Salvage Condition Assessment of Timber Volume in Disturbed Areas

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Abstract

The starting point for any planning process related to salvaging timber in disturbed areas is to estimate the volume of raw wood designated to be removed from such stands. This paper aimed to analyse the accuracy of methods used in salvage condition wood volume assessment in wind-affected pine stands. In the investigated stands the wood volume determined in the salvage condition assessment was by 21% higher than the one actually extracted. With regard to the areas, where only individual specimens or groups of trees had suffered from wind, the timber volume was overestimated by ca. 50%. The dependence between the salvage plan volume and the actually extracted one was logarithmic. The accuracy of timber volume assessment in the stands with larger wind-damaged areas was higher. The timber volume was overestimated by ca. 13% and the dependence between the salvage plan volume and the actually extracted one was linear. In respect to the widespread wind-damaged areas, the assessment of timber volume to be salvaged may be accurate providing that the estimation was made using the data from the appraisal forest management plan and that the wind-damaged areas were precisely mapped by means of the GPS device. The standard method of salvage condition timber volume assessment in stands, where wind damage affected individual trees or groups of trees, based on the calculation of the average volume of a single wind-broken or wind-fallen tree multiplied by the estimated number of all wind-damaged trees, is burdened with a greater error. Hazardous work conditions, encountered particularly in stands. where groups of trees had suffered from wind, are responsible for greater error margin in establishing the exact number of damaged individuals.

Keywords: timber salvaging, windbreaks, windfalls, salvage condition timber volume assessment

Introduction

Severe weather phenomena have always affected ecosystems; therefore, they have significantly contributed to the process of reshaping the forest environment, in many cases, being an inevitable regenerating force that determined the variability and diversification of forests (Pickett and White 1985). However, it was not until the last few decades that they were paid more attention and their destructive but reviving power was better recognised. An increase in the number of disastrous events recorded in the recent years was partly due to the swift flow of information, and partly to growing weather dynamics. With regard to the climatic zone of Poland, winds play a dominating role among other weather phenomena, being one of the most important factors apart from insect infestation, floods, fires and droughts that inflict changes to ecosystems.

Hurricane winds occur cyclically. Since the mid-20th century 130 hurricane events of various origins have been recorded in Europe, while an average annual volume of wind-damaged trees until 2000 amounted to 35 million cubic meters (Schelhaas et al. 2003). In 1990 Europe was affected by "Vivian" and "Wiebke" hurricanes (Wójcik and Orzechowski 2014). Then, in 1999 Western Europe was stricken by "Anatol". A few days later a stronger hurricane, named "Lothar", emerged (Pilzek 2000), and in 2007 there was another one, "Cyryl". Only in 2014 the total volume of wind-damaged trees in Polish forests reached the level of 180 thou. cubic meters at least.

Wind damage to forests is undoubtedly associated with severe weather phenomena, which in the opinion of some scientists are related to the increase of average temperatures all over the world (Gardiner and Quine 2000). Forest stands particularly exposed to wind damage are even-aged monocultures, especially those that have already been weakened by other biotic and abiotic factors (Zajączkowski 1991, Nyrek 1975). An essential problem in the matter in question is salvage logging, which is an extremely difficult challenge, involving hazard-related and work efficiency issues. Therefore, as far as the disturbed areas are concerned, the forest practice and science should join their efforts and take common actions in the scope of recognition of weather dynam-

ics, developing stable stand structures and designing adequate technological systems for timber salvaging.

The threats associated with timber salvaging in disturbed areas are mostly due to a direct contact between the workers (machine operators) and wind-damaged trees. Inside the trunks of such trees there occur strains that are difficult to estimate and may affect operations of cutting and processing in an unpredictable manner. Particularly hazardous work conditions are encountered at logging operations employing chainsaws for cutting trees and skidders or forwarders for extracting timber (Puchniarski 2003, Szewczyk and Stańczykiewicz 2012). Therefore, entering the disturbed areas with multi-operational forest machines has become a standard practice since the 1990s (Moskalik 2004, Frutig et al. 2007, Sowa 2009, Sowa et al. 2009, Grodecki and Stempski 2010, Dvoųįk et al. 2011, Szewczyk et al. 2014).

