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Damage and Tolerability Thresholds for Remaining Trees after Timber Harvesting: A Case Study from Southwest Romania

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Abstract: The present study analyses the damage of remaining trees after timber harvesting from 24 logging sites from southwest Romania. The purpose was to establish tolerability thresholds within which damaged trees recover in a short amount of time, reducing the possibility of further rot apparition and tree health deterioration. Observations were resumed after the growing season had passed. Healed damage was analysed in regard to damage type, width, orientation and tree circumference. By using the ratio between the width of healed damage and the circumference of trees as experimental variants, equations were elaborated to determine the tolerance threshold of trees in logging. This is expressed as a maximum value between the damage width and the damaged tree circumference for which the damage is curable. The correlation between the circumference and the abovementioned relation was analysed, and differences between the values of the analysed relation for different cardinal orientations of the damage were statistically tested. The value of this ratio, which can be considered a tolerance threshold for trees in logging, records values of 0.09 (for thinnings, for cuttings to increase the light availability for regeneration and for final cuttings from shelterwood systems) and 0.10 (for first-intervention cuttings, as well as preparatory and seed cutting from shelterwood systems or selections systems).

Keywords: residual trees; logging technology; silvicultural works; tree healed wound

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Citation: Cântar, I.-C.; Ciontu, C.-I.; Dincă, L.; Borlea, G.F.; Crişan, V.E. Damage and Tolerability Thresholds for Remaining Trees after Timber Harvesting: A Case Study from Southwest Romania. *Diversity* **2022**, *14*, 193. https://doi.org/10.3390/d14030193

Academic Editor: Tibor Magura

Received: 30 January 2022
Accepted: 4 March 2022
Published: 6 March 2022

1. Introduction

Timber extraction from forests must be realized in profitable economic conditions, with expenses accepted by society at a given moment. This means using machines with a high productivity while remaining in compliance with the objectives of sustainable forest management. For logging, this involves activities with a damage level that does not exceed the tolerance threshold of the forest ecosystem.

Timber logging affects all the forest ecosystem's components: residual trees, soil [1,2] and seedlings [3–5]. Logs are usually extracted from the forest site to the landing areas by machines on skid trails [6]. As they are moved, these transported loads harm the abovementioned components of forest ecosystems, especially trees, in which case injury can lead to death. Different management practices in timber harvesting can lead to different tree mortality rates, even within the same forest type [7]. Silvicultural treatments are sometimes applied to maintain forest health and productivity. However, the necessary interventions vary from one forest to another [8], leading to differences in the number and intensity of injuries caused to trees. Damage from harvesting using different technologies has been studied by different authors and has shown a proportion of 22–44% wounded stems for conventional logging using chainsaw and skidder and 20–31% for mechanized operations using a harvester [9]. Regarding logging technologies with reduced impact on forest ecosystems, such as cable yarding systems, higher first-year mortality rates have been observed in less severely damaged trees located in conventional logging areas than in those from logging areas with a reduced impact [10]. Wound area and the ratio of the maximum wound's width-to-tree circumference at breast height, as well as the percentage of dead crown and the growth rate, have been tested as variables in some models that determine tree mortality risks [11].

Some studies have compared the influence of timber harvesting with that of forest fires on forest biodiversity and productivity. The resulting perturbation did not decrease productivity or plant diversity when compared with fires, which represent the main natural disturbance in these areas [12]. Other researchers have shown that anthropogenic disturbances, such as timber harvesting, can promote the stability of certain non-native and invasive plants [13].

Silvicultural and harvesting activities are commonly believed to primarily affect forest populations and species content [14]. The negative impact of logging extends not only to trees, soil and seedlings but also to wildlife and the entire regional landscape [15,16]. Regardless of this, some biodiversity benefits from reduced-impact logging may accrue over longer periods after logging ends [17]. Selective logging poses a lesser threat, largely because most—although not all—of the species found in primary forests appear to be able to persist in logged forests [18]. Windstorms can improve biodiversity indicators in these areas, but salvage logging may reduce these positive impacts across most indicators [19,20]. Similarly to logging, extreme phenomena, such as storms, can cause torrential leaks, with a negative impact on forests, leading to extensive damage to trees, seedling and soil [21]. Furthermore, besides the damage caused by logging and extreme phenomena, a major impact on exploited stands can also be caused by climatic changes [22–24].

The scope and severity of residual tree damage depends on, among other things, the harvest intensities and the layout of the skid trail network. Most damage occurs due to construction of main roads, but with an increase in harvest intensity, damage resulting from tree felling and skid trails dominates [25]. Additionally, different curvatures of skid trails and different site conditions (soil moisture, soil type, terrain slope) contribute to the amount and intensity of residual tree damage [26]. A high damage rate within mechanized harvesting was reported in stands impacted by the handling of wood parts and trees. Thus, the experience of machine operators can correlate with a lower handling rate of wood in forests, resulting in a low damage rate of residual trees. The actions of operators and the harvested tree size can influence an important part of residual tree damage [27]. The choice of mechanized harvesting machines used in logging should be based on their impact on the forest ecosystem because mechanized harvesting has a longer-lasting effect for residual trees compared to non-mechanized harvesting [28]. Residual tree damage produced by forwarders is approximately half the damage produced by harvesters [29].

Another factor that influences the number and intensity of residual tree damage is the size of the harvested trees and the size of the skidded wood piece. The amount of residual tree damage significantly increases when the harvested diameter of harvested trees at breast height increases [30]. The length of wood pieces is dictated by the logging method used. Some research has shown that using the cut-to-length method can lead to residual trees being more damaged than when using the tree-length method [31]. The most widely used harvesting methods in Romania are tree-length, usually used in the mountainous and hilly area, and the cut-to-length method, used in lowland forest areas or in mountainous areas in the process of installing cable yarding capabilities [32]. The most damaging method to the forest ecosystem is the whole-tree method, which is forbidden in Romania [32].

In order to avoid tree mortality after harvesting and the previously mentioned connected negative effects on biodiversity, it is necessary to coordinate logging technologies with treatments that are appropriate for the essential characteristics of stands in order to preserve the protection potential of forests. This practice is necessary in order to harvest wood material and fulfil the necessary conditions for natural regeneration and the creation of healthy and economically valuable stands. In this way, causing damage that exceed the tolerance thresholds of trees is avoided so that the damaged samples recover in a short period of time.

Silvicultural and functional requirements can be satisfied by establishing damage thresholds (limits) for the remaining standing trees, seedlings and soil. These thresholds can be tolerated by the forest, avoiding derangement of the production and protection functions of the forest ecosystems [33]. If a wound closes quickly, the tree is less prone to decay at the stem level [34]. Based on tree DBH, as well as hierarchical and geographical positions within the stand, and based on position, size and depth of wound, some authors calculated the average synthetic index, establishing values for “tolerable” damage [35]. Knowing the tolerance thresholds of trees and the impact of logging within the limit where trees heal without developing rot can lead to management solutions that will increase the quality of the wood that will be harvested in the following periods.

Based on field observations realized before the present study, our hypothesis was that there is a link between healed damage, damage width, tree circumference and the damage cardinal orientation. Our observations have shown that only a certain percentage of tree damage heals in a short period of time after logging.

The purpose of this study was to establish the tolerance thresholds for trees under timber harvesting actions from the southwest of Romania. This purpose can be achieved by attaining objectives based on the study’s hypothesis, which are detailed below.

The first objective is to identify and evaluate tree damage from harvesting sites located in southwestern Romania from all relief forms and including a wide range of work. The healed damage was identified after the growing season had passed.

The second objective consists in establishing a link between healed damage and damage width, tree circumference and damage orientation.

The third objective consists in establishing tree tolerance thresholds against the action posed by timber extraction based on an existent relationship between healed damage and different variables.

Based on the results of this research, a series of good practices for the management of timber harvesting were brought forward in order to minimize the negative impact on both the forest ecosystem and biodiversity.

Based on the abovementioned scope and objectives, the goal of the research is to establish the tolerability thresholds for trees in logging at harvesting sites in southwestern Romania.

2. Materials and Methods

The research for this study was conducted at 24 harvesting sites in southwestern Romania in forests located in the plains, mountains and hill areas. The distribution of research variants was realized by taking into account the harvesting sites, depending on silvicultural work, for variants and, within them, depending on the relief by repeating the observations twice at harvesting sites from each relief form.

In this study, the harvesting sites were chosen as variants depending on applied silvicultural work as follows: thinnings (variant V1), shelterwood systems (variants V2, V3 and V4) and selection systems (variant V2). For variant V2, we studied harvesting sites with first-intervention cuttings, as well as preparatory and seed cuttings in shelterwood systems or selection systems.

A regular shelterwood system is a silvicultural system wherein regeneration is initiated and supported by the removal of the harvestable trees in two or more successive steps of cutting [36]. In this paper, three steps were used, which correspond to preparatory and seed cutting (V2), as well as several successive cuttings, in order to increase the light availability for regeneration (V3) and final cutting (V4). The temporarily remaining old trees provide seeds and protect the natural regeneration from climatic extremes. The higher amount of light available due to these cuttings also promotes the growth of the remaining old tress [36].

