forests

Article

Importance of the Moisture Content of Large-Sized Scots Pine (*Pinus sylvestris* L.) Roundwood in Its Road Transport

Paweł Kozakiewicz [1,*], Łukasz Tymendorf [2] and Grzegorz Trzciński [2]

[1] Department of Wood Sciences and Wood Preservation, Institute of Wood Sciences and Furniture, Warsaw University of Life Sciences—SGGW, 159 Nowoursynowska St., 02-776 Warsaw, Poland
[2] Department of Forest Utilization, Institute of Forest Sciences, Warsaw University of Life Sciences—SGGW, 159 Nowoursynowska St., 02-776 Warsaw, Poland; luktym@gmail.com (Ł.T.); grzegorz_trzcinski@sggw.edu.pl (G.T.)
* Correspondence: pawel_kozakiewicz@sggw.edu.pl

Abstract: Scots pine (*Pinus sylvestris* L.) is one of the most important forest tree species in Europe, and its wood is a main raw material in the wood industry of many countries of the region. The high variability of pine wood density in connection with its moisture content is a challenge in transport operations. An important part of the roundwood transport of pine wood by trucks is the transport of large-size roundwood (sawlogs). As part of the research, an analysis was carried out of the influence of absolute wood moisture content, determined in various ways, on selected truck transport parameters of large-size pine wood. The analyses of the supply of wood to a large sawmill in northern Poland took into account different seasons. The results indicate that the average moisture content of the transported pine wood is at a level of approximately 95% (determined by dry weight) and the density at 0.878 Mg m^{-3} (determined using the stereometric method). Quick measurement with the use of a resistance hygrometer gives significantly lower results both on the side surface and on the cross-cut end of the log. Regardless of the method of measurement, the absolute moisture content of wood in loads depends on the date of delivery (season), which is reflected in the variability of the density and weight of the loads. The indicated strong correlations between the selected, tested characteristics of roundwood transports are important for forestry practice too. It is the possibility of using the methods of quick determination of fresh wood moisture to estimate the density of wood and to predict and determine the mass of the load.

Keywords: Scots pine wood; absolute moisture content; density of wood; road transport; raw wood

check for updates

Citation: Kozakiewicz, P.; Tymendorf, Ł.; Trzciński, G. Importance of the Moisture Content of Large-Sized Scots Pine (*Pinus sylvestris* L.) Roundwood in Its Road Transport. *Forests* **2021**, *12*, 879. https://doi.org/10.3390/f12070879

Academic Editor: Angela Lo Monaco

Received: 21 May 2021
Accepted: 24 June 2021
Published: 5 July 2021

1. Introduction

Moisture content is the basic feature of wood that has a relevant effect on other properties including density and strength, suitability for further technological operations and resistance to biotic factors [1]. It is also a feature that affects the parameters of road transports of roundwood [2]. Moisture content, followed by the density of the wood, is the basis for determining the limitations capacity in the existing transport regulations [3,4]. At the same time, the high variability of these parameters, despite the guidelines in the regulations, can lead to overloading or to not using the full capacity of the trucks with wood [5–11]. Research conducted in Ireland, based on the analysis of 100 deliveries of Sitka spruce (*Picea sitchensis* L.), showed that the total weight of the truck was exceeded in 67% of cases [2]. Moisture content of roundwood is an extremely important factor in its transport, determining, among others, the weight of the load. Due to the complexity and variability of moisture content, this issue is still not fully recognized. This also applies to Scots pine wood, one of the most important species in the wood industry in many European countries. It is a species with unflagging potential [12]. Scots pine forest covers an area of 41 million hectares in Western Europe, e.g., in Finland, Sweden and Poland, and it is a dominant species on more than 50% of forestland [13]. In Poland, it finds optimal conditions for its growth. At the same time, this species, due to the wide range of occurrence and genetic variation, is characterized by high variability of morphological and fitness features, physiological growth and adaptive-immune traits [14,15]. Depending on the above factors, Scots pine will generate wood of various densities. Even the density is interchangeable due to the position in the trunk. Wood has the highest density in the butt, decreasing with the height of the trunk. Density also changes on the cross-section, increasing along with distance from the core [16–18]. The moisture content of wood in Scots pine trees also changes during the year [1,19,20], which affects the weight of logs harvested. This variability is also determined by the proportion of sapwood and heartwood with significantly different moisture levels in standing trees. The elapsing time since the trees were felled and the method of storing the harvested roundwood, which determine the speed of its drying, are also important [21,22]. The problem of determining the volume and weight of the transported wood load in the context of changes in its moisture and density is a universal problem and analyzed for various species on different continents. The aim of the work is to investigate this issue for Scots pine wood on the example of round timber deliveries to a sawmill in northern Poland. Knowing the actual weights of transported Scots pine roundwood loads and trying to relate them to the varying moisture content of the load will help to avoid overloading the trucks. At the same time, it will make it possible to optimize the capacity of the transport set. This knowledge has important practical implications and the issue itself has a universal scope.

2. Materials and Methods

2.1. Roundwood Deliveries

The research was carried out for the supply of Scots pine (*Pinus sylvestris* L.) roundwood to a large sawmill located in the northern part of Poland (Latitude: 53°23′ North, Longitude 20°56′ East), receiving homogeneous loads of large-size wood in the form of unbarked sawlogs (Figure 1).