Timber salvaging in disturbed areas is a particularly difficult operation since it requires complex planning processes, the starting point of which is an assessment of quantity and quality of the damaged wood. Before commencing an estimation of losses, a preliminary inventory should be conducted to establish the general extent of damage and its location. Then, a more precise inventory is carried out, using the data from the forest management plan and based on the outcomes of the recent years, which makes it possible to draw a salvage condition timber volume assessment. During the inventory, a number of features should be determined, such as the age of disturbed stands, their area, tree species composition, the extent of damage and raw wood quality (Giefing 1995).

Upon detecting the damage occurrence, widespread in particular, the starting point for any planning process related to timber salvaging is an accurate estimation of wind-affected wood volume. Since this assessment serves as the basis, on which the timber sale plan is elaborated and the suitable timber salvaging technology is designed, the actions taken at the very beginning significantly affect the entire process performance.

The estimation of damaged wood volume is usually carried out according to the local guidelines regarding the characteristics of the certain forest district, giving the priority to the data from the respective forest management plan. Since conditions encountered in disturbed areas are highly variable, several complementary methods for various compartments, in some cases even the adjacent ones, are often employed. Standardisation and determining the accuracy of estimating the volume and quality of damaged wood is a necessary approach aimed, in the first place, at optimisation of cost effectiveness of commercial activity conducted by forest districts.

This paper aimed to analyse, how accurate is the assessment of the volume of wood to be salvaged from wind-affected areas where widespread damage as well as damage to groups of trees and individual trees were recorded.

Materials and methods

Study area

The research was conducted in the Forest District of Ruda Maleniecka (RDSF Radom – Regional Directorate of State Forests in Radom), affected by wind in summer 2014

Figure 1. Location (geographical coordinates) of the research area – Forest District of Ruda Maleniecka

Widespread damage (i.e. a severe wind damage covering the area over 500 m^2) took up a total area of ca 27 ha. Disturbance of this extent affected forest complexes of Góra Pakulska and Góra Białkowa. Wind damage in Góra Pakulska occurred over the area of 8.5 ha. In this complex, the designed felling system involved clear-cutting Ia (Polish classification – logging performed on a felling site with a width ranged between 60-80 m, taking up an area to 6 ha) covering 7.09 ha and clear-cutting Ib (Polish classification – logging performed on a felling site with a width ranged between 30-60 m, taking up an area to 4 ha) covering 1.41 ha. In Góra Białkowa complex, the wind destroyed trees were observed over the area of 18.59 ha. Similarly, the designed felling system involved clear-cutting Ia (14.16 ha) and Ib (4.43 ha).

The analysis presented here included wind damage that affected two forest sub-districts:

1. Forest Sub-district of Krzyżówki – individual and group damage recorded over the entire area of the forest subdistrict;

2. Forest Sub-district of Radoszyce - widespread damage (Góra Pakulska and Góra Białkowa).

The issues of work safety and the necessity to remove the damaged wood from stands, preventing it from depreciation, forced the decision of employing the CTL, Cut-To-Length system, in cleaning up the disturbed areas (Pulkki 2004), en-

gaging multi-operational forest machines and forwarders (Bort et al. 1990, Mahler and Bort 1990, Moskalik and Stampfer 2003, Frutig et al. 2007). The salvaged wood was entirely processed in the wind-affected stand, and then it was skidded as merchantable timber assortments. Units of cooperating machines working in these stands (Góra Białkowa, Góra Pakulska) consisted of a harvester (Gremo 1050H, Valmet 911.3) and a forwarder (Gremo 1050F). The logs processed by the harvesters were then carried to hauling roads and upper landings by the forwarders. The logging operations in the disturbed areas lasted from August until December 2014, whereas the individual wind-damaged trees were still being removed in spring of the following year.

Estimating the degree of wind damage

The wind damage was recorded in pine stands covering the total area of ca. 967 ha. The volume of damaged wood amounted to 13 thou. cubic meters. The damage was of various types: affecting individual trees and groups of trees (a dozen or so trees) or causing widespread losses (over an area exceeding 500 m^2). The major mensuration data of the disturbed stands with widespread wind damage are presented in Table 1.