Shelterwood cutting and later thinning produce an evenly aged stand with a homogenous vertical and horizontal structure. Only at the regeneration stage, when the shelter of mature trees covers seedlings and saplings, is the shelterwood system characterized by two clear canopies [36].

A selection system (V2) is a silvicultural system that results in unevenly aged stands. Individual trees or small groups of trees are cut periodically to obtain a yield in order to improve the forest structure and growth and to support the regeneration at the same time and in the same area. There are no defined cutting areas that are managed or harvested at a specific time [36].

Considering the above descriptions of applied treatments, their structure with respect considered variants is as follows: variant V1: thinnings; variant V2: first-intervention cuttings, preparatory and seed-cutting (as part of shelterwood system) or selections system; variant V3: cuttings to increase light availability for regeneration (as part of the shelterwood system); variant V4: final cuttings (as part of the shelterwood system).

Harvesting operations on harvesting sites considered in the study were finished during the year 2018. The period between the finishing time of the harvesting operation and the assessment was one vegetation season. Tree damage was identified and evaluated during the vegetative resting period between November 2019 and March 2020. The re-evaluation of damage was conducted between September 2021 and November 2021. The research was conducted at harvesting sites in Banat region managed by the Caransebeş Experimental Basis of INCDS "Marin Drăcea" and the forest departments of the Caraş-Severin forest directorate that belong to ROMSILVA (Băile Herculane, Bocșa Montană, Bocșa Română, Moldova Nouă and Văliug) (Figure 1).

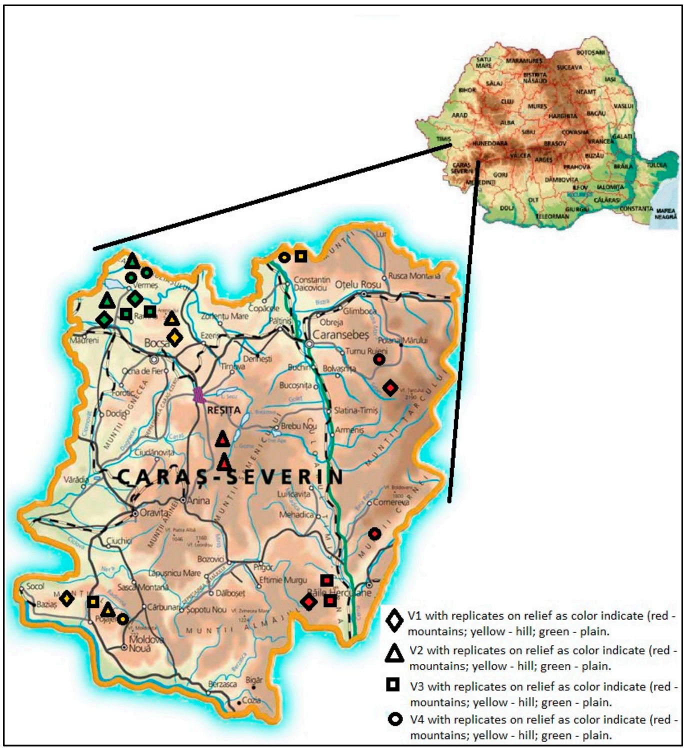


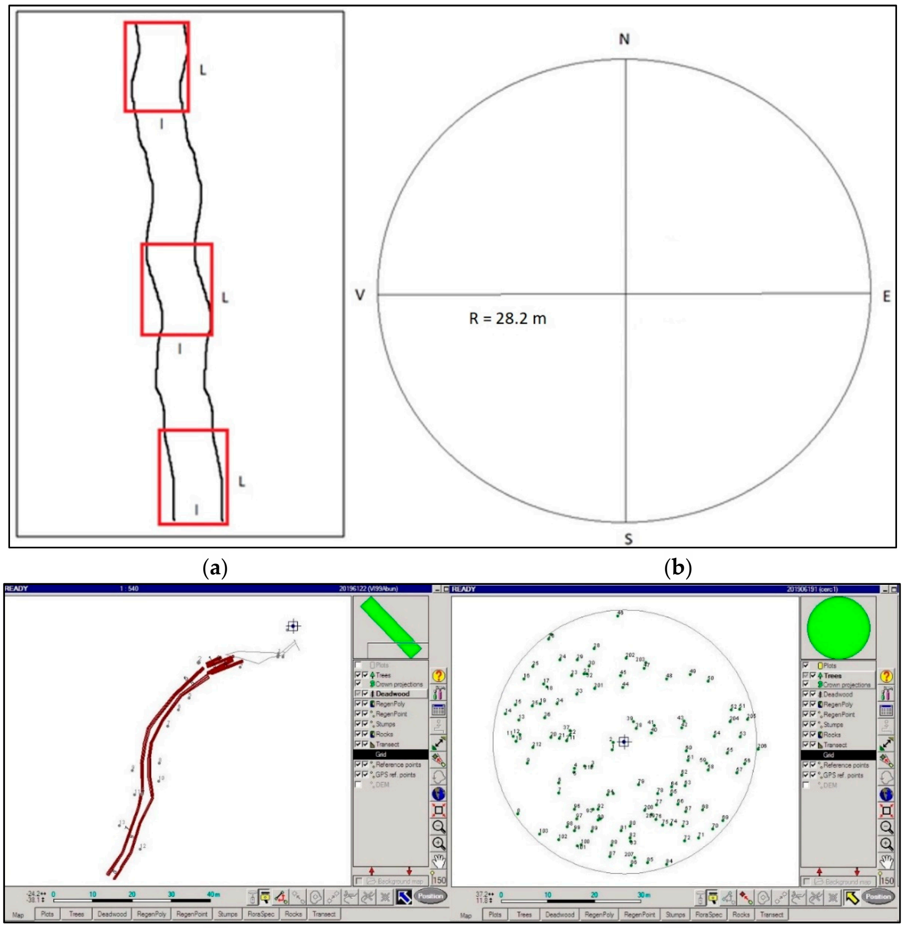
Figure 1. Location of the analysed harvesting sites [37,38].

Data collection was performed in the established sample plots with FieldMap equipment, Vertex, a compass, a riglet, and writing and labelling instruments. These were used to determine the tree position within the sample plots, to mark trees, to determine their biometric characteristics, to measure and determine the locations of the identified damage and to note the gathered data. The data were processed with specific software for table calculation and graphics processing.

The distribution of harvesting sites in terms of variants and replicates in the study is as follows (see Appendix A):

- Variant V1: harvesting sites with thinnings; two harvesting sites on each relief form;
- Variant V2: harvesting sites with first-intervention cuttings; preparatory and seed-cutting from shelterwood systems or selection systems; two harvesting sites on each relief form;
- Variant V3: harvesting sites with cuttings to increase light availability for regeneration from shelterwood systems; two harvesting sites on each relief form;
- Variant V4: harvesting sites with final cuttings from the shelterwood system; two harvesting sites on each relief form.

Tree damage was identified, evaluated and re-evaluated along skid trails in three sample plots with a length of 100 metres, measured along the driving direction of forest machines on the main skid trail for each logging site. This was done for each harvesting site on the ascent, at the middle and on the descent (Figure 2a).



(a) (b) (c) (d)

Figure 2. Location of sample plots: (**a**) along skid trails (schematic view); (**b**) inside the harvesting site (schematic view); (**c**) FieldMap representation of a sample plot from the skid trail; (**d**) FieldMap representation of a surface from inside the harvesting site.

The same tree observations were made in a circular sample plot of 2500 square metres in the middle of the harvesting site, avoiding skid trails (Figure 2b). This prevented the sample plot from overlapping with the skid trails. Random distribution of sample plots was not used because the harvesting operations took place only in certain parcels covered with regeneration or thinning works and only in certain accessible areas in which regeneration meshes were opened according to the applied treatment. In this case, inherent bias was avoided by placing sample plots according to a similar previous plan for all studied plots, regardless of the field situation, using three criteria: (1) to be as far away as possible from the border of the harvesting site; (2) to be as far away as possible from the skid trails; and (3) to be in an area where harvesting operations had been applied.

Injuries caused after timber extraction were identified and evaluated in the sections located along the skid trails. On the other hand, injuries caused during the collection and harvesting were identified and evaluated in the circular sample plot.

The classification of the identified types of tree damage was adapted from specialized literature classifications [39,40] as follows:

- Galling: partial removal of bark or rind without affecting the cambial area;
- Barking: removing parts of the bark up to the wood;
- Splintering: removing parts of bark and wood;
- Breaking branches or the trunk;
- Partial or total uprooting.

In addition to the identified types of damage, other characteristics were noted and stored, presented below in the FieldMap system.

