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Resources of dead wood in the municipal forests in Warsaw

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Abstract. Dead wood plays an important role for the biodiversity of forest ecosystems and influences their proper development. This study assessed the amount of coarse woody debris in municipal forests in Warsaw (central Poland). Based on the forest site type, dominant tree species and age class, we stratified all complexes of the Warsaw urban forests in order to allocate 55 sample plots. For these plots, we determined the volume of dead wood including standing dead trees, coarse woody debris and broken branches as well as uprooted trees. We calculated the amount of dead wood in the distinguished site-species-age layers and for individual complexes. The volume of dead matter in municipal forests in Warsaw amounted to 38,761 m^3, i.e. 13.7 m^3/ha. The obtained results correspond to the current regulations concerning the amount of dead organic matter to be left in forests. Only in the Las Bielański complex (northern Warsaw) volume of dead wood is comparable to the level observed in Polish national parks or nature reserves, which is still far lower than the values found for natural forests. In general, municipal forests in Warsaw stand out positively in terms of dead wood quantity and a high degree of variation in the forms and dimensions of dead wood.

Keywords: dead wood, sanitary condition, urban forests, Warszawa

1. Introduction

Dead wood contains lifeless tree tissues that are gradually decomposing. In the forest environment, dead wood comprises snags (whole or broken standing dead trees), fallen dead trees, uprooted trees, lying branches, bark fragments, and stumps (Harmon et al. 1986; Caza 1993; Stevens 1997; Lofroth 1998). In forests, dead wood emerges for several reasons, either as a result of the competition between trees or because of the disturbances caused by biotic (fungal diseases, insect outbreaks, animal damage) and abiotic factors (e.g., wind, fire, snow) (Harmon et al. 1986; Stevens 1997). Decaying wood forms habitats for many forest organisms, from bacteria to small forest mammals (Gutowski et al. 2004). Dead organic matter alters site environment and shapes the condition of species as well as ecosystem biodiversity (Solon 2002). It also affects nutrient cycles and other natural processes in forest ecosystems, including the energy flow. According to Bunnella et al. (2002), ap-proximately 60% of forest species are in some way associated with dead wood and/or benefit from its resources.

Some time ago, it was believed that residual dead wood material in the forest was a symbol of ample habitats for all kinds of pests and a result of mismanagement that caused economic losses (Wolski 2000). At present, dead wood has been recognized as an indispensable part of properly functioning forest ecosystems; it is an important indicator of forest naturalness and ecosystem diversity (Sokołowski 1999; Rykowski 2005). Consequently, efforts have been undertaken toward retaining large and diverse reserves of dead wood in forests and shaping its amount and structure. In Poland, this issue has been referred to in political regulations on forest management. Among others, according to the entries in the 'Instrukcja ochrony lasu' (2011), the forest district manager is responsible for dead wood management based on economic, ecological, and social aspects of sustainable forest management in a given area. Also, consistent with the 'Zasady Hodowli Lasu' (2003), dead trees (if not hazardous) are treated as beneficial and retained in managed forests. What is more, forest certification systems recommend retention of snags and coarse woody debris throughout forested areas.

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Numerous studies on the detection and evaluation of dead organic matter and determination of its role in forest ecosystems have been conducted worldwide. In the forests of the United States (Harmon et al. 1986) and Canada (Tyrell, Crow 1994; Lofroth 1998), the amount of dead wood was determined to retain them both in managed forests and in those considered as primeval/natural. Dudley and Vallauri (2004) reported data on average amounts of dead organic matter in chosen European countries. Similar estimates were published in relevant reports of the Economic Commission for Europe (http://w3.unece.org) and by Travaglini and Chiricie (2006). In Poland, the majority of studies on dead wood have been carried out in the Białowieża Primeval Forest (Faliński 1978; Bobiec 2002; Bobiec et al. 2000; Gutowski et al. 2004). Other studies were conducted in the forests of the Tatra Mts. (Zielonka, Niklasson 2001), in the Upper Silesia region (Maślak, Orczewska 2010), and in the Polesie Konstantynowskie Reserve in Łódź (central Poland) (Pawicka, Woziwoda 2011). Research concerning dead wood amounts was also conducted in forest-promotional complexes (Solon, Wolski 2002; Wolski 2000, 2001, 2002a, b, 2003), whereas Bobiec and Stachura-Skierczyńska (2007) as well as Czerepko (2008) reported the results on the role of dead wood in Poland's forest ecosystems.

