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Wood Loss in the Felling and Cross-Cutting of Trees from Spruce Stands Affected by Windthrow in the Curvature Carpathians

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Abstract

Windthrow determines major changes in tree stand evolution due to the felling or breaking of either isolated trees or entire stands. It has a major ecological, social and economic impact. Wood loss resulting from tree felling and cross-cutting operations is a less-studied aspect related to windthrow. Wood loss is represented by high stumps, broken or split stems, wood lost in the felling of trees that remain standing, wood lost in felling cuts that attempt to remove the stem from the root plate of partially or totally uprooted trees and wood lost as a result of stem cross-cutting. The study focused on estimating losses and their indices in a spruce tree stand located in the Curvature Carpathians. Windthrow took place in this tree stand in February 2020. The results showed that the total wood loss index is 7.747%. The main losses are represented by wood losses in high stumps (5.319%). The amount of wood loss depends on the proportion of uprooted or standing trees, ground inclination and the uprooting direction of trees as opposed to ground inclination, as well as on tree dimension. Tree volume significantly influences wood loss in high stumps ($p < 0.001$). The closer the uprooting direction is to the highest slope, the higher the tree stump becomes. Wood loss caused by stem breaking and splitting represents 2.280%, tree felling cuttings and stem removal from the root plate in uprooted trees account for 0.138% while loss resulting from stem cross-cutting represents 0.10%.

Keywords: windthrow; wind snap; snow break; storm damage; spruce; Carpathian Mountains; stump height

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1. Introduction

Windthrow was very much studied mainly with respect to the ecological, social and economic impact that it has [1,2], including the impact that it has on carbon balance [3–5]. Also, the literature in the field contains numerous studies that focus on the factors that contribute to windthrow. The purpose of these studies is to understand the manner in which windthrow takes place and its effects, while at the same time identifying tending operations and management methods that must be used at the tree stand level for preventing it [6–8]. Wood loss from timber harvesting, especially in the felling and cross-cutting of trees resulting from windthrow, represents a less frequently studied aspect. These losses are represented by high stumps, broken or split stem portions, wood lost as a result of felling trees that remain standing, wood lost as a result of felling cuttings aimed at removing the stem from the root plate in uprooted trees and wood lost as a result of stem cross-cutting depending on the harvesting method used.

In the last few decades, Europe has been hit by massive storms that have caused large-scale damage to forests. Reference [9] estimates that Europe registers, on average, two such storms per year. The number of these storms may increase significantly given the forecast climate change [10]. The storms that have caused major windthrow so far in the last three decades were the following: Lothar in 1999 in France, Germany and Switzerland—a volume of approximately 165 million m^3 of wood was affected; Godrun in 2005, in Sweden—a volume of 75 million m^3 of wood was affected [11]; Kyrill in 2007, in Germany and Czechia, when a volume of 49 million m^3 of wood was affected; Klaus and Xynthia in 2009–2010, in France and Spain, with a volume of 45 million m^3 of wood affected; and Vaia in 2018, in Italy, when 8.5 million m^3 of wood was affected [12,13]. In 2020, in Romania, a volume of 2.7 million m^3 of wood was affected by windthrow [14].

Throughout the years, there has been an ongoing preoccupation with reducing wood consumption and replacing it with other raw materials. Despite this, and given the needs of society and the demographic increase, wood consumption increases from one year to the next, and new strategies need to be adopted in order to meet this need. Therefore, the diminishing of wood loss during the harvesting process is one of the most important things, in addition to the priorities connected with tree stand productivity increase, biodiversity preservation, the identification of potential wood replacements, and the rational use of wood and its saving [15]. During the harvesting process, differences can exist between the gross volume resulting from tree measurement and the volume of wood assortments at the end of the timber harvesting process [16–18]. These wood losses represent 1%–3% of the resulting gross wood volume [19] in the case of tree stands where planned operations have taken place—thinnings and silvicultural treatments. In the case of tree stands affected by natural disturbances (landfall, avalanche, landslide, etc.) where unplanned operations took place, wood losses are much bigger [20]. The literature in the field records values of over 8% of the gross volume [21,22]. Similarly, the higher the wood cross-cutting degree for obtaining wood assortments becomes, the greater the losses are [23,24]. During felling operations, losses vary depending on local conditions [25]. Losses are determined by the specific characteristics of each felling area (relief, land characteristics, season, silvicultural treatment, species, etc.); by the logging and valuing of certain categories of wood (branches, broken parts and log ends); by the harvesting method, work technology, and equipment used; and, last but not least, by the organizational capacity and the natural factors that play into this process during the entire activity (thickness of the snow layer, etc.) [16,21,26].

Wood loss represents a problem for harvesting companies and landowners or administrators alike as it reduces the volume of wood that can be traded [27]. In order to meet society's demands, better timber harvesting and a decrease in wood loss are essential for the local and national economy [28]. Generally, the volume of wood from a tree stand is used after a public auction in the following ways: (1) as tree standing wood and (2) as converted wood in wood assortments either in the landing or in log depots. In the former case, the wood buyer accepts the losses resulting from the harvesting process. The buyer can control the wood loss level by training workers with respect to work techniques and methods, equipment, harvesting methods and the organization of the entire harvesting process. Thus, awareness of the wood loss level may influence the highest selling price in an auction. To put it another way, beneficiaries are able to better estimate the price they are willing to pay. In the second case, that of converted wood, knowledge of wood loss level and of the differences between the gross volume set for standing trees and the net volume of resulting wood assortments is highly important in setting the initial price in an auction. Therefore, the purpose is to recover the value of the lost wood by using wood assortments. This is easier to accomplish, assuming there is a market demand for the resulting wood assortments. It is well known that the great volume of wood resulting from windthrow significantly affects the wood market and implicitly affects price of wood.

Therefore, the aim of the present study is to identify, classify and estimate wood losses resulting from tree felling and cross-cutting in spruce stands affected by windthrow.

2. Materials and Methods

2.1. Research Venue

This study was conducted in Romania, in areas affected by windthrow in February 2020, in the Curvature Carpathians at the contact zone between Brețcului Mountains, Vrancei Mountains and Buzăului Mountains in the upper third of the watershed formed by the rivers Bâsca Mare and Bâsca Mică. The tree stand studied is represented by forest compartment 110 C from the management unit Dealul Negru, Forest District of Comandău, County Forest Administration of Covasna (Figure 1). This forest compartment has a total area of 7.13 hectares and an average slope of 26° (sexagesimal degrees), and it is located at an altitude between 1300 and 1800 m with a partly sunny (south-east) aspect. Its main characteristics are listed in Table 1.