Figure 1. Example of a typical delivery of large-sized pine sawlogs (curried by truck and semi-trailer).

Logs are transported by various types of truck units. Truck and trailer and truck and semi-trailer are dominated in transport. Most trucks do not have loader scales, and if so, they do not allow the weight of the load in the trailer to be determined. More about the road transport of roundwood in Poland and the trucks used for this purpose is presented by Trzciński et al. [10]. Large-size wood is wood with a thin end minimum diameter of 14 cm (excluding bark), calculated in single pieces. In terms of quality and size, large-size wood is divided into four classes—A, B, C, D—and into two sub-classes—general-purpose wood and special-purpose wood [23,24]. The large-size general-purpose wood is comparable to the assortment defined as sawmill wood. Medium-size wood is wood with a minimum diameter of 5 cm and more (excluding bark), with a thick end diameter of up to 24 cm, calculated in single pieces, in pieces as groups and in stakes [10,23,24]. The transport was performed by external companies acting on behalf of the sawmill. A total of 515 deliveries were investigated, at different times of the year. The research was conducted in November (fall) 2018 and in February (winter), April (spring), and June (summer) 2019 (Table 1). The volume of transported wood m^3 (solid cubic meter m^3) was determined on the basis of a sawlogs delivery note issued to the carrier by the State Forest District (forester) after verification by the Wood Reception Department at the sawmill.

Table 1. Overview of research material collected.

Parameter Date	Scots Pine Sawlogs Deliveries	Delivered Quantity of Wood (m^3)	Number of Deliveries Tested and Sampled
5–6 XI 2018	112	3.306	58
4–6 II 2019	154	4.540	61
8–9 IV 2019	93	2.763	41
17–19 VI 2019	156	4.608	31
Total	515	15.217	191

The weight of the transported wood (Mg) was determined as the difference between the gross vehicle weight (GVW) and the weight of the empty truck set (tare). Weights were determined by weighing trucks on a stationary scale at the sawmill (to the accuracy of 0.05 Mg) before unloading (with wood) and again after unloading (empty truck) (Figure 2).

Figure 2. Weighing station for whole transport sets on a stationary scale (roundwood carried by truck and trailer).

2.2. Moisture Content of Wood

In a research of 191 out of 515 roundwood deliveries, the absolute moisture content of wood was determined directly at the sawmill by the electrometric method (resistance meter) using an electric resistance moisture meter (hammer moisture meter with WRD100 needle probes). Approximately 20 measurements of absolute moisture content of sapwood (AMCSs) were made for each single delivery. These measurements were made after the sapwood had been exposed (local bark removal) on the sides of at least four randomly selected sawlogs. During the measurements of moisture contents with a resistance meter on the side of the sawlog, the guidelines of EN 13183-2:2002 [25] were used. These regulations were adapted for the needs of moisture contents assessment of roundwood. A measurement was also taken for absolute moisture content of sapwood (AMCSc) on the cross-cut ends of the sawlog. This is an easier operation because it does not require bark removal. However, this method can lead to inaccurate determinations and shall be taken as indicative. For the obtained results, the coefficient of variation and standard deviation were calculated. It was assumed that if the coefficient of variation was at the level of 20%, the variability of the absolute moisture content from the measurements with the resistive hygrometer is weak [26] and mean values were used for further comparisons (statistical analyses). At the same time, from the same transports, wood slices with a thickness of 5 to 10 cm were obtained, cut at a distance of at least 50 cm from the front of the logs. These slices were used for the evaluation of green density by the stereometric method and for an alternative method of determining the absolute moisture content of wood (AMC) by the dryer-weight method. After labeling the wood sample, it was immediately weighed on an electronic scale with an accuracy of 2 g. With the regular circular shape of the slices, their volume was determined by measuring their diameter and thickness, and with the less regular, by immersion method on the basis of the volume of water displaced. In terms of the accuracy of mass measurements, the method of drying samples and the method of calculating the absolute moisture content with the drying-weighing method, the provisions of the EN 13183-1: 2002 [27] standard have been adopted. The obtained results were analyzed statistically with the use of the STATISTICA 12 package. For comparative analyses, average values obtained from all slices from each transport were adopted. The overall results were divided into four groups related to the selected seasons (four two-day field trips during which measurements were taken). The significance of differences in the analyzed features between transports depending on the date (season) was checked by the Kruskal–Wallis test and the Dunn test (significant level was 0.05). An analysis of the relationship between the absolute moisture content (AMC) and the absolute moisture content of sapwood (AMCSs and AMCSc) with the selected tested load characteristics was also carried out, using the Spearman's rank order correlation test. The Mann–Whitney test was used for randomly selected values of density and absolute moisture content of wood.

3. Results

3.1. Characteristic of Scots Pine Sawlogs Deliveries

As part of the field work (four trips of two days), a total of 515 deliveries of Scots pine sawlogs to the sawmill were registered, which delivered 15.217 m^3 of Scots pine wood. For 37% of all deliveries (191 deliveries), wood samples (slices) were taken to measure wood density and moisture content (Table 1). The moisture content was also measured with a resistance electrometric hygrometer with a hammer probe on the side surface and cross-cut end of the log.