The aim of the present study was to evaluate the amount of dead wood retained in the urban forests in Warsaw, Poland. The results were compared with the values obtained in other European cities and those recommended for natural, protected and managed forests in Poland.

2. Materials and methods

2.1. Study area

Among Europe's capital cities, Warsaw stands out as one with a significant proportion of forested area within the city limits. At present, there are 27 forest complexes with the total area of almost 8 thousand ha, which is 15% of the whole city area. Forest complexes are mainly situated on the edges of the metropolis, and form the so called 'green forest ring'. Approximately 40% of Warsaw's forested area is managed by the administration unit called the Lasy Miejskie Warszawa (Warsaw Municipal Forests). These comprise 15 forest complexes divided into four districts, i.e., Bielany-Młociny (838 ha), Bemowo-Koło (556 ha), Kabaty (903 ha), and Las Sobieskiego (1353 ha). In the present study, these are referred to as 'the urban forests'.

In forest ecosystems under management of the Warsaw Municipal Forests, prolific sites of deciduous and mixed forests are present, which cover almost 34% and 24%, respectively, of the total area of the urban forests. Mixed coniferous or coniferous forest sites constitute 18.5% and 20%, respectively. Wet alder and riparian woodlands comprise relatively the smallest area (3.5%). In Warsaw's forest stands, the dominant forest-forming species is Scots pine (*Pinus sylvestris*), which occurs on almost 56% of the area of the urban forests. Oak (*Quercus* sp.) dominates in the stands covering 24% of the area described. The stands with dominant birch (*Betula* sp.) and alder (*Alnus glutinosa*) cover smaller areas (8% and 6%, respectively) and stands with dominant black locust (introduced *Robinia pseudoacacia*) – nearly 2% (mostly the forest complex Las na Kole). In general, forest stands in the third class of age (40–60 years) are prevalent, and these occur on almost half of the total area of the urban forests. Other stands are in the second and fourth classes of age (each approximately 15% of the total area). Old or very old (more than 140 years) stands are relatively extensive, and cover 9% of the total area of all the forest complexes studied.

2.2. Field works

A database on all forest areas in Warsaw provided by the Warsaw Municipal Forests was used to select the stands for further analyzes. Information obtained allowed for designation of sampling plots, consistent with the forest site type, dominant species, and age classes in a given stand. Based on the data analyzed, forest site-species layers were determined, including their areas and contributions in the total urban forest area. The most prevalent tree species (Scots pine and oak) were analyzed with reference to the age class as well. Due to relatively small areas occupied by other tree species, the age class was not considered in the prepared forest site-species layers (Table 1).

Field measurements were performed on the sampling plots and study transects accordingly to the methodology described by Wagner (1968) and Wolski (2002 a, b). Each study plot comprised 50 × 50 m square and 100 m long transect that led along two adjoining sides (randomly selected) of the plot. The plots were established with 50 m long measuring tapes.

The sampling plots represented the determined forest site–species–age layers (Table 1). Within each forest complex examined, at least one sampling plot was established. The one exception was the Wydma Żerańska complex (6.6 ha), where forest stand compartments are smaller than the assumed sampling plot (0.25 ha). Analogous approach was applied for the coniferous tree species other than Scots pine that occur on small areas. No sampling area was established in the Dąbrówka forest complex due to the lack of data for this area. Instead, an additional sampling plot was established within the Białołęka Dworska forest complex. As a result of the experiment design, ca. 55 ha of forest stands represented a given forest site–species–age layer.

Dead wood material observed in this study was divided into the following categories: snags (standing or broken

Table 1. Share of distinguished habitat–age–species classes in total area of urban forests in Warszawa and number of sample plots allocated to them