Table 1. Mensuration data of the disturbed stands: widespread damage. Data from the Forest Management Plan developed for the Forest District of Ruda Maleniecka for the years 2009-2018 drawn by Biuro Urządzania Lasu in Radom

Compartment	Site type	Area (ha)	Share of dominating species	Stocking index	Age (years)	Diameter at breast height (cm)	Height (m)	Large timber volume per area – above 7 cm DBH (m^3/ha)
464b	Fresh upland deciduous forest	7.34	9 Pine	0.7	63	23	21	236
465a	Fresh upland mixed deciduous forest	11.11	10 Pine	0.7	65	22	21	265
518a	Fresh upland mixed deciduous forest	11.65	10 Pine	0.8	58	23	21	274
518b	Fresh upland mixed deciduous forest	9.08	10 Pine	0.9	68	25	23	312
518c	Fresh upland mixed deciduous forest	2.55	7 Birch	0.8	58	27	22	161
519a	Fresh upland mixed deciduous forest	20.92	6 Pine	0.8	60	23	22	180
521a	Fresh upland mixed deciduous forest	27.61	4 Pine Larch	0.7	60	25	21	90

A preliminary assessment of wind damage was based on the aerial photographs. The boundaries between the stands designated for wood salvaging were established based on the on-ground (visual inspections in stands) measurements using the GPS equipment. Two methods of damage assessment were employed: method I for damage to individual trees or groups of trees, and method II for widespread damage.

Method I

In the areas where wind affected individual trees or groups of trees (method I), the salvaged wood volume was calculated based on measuring a diameter (DBH) – over 7 cm – and a length of an average damaged tree, and multiplied by a number of all damaged specimens determined using the method of counting damaged individuals one by one. This method was consistent with the method employed at the pre-harvest timber volume assessment for the model trees (Instruction 1959).

Method II

In areas with widespread damage (method II), the volume of damaged wood was evaluated according to the average growing stock volume of the respective stands, as referred to in the Forest Management Plan (a document drawn for the years 2009-2018 for the Forest District of Ruda Maleniecka), and the area of actually disturbed stand mapped with the use of the GPS device. The boundaries of the wind-damaged areas were determined by the GPS operator, who personally inspected the wind-affected area. Results of the measurements were then transferred onto the forest management layer of the State Forests Numerical Map, which allowed the investigators to determine the extension of widespread damage.

Execution of wood salvage plan based on the methods I and II

The volume of damaged wood assessed before the salvaging operations performed was compared with the volume of wood actually extracted from the disturbed areas. The comparison was made within the respective areas. The volume of salvaged logs was determined based on the measurements of an upper diameter – over 7 cm – and a length of every log. The data relating to the execution of timber salvage plan (volume and structure of assortments) in the disturbed areas was generated from the SILP (IT system administrated by the State Forest in Poland) database, using the

Business Objects software. The database was employed in the studies presented in this paper.

Statistical analyses

Statistical analyses were based on two variables: a) a plan based on the salvage condition timber volume assessment, and b) a salvage plan execution determined after the disturbed areas had been cleaned up. These variables were estimated for the particular research areas (standing timber), and then tested for statistical significance of differences. Upon establishing the consistency between the distribution of the above-mentioned variables and the normal distribution, statistical significance of differences in mean values was investigated with the use of *T*-test. Moreover, linear functions describing the relationships between the examined parameters were matched.

Results

Damage to individual trees or groups of trees (a few damaged, neighbouring trees), causing a decrease in stocking index by 0.1-0.3, affected the stands over the area of ca. 940 ha. The most severe disturbances were recorded in stands of the III and IV age classes (40-80 years old), growing at the farmland-woodland boundary and in the areas, where thinning treatments had been conducted until recently.

The total estimated volume of wood to be salvaged in the analysed forest districts amounted to 9,651 m³, which constituted 73% of all losses recorded within this Forest District (Table 2).