The average volume of transported wood (from 515 transports) was 29.64 m^3 with the result range from 22.87 to 35.85 m^3 with SD = 1.87 (Table 2). The average weight of the load was 30.88 Mg with SD = 2.52, with range from the minimum value of 22.10 Mg up to 37.60 Mg. The calculated weight of 1 m^3 of the load is 1.042 Mg m^{-3} with low variability SD = 0.069. This parameter was calculated as the weight of the load divided by volume of the load.

Table 2. Characteristic of Scots pine sawlogs deliveries parameters.

Measure	Mean	SD	Min	Max	Q1	Median	Q3
Weight of load (Mg)	30.88	2.52	22.10	37.60	29.15	31.00	32.50
Load volume (m^3)	29.64	1.87	22.87	35.85	28.43	29.17	30.95
Weight of 1 m^3 of load from weighing the trucks (Mg m^{-3})	1.042	0.069	0.805	1.309	1.004	1.041	1.082
Green density (Mg m^{-3})	0.878	0.162	0.392	1.698	0.782	0.861	0.935

Notes: SD. standard deviation; Q1. first quartile; Q3 third quartile.

The volume of transported wood is very similar throughout the period and there are no statistically significant differences (Kruskal–Wallis test p = 0.735) between transports depending on the delivery date (Figure 3a). Small variability of the weight of the load (mean, median and Q1 and Q3 values) depending on the delivery date (Table 2) was confirmed by the statistical analysis using the Kruskal–Wallis test (p = 0.073), showing no significant differences (Figure 3b). The weight of 1 m^3 of the load varies greatly depending on the time of delivery (p = 0.001), and statistical analyses (Dunn's test) showed no differences between the data from IV and VI and for XI from II. Fresh wood density (green density) obtained from collected slices significantly differs depending on the date of delivery (p = 0.001 Kruskal–Wallis). There are similar results for selected pairs of months (Dunn's test) IV with VI (p = 0.055) and XI with II with p = 0.550 (Figure 3d). There are clear differences for both parameters between XI (autumn) and II (winter) and IV (spring) and VI (summer). An interesting relationship is revealed on the basis of the density analysis of fresh Scots pine wood. In all analyzed periods, the average density of the wood slices is lower than the weight of 1 m^3 of the load obtained from the trucks' weighing (Figure 3c,d). The weight of 1 m^3 of the load obtained from weighing transport sets (dividing the weight by the volume), on average 1.042 Mg m^{-3}, differs from the obtained density of (fresh) wood determined on the slices (0.878 Mg m^{-3}). This was confirmed by statistical analysis with the Mann–Whitney test (p = 0.001) and shown in (Figure 4).