Layer	Share in total area [%]						Number of sample plots						
	B	BM	LM	L	O	total	B	BM	LM	L	O	total	total [%]
So $_{I+II}$	4.0	1.0	4.0	0.7	-	9.7	2	1	2	-	-	5	9.1
So $_{III}$	11.6	7.0	4.9	3.7	-	27.2	6	4	3	2	-	15	27.3
So $_{IV}$	2.4	3.2	0.2	3.2	-	9.1	2	2	-	2	-	6	10.9
So $_{V}$	-	0.2	1.8	2.3	-	4.4	-	-	1	1	-	2	3.6
So $_{VI+}$	0.1	0.5	2.7	2.7	-	6.1	-	-	1	2	-	3	5.5
Db $_{I+II}$	0.1	0.1	1.1	2.1	0.1	3.5	-	-	1	1	-	2	3.6
Db $_{III}$	1.1	1.6	2.3	5.3	-	10.3	1	-	1	3	-	5	9.1
Db $_{IV}$	0.0	0.8	2.6	0.2	-	3.7	-	-	2	-	-	2	3.6
Db $_{V}$	-	0.2	0.9	5.7	-	6.9	-	-	1	3	-	4	7.3
Brz	0.5	2.7	2.5	2.3	-	8.0	-	2	2	1	-	5	9.1
Ol	-	0.3	0.4	2.9	2.7	6.2	-	-	-	2	1	3	5.5
Ak	0.3	0.8	0.0	0.7	-	1.8	-	1	-	-	-	1	1.8
Lsc	-	0.1	0.3	1.9	0.5	2.8	-	-	-	1	1	2	3.6
Igl	-	-	0.2	0.2	0.0	0.4	-	-	-	-	-	0	0.0
Total	20.3	18.6	23.8	34.0	3.4	100.0	11	10	14	18	2	55	100.0

Site types: B – oligotrophic. BM – meso-oligotrophic. LM – meso-eutrophic. L – eutrophic. O – water-dependent; dominant species: So – *Pinus sylvestris*. Db – *Quercus* sp.. Brz – *Betula* sp.. Ol – *Alnus glutinosa*. Ak – *Robinia pseudoacacia*. Lsc – other deciduous. Igl – other coniferous; I. II. … – consecutive age classes of 20 years

dead trees, stumps) and woody debris. The latter was divided into coarse woody debris (above 2.5 cm diameter) and fine woody debris (below 2.5 cm diameter) (Harmon et al. 1986). On every sampling plot, dead wood inventory concerned snags, whereas woody debris were examined on the transect. Dead standing trees were examined with regard to their species, breast height diameter (measured with ca-liper), and height (measured with Vertex III hypsometer). Coarse woody debris volume was assessed based on wood fragments with the diameter ≥ 2.5 cm, lying on the ground (those recessed in the litter were neglected). Smaller wood elements were only counted. The length of a wood piece was measured along its morphological axis, while the diameter was measured perpendicularly to the morphological axis at the point where the axis of an individual piece crossed the transect line. Diameter measurements were carried out individually for every wood piece on its intersection with the transect, which means that one piece of wood could be measured for some time if it intersected with the transect line more than once (Wolski 2002b). The length was measured with use of Vertex III hypsometer. For each wood piece, the tree species was determined as well as wood decay degree was assessed in accordance to the 5-point scale (Masera et al., 1979).

Additionally, on each sampling plot, all the stumps were counted and examined with regard to the species and wood decay degree.

2.3. Calculations

The volume of dead wood was calculated separately for each sampling plot. The volume of standing dead trees was calculated based on the obtained measurements and relevant form-factor formulas available in literature. Scots pine volume was calculated based on form factors elaborated by Bruchwald and Rymer-Dudzińska (1996), that of oak based on Bruchwald et al. (1996) and birch following Tomusiak (2003). The volume of dead wood of beech, hornbeam, and maple was calculated based the form factors presented for beech by Dudzińska (2003). The formula elaborated for alder by Dudzińska and Bruchwald (2003) was used for calculations concerning black locust, willow, and alder. The volume of broken standing dead trees and that of standing dead underbrush was calculated as the volume of a cylinder with dimensions identical as the parameters measured (i.e., given tree breast height diameter and height). Coarse woody debris volume was calculated following the formula by van Wagner (1968):

$$V_l = \frac{\pi^2}{8 \cdot L} \cdot \sum d^2$$

where:
d = wood piece diameter [cm],
L = transect length [m].