Table 2. Comparison between the anticipated salvaged wood volume and the actually extracted one (execution of the salvage plan)

Type of damage/ Forest Sub-district	salvage plan [m³]	execution [m³]	execution [%]
Individual and group damage – Forest Sub-district of Krzyżówki	1983	998	50
Widespread damage – Forest Sub-district of Radoszyce	7668	6657	87
Total	9651	7655	79

In respect to damage to individual trees the volume of wood to be salvaged was estimated at 1,983 m³. In the course of removing wind-fallen and wind-broken tress from the stand, 998 m³ of timber was extracted, which constituted 50.4% of the estimated salvaged wood volume. The actual volume of damaged wood obtained in the forest complex of Góra Białkowa slightly exceeded the anticipated salvage volume, amounting to 107.7%. Whereas, in Góra Pakulska merely 36.8% of the anticipated salvage wood volume was extracted (Figure 2). With regard to widespread damage the volume of wood to be salvaged was estimated at 7,668 m³ in total, which constituted over 86% of the salvage plan (salvage condition wood volume assessment).

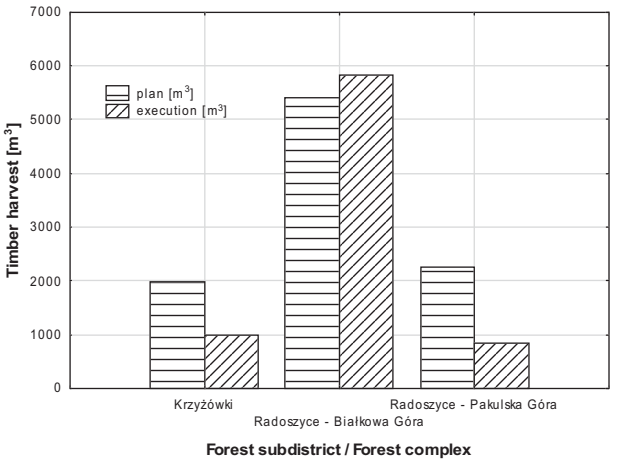

Figure 2. Volume of the anticipated salvaged timber volume and the actually extracted wood volume in the disturbed areas

In both of the analysed classes of damage there were no significant differences in respect of the average value of anticipated and actually extracted volume (individual and group damage $t = -0.07$, $p = 0.95$; widespread damage $t = 0.27$, $p = 0.79$). Due to different dynamics of variability of the evaluated parameters (salvage plan and its execution), which was particularly legible in stands with damage to individual and groups of trees, an analysis of regression was performed.

Regarding the stands with widespread damage, where clear-cutting was performed, the anticipated salvaged timber volume only slightly exceeded the actually extracted wood volume, while the dependence between the salvage plan and its execution was linear (Figure 3). The method of salvage condition timber volume assessment, employed in this study, and based on the data from the Appraisal Forest Management Plan and the extent of the disturbed areas measured with the use of GPS device, appeared to be very successful. A greater misjudgement of the anticipated salvaged wood volume was observed in the stands with damage to individual trees and groups of trees. The estimated dependence between the salvage plan and its execution was logarithmic. With regard to smaller salvage volume plans, concerning the stands with damage to individual trees (up to 100 m³), the actually extracted volume clearly exceeded the anticipated one (Figure 4). In respect to timber volume beyond the above-mentioned value, the situation was reverse.

The total volume of salvaged wood amounted to 7,655 m³, 52% of which was large-sized timber (with an upper diameter inside bark equal to and exceeding 14 cm), while the middle-sized timber (with diameters inside bark as follows: over 5 cm for the upper diameter, and up to 24 cm for the lower one) constituted 48% (Figure 5). When compared with undamaged stands, where large-sized wood usually constitutes 42% of the harvested merchantable timber (CSO Forestry 2014), a higher share of the large-sized wood recorded

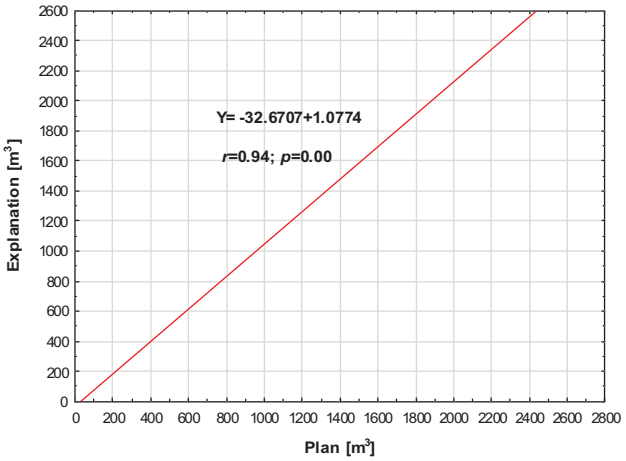

Figure 3. Dependence between the anticipated salvaged wood volume and the actually extracted one in the areas with widespread damage