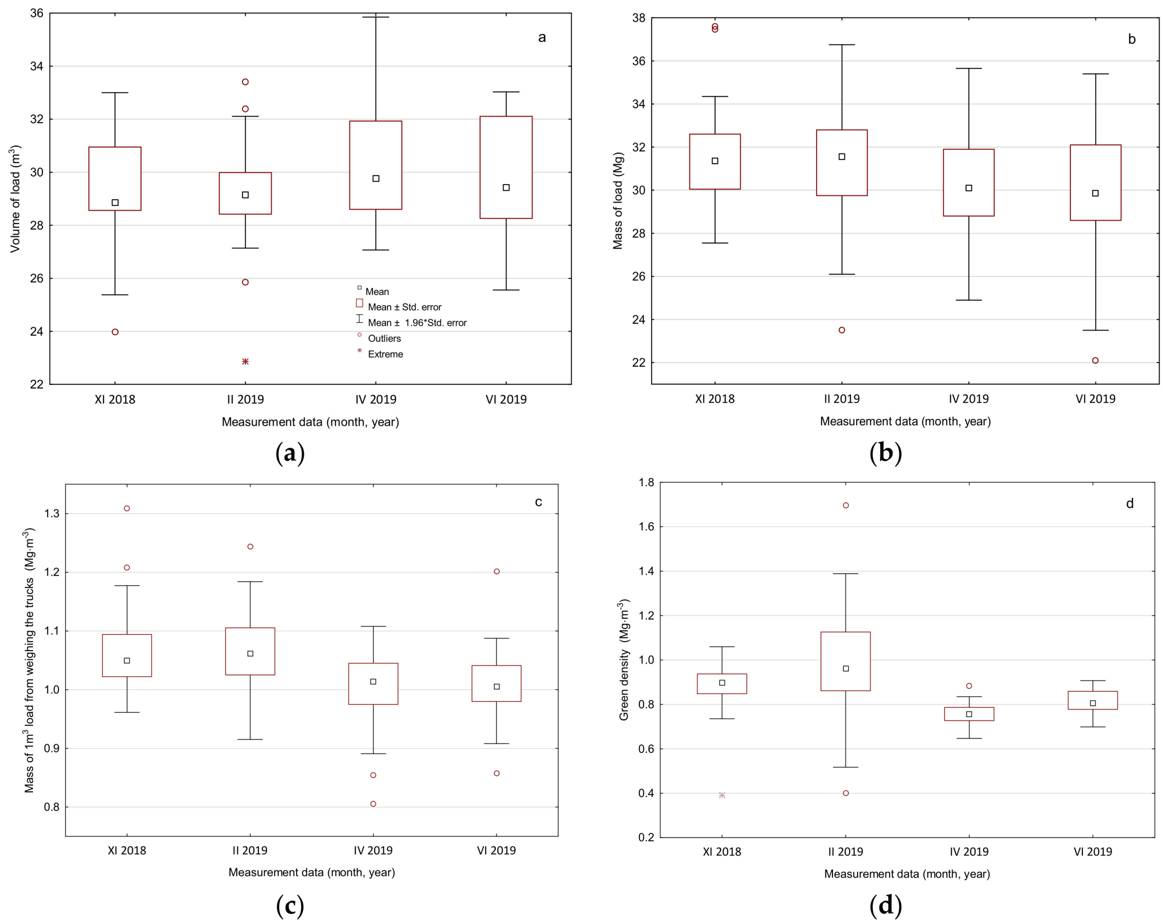

Figure 3. Characteristics of Scots pine sawlogs deliveries parameters depending on the delivery date: (**a**) Load volume (m^3), (**b**) Weight of load (Mg), (**c**) Weight of 1 m^3 of load from weighing the trucks (Mg m^{-3}), (**d**) Green density (Mg m^{-3}).

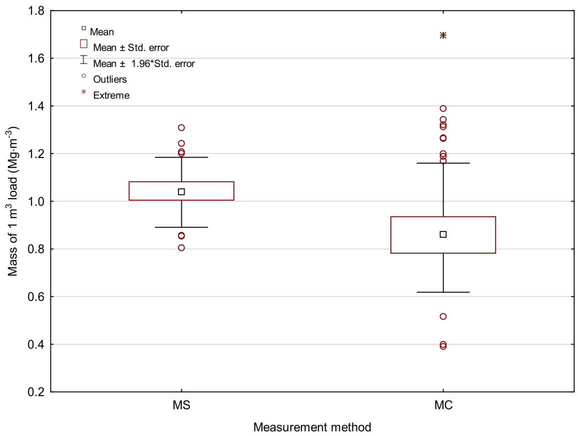

Figure 4. Comparison of the weights of 1 m^3 of load depending on the measurement method. MS-from weighing of transport sets, MC-from collected wood slices.

3.2. Moisture Content of Scots Pine Sawlogs Deliveries

For each delivery, the mean values of absolute wood moisture content from the collected slices and for absolute moisture content of sapwood measured along the length of the log (AMCSs) and on the fronts of the log (AMCSc) were calculated using a resistance electrometric hygrometer with a hammer probe. Average values for each delivery were used for further comparative analyses. The mean absolute wood moisture content for all collected samples (515 slices) was 94.17%, with the standard deviation SD = 21.53% with the range of occurrence of results from 40.26% to 157.00% (Table 3). Absolute moisture content of sapwood on the side of logs (AMCSs) was on average 58.31% for all tested deliveries, with a range from 30.11% to 89.05%, and it is greater than the average value for absolute moisture content of sapwood on cross-cut ends of the log (AMCSc)—52.60%. The result range for AMCSc measurements is 27.18% up to 87.80%. (Table 3).

Table 3. Characteristics of average values of absolute moisture content of Scots pine sawlogs loads.

Measure	Mean	SD	Min	Max	Q1	Median	Q3
Absolute moisture content of wood (AMC) (%)	94.17	21.53	40.26	157.00	79.91	95.33	108.60
Absolute moisture content of sapwood on side of log (AMCSs) (%)	58.31	11.43	30.11	89.05	50.20	56.68	66.69
Absolute moisture content of sapwood on cross-cut end (AMCSc) (%)	52.60	14.31.	27.18	87.80	41.35	47.27	65.60

Notes: SD, standard deviation; Q1, first quartile; Q3, third quartile.

The absolute wood moisture content in the loads depends on the delivery date, which was confirmed by statistical analysis (Kruskal–Wallis test $p = 0.001$). Comparison of the sampling terms with each other (Dunn's test) shows no statistically significant differences only for the absolute moisture content of wood from terms XI with II, and the collected data for IV and VI differ with all terms (Figure 5).

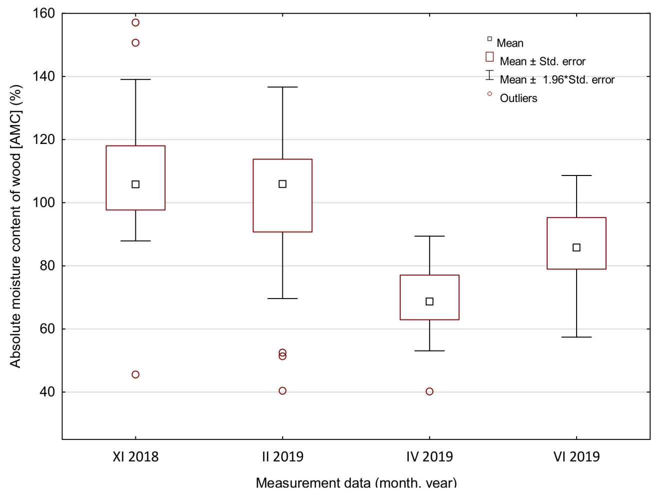

Figure 5. Absolute moisture content (AMC) of Scots pine sawlogs depending on the delivery date.