The total volume of dead wood (altogether dead standing trees and dead broken trees, underbrush, and coarse woody debris) on the sampling plot was converted to dead wood volume per 1 ha [m^3/ha]. The mean values were calculated when more than one sampling plot was established within a given forest site–species–age layer. The volume of dead wood per given stand was calculated based on the conversion of dead wood volume per area unit in a given forest site–species–age layer into given stand area. Dead wood resources in the analyzed forest complexes were calculated by summing up the volume obtained for all the stands in a given forest complex. At the same time, we calculated dead wood amounts in the forest site, species, and age class layers:

3. Results

The total amount of the dead wood in the forest complexes under the administration of the Warsaw Municipal Forests was estimated to be 38,761 m^3 (Table 2). Unquestionably, the largest amounts of deadwood were observed in the forest complex of Las Kabacki (16,463 m^3), and the lowest in small complexes such as Wydma Żerańska (71 m^3) and Las Matki Mojej (95 m^3). The size of forest complexes was not always reflected in the amount of dead wood observed. In relatively small forest complexes, such as Las Młociny and Olszynka Grochowska, we found larger deadwood resources than in the considerably large forest complex Białołęka Dworska (Table 2). The amount of dead wood in Warsaw urban forests ranged from 3.66 m^3/ha in the Białołęka Dworska forest complex to 33.50 m^3/ha in the Las Bielany, and on the average it was 13.7 m^3/ha (Table 2).

Dead wood abundance was the highest (in total 24,000 m^3 registered) in the stands growing on deciduous forest sites, while the lowest in alder and coniferous sites (1,250 m^3 and 2,200 m^3, respectively). The average amount of dead wood/area unit was the largest on deciduous sites (25 m^3/ha), and the smallest on coniferous sites (less than 4 m^3/ha). The share of the dead wood volume on wet forest site types is similar to the fraction of the area covered by this type of forests in the total area of urban forests, while for the coniferous forest sites, it is fourfold lower (Fig. 1). Only in case of deciduous forest sites, the share of the dead wood on the given forest site type is larger than its fraction in the total area of urban forests. The highest dead wood amounts were amassed in the stands in the

Table 2. Characteristics of the individual complexes of urban forests in Warsaw in terms of area and resources of coarse woody debris

Forest complex	Area		Coarse woody debris volume		Average volume of dead wood [m^3/ha]
	[ha]	[%]	[m^3]	[%]	
Las Bemowo	445.70	15.8	5998.11	15.5	13.46
Białołęka Dworska	241.59	8.5	884.55	2.3	3.66
Las Bielański	142.21	5.0	4763.85	12.3	33.50
Las Bródno	128.34	4.5	2038.57	5.3	15.88
Dąbrówka	25.93	0.9	130.35	0.3	5.03
Henryków	18.64	0.7	106.55	0.3	5.72
Las Kabacki	867.00	30.7	16462.9	42.5	18.99
Lasek na Kole	45.78	1.6	617.50	1.6	13.49
Las Lindego	20.27	0.7	180.74	0.5	8.92
Las Młociny	83.38	2.9	1303.62	3.4	15.63
Las Matki Mojej	14.01	0.5	95.10	0.2	6.79
Las Nowa Warszawa	166.51	5.9	726.40	1.9	4.36
Olszynka Grochowska	61.09	2.2	1001.09	2.6	16.39
Las Sobieskiego	560.37	19.8	4380.41	11.3	7.82
Wydma Żerańska	6.61	0.2	71.05	0.2	10.75
Total	2827.43	100.0	38760.80	100.0	13.71

third age class (approximately 13,5000 m^3), and the lowest in the first age class (approximately 400 m^3). Dead wood abun-dance in the oldest stands was almost 37 m^3/ha, and in the youngest about 9 m^3/ha. Dead wood contribution in the total dead wood volume of the whole urban forests was propor-tional to the share of the area occupied by these stands in the urban forests (Fig. 2). The biggest differences were observed between the third age class stands (49% share of the area and 35% contribution to dead wood) and seventh age class stands (9% and 24%, respectively). The highest amounts of dead wood were observed in the stands with dominant Scots pine (more than 12,700 m^3) or oak (slightly more than 10,000 m^3). Dead wood was more than ever abundant in birch and other deciduous stands (e.g., poplar, hornbeam, maple, willow, lime). In all these, average dead wood volume was 38–39 m^3/ha, whereas in Scots pine stands, it was approximately 8 m^3/ha. Taking into consideration area shares in the total area of the urban forests analyzed, the contribution of Scots pine dead wood to the total dead wood abundance was 1.5 times lower. The contribution of dead wood of other forest tree species was proportional to their area shares in the urban forests (Fig. 3).