During the initial evaluation of trees with injuries, several aspects were recorded: the species, damage type, age of damage based on previous forestry work (new/old), position of the damaged tree (FieldMap or polar coordinates), tree height (measured with VERTEX), tree circumference (at 1.3 m high), damage measurements (length, width and depth), position on the tree (trunk, crown or root insertion), height of the damage, cardinal position (exposition) of the damage and phase of the timber-harvesting technological process. When re-evaluating trees, we aimed to identify the tree, observe the status of the tree (dead/alive), identify the previously determined damage based on its type (galling, barking, splintering, breaking or uprooting) [39,40], remeasure the width of the damage, frame a new type of damage if it had changed and identify repeated damage.

The width of the damage that was taken into account represents the maximum distance between the edges of the damage found on the trunk of the tree, measured horizontally along the circumference of the tree (Figure 3).

We established a link between the healed damage width, tree circumference and the damage cardinal orientation by analysing the considered variants; the minimum and maximum value of the ratio between the healed damage's width; and the tree's circumference, amplitude, average, standard deviation and variation coefficient for ratio values.

The average value of cardinal orientation for the ratio between the healed width of the damage and the circumference of the damaged tree was identified, together with the standard deviation and the variation coefficient of the obtained value. An *ANOVA* test was applied in order to test the hypothesis that significant differences exist between the values of the ratio between the healed damage widths and the tree circumference for different damage orientations. The cardinal orientation of the damage was considered the cardinal orientation from the middle of the width of the damage, measured in the horizontal direction. The correlation between the studied relation and the circumference of the damaged tree was analysed with the help of the *Pearson* correlation coefficients.

Assuming that tree-growth reduction and the possible death of trees is mainly caused by reduced sap flow, some authors have used the ratio between the width of the damage and circumference of the damaged trees to describe the severity of damage [41,42]. In the case of similar investigations, because the normality of wound size and data regarding wound–stem size was not satisfying in the initial assumption, wound size and wound–stem ratio values were analysed [43].

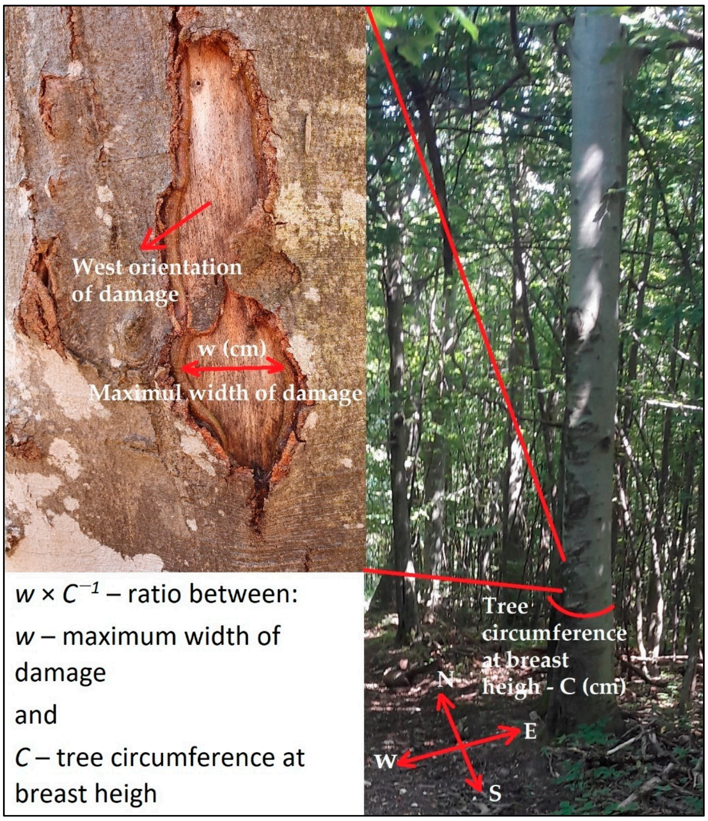


Figure 3. Diagram of measuring damage width and tree circumference and determining damage orientation.

We establishing the tree tolerance thresholds for the remaining trees after timber harvesting based on the relationship between the tree circumference (C) and the ratio of healed damage width and tree circumference ($w \times C^{-1}$). We assumed that damage that does not heal is more likely to develop rot, which can cause wood and tree health to depreciate. Tolerance thresholds were established for damage, considering silvicultural works from the harvesting sites and the cardinal orientation of the damage. This fact was obtained by analysing the value of the ratio between the damage width and the tree circumference for the damage that healed during the analysed period, modelling the statistical connections between the considered variables (w and C) using power functions.

Equations that lead to tree tolerance thresholds towards harvesting operations were elaborated. In order to see whether the observed data corresponded sufficiently to the expected values, χ^2 for goodness of fit was used to test the obtained models. The tolerance threshold was expressed as a maximum value of the relation between the damaged width and the tree circumference, for which the damage is curable. The correlation between the circumference and the abovementioned relation was analysed with the *Pearson* correlation coefficient. A model for the tolerance threshold concerning the main species was also elaborated.

For each silvicultural works, according to the considered variants, we identified the minimum and the maximum value of the ratio between the width of the healed damage and the circumference of the tree, the amplitude and average values of this ratio, the standard deviation and the coefficient of variation of values obtained from this ratio. As for tolerance threshold, expressed as the value of the ratio between the width of the healed damage and the circumference of the tree, we used the averages of the data sets with the lowest spread (lowest coefficient of variation) among the studied variants.

The experimental design of the conducted research, as well as the workflow of field work and data processing, according to the method presented above, is schematically represented in Figure 4 [44].

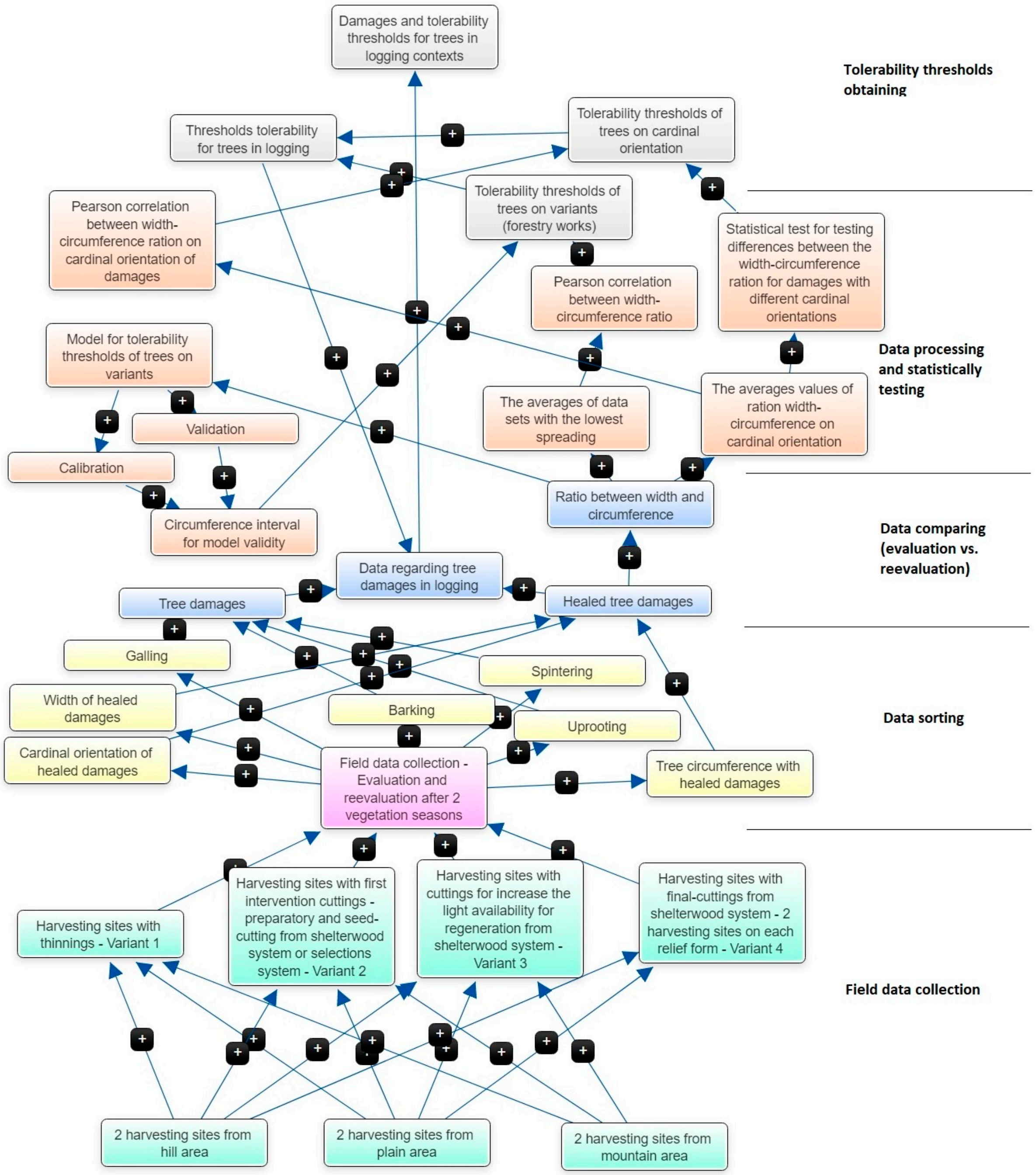


Figure 4. Design of conducted research and the workflow of field work and data processing [44].