The mean values of the absolute moisture content of sapwood regardless of the measurement places (AMCSs and AMCSc) vary greatly depending on the delivery date. This was confirmed by analysis by the Kruskal–Wallis test $p = 0.001$ (Figure 6). At the same time, in both cases the measurements (AMCSs and AMCSs) show high variability. There are no statistically significant differences only for the measurements from IV and VI (Dunn's test).

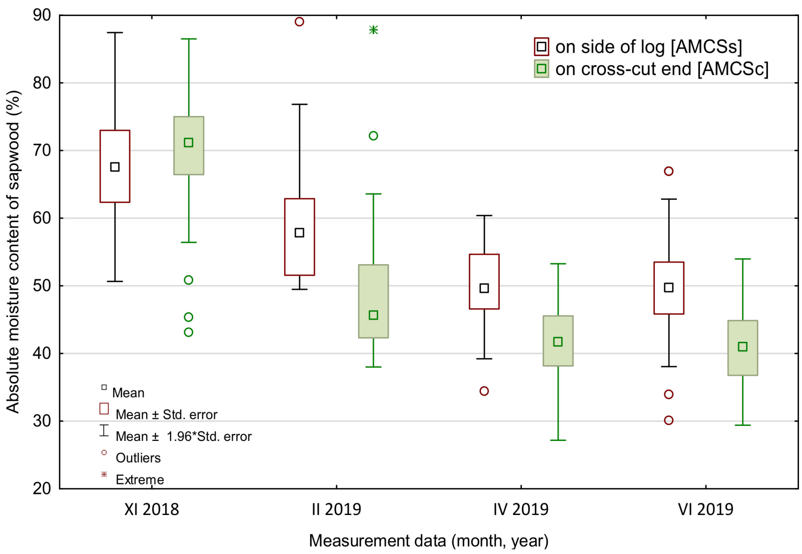

Figure 6. Absolute moisture content of sapwood depending on the measurement place (on side of log and on cross-cut end) and delivery date.

Absolute moisture content values of sapwood depending on the measurement point (AMCSs) and (AMCSc) are very different from each other (Figure 7), which was confirmed by the Mann–Whitney test analysis ($p = 0.001$). The average moisture content indicated on the cross-cut ends of the log is lower than indicated on the side of the log.

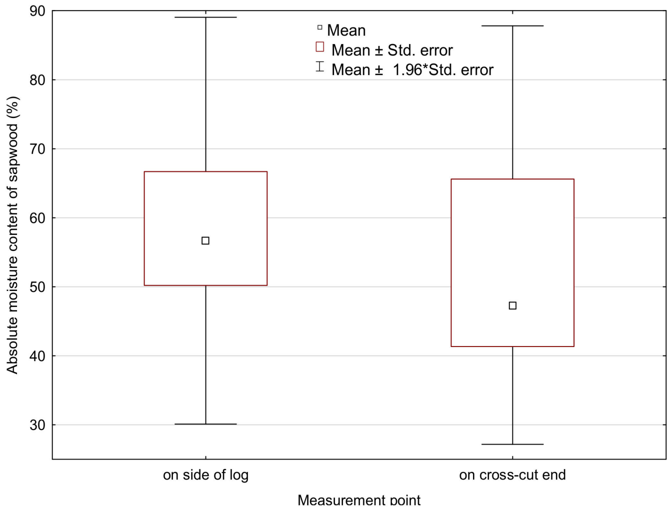

Figure 7. Comparison of the absolute moisture content of sapwood by measurement point (AMCSs with AMCSc).

3.3. Relationships between Scots Pine Sawlogs Moisture Content and Wood Deliveries Parameters

The obtained statistically significant coefficients of Spearman's correlation between the selected analyzed features are presented in Table 4. The performed analyses show that in the case under consideration, the absolute moisture content (AMC) is a factor that significantly influences (0.6804) the wood density, as well as the moisture content of sapwood (AMCSs) and (AMCSc) with correlation coefficients 0.4936 and 0.3692, respectively. The high correlation coefficient of 0.8039 between AMC and AMCSs proves the strong relationship of these features. The absolute moisture content of sapwood on the side of the log (AMCSs) measurement method can be useful for quick determination of the moisture content of fresh wood, and hence the wood density, to determine the weight of the load.

Table 4. Spearman's correlation coefficients (r) for the analyzed parameters.

Measure Parameters	Load Volume (m^3)	Weight of Load Volume (Mg)	Weight of 1 m^3 of Load ($Mg\ m^{-3}$)	Green Density ($Mg\ m^{-3}$)	AMC (%)	AMCSs (%)	AMCSc (%)
Load volume (m^3)	-	0.6120	-	-	-	-	-
Weight of load (Mg)	0.6120	-	0.4653	0.2445	0.1724	0.2253	0.2335
Weight of 1 m^3 of load ($Mg\ m^{-3}$)	-	0.4653	-	0.3729	0.3216	0.3520	0.3337
Green density ($Mg{\cdot}m^{-3}$)	-	0.2445	0.3729	-	0.6804	0.4936	0.3692
AMC (%)	-	0.1724	0.3216	0.6804	-	0.5975	0.5062
AMCSs (%)	-	0.2253	0.3520	0.4936	0.5975	-	0.8039
AMCSc (%)	-	0.2335	0.3337	0.3692	0.5062	0.8039	-

'-' means no statistically significant correlation (significant level 5%).