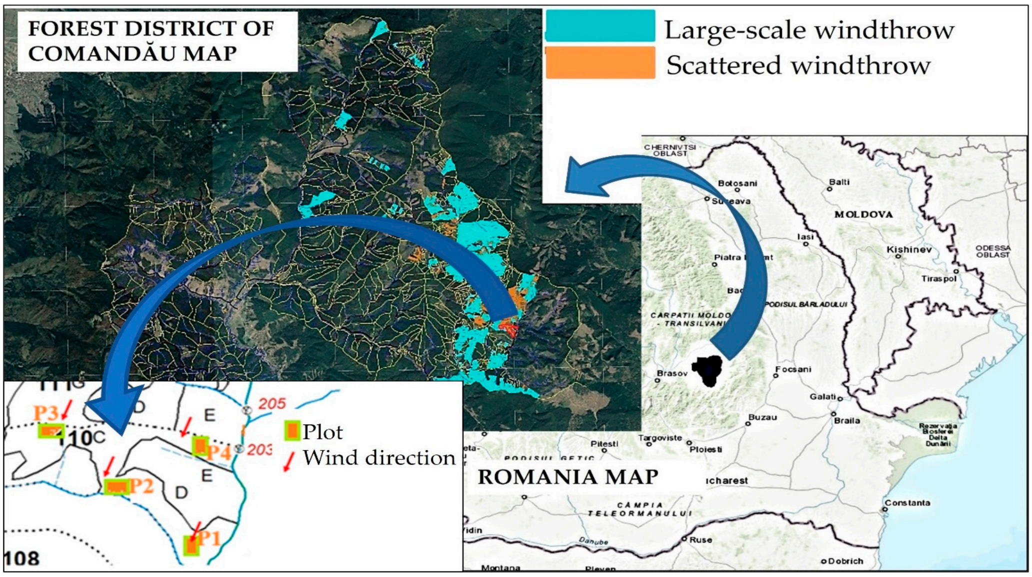

Figure 1. Research venue and location of sample plots.

Table 1. Tree stand characteristics.

Forest Compartment	Species	Age	Composition (%)	Site Class	Crown Density	Pruning (%)	Average Diameter (cm)	Average Height (m)
110 C	Spruce	85	50	II	0.8	20	34	28
	Spruce	60	30	III		20	26	21
	Spruce	105	20	II		40	40	30

2.2. Study Design

In order to highlight the wood loss level, four distinct sample plots of 2000 m^2 (50 × 40 m) were installed. The sample plots were installed in the forest compartment with the help of a GPS unit (Garmin Corporation, New Taipei City, Taiwan, GPSMAP 64SX, year of manufacture 2015) and set up along the slope length (Figure 2).

Figure 2. The setting up of sample plots.

In order to determine the number of sample plots, an error limit (Δ) of ±15% and a transgression possibility (α) of 10%, both characteristic of non-harvestable tree stands, were adopted [29]. The number of sample plots was calculated using the following formula [29,30]:

$$n = \frac{u^2 \cdot S_{\%}^2 \cdot F}{F \cdot \Delta_{\%}^2 + u^2 \cdot S_{\%}^2 \cdot f} \tag{1}$$

where

n—number of sample plots;
$u = 1.645$—standard deviation of the normal distribution, corresponding to the transgression possibility $\alpha = 10\%$;
$S_{\%} = 12.5\%$—the variation coefficient of volumes was determined in accordance with recommendations from the literature in the field [29] depending on the tree stand structure and crown density, using the variation coefficients established for sample plots of 500 m^2;
F—surface of the forest compartment to be inventoried, expressed in hectares;
$f = 0.2$—size of sample plot, expressed in hectares;
Δ—limit error adopted (±15%).

Knowing the parameters that come into play when establishing the number of sample plots, the use of the above-mentioned formula led to the following result:

$$n = \frac{1.645^2 \cdot 12.5^2 \cdot 7.13}{7.13 \cdot 15^2 + 1.645^2 \cdot 12.5^2 \cdot 0.2} = 1.79 \cong 2 \text{ sample plots} \tag{2}$$

The representation error was calculated, using the formula for finite population [30]. It was noted that if the number of sample plots is 4, the representation error does not exceed the limit error admissible. As a result, a number of 4 sample plots was used in the end.

$$S\overline{x}_{\%} = \frac{t \cdot S_{\%}}{\sqrt{n}} \cdot \sqrt{\frac{F - n \cdot f}{F}} = \frac{2.353 \cdot 12.5}{2} \cdot \sqrt{\frac{7.13 – 4 \cdot 0.2}{7.13}} = 13.86 < \pm 15\% \tag{3}$$

where t, $S_{\%}$, n, F and f have the same significance and t was calculated for $n - 1 = 3$ degrees of freedom; $t = 2.353$.

2.3. Field Data Collection

Within each sample plot, all existing trees were inventoried (Table 2). For both the uprooted trees and the standing ones, the breast height diameter (dbh) and height were measured.

Table 2. General data from sample plots.

Sample Plots	Coordinates		Number and Volume of Trees				
	Latitude	Longitude	Uprooted	Standing	Total	Average Tree Volume (m^3)	Total
P1	45.748840	26.411710	43	80	123	0.675	82.991
P2	45.750980	26.408540	86	12	98	0.772	75.656
P3	45.752480	26.406440	52	8	60	2.163	131.918
P4	45.752060	26.411450	105	14	119	1.054	125.370
Total	-	-	286	114	400	-	415.935

In order the capture reality as accurately as possible, data collection was conducted at the same time as the timber harvesting from sample plots. The system used most frequently in timber harvesting, in the Romanian Carpathians, is a partially mechanized system consisting in the felling, delimbing and cross-cutting of trees with chainsaw and logging by skidders [31]. Thus, it should be mentioned that the harvesting method was the tree length method. A characteristic of this method is the movement during the logging process of long logs that correspond to the tree stem [21,32]. When the tree was broken or when the cross-cutting of the stem was necessary because of safety reasons for workers, the timber was shorter (Figure 3). The work team was made up of a chainsaw operator (the chainsaw used was Husqvarna 372, Husqvarna Group, Stockholm, Sweden, year of manufacture 2018, 541 operating hours), one helping worker and one operator for the TAF 690 Perkins skidder (Irum S.A., Reghin, Romania, year of manufacture 2018, 4413 operating hours). The members of the team had been working together for more than 5 years and were instructed with respect to the safety methods and work procedures, both with a chainsaw and with a skidder, knowing the high injury risk in the case of windthrow.

Figure 3. Tree length method and harvesting work team.

Wood losses registered at the level of sample plots in the felling and cross-cutting of trees were classified in the following manner:

(1) Wood loss in high stumps (WLHS): It is the loss of wood between the stump legal height (SLH) (maximum 1/3 of stump diameter at the cutting level) [33] and the height at which the stem is removed (SH). These high stumps are left there by chainsaw operators as a measure of protection in order to avoid the turning of the root plate over workers, especially in the case of uprooted trees with the tip facing the valley [34] (Figure 4A). Their volume was calculated with the formula for calculating the volume of a truncated cone (Table 3). In the four sample plots, trees were identified where the stump height was bigger than the legal height; these were noted with SH+. There were also trees where the stump height was lower than the legal height; these were

noted with SH-. Both categories of trees are used further in the interpretation of the results.