4. Discussion

Responsible management of the dead wood abundance is essential for sustainable management of properly functioning, healthy, and stable forest ecosystems (Sokołowski 1999; Wolski 2002a; Rykowski 2005).

According to Wolski (2002a), in Scots pine stands (the most common in Poland), about 3 m^3 of dead wood is pre-sent, while Holeksa and Maciejewski (2006) report 2 to 5 m^3/ha of dead wood. The results of the large-scale forest inventory (Neroj 2011) indicate a comparable value (5.2 m^3/ha) for dead wood abundance in forests managed by the State Forests-National Forest Holding. On the other hand, Czerepko (2008) reports a higher value (9.6 m^3/ha). The results of a study carried out on 50-year-old pine stands in the United States showed on average 30 m^3 of dead wood per hectare (Harmon et al. 1986). Dead wood abundance in forest complexes managed by the Warsaw Municipal Forests is nearly 14 m^3/ha. This value is similar to that reported by the Economic Commission for Europe (ECE) with reference to the managed forests in the western part of Europe. The ECE report points out that Polish managed forests retain one of the lowest average amounts of dead wood. However, the amount observed in the urban forests in Warsaw was almost three times higher. In the majority of European countries (e.g., Austria, Switzerland, Germany, and Slovenia), a trend of increase in increase dead wood abundance in the managed forests is observed. Some of the countries (Slovakia, Lithuania, and Russia) have retained substantial amounts of dead wood in their forests. The urban forests in Warsaw indicate medium dead wood abundance, similar to that in Estonia and Germany, and it is definitely higher than that in many other countries (e.g., France, Finland, and Belgium).

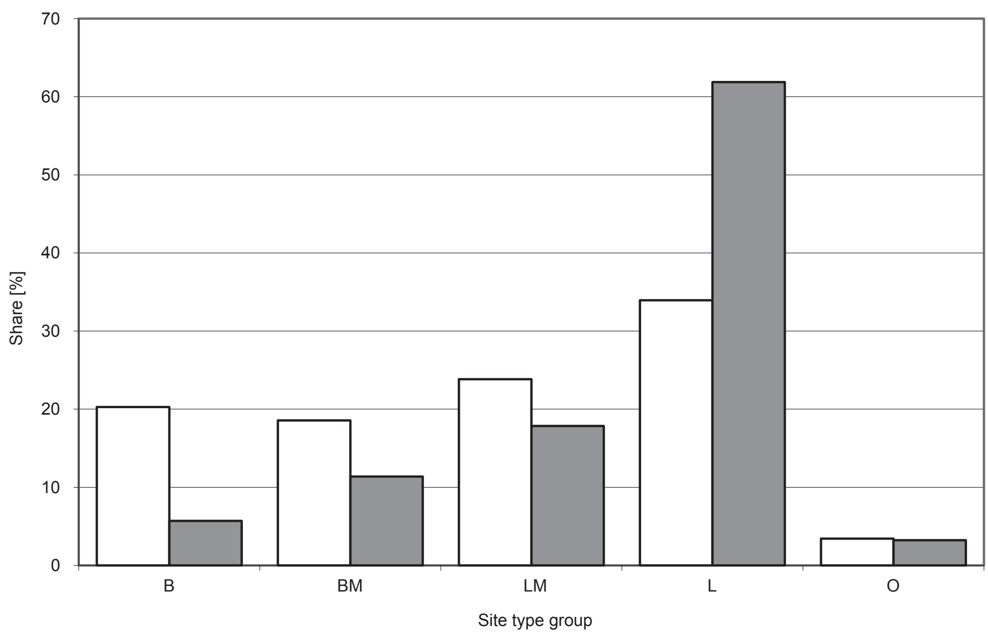

Figure 1. Share [%] of site types groups in total area (white) and coarse woody debris volume (grey) of urban forests in Warszawa