The highest correlation between absolute moisture content and load parameters was obtained for green density of 0.6804, which indicates the possibility of searching for a regression equation. The linear regression model was developed using the least squares method (OLS), and the significance of the calculated coefficients was assessed using the Student's *t*-test at $\alpha = 0.05$ and the results are presented in Table 5 and Figure 8.

Table 5. Evaluation of model parameters on green density depending on absolute moisture content of wood (AMC).

Parameter	Parameter Value	Standard Error	*t*-Statistic	*p*-Value	Standard Error of Estimation	r^2-Coefficient of Determination
Constant term	0.48144	0.04393	10.9595	0.0000	0.1349	0.3116
AMC	0.00421	0.00046	9.2487	0.0000		

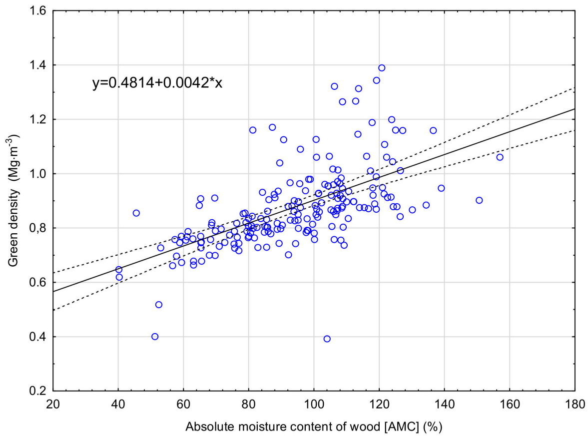

Figure 8. Relationship of the density of fresh wood on the absolute moisture content (AMC).

Determining absolute moisture content (AMC) by the dryer-weighing method is very laborious and impossible in the field. In opposite, absolute moisture content of sapwood (AMCSs), as measured by a hammer probe resistance electrometric hygrometer, produces an immediate result. These moisture contents are strongly correlated with each other, where the Spearman correlation coefficient was 0.5975 (Table 4). A model of the linear relationship of AMC on AMCSs was developed, where statistically significant coefficients of the equation are presented in Table 6 and Figure 9.

Table 6. Assessment of model parameters for absolute moisture content of wood (AMC) depending on absolute moisture content of sapwood on the side of the log (AMCSs).

Parameter	Parameter Value	Standard Error	*t*-Statistic	*p*-Value	Standard Error of Estimation	r^2-Coefficient of Determination
Constant term	33.82887	7.90207	4.24102	0.0000	18.236	0.2808
AMC	0.99382	0.13302	7.47148	0.0000		

The problem in the transport of fresh roundwood is determining the weight of the load that can be taken in order not to exceed the permissible weight of the wood transport set when determining the load by the forester in m^3, which was already described in the introduction. The volume of the wood as well as the moisture content of the wood have an influence on the large variability of the weight of the load. We have developed a linear dependence on the weight of the wood load on the volume of the load and the absolute moisture content of sapwood on the side of the log (AMCSs) due to its easy measurement. The obtained linear equation, for which the constant term can be omitted because its values are not statistically significant ($p = 0.0960$), is presented in Table 7.

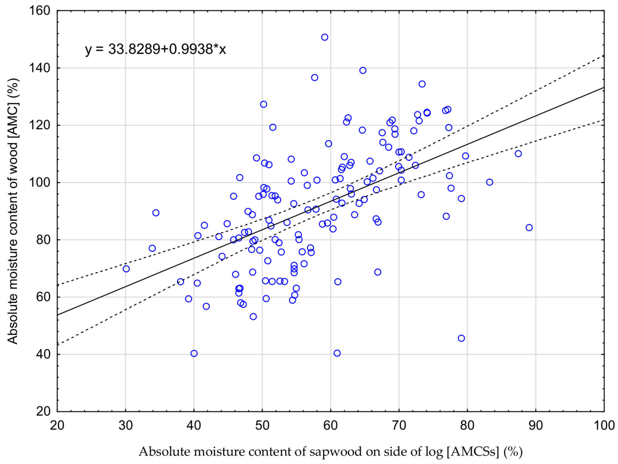

Figure 9. Relationship of the absolute moisture content (AMC) on the absolute moisture content of sapwood on the side of the log (AMCSs).

Table 7. Evaluation of the model parameters for weight of wood delivery depending on the volume of the load and absolute moisture content of sapwood on the side of the log (AMCSs).

Parameter	Parameter Value	Standard Error	*t*-Statistic	*p*-Value	Standard Error of Estimation	r^2-Coefficient of Determination
Constant term	4.26925	2.54496	1.67753	0.09564	1.8465	0.4385
Load volume (m^3)	0.77451	0.08119	9.53947	0.00000		
AMCSs	0.06060	0.01347	4.49967	0.00001		