The specific work conditions from the 24 harvesting sites (Table 1) have a direct impact on the development of the harvesting operations, as they define the spaces in which this work occurs. The cut-to-length-method was the harvesting method used in 23 of the 24 harvesting sites. The tree-length-method was applied only in one harvesting site. These are most often used harvesting methods in Romania, but depending on the operational conditions and the equipment used, many intermediary adaptations are in practice [32]. This is also the case of western Romania, which is the reason for taking into consideration the last harvesting site with a different harvesting method than the others, respecting the percentage of usage of this method in the studied area. Considering the above, the obtained results below are representative from this point of view.

Table 1. Characteristics of case-study areas in terms of stand, terrain and harvesting operations *.

Variant	Harvesting Site	Forest District, Production Unit, Management Unit	Average Tree Volume (m^3)	Total Number of Extracted Trees/ha (pcs.)	Trunk Volume of the Harvested Trees (m^3)	Extracted Wood Volume per ha (m^3)	Number of Trees per ha (pcs.)	Slope in the Sample Surface (%)
V1—Thinnings	h1	Bocșa Română, III, 49	0.52	35	166.6	18.4	554	2
	h2	Bocșa Română, II, 58A	0.13	133	22.8	17.5	762	5
	h3	Bocșa Montană, VI, 95A	0.19	500	34.4	93	1246	22
	h4	Moldova Nouă, III, 15B	0.10	28	176.6	28.1	1440	30
	h5	Băile Herculane, II, 23	0.32	286	466.1	91	903	23
	h6	Caransebeș, VI, 99A	0.29	101	324.7	30	1390	30
V2—First-intervention cuttings	h1	Bocșa Română, II, 55	0.6	161	160.7	100	525	5
	h2	Bocșa Română, I, 11C	0.7	137	136.9	88.9	319	13
	h3	Bocșa Montană, IV, 62B	0.9	139	139.2	126	306	26
	h4	Moldova Nouă, III, 212A	1.1	105	105.1	116	308	22
	h5	Văliug, VI, 15A	1.19	15	379.9	18	263	25
	h6	Văliug, VI, 16A	1.39	29	741.6	40	336	25
V3—Cuttings to increase light availability for regeneration	h1	Bocșa Română, III, 76A	0.9	137	136.5	121.4	429	6
	h2	Bocșa Română, III, 28B	1	141	140.8	135.7	282	0
	h3	Moldova Nouă, III, 176A	1	79	79.3	75.4	143	30
	h4	Caransebeș, II, 30B	0.8	114	113.7	90.4	235	23
	h5	Băile Herculane, II, 99	1.19	107	606.8	127	224	30
	h6	Băile Herculane, II, 100A	2.24	44	1638.4	99	123	29

Table 1. *Cont.*

Variant	Harvesting Site	Forest District, Production Unit, Management Unit	Average Tree Volume (m^3)	Total Number of Extracted Trees/ha (pcs.)	Trunk Volume of the Harvested Trees (m^3)	Extracted Wood Volume per ha (m^3)	Number of Trees per ha (pcs.)	Slope in the Sample Surface (%)
V4—Final cuttings	h1	Bocșa Română, I, 1E	1.2	192	191.6	230.1	163	14
	h2	Bocșa Română, I, 14A	0.6	167	166.5	92.5	150	14
	h3	Moldova Nouă, III, 162B	1.7	74	74.1	122.8	36	25
	h4	Caransebeș, I, 46D	0.9	234	234.1	218.6	238	30
	h5	Băile Herculane, IV, 98A	3	40	1122.3	120	25	28
	h6	Caransebeș, V, 16A	3.27	114	3134.8	371	58	32

* Data were processed using the sources of technical documentation from the studied harvesting sites, as well as from forest management plans, within the forest management headquarters.

3. Results

3.1. Tree Damage and Healed Damage

The research allowed us to compare data from re-evaluations to those from initial evaluations and to emphasize the damage dynamics regarding dimension, migration towards other types of damage (e.g., transforming galling in barkings by slicing bark under the pressure of cambial growth), the apparition or evolution of rot, or, on the contrary, the healing of damage.

The tree tolerance threshold was established in relation to the size of the damage identified in the initial evaluation but considered healed during re-evaluations. The other evaluated variables were also taken into account.

A total of 1237 damaged trees were identified in the sample plots from analysed harvesting sites in the initial evaluation. These were distributed as follows: 537 trees in variant V1, 254 trees in variant V2, 215 trees in variant V3 and 231 trees in variant V4. We identified 1945 injuries, with many trees presenting multiple injuries. Barking represented the majority of injuries (78.9%), followed by splintering (11%), galling (7.7%), broken trees (1.8%) and uprooting (0.6%).

Most cases of damage were identified as thinnings (V1), where stand density was the highest (Figure 5).

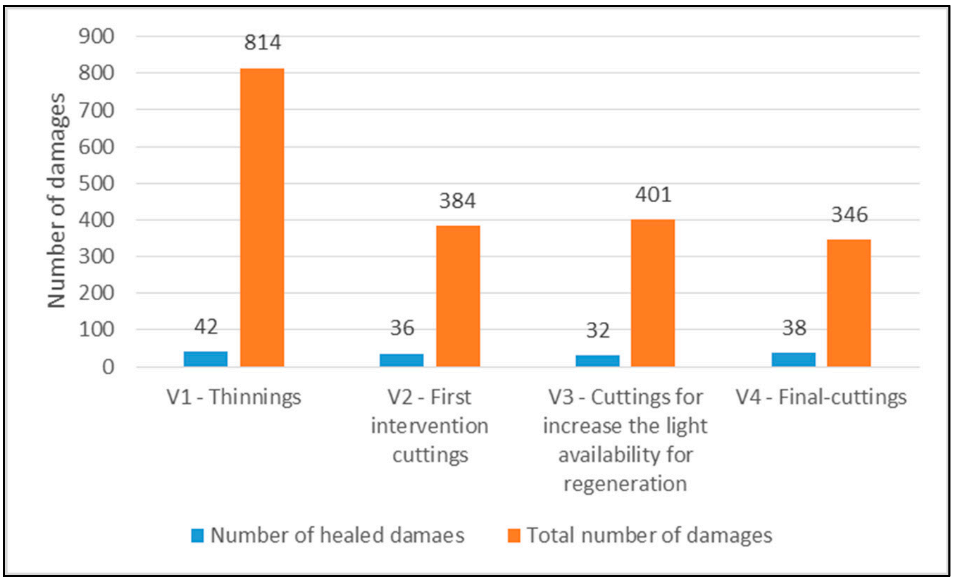


Figure 5. Distribution of healed and unhealed damage by variant.

The synthesis shown in Table A1 was created based on the field data gathered from the sample plots.

Taking into account the fact that a significant amount of the studied damage healed during the analysed period, it is important to find a dimensional damage threshold up to which healing was possible. In the analysed sample plots, 64 cases of damage were initially identified as healed, whereas 108 cases of damage healed during the two years in which the research was realized. From a percentage perspective, healed damage represents 8.8% of the total amount of damage.

The research was carried out mostly in beech stands in the mountains and hills and in mixed stands in the plains, with resinous species found in a small percentage of the analysed areas. However, the percentage of injuries healed in the specimens of sampled conifers was 28% (17 cases of damage healed out of a total of 60 cases found). In deciduous species, the healing rate of damage was only 8.2%.

3.2. Tolerance Thresholds concerning Types of Forestry Work and Species

If the growing type of damaged bark and field observations are taken into consideration, it can be said that the most significant influence on damage healing is represented by damage width in relation with the entire circumference of the damaged tree. As such, in the analysed sample plots, the average of the ratio between the healed damaged widths and the tree circumference is approximately 0.10 (0.09 for damage healed during the analysed period and 0.12 for damage identified as healed in the initial evaluation).

The value of the ratio between the damage width and the tree circumference for the damage healed in the studied variants, as well as the statistical indicators that characterize the value of this relation, is presented in Table 2.

Table 2. Values of the ratio between the healed damage width (w) and the tree circumference (C) in the studied variants.