Denotes as in Table 1

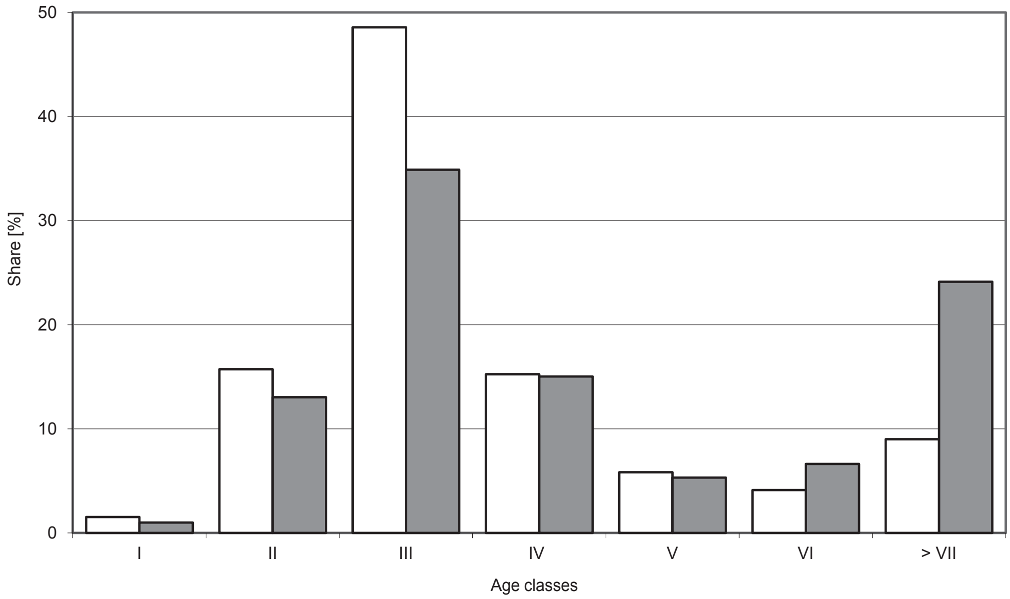

Figure 2. Share [%] of age classes in total area (white) and coarse woody debris volume (grey) of urban forests in Warszawa

Denotes as in Table 1

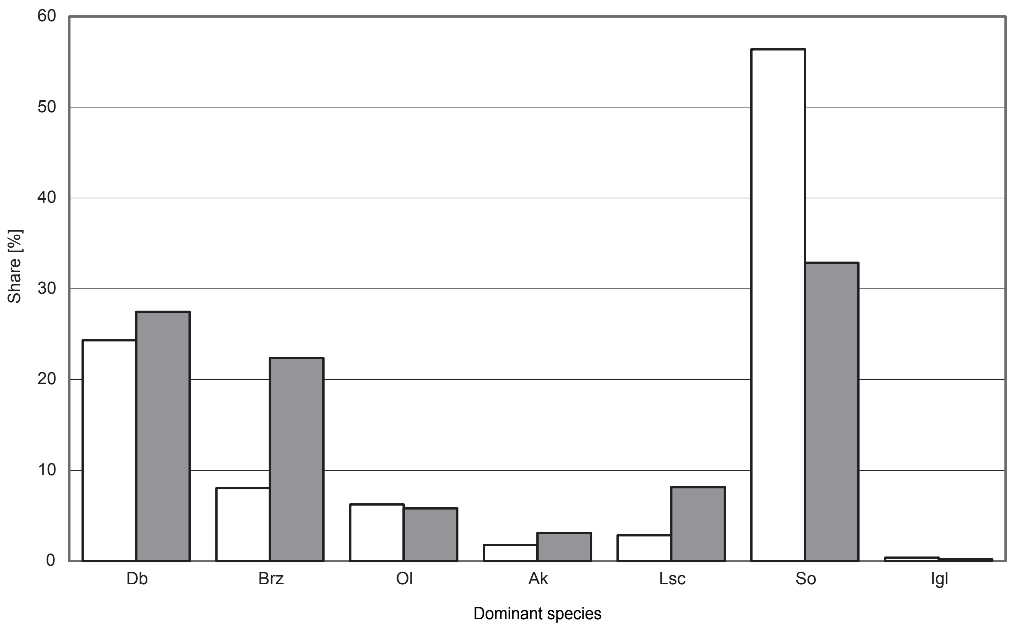

Figure 3. Share [%] of individual species in total area (white) and coarse woody debris volume (grey) of urban forests in Warszawa