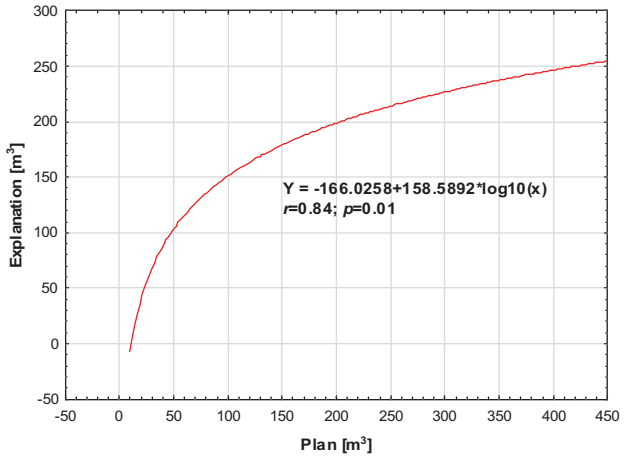

Figure 4. Dependence between the anticipated salvaged wood volume and the actually extracted one in the areas with damage to individual trees and groups of trees

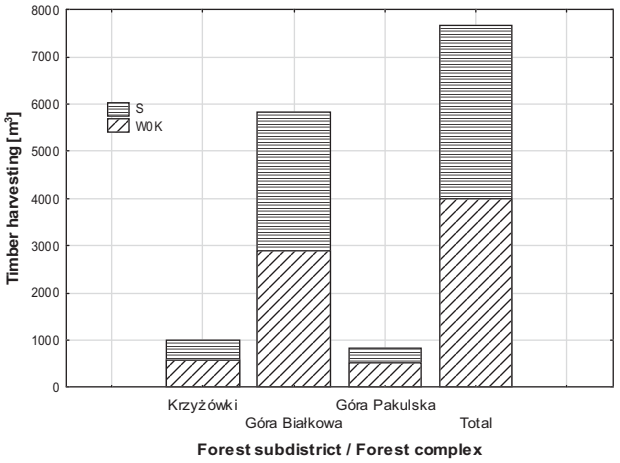

Figure 5. Structure of the processed timber in terms of the assortment categories (S – middle-sized timber, W0K – large-sized timber processed in the CTL system)

in the disturbed stands must be stressed. The considerably increased share of large-sized timber was most likely due to a huge concentration of wood that needed to be removed quickly. This problem was tackled by engaging harvesters, on a large scale, to process the salvaged wood into logs.

The disturbed stands were mostly pine stands. The share of pine wood in the extracted timber amounted to ca. 90%. The remaining 10% included larch (4.7%), birch (3.8%), oak (1.4%), aspen (0.3%) and beech wood (0.1%) (Figure 6). The share of particular tree species within the extracted timber volume was strictly associated with the tree species composition of the stands. The share of pine trees in the stands constituted over 80% of all trees. Individual damage mostly concerned pine, birch (5%) and few oak trees. The species-based structure of trees affected by widespread damage corresponded with the tree species composition of the stands.

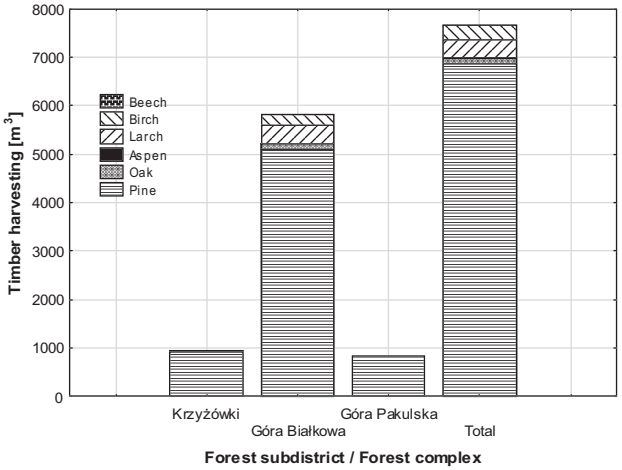

Figure 6. Structure of the processed timber in terms of the tree species classification (before the disturbance occurrence)