(2) Wood loss in the stem (WLS): It refers to broken or split stem portions that have no economic value any longer. They are caused by the stem breaking or splitting at a certain height and by the tips of the trees (with a diameter above 5 cm) that remain in the felling area (Figure 4B). Their volume was calculated with Smalian's formula (Table 3).

(3) Wood loss caused by felling cuttings (WLF): Cuttings for the removal of buttress and the buttress proper, for notch extraction (horizontal and oblique cuttings) and the notch proper, for the back cut and for the removal of the hinge wood and the hinge wood itself are included here (Figure 4C–E). The wood volume lost was calculated depending on the section area (the section areas were approximated by using specific geometry formulas for the triangle, trapezoid, circular sector and ellipse) and on the average thickness of cuts (0.77 cm). For the notch, buttress and other parts of wood, xylometry was used (Table 3).

(4) Wood loss caused by stem cross-cutting (WLC): The wood volume lost because of cuts that aim to remove broken stem portions and tree tips is included here. The wood volume lost as a result of cross-cutting was calculated depending on the section area and the thickness of the cut (Table 3).

Figure 4. Wood losses: (**A**) WLHS—wood loss in high stumps; SH—stump height; SLH—stump legal height; (**B**) WLS—wood loss resulting from stem breaking and splitting; (**C**,**D**) wood loss because of the notch, buttress and back cut; (**E**) wood loss due to the removal of hinge wood.

Table 3. Calculation methods for wood loss indices.

Loss Type	Wood Volume Lost (Per Tree)	Loss Indices (Per Sample Plot)
WLHS	$V_{WLHS} = \frac{\pi \cdot L_{WLHS} \cdot \left(R_{SLH}^2 + r_{SH}^2 + R_{SLH} \cdot r_{SH}\right)}{3}$ V_{WLHS}—volume of WLHS in m^3; L_{WLHS}—length of the WLHS in m; R_{SLH}—radius of the SLH section in m; R_{SH}—radius of the SH section in m.	$I_{WLHS} = \frac{VT_{WLHS}}{V} \cdot 100$ VT_{WLHS}—sum of the volumes V_{WLHS} from the sample plot in m^3; I_{WLHS}—wood loss index WLHS in %; V—volume of the trees from the sample plot in m^3.
WLS	$V_{WLS} = \frac{A_1 + A_2}{2} \cdot L_{WLS}$ V_{WLS}—volume of WLS in m^3; A_1—area of the small end of WLS or of the SH section in m^2; A_2—area of the large end of WLS or of the SLH section in m^2; L—length of the WLS in m.	$I_{WLS} = \frac{VT_{WLS}}{V} \cdot 100$ VT_{WLS}—sum of the volumes V_{WLS} from the sample plot in m^3; I_{WLS}—wood loss index WLS in %; V—volume of the trees from the sample plot in m^2.
WLF	V_{WLF}—sum of wood volume lost due to cuttings for the removal of buttress and the buttress proper, for notch extraction (horizontal and oblique cuttings) and the notch proper, for the back cut and for the removal of the hinge wood and the hinge wood itself	$I_{WLF} = \frac{VT_{WLF}}{V} \cdot 100$ VT_{WLF}—sum of the volumes V_{WLF} from the sample plot in m^3; I_{WLF} –wood loss index WLF in %; V—volume of the trees from the sample plot in m^3.
WLC	V_{WLC}—sum of wood volume lost because of cuts for the removal of broken stem portions and tree tips	$I_{WLC} = \frac{VT_{WLC}}{V} \cdot 100$ VT_{WLC}—sum of the volumes V_{WLC} from the sample plot in m^3; I_{WLC}—wood loss index WLC in %; V—volume of the trees from the sample plot in m^3.
WL	$V_{WL} = V_{WLHS} + V_{WLS} + V_{WLF} + V_{WLC}$ V_{WL}—sum of all wood losses.	$I_{WL} = \frac{V_{WL}}{V_1 + V_2 + V_3 + V_4} \cdot 100$ V_{WL}—sum of the volumes of V_{WL} from the sample plot in m^3; I_{WL}—wood loss index WL in %; V_1, V_2, V_3, V_4—volume of the trees from the sample plot in m^3.

In order to determine the indices characteristic of each type of loss, the volume of losses and the wood volume from each sample plot were calculated according to current legislation [35]. This was carried out starting from the volume of each tree using the following regression equation:

$$\log v = a_0 + a_1 \log d + a_2 \log^2 d + a_3 \log h + a_4 \log^2 h \tag{4}$$

where

v—unitary tree volume.
d—dbh (breast height diameter measured at the height of 1.30 m).
h—total tree height determined after the tree felling as the sum of the stump height and stem length. For the trees whose tip was broken and could not be identified, the height was determined by measuring the tips of trees with the same dbh from the sample plot.
a_0, a_1, a_2, a_3, a_4—regression coefficients established for spruce (a_0 = −4.18161, a_1 = 2.08131, a_2 = −0.11819, a_3 = 0.70119, a_4 = 0.148181) [36].

The wood volume from each sample plot is presented in Table 2.

2.4. Data Analysis

The analysis of the distribution of wood loss was performed individually for each sample plot. The first step in the statistical analysis was to test the normality of the distribution of wood loss using the Kolmogorov–Smirnov test (the XLSTAT version 2023.2.0.1411 was used) for a significance level of 5%. Statistical analysis showed that in all sample plots, the variation of wood loss in high stumps (WLHS) is normally distributed. For normal distributions, by using ANOVA and linear regression, statistical connections between wood loss (dependent variable) and tree volume (independent variable) were analyzed. Regression significance was tested with the Fisher test (F), while the significance of the independent variable coefficients was tested using the Student t-test for a level of significance of 5%, 1%, and 0.1%.

3. Results

The results concerning wood loss in the four sample plots and their indices are presented in Table 4. Further on, all types of wood loss identified in this study are presented in detail.

Table 4. Wood losses and loss indices.

Sample Plot	V	VT_{WLHS}	I_{WLHS}	VT_{WLS}	I_{WLS}	VT_{WLF}	I_{WLF}	VT_{WLC}	I_{WLC}	V_{WL}	I_{WL}
	m^3	m^3	%	m^3	%	m^3	%	m^3	%	m^3	%
P1	82.991	1.209	1.457	1.349	1.625	0.237	0.286	0.015	0.018	2.810	3.386
P2	75.656	4.645	6.139	0.846	1.118	0.085	0.113	0.006	0.009	5.582	7.378
P3	131.918	9.414	7.137	3.880	2.941	0.130	0.098	0.008	0.006	13.432	10.182
P4	125.370	6.856	5.468	3.409	2.719	0.123	0.098	0.011	0.009	10.399	8.294
Total	415.935	22.124	5.319	9.484	2.280	0.575	0.138	0.040	0.010	32.223	7.747

3.1. Wood Loss in the Stump (WLHS)

With respect to WLHS, the study showed that by considering only the volume of trees (SH+) that suffered such losses, I_{WLHS} was greater. However, at the level of sample plots, there are trees with a stump that has a lower height than the maximum admissible one (SH−). Therefore, there is some sort of compensation for the lost wood volumes (Table 5). Standing trees prevail in sample plot 1 (80 pcs) as compared to the uprooted ones (40 pcs). However, in the case of standing trees, the number of SH+ trees is higher. The main cause is the presence of stems and broken tips from other trees next to these trees and, therefore, the impossibility of performing felling cuts while preserving the stump maximum height. In sample plots 2, 3 and 4, the number of SH+ trees is closer to the number of uprooted trees, which means that operators adapted the work methods to existing risks, namely the risk of the root plate turning over them. This situation is encountered especially in uprooted trees with a downstream tip [34]. It is noted that this compensation represents 0.304 m^3, which is 1.35% of the total loss volume VLHS of SH+ trees. A comparative analysis of the differences existing between the stump height and the legal height in standing and uprooted trees in all four plots is presented below (Table 6).