Galling					
Statistical indicator	**Minimum value of $w \times C^{-1}$**	**Maximum value of $w \times C^{-1}$**	**Average value of $w \times C^{-1}$**	**Standard deviation**	**Variation coefficient**
V1—Thinnings	0.0164	0.2128	0.0696	0.0493	70.8320
V2—First-intervention cuttings	0.0192	0.2963	**0.1047**	0.0799	**76.2434**
V3—Cuttings to increase light availability for regeneration	0.0195	0.2286	**0.0868**	0.0595	**68.5909**
V4—Final cuttings	0.0323	0.2429	**0.0914**	0.0676	**73.9230**
TOTAL	0.0164	0.2963	0.0896	0.0650	72.5425
Barking					
Statistical indicators	**Minimum value of $w \times C^{-1}$**	**Maximum value of $w \times C^{-1}$**	**Average value of $w \times C^{-1}$**	**Standard deviation**	**Variation coefficient**
V1—Thinnings	0.0088	0.2222	0.0889	0.0529	59.5267
V2—First-intervention cuttings	0.0244	0.3684	0.1265	0.1002	79.1722
V3—Cuttings to increase light availability for regeneration	0.0137	0.1852	0.0734	0.0547	74.5544
V4—Final cuttings	0.0072	0.2653	0.0954	0.0797	83.6130
TOTAL	0.0072	0.3684	0.0969	0.0729	75.2008
Splintering					
Statistical indicators	**Minimum value of $w \times C^{-1}$**	**Maximum value of $w \times C^{-1}$**	**Average value of $w \times C^{-1}$**	**Standard deviation**	**Variation coefficient**
V1—Thinning	0.0781	0.3214	0.1792	0.1268	70.7651
V4—Final cuttings	0.0606	0.3846	0.2226	0.2291	10.9195
TOTAL	0.0606	0.3846	0.1965	0.1474	74.9960

Table 2. *Cont.*

Amount of total damage					
Statistical indicators	**Minimum value of $w \times C^{-1}$**	**Maximum value of $w \times C^{-1}$**	**Average value of $w \times C^{-1}$**	**Standard deviation**	**Variation coefficient**
V1—Thinnings	0.0088	0.3214	0.0886	0.0592	66.7758
V2—First-intervention cuttings	0.0192	0.3684	0.1186	0.0908	76.6220
V3—Cuttings to increase light availability for regeneration	0.0137	0.2286	0.0827	0.0564	68.2538
V4—Final cuttings	0.0072	0.3846	0.0994	0.0869	87.4290
TOTAL	0.0072	0.3846	0.0971	0.0744	76.6439

The variation coefficient of the ratio between the damage width and the circumference had values over 50% in all analysed cases, namely for all three damage types identified as healed and for all studied variants. The highest values for the variation coefficient were recorded in splintering, for which the amount of healed damage was very small. Generally speaking, splintering is a type of width damage that affects not only the bark but also the wood. In the current research, the average diameter of splintered and healed trees was 11.5 cm during the studied period. Most of these trees were young and identified in thinnings and final cuttings. They had some of the lowest values of the ratio between the width of the healed damage and the circumference of the tree when compared with other splinterings.

A high variation coefficient signals a spreading of the studied relation in all variants. This means that the damage with a small width reported to the tree circumference is most likely to heal. However, over time, the amplitude value of this relation increases.

As can be seen in Table 2, the amplitude value of the ratio between the healed damage width and the tree circumference has the lowest values for variant V3.

The low amplitude of variant V3 indicates that the healing process occurs only at a low value within this relation. The widest healed damage reported in relation the tree circumference was observed in the variant where forestry work opening regeneration areas was applied, namely V2. Here, the amplitude of the studied relation is the highest, with the exception of splintering. However, the maximum value of the studied relation for most cases is higher than 0.2.

Taking this information into account, in order to determine the tolerance threshold (expressed as the value of the ratio between the healed damage width and tree circumference), one can use the average of data sets with the lowest spreading rounded to decimals (the lowest variation coefficient) from the studied variants (emphasized in the last column of Table 2).

As such, the following tolerance thresholds for timber harvesting were proposed. They are expressed as a ratio between the damage width (l) and the circumference of the damaged tree (C):

- V1—Thinnings: $w \times C^{-1}$ = 0.09;
- V2—First-intervention cuttings: $w \times C^{-1}$ = 0.10;
- V3—Cuttings to increase light availability for regeneration: $w \times C^{-1}$ = 0.09;
- V4—Final cuttings: $w \times C^{-1}$ = 0.09.

As can be seen, the value of the ratio between the damage width and the tree circumference, which can be considered a tolerance threshold for trees from timber harvesting operations, has similar values for all studied variants. The value of this ratio is of 0.09 for thinnings, cuttings to increase light availability for regeneration and final cuttings and 0.10 for first-intervention cuttings.

If the ratio of damage width to circumference is higher than 0.10 in first-intervention cuttings or higher than 0.09 for the other cuttings, the damage is not likely to heal within three years of the end of harvesting operations.

Although the variation coefficient of $w \times C^{-1}$ is big, a connection was observed to exist between tree circumference and the ratio between damage width and circumference (Figure 6).

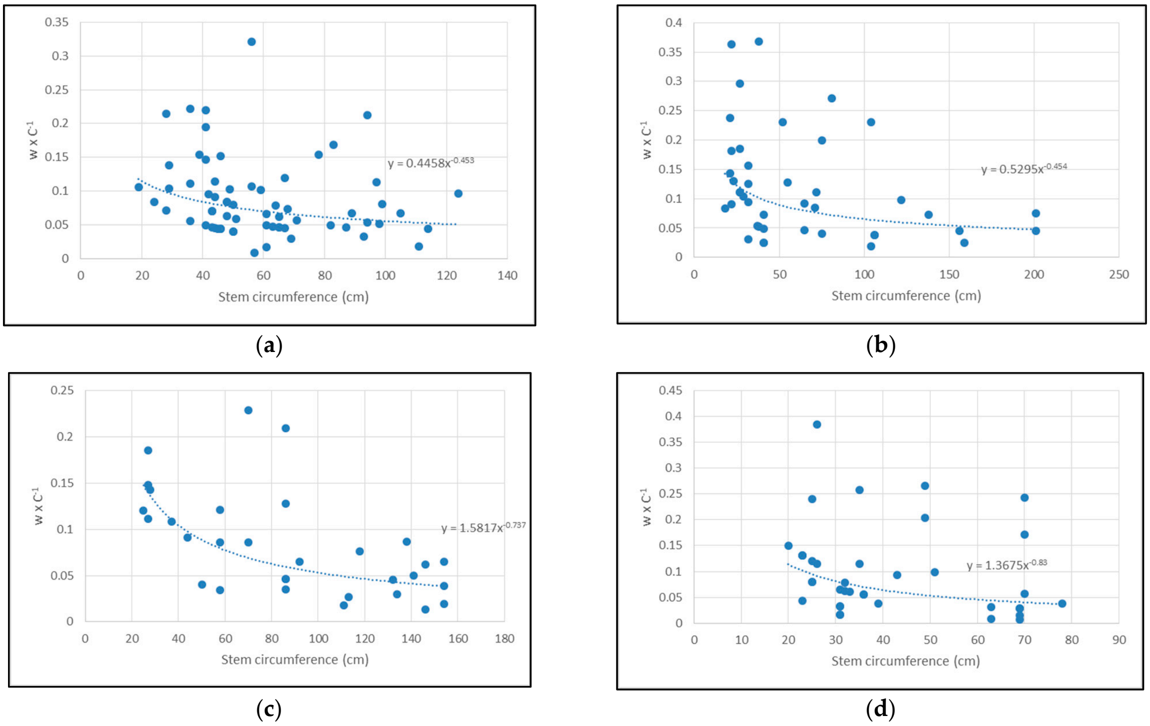


Figure 6. The relation between tree circumference and the ratio between healed damage width and tree circumference: (**a**) V1 –thinnings; (**b**) V2—first-intervention cuttings; (**c**) V3—cuttings to increase light availability for regeneration; (**d**) V4—final cuttings.

In the above figure, the average values for $w \times C^{-1}$ (y axis) are as shown in Table 2. The average values for circumference (C; x axis) are as follows: 60 for V1, 64 for V2, 88 for V3 and 42 for V4.

For all variants, the functions that define the abovementioned relation are exponential monotonous decreasing functions of data intervals of studied circumferences in the following form:

$y = 0.4458x^{-0.453}$ for V1—Thinnings;

$y = 0.5295x^{-0.454}$ for V2—First-intervention cuttings;

$y = 1.5817x^{-0.737}$ for V3—Cuttings to increase light availability for regeneration;

$y = 1.3675x^{-0.830}$ for V4—Final cuttings.

where $y = w \times C^{-1}$; $x = C$, in which:

w—the width of the healed damage;

C—the circumference of the damaged tree.

The equations for models that establish the link between circumference and $w \times C^{-1}$ for the healed damage are presented in Figure 6. By calibrating the models presented above using the average values obtained for the studied ratio of 0.10 in V2 and 0.09 in the other variants, it can be observed that the $w \times C^{-1}$ value can exceed these values for some small circumferences ($C < 35$ in V1; $C < 40$ in V2; $C < 49$ in V3; $C < 27$ in V4; values determined with the obtained equations). By calibrating the models for the minimum values of the ratio between width and circumference for which healed damage was identified as respecting the equations from the figure above, namely solving the equations, we obtained the maximum circumferences for proposed models of 124 cm in V1 (thinnings), 201 cm in V2 (first-intervention cuttings), 154 cm in V3 (cuttings to increase light availability for regeneration) and 78 cm in V4 (final cuttings).

Therefore, the validity of the models presented above may be applied to damage in trees with circumferences within the above values but larger than 35 cm in thinnings, 40 cm in first-intervention cuttings, 49 cm in cuttings to increase light availability for regeneration and larger than 27 cm in final cuttings.