4. Discussion

The obtained results and the observed differences between the distinguished periods (autumn–winter and spring–summer) effect from the natural cyclicality of wood moisture in living Scots pine trees (higher moisture content during the rest period and lower moisture content during the growing season) [1]. This is confirmed by Millers and Magaznieks [19] conducting research of Scots pine steam wood in the whole territory of Latvia in 2011. Sapwood moisture content changes from 113% (in the summer) to 130% (in the winter), without any reference to the age of the tree. The observed differences in wood humidity are also a consequence of typical weather conditions for a given season in the temperate climate in northern Poland (usually high relative air humidity in autumn and winter compared to average relative air humidity in spring and summer) [28]. Air with lower relative humidity has stronger drying properties and, in such conditions, the wood after harvest, in forest warehouses, loses moisture faster [22], and consequently its density decreases [1]. Regardless of the season (in all analyzed periods), the average density of the wood from the slices is lower than the weight of 1 m^3 of the load obtained from weighing trucks (Figure 3c,d and Figure 4). The density of fresh Scots pine wood, determined on the basis of the slices taken, seems more probably (correct) closer to the actual density of Scots pine wood with a moisture content of 95%. According to collective data provided in wood atlases [29], the typical density of fresh Scots pine wood ranges from 0.750 to 0.850 Mg m^{-3}, with an average value of 0.820 Mg m^{-3}. According to Shmulsky and Jones [30], in the case of freshly harvested pine wood, the weight of 1 m^3 is estimated at 0.750 Mg. The density of the wood also depends on the part of the tree from which the assortment comes. The butt-end section is characterized by the highest density of 0.816 Mg m^{-3}, and the lowest values are recorded in the top parts of the tree, at 0.707 Mg m^{-3} [20]. The large-size Scots pine sawlogs investigated in this study came mainly from the butt-end parts and possibly from the middle part of the tree. The density of 1.042 Mg m^{-3} calculated on the basis of the quotient of weight and the volume of whole loads is overestimated, and the error most likely results from the method of determining the volume of the load [23,24]. The bark is not included in this volume, while its weight is added to the weight of the wood loads. Additionally, in winter, it can be increased by layers of crushed snow and ice attached to the logs. It should also be noted that the variability of the weight of the transported Scots pine wood volume is also influenced by the season of the year, which is confirmed in previous research [4,8,10]. As in the case of density, when measuring Scots pine wood moisture content, the influence of the seasons (Figures 5 and 6) is also significant, which determines the level of moisture content in living trees, as well as after cutting, depending on the drying properties of the air (its parameters: temperature and relative humidity) [31]. The analyzed parameters are also influenced by the fastness of the supply chain. According to Tomczak et al. [22], naturally dried (after cutting) small-diameter Scots pine wood for three summer months may have lost over 10 percentage points of its initial moisture content. The processes of natural drying of sawmill roundwood can be modeled similarly to wood for energy purposes [32]. Unfortunately, so far there are insufficient data to perform such simulations for large-size roundtimber. When measuring wood moisture using various methods, the most correct one should be the moisture obtained by the dryer-weight method. This method is considered to be more accurate and it is the so-called arbitrator's method, checking the uncertainty of determinations using resistance hygrometers, which, when measuring humidity in the range above the fiber saturation point (above 30%), give results with an accuracy of ±5%. The correctness of the measurement also depends on the depth of insertion of the hammer probe needles [1]. In the performed measurements, it was small in relation to the diameter of the logs. The results of the research show that the mean values of absolute moisture content of sapwood regardless of the measurement place (AMCSs and AMCSc) differ significantly depending on the delivery date (Figure 6). The average moisture content marked on the cross-cut ends is lower than that marked on the side surface of the log. This result seems obvious. The exposed cross-cut ends of the logs dry the fastest compared to the side surface covered with bark. The unbarked roundwood at the cross-cut ends usually has a lower moisture content, which is not fully representative of the entire volume of the log, it is lower than the average [31]. One of the basic problems in the transport of roundwood is the correct determination of the weight of 1 m^3 of load, which would allow transport companies to determine the permissible volume of roundwood loads, while using the maximum GVW (gross vehicle weight) and the capacity of the transport set, which is the subject of many studies [5,7,9,11,33–36]. The determined and described correlations between the examined characteristics of roundwood deliveries (Table 7) are an important hint for forest practice to estimate and predict the weight of roundwood loads.

5. Conclusions

As part of the work, an analysis was conducted of the influence of absolute wood moisture content, determined in various ways, on selected parameters of transports of large-size Scots pine sawlogs, taking into account the seasons of the year. Depending on how the absolute moisture content of the wood is measured, different values are obtained. The highest average value was obtained when determining this feature with an accurate dryer-weight method on slices obtained from logs (the average mositure content of wood was 94%), and significantly lower values were obtained when using a resistance hygrometer and measurements on whole logs, especially on log cross-cut ends. Regardless of the method of measurement, the absolute moisture content of wood in loads depends on the date of delivery (season), it translates into the density and weight of the delivery. The density of 1 m^3 of Scots pine wood load obtained from weighing transport sets in relation to the estimated volume of wood is overstated (significantly higher) compared to the density of fresh wood, the density determined in a laboratory by the stereometric method on slices taken from the logs. As a consequence, it is difficult to correctly determine the permissible load volume in truck transports. As part of the analyses, high and statistically significant correlation coefficients were obtained between the selected, tested characteristics of the transported Scots pine wood. They found that correlations are of practical importance, because they open up new possibilities, including the use of methods of quick determination of the moisture content of fresh wood, to estimate the density of wood and to predict and determine the weight of the load still in the forest depots (before loading the wood).

Author Contributions: Conceptualization, P.K. and G.T.; methodology, P.K. and G.T.; formal analysis, P.K. and G.T.; investigation, P.K. and G.T.; data curation, P.K. and G.T.; writing—original draft preparation, P.K., G.T. and Ł.T.; writing—review and editing, Ł.T.; visualization, P.K. and G.T.; supervision, P.K. and G.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data sharing not applicable.