Considering the stump height, it could be stated that the thicker the trees are, the greater the volume of these losses becomes. Figure 5 presents the correlation between the WLHS loss and tree volume. The analysis of this correlation is detailed in Table 7. It can be noticed that, in sample plot 2, this correlation is stronger (R^2 = 0.81). This is the sample plot where the tree felling direction is closest to the line of the steepest slope, where land inclination is the highest. In all four sample plots, the influence of tree dimensions expressed through their volume on WLHS is very significant ($p < 0.001$).

Table 5. Volume compensation VT_{WLHS} in SH+ and SH− trees.

Sample Plot		No. of Trees	V (m^3)	VT$_{WLHS}$ (m^3)	I$_{WLHS}$ (%)	Sample Plot		No. of Trees	V (m^3)	VT$_{WLHS}$ (m^3)	I$_{WLHS}$ (%)
P1	SH+	82	58.881	1.331	2.257	P3	SH+	54	119.701	9.503	7.939
	SH−	41	24.110	0.122	-		SH−	6	12.217	0.089	-
	Total	123	82.991	1.209	1.457		Total	60	131.918	9.414	7.137
P2	SH+	93	71.941	4.668	6.489	P4	SH+	103	113.627	6.925	6.094
	SH−	5	3.715	0.024	-		SH−	16	11.743	0.069	-
	Total	98	75.656	4.644	6.139		Total	119	125.37	6.856	5.468
TOTAL	SH+	333	364.15	22.427	6.159						
	SH−	67	51.785	0.303	-						
	Total	400	415.935	22.124	5.319						

Note: SH+—trees in which the stump height was higher than the legal one; SH−—trees in which the stump height was lower than the legal one.

Table 6. Differences between stump height and legal height.

Sample Plot	Difference (cm)	Uprooted Trees	Standing Trees	Ground Inclination
P1	Average	25.2	3.6	15°
	Min–max	0.7–126.2	0.2–11.5	
P2	Average	61.6	18.6	30°
	Min–max	1.7–243.3	2.2–57.7	
P3	Average	98.2	1.7	20°
	Min–max	2.5–243.7	0.3–3.2	
P4	Average	59.0	4.1	25°
	Min–max	2–248.2	0.8–9.8	

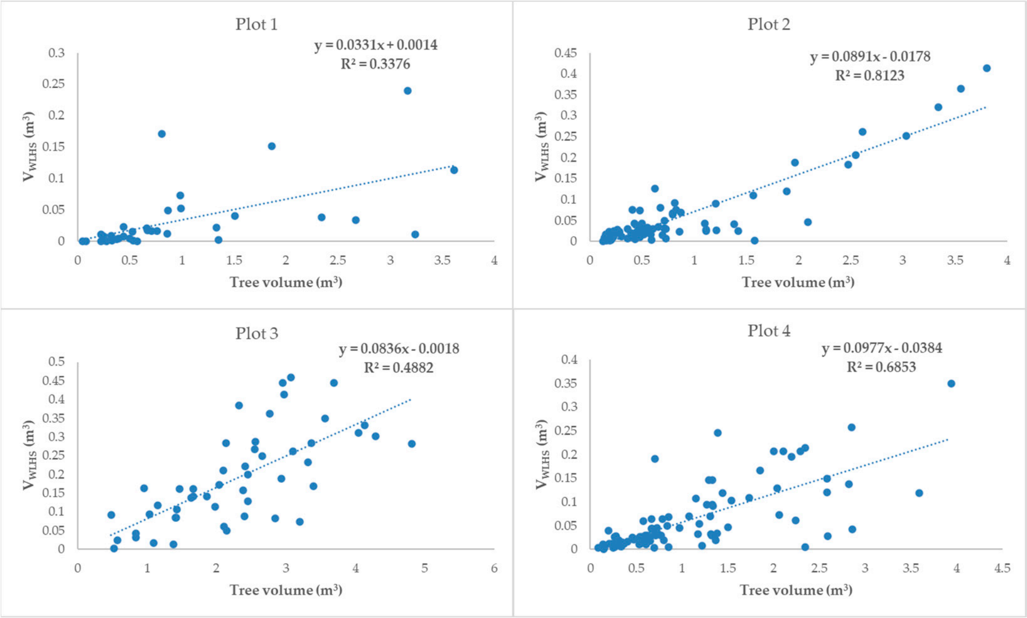

Figure 5. Correlation between loss volume V_{WLHS} and V (tree volume).

Table 7. Simple linear regression analysis of V_{WLHS} in relation to V (tree volume).

ANOVA				Significance of Variable Coefficient				
R^2	Standard Error	Degrees of Freedom	F	Variable	Coefficient	Standard Error	t Statistic	p-Value
				Plot 1				
0.34	0.044	Regression 1 Residual 34	17.331 ***	Constant	0.0014	0.0106	0.1321	0.895
				V	0.0331	0.0079	4.1631	<0.001 ***
				Plot 2				
0.81	0.034	Regression 1 Residual 84	559.213 ***	Constant	−0.0177	0.0053	−3.3184	0.001
				V	0.0890	0.0047	18.9529	<0.001 ***
				Plot 3				
0.49	0.090	Regression 1 Residual 49	45.788 ***	Constant	−0.0017	0.0310	−0.0565	0.955
				V	0.0835	0.0123	6.7667	<0.001 ***
				Plot 4				
0.69	0.069	Regression 1 Residual 96	206.030 ***	Constant	−0.0383	0.0103	−3.7237	0.0003
				V	0.0977	0.0067	14.4578	<0.001 ***

Note: Asterisks denote F significance and significant correlations, *** p-value < 0.001; V_{WLHS}—the volume of WLHS in m^3; V—the volume of the trees from the sample plot in m^3.

3.2. Wood Loss in the Stem (WLS)

Considering what has been mentioned when the research method was discussed, these losses represent the cumulative volume of broken or split stem portions and of the tree tips between the cross-cutting area and the area where the tip has a 5 cm diameter. Losses caused by the breaking of the stem are located in both the lower and the upper part of trees in 11 trees from the four sample plots, especially in felled trees (10 pcs). They have a total volume of 0.363 m^3, which corresponds to a loss index of 0.087% when compared with the tree volume from sample plots (Table 8).