The fitting of models was tested using χ^2 for goodness of fit between observed values for $w \times C^{-1}$ and expected values of this ratio obtained using the above models for studied variants (Table 3).

Table 3. Statistical data used to test models for goodness of fit.

Variant	χ^2 Values	Confidence Level	Degree of Freedom	Critical Values of χ^2
V1—Thinnings	3.109	95%	64	63.335
V2—First-intervention cuttings	3.451	95%	41	56.943
V3—Cuttings to increase light availability for regeneration	1.107	95%	30	43.773
V4—Final cuttings	4.777	95%	37	52.192

As can be observed for all variants, the proposed models fit the obtained experimental data; in all cases χ^2 obtained by testing was lower than the critical value for χ^2 for a specific degree of freedom. With 95% confidence, we conclude that the observed data follow the distribution of the proposed models.

By calculating the *Pearson* correlation coefficient between circumference and $w \times C^{-1}$ for healed damage, negative correlation coefficients were obtained. This marks an inverted correlation of different degrees, which are presented below, together with the value of the correlation coefficient for each variant:

- In V1, $r = -0.21$—weak correlation;
- In V2, $r = -0.33$—weak correlation;
- In V3, $r = -0.57$—reasonable correlation;
- In V4, $r = -0.20$—weak correlation.

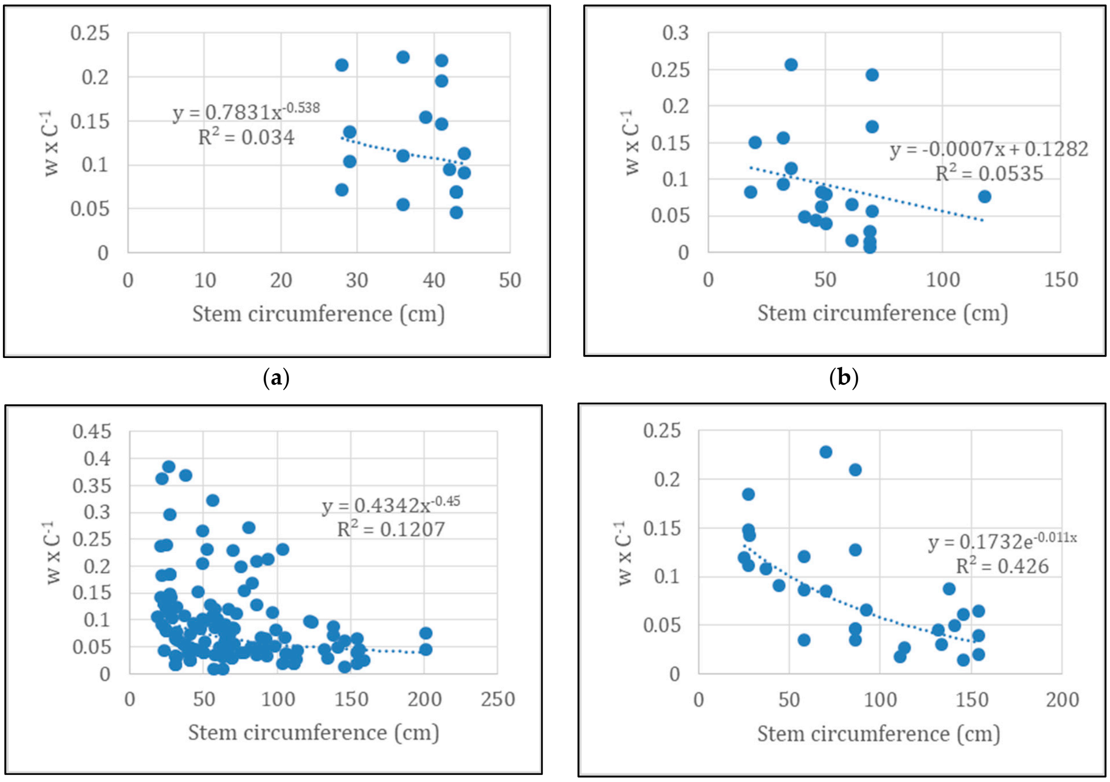
Neither variant showed an inexistent correlation ($r > -0.2$). A linear Person correlation (not only exponential, as shown above) is also present in all variants, although this correlation is between weak and reasonable.

For each variant (type of silvicultural work), if we replace x from the equations in Figure 6 with the circumference of the damaged tree, we obtain the tolerance threshold (y), expressed as a maximum value of the ratio between damage width and tree circumference from which the damage can heal.

The relationship between the circumference of the trees and the ratio between the width of the healed injury and the circumference for groups of species and for the main species is shown in Figure 7.

As can be seen, the small amount of damage in conifers and various deciduous species and the implicitly low percentage of participation of these species in the studied stands led to a poor statistical fitting of the above relationship. (Figure 7a,b).

For European beech, the coefficient of determination, R^2, takes the highest values in the case of variant V3 (cuttings to increase light availability for regeneration). In this variant, the damage was not exposed to sunstroke as in the case of sparse stands in variant V4; the trees were mature, unlike variant V1 (thinnings) and were not diseased with rot or other defects because they were extracted at the first cutting of the shelterwood system.



(**a**) (**b**)

(**c**) (**d**)

Figure 7. The relation between the tree circumference and the ratio between healed damage width and tree circumference: (**a**) coniferous species, all variants; (**b**) various deciduous species, all variants; (**c**) European beech, all variants; (**d**) European beech in V2 (first-intervention cuttings).

In view of the above, the maximum value of the relationship between the damage width and the circumference described by the model below can be proposed as a threshold of tolerability for beech:

$$y = 0.1732\, e^{-0.011x}$$

where $y = w \times C^{-1}$; $x = C$, in which:

w—the width of the healed damage;

C—the circumference of the damaged tree.

The value of the correlation coefficient of $r = -0.61$ is obtained by calculating the *Pearson* correlation coefficient between the circumference and $w \times C^{-1}$ of the healed damage in European beech in V3. There is therefore a high inverse correlation between the values considered in the proposed model ($r < -0.6$).

3.3. Tolerance Threshold and the Orientation of Damage

A factor with an important influence on the healing of damage in trees is represented by damage orientation. This is expressed through the cardinal position towards which the damage is oriented. It can be observed that healed damage is oriented towards all cardinal orientations, with N as the most common orientation (Table 4).

Analysing Table 4 and Figure 8 regarding the percentage of healed damage in relation to the total amount of damage (without breaks and uprooting) in each cardinal orientations (N, NE, E, SE, S, SW, W, NW), it can be seen that the most important percentage of healed damage is oriented in the N orientation, with 13.5% of the observed damage already healed. High percentages of healed damage are also observed in the neighbouring cardinal orientations, namely NW (11.3%) and NE (10.3%).

Table 4. Healed tree damage in relation to the orientation of damage and total damage.

Damage Orientation	Amount of Healed Damage	Total Amount of Damage	Percentage of Healed Damage Based on Orientation (%)
N	35	260	13.5
NE	19	184	10.3
E	26	310	8.4
SE	17	188	9.0
S	19	226	8.4
SW	12	191	6.3
W	21	337	6.2
NW	23	203	11.3

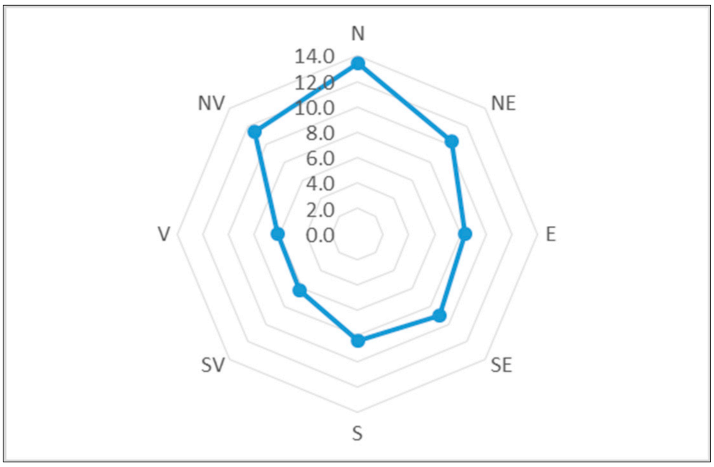


Figure 8. Percentage expression of the amount of healed damage based on orientation.

The lowest percentage of healing is in the W (6.2%) and SW orientations (6.3%).

The differences regarding the healing rate depending on the orientation of the damage may be due to the fact that the sunstrike is stronger in the case of south-facing injuries. These are exposed to drying, and bark growth is inhibited, which leads to a lower healing rate compared to that of north-facing damage. In the latter case, at the level of injury, the humidity is higher and does not negatively influence the healing rate but favours the long-term development of rot for the injuries that fail to heal.

In regard to the tolerance threshold of damaged trees according to cardinal orientation, as can be seen in Table 5, the $w \times C^{-1}$ average, which can be considered a tolerance threshold, varies based on the orientation. The values range between 0.076 in NE and 0.138 in SW orientation.