Discussion and conclusions

In the disturbed areas under analysis with widespread damage the anticipated salvaged wood volume was overestimated by ca. 21% (Figure 2). Results of other studies indicated quite the opposite tendencies. Wójcik and Orzechowski (2014), having conducted their research in the Forest District of Przedbórz, which had suffered from a large-scale natural disaster in 2007, emphasized the underestimation of salvaged timber volume, amounting to ca. 12%. Slightly smaller differences between the anticipated and actually extracted timber volume in disturbed areas were reported by Piskonowicz et al. (2010). Basing on the studies conducted in the area managed by the Regional Directorate of the State Forests in Poznań, affected by a hurricane that passed through those stands in 2009, the above-quoted researchers recorded an underestimation of losses at the level

of ca. 5%. Possibly, the identified discrepancies were due to different manners of the salvage condition timber volume assessment employed in those cases. In respect to the investigations carried out in Przedbórz, the assessment of timber volume to be salvaged was based on the analyses of the damage extent and growing stock volume of the stand.

The accuracy of assessment of damaged wood volume could have been affected by a method of measuring the volume of both, salvaged trees and processed timber (Kubiak 1977). While estimating the extent of damage to individual or groups of trees, the raw wood measurement was performed based on the rules of measuring long wood one by one, according to which the volume is calculated from the length and the mid-diameter of stems. However, for all of the large-sized timber that was processed in the CTL system, the registration of logs was performed per piece in groups: measuring the length, the upper diameter and determining the number of logs of identical upper diameter.

Nevertheless, an adequate assessment of volume of slanting trees, with unpredictable strains inside their trunks, or slightly slanting individuals due to rupturing of their root systems, seems to be one of the major problems. There are methods of wood preservation in disturbed areas that require leaving the trees in the stand where the damage occurred, *in situ* methods. The wind-affected living trees are left in the stand, where the properly assured contact of roots with moist soil keeps them alive. However, the contact between the root system and the soil must be intact, covering at least 20-25% of the root ball volume (Centre Technique du Bois et de l'Ameublement 2005). Applying this method allows foresters to extend the operation of removing wind-affected trees in time, and minimise the accumulation of extracted raw wood, which releases forests managers from being dependant on timber buyers. Deforestation of vast areas and usually short time for cleaning them up are responsible for neglecting those partly damaged trees in the salvage condition timber volume assessment. It is no sooner than during the salvage logging works when larger damage to stands are actually revealed: a part of suspended trees breaks after their support (severely affected individuals) has been removed, or they are classified to be removed due to detected considerable strains within their trunks. Sometimes the decision of removing particular trees may also be determined by the necessity to regularise the boundaries of adjacent stands.

Conclusions

1. In the areas where damage to individual and groups of trees occurred, ca. 50% of the anticipated salvaged wood volume was actually extracted. With regard to widespread damage, the volume of trees designated to be salvaged was overestimated by ca. 13%;

2. The dependence between the salvage plan and its execution in the stands where individual and groups of trees were wind-damaged was logarithmic. In the stands affected by widespread wind damage, the above-mentioned dependence was linear;

3. With regard to the stands that suffered from widespread damage, the high accuracy of the salvage condition timber volume assessment may be reached when applying the estimation method based on the stand mensuration data from the appraisal of forest management plans and determination of the extent of the wind-affected area with the GPS device. In respect to the stands with damage to individual or groups of trees, the method based on calculating the average tree volume and determining the number of damaged individuals one by one was proved to be insufficiently accurate. In Poland there are no standards describing the accuracy of estimation of the quality and volume of timber salvaged from disturbed stands, however there is a commonly accepted maximum level of the volume assessment error amounting to 30%.

4. The accuracy of the salvage condition timber volume assessment in disturbed areas is highly variable and dependent on the concentration of damage and the stand accessibility. The equations developed in the course of studies presented here, determining the dependence between the salvage plan and its actual execution, indicated only general tendencies; however, they may be used as a supporting tool in planning processes of removing damage from wind-affected pine stands.

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