Table 8. Wood loss in the stem.

Sample Plot		Trees				VT_{WLS} (m^3)	V (m^3)	I_{WLS} (%)
		Standing		Uprooted				
		No.	V_{WLS} (m^3)	No.	V_{WLS} (m^3)			
P1	Broken stems	1	0.240	6	0.121	0.361	-	0.435
	Broken tips	62	0.420	41	0.568	0.988	-	1.190
	Total 1	-	0.660	-	0.689	1.349	82.991	1.625
P2	Broken stems	0	0	1	0.001	0.001	-	0.001
	Broken tips	12	0.400	73	0.445	0.845	-	1.117
	Total 2	-	0.400	-	0.446	0.846	75.656	1.118
P3	Broken stems	0	0	0	0	0	-	0
	Broken tips	8	0.997	48	2.883	3.880	-	2.941
	Total 3	-	0.997	-	2.883	3.880	131.918	2.941
P4	Broken stems	0	0	3	0.001	0.001	-	0.001
	Broken tips	10	0.664	88	2.744	3.408	-	2.718
	Total 4	-	0.664	-	2.745	3.409	125.370	2.719
Total	Broken stems	1	0.240	10	0.123	0.363	-	0.087
	Broken tips	92	2.481	250	6.640	9.121	-	2.193
	(1 + 2 + 3 + 4)	-	2.721	-	6.763	9.484	415.935	2.280

The results have shown that wood losses located at the level of tree tips were present in 342 trees, of which 250 were uprooted. From a quantitative point of view, these losses amount to a volume of 9.121 m^3, resulting in an index loss of 2.193%. Overall, WLS represents 9.484 m^3, which means a loss index of 2.280% as compared to the volume of trees from all four sample plots (Table 8). WLS is approximately 2.5 times bigger in uprooted trees as opposed to standing trees. Wood losses resulting from the breaking of tips are approximately 25 times greater than those resulting from stem breaking or splitting. It should be mentioned that 58 trees did not suffer WLS (20 trees in P1, 13 trees in P2, 5 trees in P3 and 20 trees in P4). Also, 10 trees suffered WLS in both the stem and the tip area (7 trees in P1, 1 tree in P2 and 2 trees in P4).

3.3. Wood Loss Caused by Felling Operations (WLF)

In standing trees, these losses represent the volume of wood that is lost as a result of the cuts made during the tree felling and the removal of buttress, notch and hinge wood. In uprooted trees, this is the wood volume that is lost as a result of making the cuts that are meant to remove the stem from the root plate (Table 9).

Table 9. Wood loss caused by felling operations/removal of stems from the root plate.

Loss Type WLF		**WLF Volume in Sample Plots**				
		P1 (cm^3)	**P2 (cm^3)**	**P3 (cm^3)**	**P4 (cm^3)**	**Total (m^3)**
Standing trees						
Buttress removal	Horizontal cut	772	133	63	0	0.018
	Vertical cut	1845	237	187	0	
	Buttress	10,992	1180	2573	0	
Notch removal	Horizontal cut	12,569	2385	3459	2382	0.179
	Oblique cut	16,224	3089	3718	3477	
	Notch	76,129	15,415	25,785	14,235	
Back cut		26,674	3738	6193	5617	0.042
Hinge wood removal	Removal cut	8526	1455	1988	2568	0.091
	Hinge wood	47,353	7835	10,055	11,295	
Total (m^3)		0.201	0.035	0.054	0.040	0.330
Tree volume (m^3)		42.890	6.999	11.320	9.320	70.529
Loss index (%)		0.469	0.500	0.477	0.429	0.468
Uprooted trees						
Cut to remove the stem from the root plate		36,395	49,812	75,861	83,706	0.246
Total (m^3)		0.036	0.050	0.076	0.084	0.246
Tree volume (m^3)		40.101	68.657	120.598	116.050	345.406
Loss index (%)		0.090	0.073	0.063	0.072	0.071
Standing trees + uprooted trees						
Total (m^3)		0.237	0.085	0.130	0.124	0.576
Tree volume (m^3)		82.991	75.656	131.918	125.370	415.935
Loss index (%)		0.286	0.112	0.099	0.099	0.138

In the case of standing trees, these losses have a cumulative volume of 0.330 m^3, which leads to a loss index of 0.468% as compared to the tree volume. In the case of uprooted trees, the volume of lost wood is 0.246 m^3, which represents a loss index of 0.071%. The cumulative volume of lost wood in both standing and uprooted trees is 0.576 m^3, which leads to a loss index of 0.138%.

3.4. Wood Loss Caused by Stem Cross-Cutting (WLC)

These wood losses are the result of stem cross-cutting and the cut for tree tip removal. The stem fragmentation degree depends on the harvesting method used, on wood tension and on the work task that must be dealt with at a certain point. In this case, there was no need for more than two cuts in the stem cross-cutting operation. In the case studied here, the volume of losses is 0.041 m^3, which corresponds to a loss index of 0.10% (Table 10).

Table 10. Wood loss caused by stem cross-cutting.

WLC		**WLC Volume in Sample Plots**				
		P1 (cm^3)	**P2 (cm^3)**	**P3 (cm^3)**	**P4 (cm^3)**	**Total (m^3)**
Cross-cutting cuts	To remove broken stem portions and according to the harvesting method	9737	1608	0	933	0.012
	To remove the tip of the trees	5548	4826	8115	10,357	0.029
Total (m^3)		0.015	0.006	0.008	0.011	0.041
Tree volume (m^3)		82.991	75.656	131.918	125.370	415.935
Loss index (%)		0.018	0.009	0.006	0.009	0.010

4. Discussion

The level of wood losses is strictly connected with the organization of the timber harvesting process in terms of the appropriate planning of operations, using the right equipment and adequate technical coordination [16]. Windthrow locations are extremely randomized, being present on entire slopes or just parts of slopes, at the base or the top of slopes, in valleys or on plateaus, on smooth or rough areas, in harvestable or non-harvestable tree stands with either easy or difficult access. All these increase the difficulty of organizing harvesting operations, the cost of timber harvesting and, eventually, the level of wood loss [22].