Although the percentage of healed damage is the highest for damage with a NW-N-NE orientation, the widest damage reported in relation the damaged tree circumference was found in the SW orientation (Table 5). Here, the variation coefficient is relatively small when compared with the other cases (Table 5). Furthermore, the average of the studied relation is higher than 0.1 for healed damage oriented to the N, NW and W.

An *ANOVA* test was applied in order to test the hypothesis that significant differences exist between the $w \times C^{-1}$ values between different damage orientations. These types of significant differences ($p^* < 5\%$) can be observed only for two pairs of samples, namely between SW and S orientations and between SW and NE orientations (Table 6).

Table 5. Values of the ratio between healed damage width and damaged tree circumference based on cardinal orientation.

Damage Orientation	Average	Standard Deviation	Variation Coefficient
N	0.101	0.101	100.000
NE	0.076	0.045	59.278
E	0.091	0.081	88.792
SE	0.087	0.058	66.173
S	0.075	0.053	70.198
SW	0.138	0.094	67.941
W	0.110	0.082	74.216
NW	0.106	0.076	71.802

Table 6. p values (*ANOVA* test) to test different $w \times C^{-1}$ values between different damage orientations (significant (p < 5%) = *).

Damage Orientation	N	NE	E	SE	S	SW	W	NW
N	1	0.207	0.635	0.532	0.221	0.192	0.705	0.836
NE	0.207	1	0.440	0.519	0.952	0.016 *	0.111	0.129
E	0.636	0.440	1	0.845	0.446	0.114	0.446	0.519
SE	0.532	0.519	0.845	1	0.527	0.084	0.349	0.407
S	0.221	0.952	0.446	0.527	1	0.024 *	0.130	0.147
SW	0.192	0.016 *	0.114	0.084	0.024 *	1	0.384	0.261
W	0.705	0.111	0.446	0.349	0.130	0.384	1	0.851
NW	0.836	0.129	0.519	0.407	0.147	0.261	0.851	1

As such, differences between samples with different damage orientations are mainly insignificant, so representative $w \times C^{-1}$ values could not be determined to be considered tolerance thresholds based on cardinal orientation.

The *Pearson* correlation coefficients between the studied relation and the tree circumference indicate a reverse correlation for some orientations, as follows:

- N, $r = -0.23$—weak correlation;
- NE, $r = -0.13$—very weak correlation;
- E, $r = -0.21$—weak correlation;
- SE, $r = -0.29$—weak correlation;
- S, $r = -0.54$—reasonable correlation;
- SW, $r = -0.44$—reasonable correlation;
- On V, $r = -0.31$—weak correlation;
- On NV, $r = -0.32$—weak correlation.

A very weak correlation ($r > -0.2$) is present in the NE orientation between $w \times C^{-1}$ and the circumference, whereas the correlation is reasonable in the S and SW orientations ($-0.6 < r < -0.4$). All the other cases present a weak correlation ($-0.4 < r < -0.2$).

If all this is considered, the lack of significant differences from a statistical perspective regarding the $w \times C^{-1}$ value between different orientations, as well as the existence of a linear *Pearson* correlation between the relation's value and the circumference, the previously obtained average values (Table 5) are proposed as tolerance thresholds with respect to circumference intervals obtained by calibrating and validating the models presented above.

4. Discussion

4.1. Tree Damage and Tolerance Thresholds

Similar results regarding tree damage were obtained in studies focused on animal logging in which barking was identified as the most common damage (61.5%), a lower percentage than that obtained in the present study (78.9%) [39]. Unlike the current study, the higher percentage of minor damage was due to the use of animal logging, a low-impact logging technique. Thus, animal logging is correlated with a high percentage of light damage, such as squashed bark (23.1%), compared to the percentage obtained in the current study (7.7%), where conventional logging was used. Other studies have shown that, on average, logging damage affected 40% of residual trees, with 21% injured and 19% killed trees [45].

Related investigations have shown similar values for healed damage, representing 12% of the total amount of identified damage but in smaller samples (10 healed damage) [34]. The present study comprises 172 cases of healed damage during the research period, representing 13.5% of the total amount of identified damage.

In young trees, some authors have mentioned that the cambial tissue never survives exposure. Thus, even if only small bark pieces are removed, the xylem is open to an invasion of pathogenic agents [8]. In the studied variants in the present study, the amount of healed damage was superior in variants where thinnings were applied, where the trees' healing power is higher than in old stands. The healing of bark lesions varies by the quantity of removed bark, as well as by vigour and species, whereas all damaged trees maintain rot pockets even after minor injury, regardless of age. Heavier damage results in interior trunk rot over the following decades [8]. Healing tree damage to the greatest extent possible in stands where thinnings were applied reduced the risk of obtaining depreciated wood with root at harvesting age. In the present study, most of the damage was found in thinnings. This is due to the space between the residual trees because when spacing is narrow, there is a higher probability of increased residual tree damage when logs are skidded [46].

Regarding the ratio between damage width and tree circumference, some research has shown that in the case of using skidders, the ratio between damage width and the stem circumference has values of 0.093 (9.3%) for the most frequent damage and 0.12 (12%) for the most severe damage [42]. These data are similar to those obtained in the current study, where the average of the ratio between the width of healed damage and tree circumference was approximately 0.10 in the analysed sample plots (0.09 for damage healed during the analysed period and 0.12 for damage identified as healed in the initial evaluation). The wound healing rate is related to DBH (circumference in the present study), and the rate decreases with increasing wound width [47].

The results of other investigations regarding the ratio between stem and wound for scrapes were similar among treatments, but the same ratios for gouges and scuffs were larger under high-intensity treatment [43]. In the present study, there was an increase in the value of this ratio from 0.09 for thinning to 0.10 for first-intervention cuttings.

Observations in beech stands show that all wounds with an initial width of less than 5 cm were healed [48]. Results of the present study reveal a high inverse correlation between the width and the circumference of damage in beech trees.

Similar investigations studying the healing rate of damage from poplars have found similar healing rates. This is especially true in the N orientation, where the highest percentage of healed damage is recorded [49]. Similarly, in the present study, the highest percentage of healed damage was recorded for damage with N orientation (13.5%), although significant percentages of healed damage were also maintained in the neighbouring cardinal orientations, namely NW (11,3%) and NE (10.3%).

4.2. Discussion and Recommendations Regarding Good Practices for Logging Management and Respecting Tolerance Thresholds

To protect the forest ecosystem, some studies have shown that applying specific measures can reduce the damage to residual trees by 25–33% [50]. One such measure is equipping forests with a network of roads to reduce the average distances for collecting wood [51].

A basic necessity for the ecological harvesting of forests is the use of a method with a low impact on the forest ecosystem. This includes the cut-to-length harvesting method [52]. This method was used in 23 out of the 24 studied harvesting sites. As previously mentioned, this harvesting method causes the fewest seedling and soil injuries, as well as using collecting methods at capacity. Using the shortwood system in the final cutting is the dominant practice in Nordic countries [53]. Studies from Poland have shown that the shortwood system caused the fewest tree injuries in stands of all ages [54].

Another basic condition for the long-lasting development of forests that is not widely used in Romania (a fact also observed in the studied variants) is represented by linking a system of improved machines with the forest regeneration regimes and treatments. For example, modern machines were used in the thinning work and in certain field conditions that were developed and improved along with other adaptations for agricultural tractors [55]. Different adaptations and improvements of forest equipment are necessary, as the damage potential increases in some cases due to the difficulty of manipulating machines in very dense stands [56].

By studying the ratio between the damage width and tree circumference, research comparing crawlers with cable yarders for collecting timber has shown a smaller surface affected by damage in the latter case [42]. A series of additional measures are recommended to ensure favorable effects after harvesting operations. These measures must be technically feasible and economically acceptable [57].

These measures were not typically seen in the analysed parcels; however, some of the practical measures that can decrease the damage caused by timber harvesting will be mentioned. The measures that can be applied include using sustaining coils for load cables to transport pieces by semi-suspension and using direction coils to form the load; using tractors equipped with roller chains in fields with a low carrying capacity; proper assignments; protecting the soil and trees in places where timber is stocked; protecting trees that border skid trails; protecting seedlings by placing paths and collecting tracks outside seedling loci; protecting seedlings with wood ramparts; and using harvest remains to reduce erosion in certain areas.

The results of these studies suggest that low-impact timber harvesting operations should be accompanied by a close surveillance of field personnel, by a financial motivation to encourage—or, based on the case, to discourage—negative activities and by post-harvest inspections to verify proper implementation [58].

5. Conclusions

Based on the data obtained from sample plots, we established that the value of the ratio between the damage width and the tree circumference can be considered a tolerance threshold for trees in logging. The value of this ratio is of 0.09 for thinnings, cuttings to increase light availability for regeneration and final cuttings and 0.10 for first-intervention cuttings.

Equations for each variant and for the main species have been elaborated. The equations were used to obtain the tolerance threshold expressed as the maximum value of the relation between the damage width and the tree circumference, for which the damage is curable.