Denotes as in Table 1

Higher amounts of dead wood occur in Polish forests with natural character and in those under the protection (Ciach 2011). The results of the measurements carried out in a frame of the large-scale forest inventory showed that dead wood abundance in national parks in Poland exceeded 35.8 m^3/ha (Neroj 2011). Similar dead wood volume was observed in the present study—in the urban forest complex Las Bielański, with old forest stands (mainly oak) on fertile sites and abundance of sizeable dead wood pieces. Slightly more (38.9 m^3/ha) dead wood was observed in the urban reserve Polesie Konstantynowskie in the city of Łódź (Pawicka, Woziwoda 2011). According to Maślak and Orczewska (2009), the amount of dead wood observed in protected areas in the Upper Silesia region, ranged from 42 to 166 m^3/ha. Ample dead wood amounts are observed in natural forests. Nilsson et al. (2002) estimate that before anthropogenic expansion, in European forests, on average 130–150 m^3/ha of dead wood can be observed. Furthermore, Dudley and Vallauri (2004) report the values up to 275 m^3/ha (Fontainebleau Forest in France or Hanger Wood in the United Kingdom).

The recommendations on dead wood amounts to retain in the forests have changed with time. The advocated amount used to be 3 m^3/ha or 5–10 m^3/ha (Ammer 1991; Utschik 1991). The recommended dead wood amounts increased with the progress of research. Now it is believed that the amount of dead wood retained in forest should range from 15 to 30 m^3/ha (Colak 2002; Jankovský et al. 2004; Bütler, Schlaepfer 2004). Some authors recommend the amount comprising 5–10% (Möller 1994; Jedicke 1995; Bütler, Schlaepfer 2004; Vandekerkhove et al. 2009) or even 20% (Humphrey, Bailey 2012) of the total stand volume. Gutowski et al. (2004) suggest that in managed forests, dead wood amounts should constitute not less than 5% of the volume of a mature stand. These should comprise at least five thick (with diameter above 40 cm) decaying trees or logs per forest ha and as many as possible hallow trees. However, one should keep in mind that the proposed values do not neces-sarily reflect the requirements of given ecosystems (Solon, Wolski 2002). In view of the abovementioned values, the urban forests in Warsaw meet current recommendations on dead wood amounts to be retained in forests.

The results of the assessment of dead wood amounts in forest ecosystem depend on many factors. Dead matter abundance in forest is reliant upon the climatic zone, potential vegetation type, stand utilization, stand features (age, species composition, density), site conditions (substrate wetness) as well as conservation status of a given area (Harmon et al. 1986; Wolski 2003; Bujoczek 2012). Human activity, either forest management or tourism and recreation, plays a considerable role in dead wood retention. In the present study, low amounts of dead wood observed in the stands with dominant Scots pine–growing on infertile sites is a result of pine ecology. During its lifetime, Scots pine does not produce too many dead elements. Only already dead specimens can contribute to the dead wood amounts, but this process is often long term. On the other hand, high dead wood abundance in deciduous stands (especially birch and oak) is associated with the development of tree crowns, which provide large elements. Since birch is not a long-life species, it supplies ecosystem with dead wood on short-term basis, and as a result accumulation of dead matter is frequently observed in the stands with birch. Also, stand growth stage has a decisive influence on dead wood category and size. In younger stands, fine woody debris are seen, whereas in those older, bigger tree branches and logs occur. That is why high dead wood amounts are observed in the old stands. Dead wood abundance observed in the urban forests examined in this study could be affected by anthropogenic factors such as tourism and recreation. The urban forests in Warsaw are subject to excessive tourist traffic being very popular recreation area for Warsaw public community (Gołos 2013). Lying dead wood could be used up in fireplaces as it is easily available material. Moreover, there is a social pressure toward the forest management to remove such wood from the forests for aesthetical reasons.

5. Conclusions

1. Average amount of deadwood in the urban forests of Warsaw is approximately 14 m^3/ha. This level meets current recommendations on the quantity of dead wood retained forest.

2. Dead wood resources in the urban forests in Warsaw is comparable with that reported for managed forests in western Europe, and two to three times higher than in managed forests in Poland.

3. In Warszawa, only the Las Bielański forest complex shows dead wood abundance similar to the one observed in Polish national parks. None of the analyzed forest complexes showed dead wood resources analogous to that observed in natural forests.

Conflict of interest

The authors declare no interest conflict.

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Author's contribution

K.S. – field measurements, manuscript preparation; Sz. B. – study conception, field measurements, manuscript revision.

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