In normal felling operations, the stump height is influenced by the inclination of the ground and by the equipment used. Generally speaking, the use of a mechanical chainsaw in tree felling operations leads to higher stumps than in the case of using feller buncher heads [37–40]. With respect to the losses of industrial round wood when different harvesting systems are used in resinous trees stands where normal felling operations have taken place, ref. [41] analyzes the following harvesting systems: cut-to-length (CTL—harvester + forwarder; CTL—chainsaw + forwarder), full-tree (chainsaw +skidder + delimber; feller buncher + skidder + delimber) and tree length (chainsaw + skidder). The results indicate that the smallest losses and the smallest rate of industrial round wood rejection (3%) was obtained with the harvester + forwarder CTL system. The highest number of defects was represented by the following: unprocessed branches (2%), log end splits and cracks during felling and cross-cutting (2%), torn and loosened grain (2%) including barked stems or even lost layers of stem wood and logs damaged by harvester head saws or forwarder′ grapples (about 1%). The greatest losses and the highest rate of industrial round wood rejection (7%–10%) resulted from the use of the tree length (chainsaw + skidder) system. In this case, the identifiable defects are the following: cuts in stem wood and gouges made by grapples (2%–3%), unprocessed branches (1%), and log end splits and cracks (1%). Contamination with dirt was also found in up to 9% of observed logs. The other systems analyzed were situated between the former two that have just been presented. On the other hand, ref. [20] shows that the CTL system produces more losses than the full-length system in broadleaf species. As already shown, the system used most frequently in timber harvesting, in the Romanian Carpathians, is a partially mechanized system consisting in the felling, delimbing and cross-cutting of trees with a chainsaw and logging by skidders. From 2000 onwards, landowners and logging companies have tried to import the CTL system from Northern European countries. At present, this system is rather scarcely applied, on the one hand, because of the high purchase cost, and, on the other hand, because of the small prevalence of resinous species (approximately 30%) and also because approximately 60% of forests are situated on slope terrains [31].

In the case of windthrow, partial or total uprooting requires special attention and work safety measures that need to be taken when removing the stem from the root plate. This is because completely uprooted root plates can turn over and roll downwards, while partially uprooted ones can go back to vertical positions [21,22,34]. Leaving higher stumps, as compared to normal felling operations, is one of the measures taken in order to control injury risk in harvesting windthrow from areas with uneven relief [21,34,42]. Because of this, wood losses increase significantly due to the round wood left in these stumps [22,43]. Such losses are registered even in standing trees (with the compensation that exists between stumps that exceed and stumps that do not exceed the legal height), and they are caused, as it has been shown before, by the impossibility of making the felling cuts and complying with the maximum legal stump height. This happens because boulders, stems, broken tree tips, etc., are present near the stump.

The results showed that wood losses in high stumps are the main wood losses in harvesting windthrow. The extent of these losses depends on the proportion of uprooted or standing trees, on ground inclination, on the uprooting direction as opposed to the slope and on tree dimension. In general, the closer the uprooting direction is to the highest slope when the trees are uprooted with the tip facing downslope, the higher the stump height is as opposed to the legal one, and hence, the bigger the losses are. Likewise, it was shown that tree volume provides a fairly good estimate of WLHS. These losses represent WLHS and amount to 68.65% of the volume of losses, which corresponds to a loss index of 5.319%. Reference [44] obtained the following values of the loss index depending on the inclination of the ground: 4.94% for ground with an inclination lower than 15° and 7.05% for ground with an inclination greater than 15°, establishing an average value of 6.36% for windthrow in resinous tree stands. Similar research studies in resinous tree stands [22,44–46] centralized existing data in the following way: 4.94% for ground with an inclination lower than 25° and 7.79% for ground with an inclination greater than 25°. In order to reduce WLHS, the stump height must be as small as possible. In standing trees, this is achievable by carefully preparing the workplace around the tree in order for the chainsaw operator to be able to perform the felling cuts safely and as close as possible to the ground. With the purpose of reducing stump height, in the case of uprooted and partially uprooted trees, the root plate must be given stability in order to prevent it from falling on the workers during felling cuts. For safety reasons, root plates must be tied with a winch or skidder cable. Escape routes must be created so that chainsaw operators can safely withdraw from the dangerous area near the root plate or near trees or tree parts under tension. With respect to stem wood losses (WLS) caused by stem breaking or splitting and by the tree tip breaking, the results showed that wood losses produced by breaking the tip at diameters over 5 cm represent 96% of these losses. The breaking of the tip in standing trees is caused by the movement of the stem under the influence of wind gusts, while stem breaking is frequently associated with the presence of wood defects (decay, cancers, tree cavities, etc.). In trees with defects, the breaks take place at the level of the defect; in healthy trees, the breaks take place at various heights depending on each tree's bending resistance and uprooting, on the attack height, on wind speed, etc. Usually, there is one single break, the form of which varies from very regular (like a neat cut) to very irregular (with chips, splits, etc.) [22]. In uprooted trees, tips and stems also break and split when trees hit the ground or other trees lying on the ground. Stem breaking in the lower part can also be produced by frozen soil, which provides a better rooting of trees within the ground [14]. WLS is a form of expression of storm intensity. It is not determined by the actions of chainsaw operators. However, inappropriate felling when it comes to tensioned or cracked wood may lead to an increase in these losses and a heightened injury risk for workers.

Wood loss caused by felling cuttings (WLF) and that caused by stem cross-cutting (WLC) are frequently referred to in the field as wood technological consumption, representing those quantities of wood that are lost in the harvesting process as a result of mandatory chainsaw cuttings [21]. Reference [47] determined notch wood loss as compared to the volume of trees to be as follows: 0.89% in oak, beech and common hornbeam trees; 1.11% in spruce trees; and 1.20% in fir trees. Reference [20] estimates that these wood losses represent 0.18% in resinous species. In this case, the results indicated that the wood loss index as a result of the notch is 0.25% of the tree volume and represents 54% of the total WLF. The extraction of an oversized notch must be avoided in order to reduce WLF. This situation requires a lot of experience from the part of chainsaw operators so that a potential reduction in losses will not result in a heightened injury risk and tree splitting risk or an accidental change in the felling direction. According to [48], wood losses as a result of buttress removal are insignificant and usually neglected. It is true that, according to this study, they represent a smaller part of WLF, approximately 5%, the loss index being 0.025% of the total tree volume. The explanation for this is the fact that the removal of the buttress is not mandatory in tree felling operations [49]. Some trees do not have a buttress that would make the felling operation more difficult or that would require removal. In uprooted trees, the techniques of removing the stem from the root plate must be adapted to wood tension. The cuts must start from the compressed wood and then from the part of wood with tension. Sometimes, in order to release the tension from the wood, the extraction of a notch from the part with compressed fibers is necessary [34,49]. In the current study, these losses represent 0.071% from the volume of uprooted trees.

Wood loss caused by stem cross-cutting (WLC) depends, on the one hand, on the harvesting method used, and, on the other hand, on wood tension. The tree length method, in planned felling operations, involves the wood being moved as a stem during the logging process, and at most 20% of the wood is subject to cross-cutting in the felling area, while the remaining 80% is subject to cross-cutting in the landing. The cross-cutting degree is imposed by existing ecological requirements that aim to minimize damage to seedling and standing trees and the soil [21]. In the case of windthrow, the cross-cutting degree is imposed by wood tension, worker injury risk and the work task that must be dealt with at a certain point. The smaller the cross-cutting degree is, the longer the wood pieces will be and the smaller the wood losses will become. From this perspective, the tree length method should be superior to the CTL method. In this case, WLC is the smallest one, with a total volume of 0.041 m^3, which is a loss index of 0.01% for the tree volume in all four sample plots.