The *ANOVA* test showed significant differences ($p^* < 5\%$) between the damage width and the tree circumference ratio for two pairs of samples, namely SW and S orientations, as well as SW and NE. As such, differences between samples based on damage orientation are mainly insignificant, so it is not possible to determine representative values that can be considered tolerance thresholds according to cardinal orientation. Therefore, we adopted values obtained previously in silvicultural work as tolerance thresholds concerning the limit to which tree damage in different cardinal orientations is healed in a certain time period.

Author Contributions: Conceptualization, I.-C.C. and L.D.; methodology, I.-C.C.; software, V.E.C.; validation, L.D., G.F.B. and V.E.C.; formal analysis, I.-C.C.; investigation, I.-C.C. and C.-I.C.; resources, I.-C.C.; data curation, C.-I.C.; writing—original draft preparation, I.-C.C. and L.D.; writing—review and editing, I.-C.C., L.D. and V.E.C.; visualization, C.-I.C. and G.F.B.; supervision, L.D.; project administration, I.-C.C.; funding acquisition, I.-C.C. All authors have read and agreed to the published version of the manuscript.

Funding: This paper was carried out with the support of the Ministry of Research, Innovation and Digitization (MCID) through the "Nucleu" program—project no. 19070507 and through "Programul 1—Dezvoltarea sistemului naţional de cercetare—dezvoltare, Subprogram 1.2—Performanţă instituţională—Proiecte de finanţare a excelenţei în CDI"—project "Creșterea capacității și performanței instituționale a INCDS "MarinDrăcea") în activitatea de CDI—CresPerfInst" (Contract No. 34PFE./30.12.2021).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The data presented in this study are available from the corresponding author upon request. The data are not publicly available becuase the project through which the research was funded is not yet completed.

Acknowledgments: We are thankful to all colleagues for constructive advice and especially to Ion Chisăliţă, former director of Timişoara Research Station.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The arrangement of the harvesting sites in variants and relief forms is the following:

- V1—harvesting sites with thinnings from:
    - Plains: Forest department (OS) Bocşa Română—Production unit (UP) II, management unit (u.a.) 58A and UP III, u.a. 49;
    - Hill: OS Bocşa Montană—UP VI, u.a. 95A and OS Moldova Nouă—UP III, u.a. 15B;
    - Mountain: OS Băile Herculane—UP II, u.a. 23 and Caransebeş experimental basis (BE)—UP VI, u.a. 99A.
- V2—harvesting sites with first-intervention cuttings—preparatory and seed-cutting from shelterwood system or selections system, from:
    - Plains: OS Bocşa Română—UP I, u.a. 11C and UP II, u.a. 55;
    - Hill: OS Bocşa Montană—UP IV, u.a. 62B and OS Moldova Nouă—UP III, u.a. 212A;
    - Mountain: OS Văliug—UP VI, u.a. 15A and u.a. 16A.
- V3—harvesting sites with cuttings to increase light availability for regeneration from shelterwood system, from:
    - Plains: OS Bocşa Română—UP III, u.a. 28B and 76A;
    - Hill: BE Caransebeş—UP II, u.a. 30B and OS Moldova Nouă—UP III, u.a. 176A;
    - Mountain: OS BăileHerculane—UP II, u.a. 99A and 100A.
- V4—harvesting sites with final cuttings from shelterwood system, from:
    - Plains: OS Bocşa Română—UPI, u.a. 1E and 14A;
    - Hill: BECaransebeş—UP I, u.a 46D şi OS Moldova Nouă—UP III, u.a. 15B;
    - Mountain: OS BăileHerculane—UP IV, u.a. 98A şi BE Caransebeş—UP V, u.a. 16A.

Appendix B

Table A1. Synthesis of data regarding damage and characteristics.

Variant	Harvesting Site—Forest District, Production Unit, Management Unit	Healed Damage				Total number of Injuries in Sample Plots	from Which:				
		Initial Assessment		Revaluation							
		Number of Healed Injuries	Ratio between the Initial Damage Width and Tree Circumference	Number of Healed Injuries	Ratio between the Initial Damage Width and Tree Circumference		Galling	Barking	Splintering	Breaking	Uprooting
V1	h1—Bocșa Română, III, 49	0	0	1	0.07	38	2	33	3	0	0
	h2—Bocș aRomână, II, 58A	0	0	1	0.08	18	2	15	0	1	0
	h3—Bocșa Montană, VI, 95A	0	0	1	0.03	92	18	70	1	1	2
	h4—Moldova Nouă, III, 15B	0	0	6	0.04	229	28	190	11	0	0
	h5—Băile Herculane, II, 23	6	0.08	9	0.08	230	2	189	39	0	0
	h6—Caransebeș, VI, 99A	28	0.12	14	0.08	207	8	162	32	4	1
Total plain		0	0.00	2	0.08	56	4	48	3	1	0
Total hill		0	0.00	7	0.04	321	46	260	12	1	2
Total mountain		34	0.11	23	0.08	437	10	351	71	4	1
Total thinnings		34	0.11	32	0.07	814	60	659	86	6	3

Table A1. *Cont.*

Variant	Harvesting Site—Forest District, Production Unit, Management Unit	Healed Damage				Total number of Injuries in Sample Plots	from Which:				
		Initial Assessment		Revaluation							
		Number of Healed Injuries	Ratio between the Initial Damage Width and Tree Circumference	Number of Healed Injuries	Ratio between the Initial Damage Width and Tree Circumference		Galling	Barking	Splintering	Breaking	Uprooting
V2	h1—Bocșa Română, II, 55	0	0	0	0	14	0	12	2	0	0
	h2—Bocșa Română, I, 11C	0	0	0	0	36	0	33	2	0	1
	h3—Bocșa Montană, IV, 62B	0	0	0	0	40	4	33	3	0	0
	h4—Moldova Nouă, III, 212A	1	0.04	5	0.08	87	20	57	10	0	0
	h5—Văliug, VI, 15A	3	0.22	9	0.11	118	5	90	23	0	0
	h6—Văliug, VI, 16A	8	0.17	10	0.12	89	7	67	12	3	0
Total plain		0	0.00	0	0.00	50	0	45	4	0	1
Total hill		1	0.04	5	0.08	127	24	90	13	0	0
Total mountain		11	0.18	19	0.12	207	12	157	35	3	0
Total first-intervention cuttings		12	0.17	24	0.11	384	36	292	52	3	1

Table A1. *Cont.*

Variant	Harvesting Site—Forest District, Production Unit, Management Unit	Healed Damage				Total number of Injuries in Sample Plots	from Which:				
		Initial Assessment		Revaluation							
		Number of Healed Injuries	Ratio between the Initial Damage Width and Tree Circumference	Number of Healed Injuries	Ratio between the Initial Damage Width and Tree Circumference		Galling	Barking	Splintering	Breaking	Uprooting
V3	h1—Bocșa Română, III, 76A	0	0	0	0	53	0	39	8	4	2
	h2—Bocșa Română, III, 28B	0	0	1	0.08	18	1	13	1	3	0
	h3—Moldova Nouă, III, 176A	0	0	13	0.09	105	15	79	10	1	0
	h4—Caransebeș, II, 30B	0	0	0	0	43	1	38	2	2	0
	h5—Băile Herculane, II, 99	2	0.05	3	0.08	76	2	60	12	2	0
	h6—Băile Herculane, II, 100A	2	0.04	11	0.10	106	12	78	9	4	3
Total plain		0	0.00	1	0.08	71	1	52	9	7	2
Total hill		0	0.00	13	0.09	148	16	117	12	3	0
Total mountain		4	0.05	14	0.10	182	14	138	21	6	3
Total cuttings to increase light availability for regeneration		4	0.05	28	0.09	401	31	307	42	16	5

Table A1. *Cont.*

Variant	Harvesting Site—Forest District, Production Unit, Management Unit	Healed Damage				Total number of Injuries in Sample Plots	from Which:				
		Initial Assessment		Revaluation							
		Number of Healed Injuries	Ratio between the Initial Damage Width and Tree Circumference	Number of Healed Injuries	Ratio between the Initial Damage Width and Tree Circumference		Galling	Barking	Splintering	Breaking	Uprooting
V4	h1—Bocșa Română, I, 1E	0	0	0	0	32	2	28	1	1	0
	h2—Bocșa Română, I, 14A	0	0	0	0	27	1	23	2	1	0
	h3—Moldova Nouă, III, 162B	1	0.26	6	0.17	75	9	56	8	1	1
	h4—Caransebeș, I, 46D	5	0.09	8	0.05	91	7	68	13	3	0
	h5—Băile Herculane, IV, 98A	2	0.15	5	0.04	65	1	58	4	2	0
	h6—Caransebeș, V, 16A	6	0.05	5	0.17	56	4	43	6	2	1
Total plain		0	0.00	0	0.00	59	3	51	3	2	0
Total hill		6	0.12	14	0.10	166	16	124	21	4	1
Total mountain		8	0.08	10	0.11	121	5	101	10	4	1
Total final cuttings		14	0.09	24	0.10	346	24	276	34	10	2
TOTAL		64	0.12	108	0.09	1945	151	1534	214	35	11

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