woody detritus was formed by three species – *T. cordata*, *P. sylvestris* and *Q. robur*, the total share is 78.0%. The other two tree species formed only 22.0% of the detritus volume, respectively (Fig. 5).

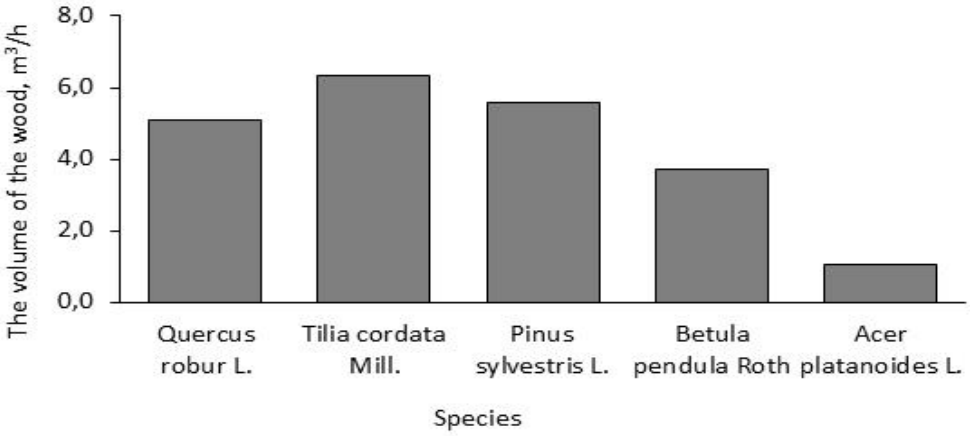

Figure 5. The total volume of deadwood is distributed by tree species.

Q. robur and *A. platanoides* are characterized by the predominance of dry, standing trunks, while other tree species are characterized by logs. All tree species, with the exception of *B. pendula*, have wood detritus of both fractions (Fig. 6).

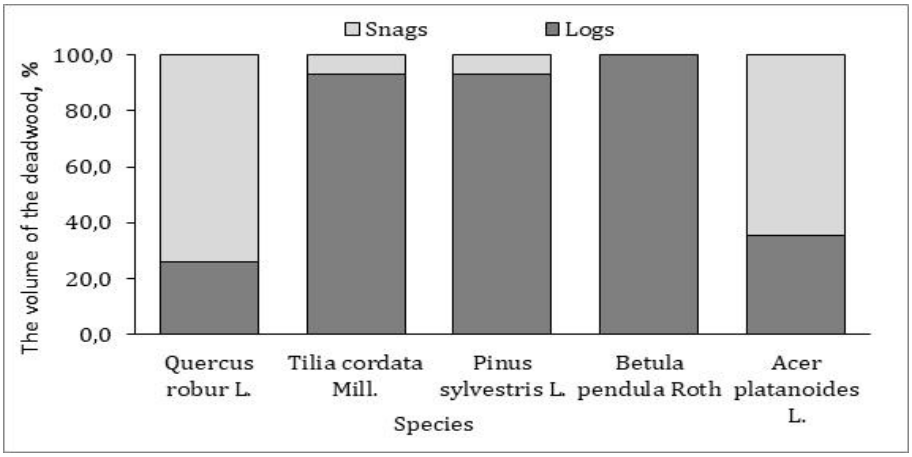

Figure 6. The total volume of deadwood (%) is divided by fractions and types of wood species.

The structure of the distribution of wood detritus by fractions for *Q. robur* contains - logs 74.5%, and snags - 25.5%. Total DW volume is characterized by classes of destruction I–V, while detritus of class II of destruction (45.7%) has a significant advantage, slightly less than class I (25.8%) and III (21.7%) of decomposition. Detritus other classes of destruction have insignificant shares (IV class – 6.2%; V class – 0.6%) in the studied forest ecosystem.
The obtained results were compared with the data of studies of CWD in forest ecosystems of Ukraine. According to the data of the report "The State of European Forests" (2015), the average volume of dead wood in the forests of Ukraine estimated at 6.0 $m^3 \cdot ha^{-1}$ (dry snags – 3.7 $m^3 \cdot ha^{-1}$, logs – 2.3 $m^3 \cdot ha^{-1}$). The researchers found that the average volume of dead wood in the forests of the North-East of Ukraine was 10.4 $m^3 \cdot ha^{-1}$ (Pasternak V. P., Yarotskyi V.Yu. 2013). According to the materials of forest management in the forests of the Slobozhanskyi NNP (Furdychko O. I. et al. 2021) the average volume of CWD was 9.1 $m^3 \cdot ha^{-1}$, for fresh linden-oak-pine suhrud 10.5 $m^3 \cdot ha^{-1}$.

The obtained data of dead wood stocks in the forests of the Slobozhanskyi NPP generally agree with the results of the mentioned studies. The excess of the results obtained in comparison with the data presented by Furdychko O. I. et al. 2021, is explained by the fact that the authors in the mentioned work used the forest management data provided in 2010. Studied woody detritus in a trial sample plot established in 2020. In addition, it should be admitted, only a part of the dead wood present in the forest area stand may be detected during forest management.
At the same time, the dead wood volumes received on volumes of woody detritus are very low compared to the data of other protected areas, with the priority of biodiversity preservation. According to the authors (Rahman et al., 2008) in forests dominated by *Quercus sp*. in a nature reserve in Austria, the average volume of CWD was 107.3 $m^3 \cdot ha^{-1}$. The share of dead standing trees was 22%, and dead lying trees was 78%. In the natural linden-ash-oak forests of the Holosiivskyi NNP (Kyiv, Ukraine) within the strictly protected zone, the volume of dead wood is 94.2 $m^3 \cdot ha^{-1}$, the share of standing dead wood is 25.4%, and lying dead wood is 74.6% (Chornobrov et al., 2020).

Volumes of deadwood in forest ecosystems depend on the trophic and humidity of growing conditions, the forest type, the species composition of the stand, natural disturbances in the region (windstorms, fires, etc.), and the influence of biotic factors (insects, pathogens, etc.) (Hahn, Christensen, 2004; Bujoczek et al., 2018). Forestry activity is an important factor that negatively affects the accumulation of dead wood in forests, as dead or damaged trees resulting from natural causes are often removed during silvicultural activities such as sanitary cuttings. As a result, the amount of dead wood in forest stands is reduced.

Another factor influencing the volumes of woody detritus may be the duration since the declaration of the respective nature conservation area and the establishment of a strict protection regime. The forest stand studied by us have been developed without human intervention only for the last 10 years. Before that, forestry activities were carried out in it , in particular, selective sanitary cuttings and fallen dead wood removal, which could be an important factor in the relatively low DW volume.

CONCLUSION

The stock of dead wood in the linden-pine-oak forest of natural origin within the strictly protected zone of the Slobozhanskyi National Park is not high, which can be explained by the short period of strict protection of the studied forest ecosystem. However, a certain diversity of wood detritus was noted in terms of tree species composition, component sizes, and classes of destruction, which is very important for the formation of substrates and habitats for wildlife. Further research aimed at a detailed study of the quantitative and qualitative indicators of dead wood in such valuable forest ecosystems of the Slobozhanskyi National Park and their roles in the preservation of biodiversity is needed.

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