In general, windthrow harvesting is one of the most hazardous operations in forestry. Only workers very well trained in the felling operations of standing trees, hung-up trees, delimbing and cross-cutting of tensioned wood must work in areas affected by windthrow [42]. And, maybe most importantly, workers must be trained in workplace risk assessment in order to be able to identify and anticipate both existing injury risks and those that occur as a result of their actions. The safest and the least hazardous work methods will be chosen all the time.

5. Conclusions

In contrast with planned felling operations, windthrow harvesting raises complex problems when it comes to organization and management, the selection of qualified and properly trained workers, and the choice of the harvesting method and the equipment that would allow wood loss reduction. Preoccupations related to operators' health and safety must come first at all times.

This present study, coupled with other resources from the literature in the field, leads to the conclusion that wood losses resulting from the felling and cross-cutting of trees from windthrow are two to three times greater as compared with those from planned felling operations. The highest percentage is represented by WLHS (5.319%), followed by WLS (2.280%), WLF (0.138%) and finally WLC (0.010%).

An analysis of the causes of these wood losses leads to the conclusion that WLHS can be diminished by the careful preparation of the workplace and by the removal of obstacles from around standing trees so that the felling cuts can be made as close as possible to the ground. In the case of uprooted trees, stem and tensioned wood stability must be provided with the help of winch and skidder cables and equipment in general. The choice of incorrect work techniques can lead to an increase in WLS by increasing cracked and split wood parts. A proper match of notch size and felling cuts with the condition of the tree (standing, hung-up, with a tensioned stem, etc.) may lead to a certain reduction in WLF. A lower wood cross-cutting degree in the felling area can result in a decrease in WLC.

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Abbreviations

The following abbreviations are used in this manuscript:

WLHS	Wood loss in high stumps
WLS	Wood loss in the stem
WLF	Wood loss caused by felling cuttings
WLC	Wood loss caused by stem cross-cutting
SH	Stump height
SLH	Legal stump height
dbh	Breast height diameter
SH+	Trees in which the stump height was higher than the legal one
SH−	Trees in which the stump height was lower than the legal one

References

1. Ulanova, N.G. The effects of windthrow on forests at different spatial scales: A review. *For. Ecol. Manag.* **2000**, *135*, 155–167. [CrossRef]
2. Brüchert, F.; Gardiner, B. The effect of wind exposure on the tree aerial architecture and biomechanics of Sitka spruce (Picea sitchensis, Pinaceae). *Am. J. Bot.* **2006**, *93*, 1512–1521. [CrossRef] [PubMed]
3. Thürig, E.; Hagedorn, F.; Lindroth, A. Influence of storm damage on the forest carbon balance. In *Living with Storm Damage to Forest: What Science Can Tell Us 3*; European Forest Institute: Joensuu, Finland, 2013; pp. 47–54.
4. Seidl, R.; Rammer, W.; Spies, T.A. Disturbance legacies increase the resilience of forest ecosystem structure, composition, and functioning. *Ecol. Appl.* **2014**, *24*, 2063–2077. [CrossRef] [PubMed]
5. Samariks, V.; Krisans, O.; Donis, J.; Silamikele, I.; Katrevics, J.; Jansons, A. Cost–Benefit Analysis of Measures to Reduce Windstorm Impact in Pure Norway Spruce (*Picea abies* L. Karst.) Stands in Latvia. *Forests* **2020**, *11*, 576. [CrossRef]
6. Martínez-Alvarado, O.; Gray, S.L.; Catto, J.L.; Clark, P.A. Corrigendum: Sting jets in intense winter North-Atlantic windstorms. *Environ. Res. Lett.* **2012**, *9*, 039501. [CrossRef]
7. Schindler, D.; Bauhus, J.; Mayer, H. Wind effects on trees. *Eur. J. For. Res.* **2012**, *131*, 159–163. [CrossRef]
8. Birot, Y.; Gardiner, B. Challenges for forestry in relation to storms. In *Living with Storm Damage to Forests*; Gardiner, B., Schuck, A., Schelhaas, M.J., Orazio, C., Blennow, K., Nicoll, B., Eds.; European Forest Institute: Joensuu, Finland, 2013; pp. 123–129.
9. Schuck, A.; Schelhaas, M.-J. Storm damage in Europe—An overview. In *Living with Storm Damage to Forests: What Science Can Tell Us 3*; Gardiner, B., Schuck, A., Schelhaas, M.-J., Orazio, C., Blennow, K., Nicoll, B., Eds.; European Forest Institute: Joensuu, Finland, 2013; pp. 15–23.
10. Honkaniemi, J.; Rammer, W.; Seidl, R. Norway spruce at the trailing edge: The effect of landscape configuration and composition on climate resilience. *Landsc. Ecol.* **2020**, *35*, 591–606. [CrossRef]
11. Gardiner, B.; Blennow, K.; Carnus, J.; Fleischer, P.; Ingemarson, F.; Landmann, G.; Lindner, M.; Marzano, M.; Nicoll, B.; Orazio, C.; et al. *Destructive Storms in European Forests: Past and Forthcoming Impacts*; Final Report to European Commission—DG Environment (07.0307/2009/SI2.540092/ETU/B.1); European Forest Institute: Joensuu, Finland, 2010; p. 138. [CrossRef]
12. Forzieri, G.; Pecchi, M.; Girardello, M.; Mauri, A.; Klaus, M.; Nikolov, C.; Rüetschi, M.; Gardiner, B.; Tomaštík, J.; Small, D.; et al. A spatially explicit database of wind disturbances in European forests over the period 2000–2018. *Earth Syst. Sci. Data* **2020**, *12*, 257–276. [CrossRef]
13. Menegatto, M.; Freschi, G.; Bulfon, M.; Zamperini, A. Collectively Remembering Environmental Disasters: The Vaia Storm as a Case Study. *Sustainability* **2024**, *16*, 8418. [CrossRef]
14. Ciocirlan, M.; Câmpu, V.R. Characteristics of Forest Windthrow Produced in Eastern Carpathians in February 2020. *Forests* **2024**, *15*, 176. [CrossRef]
15. Rotaru, C. *Tehnologia Exploatarii Lemnului*; C.D.P.T.—M.I.M.: București, Romania, 1974.
16. Andreescu, V.; Amzică, A. *Exploatarea Pădurilor*; Ministerul Învățământului și Culturii, Institutul Politehnic, Orașul Stalin, Facultatea de Silvicultură: Stalin, Romania, 1959; p. 689.
17. Copaceanu, D.; Pavelescu, I. *Cartea Maistrului de Exploatari Forestiere*; Editura Agro-Silvica: Bucuresti, Romania, 1964; p. 335.
18. Köhl, M.; Magnussen, S.; Marchetti, M. *Sampling Methods, Remote Sensing and GIS Multiresource Forest Inventory*; Springer: Berlin/Heidelberg, Germany, 2006; p. 373.
19. Ciubotaru, A.; Câmpu, V.R.; David, E.C. *Exploatarea și Prelucrarea Lemnului*; Editura Universitatii Transilvania din Brașov: Brașov, Romania, 2012; p. 119.
20. Behjou, F.K.; Ramezani, M.; Esfahan, E.Z.; Eftekhari, A. Wood waste during full-length and cut-to-length harvesting systems in caspian forests. *Int. J. Adv. Appl. Sci.* **2016**, *3*, 52–56. [CrossRef]
21. Ciubotaru, A. *Exploatarea Pădurilor*; Editura Lux Libris: Brasov, Romania, 1998; p. 351.
22. Pavelescu, I.M. *Tehnologii noi in Exploatare Doboraturilor de Vânt*; Ministerul Industriei lemnului, Centrul de documentare tehnica pentru industria lemnului: Bucuresti, Romania, 1971; p. 59.
23. McKeever, D.B. Inventories of woody residues and solid wood waste in the United States. In Proceedings of the Ninth International Conference on Inorganic-Bonded Composite Materials Conference, Vancouver, BC, Canada, 10–13 October 2004.
24. Malik, J.; Hopewell, G.P. Sawing Recovery of Several Sawmills in Jepara. *J. Penelit. Has. Hutan* **2011**, *29*, 331–342. [CrossRef]
25. Koopmans, A.; Koppejan, J. Agricultural and forest residues-generation, utilization and availability. In Proceedings of the Regional Consultation on Modern Applications of Biomass Energy, Kuala Lumpur, Malaysia, 6–10 January 1997.
26. Aryal, U.; Neupane, P.R.; Rijal, B.; Manthey, M. Timber Losses during Harvesting in Managed Shorea robusta Forests of Nepal. *Land* **2022**, *11*, 67. [CrossRef]
27. Šafařík, D.; Hlaváčková, P. Losses in the Amount of Produced and Sold Timber. *Procedia Econ. Financ.* **2015**, *34*, 51–57. [CrossRef]
28. Sofuoğlu, S.D.; Kurtoğlu, A. A survey for determination of wastage rates at massive wood materials processing. *Wood Res.* **2012**, *57*, 297–308.
29. Giurgiu, V. *Metode ale Statisticii Matematicii Aplicate în Silvicultură*; Editura Ceres: București, Romania, 1972; p. 566.

30. Leahu, I. *Dendrometrie*; Editura didactică și pedagogică: București, Romania, 1994; p. 373.
31. Câmpu, V.R.; Borz, S.A. Amount and structure of tree damage when using cut-to-length system. *Environ. Eng. Manag. J.* **2017**, *16*, 2053–2061. [CrossRef]
32. Staff, K.A.G.; Wiksten, N.A. *Tree Harvesting Techniques*; Martinus Nijhoff/DR. W; Junk Publishers: Dordrecht, The Netherlands, 1984; p. 371.
33. Ministry of Environment (Romania). *O.M. 1540/20.07.2011 Pentru Aprobarea Instrucţiunilor Privind Termenele, Modalităţile şi Perioadele de Colectare, Scoatere şi Transport al Materialului Lemnos*; Monitorul Oficial al României nr. 430, Partea I, Ministerul Mediului și Pădurilor; Ministry of Environment (Romania): Bucharest, Romania, 2011; p. 268.
34. Câmpu, V.R.; Robb, W. *Chainsaw Safety & Tree Felling Guide*; Litera Brno Press: Brno, Czech Republic, 2022; p. 177.
35. Ministry of Environment (Romania). *O.M. 1323/31.08.2015 Privind Aprobarea Metodelor Dendrometrice Pentru Evaluarea Volumului de lemn Destinat Valorificării şi Valorile Necesare Calculului Volumului de lemn Destinat Valorificării*; Monitorul Oficial al României nr. 742 bis, Partea I, Ministerul Mediului, Apelor și Pădurilor; Ministry of Environment (Romania): Bucharest, Romania, 2015; p. 268.
36. Giurgiu, V.; Decei, I.; Drăghiciu, D. *Modele Matematico-Auxologice și Tabele de Producție Pentru Arborete*; Editura Ceres: București, Romania, 2004; p. 607.
37. Boston, K.; Dysart, G. A comparison of felling techniques on stump height and log damage with economic interpretations. *West. J. Appl. For.* **2000**, *15*, 59–61. [CrossRef]
38. Han, H.-S.; Renzie, C. Effect of ground slope, stump diameter, and species on stump height for feller-buncher and chainsaw felling. *Int. J. For. Eng.* **2005**, *16*, 81–88. [CrossRef]
39. Hall, R.; Han, H.-S. Improvements in value recovery through low stump heights: Mechanized versus manual felling. *Wester J. Appl. For.* **2006**, *21*, 33–38. [CrossRef]
40. Gülci, N.; Gülci, S.; Akay, A.E.; Sessions, J. A Comparison of two felling techniques considering stump-height-related timber value loss. *Croat. J. For. Eng.* **2023**, *44*, 103–110. [CrossRef]
41. Gerasimov, Y.; Seliverstov, A. Industrial round-wood losses associated with harvesting systems in Russia. *Croat. J. For. Eng.* **2010**, *31*, 111–126.
42. ILO. *Safety and Health in Forestry Work: An ILO Code of Practice.*; International Labour Office Geneva: Geneva, Switzerland, 1998; p. 116.
43. Ramantswana, M.; Mcewan, A.; Spinelli, R. The effect of coppice management on stump volume recovery in mechanized operations. *Ann. For. Sci.* **2017**, *74*, 58. [CrossRef]
44. Pavelescu, I.M. Consumuri tehnologice in cioate și rupturi în exploatările de doborâturi din raza C.E.I.L. Piatra Neamț. *Rev. Pădurilor* **1971**, *86*, 133–137.
45. Pavelescu, I.M. Aspecte particulare ale doboraturilor de vânt în legatura cu activitatile de exploatare-valorificare. *Rev. Pădurilor* **1971**, *86*, 196–199.
46. Andreescu, V.; Muresan, G. *Tehnologia Exploatarilor Forestiere*; Editura didactică și pedagogică: București, Romania, 1967; p. 260.
47. Borz, S.A.; Ignea, G.; Vasilescu, M.M. Small gains in wood recovery rate when disobeying the recommended motor-manual tree felling procedures: Another reason to use the proper technical prescriptions. *Bioresources* **2014**, *9*, 6938–6949. [CrossRef]
48. Đuka, A.; Sertić, M.; Pentek, T.; Papa, I.; Janeš, D.; Poršinsky, T. Round wood waste and losses—Is rationalisation in scaling possible? *Croat. J. For. Eng.* **2020**, *41*, 1–12. [CrossRef]
49. Câmpu, V.R. *Ghidul Utilizatorilor de Fierăstraie Mecanice*; Editura Universității Transilvania din Brașov: Brașov, Romania, 2018; p. 145.