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

References

1. Kozakiewicz, P. *Fizyka Drewna w Teorii i Zadaniach (Physic of Wood in Theory and Practice)*, 4th ed.; Changed; SGGW: Warsaw, Poland, 2012. Available online: https://www.researchgate.net/publication/326557330 (accessed on 15 January 2021). (In Polish)
2. Sosa, A.; Acuna, M.; McDonnell, K.; Devlin, G. Controlling moisture content and truck configurations to model and optimise biomass supply chain logistics in Ireland. *Appl. Energy* **2015**, *137*, 338–351. [CrossRef]
3. Koirala, A.; Kizhal, A.R.; Roth, B.E. Perceiving Major Problems in Forest Products Transportation by Trucks and Trailers: A Cross-sectional Survey. *Eur. J. Forest Eng.* **2017**, *3*, 23–34.
4. Trzciński, G.; Tymendorf, Ł. Dostawy drewna po wprowadzeniu normatywnych przeliczników gęstości drewna do określenia masy ładunku (Deliveries of wood after the normative calculators wood density to determine the weight of the load). *Sylwan* **2017**, *161*, 451–459. (In Polish)
5. Hamsley, A.; Greene, W.G.; Siry, J.; Mendell, B. Improving timber trucking performance by reducing variability of log truck weights. *South. J. Appl. For.* **2007**, *31*, 12–16. [CrossRef]
6. McDonell, K.M.; Devlin, G.J.; Lyons, J.; Russell, F.; Mortimer, D. Assessment of GPS tracking devices and associated software suitable for real time monitoring of timber haulage trucks. In *Annual Report*; COFORD: Ireland, UK, 2008. Available online: http://www.coford.ie/media/coford/content/researchprogramme/thematicareaharvestingandproducts/08gpstrack.pdf (accessed on 5 July 2021).
7. Ghaffariyan, M.R.; Acuna, M.; Brown, M. Analysing the effect of five operational factors on forest residue supply chain costs: A case study in Western Australia. *Biomass Bioenergy* **2013**, *59*, 486–493. [CrossRef]
8. Owusu−Ababio, S.; Schmitt, R. Analysis of Data on Heavier Truck Weights. *Transp. Res. Rec. J. Transp. Res. Board* **2015**, *2478*, 82–92. [CrossRef]
9. Brown, M. The Impact of Tare Weight on Transportation Efficiency in Australian Forest Operations. In *Harvesting and Operations Program, Research Bulletin 3*; CRC Forestry Harvesting and Operations Program: Hobart, TAS, Australia, 2008. Available online: https://fgr.nz/documents/download/4740 (accessed on 8 December 2017).
10. Trzciński, G.; Moskalik, T.; Wojtan, R. Total weight and axle loads of truck units in the transport of timber depending on the timber cargo. *Forests* **2018**, *9*, 164. [CrossRef]
11. Tymendorf, Ł.; Trzciński, G. Multi-Factorial Load Analysis of Pine sawlogs in Transport to Sawmill. *Forests* **2020**, *11*, 366. [CrossRef]
12. Ruotsalainen, S.; Persson, T. Scots pine–*Pinus sylvestris* L. In *Best Practice for Tree Breeding in Europe*; Springer: Dordrecht, The Netherlands, 2013; pp. 49–63.
13. Krakau, U.K.; Liesebach, M.; Aronen, T.; Lelu-Walter, M.A.; Schneck, V. Scots pine (*Pinus sylvestris* L.). In *Forest Tree Breeding in Wurope*; Pâques, L.E., Ed.; Springer: Berlin/Heidelberg, Germany, 2013; Volume 25, pp. 267–323. [CrossRef]
14. Giertych, M.; Oleksyn, J. Studies on genetic variation in Scots pine (*Pinus sylvestris* L.) coordinated by IUFRO. *Silvae Genet.* **1992**, *41*, 133–143.
15. Andrzejczyk, T.; Żybura, H. *Sosna Zwyczajna. Odnawianie Naturalne i Alternatywne Metody Hodowli (Scots Pine. Natural Regeneration and Alternative Breeding Methods)*; State Agricultural and Forest Publishing House: Warsaw, Poland, 2012. (In Polish)
16. Dzbeński, W.; Kozakiewicz, P.; Krutul, D.; Hrol, J.; Belkova, L. Niektóre właściwości fizyko-mechaniczne drewna sosny zwyczajnej (*Pinus sylvestris* L.) rogowskiej jako materiału porównawczego do badań na sośnie prowieniencji łotewskiej (Some Physical and Mechanical Properties of Scots Pine (*Pinus sylvestris* L.) Rogów Pine as a Comparative Material for Research on the Latvian Pine Provenance). In Proceedings of the Materials of the 14th WTD Conference of the Warsaw University of Life Sciences "Wood-the material of all times", Rogów, Poland, 13–15 November 2000; pp. 31–36. (In Polish).
17. Auty, D.; Achim, A.; Mscdonald, E.; Cameron, A.D.; Gardiner, B.A. Models for predicting wood density variation in Scots pine. *Forestry* **2014**, *87*, 449–458. [CrossRef]

18. Chmielowski, J.; Kozakiewicz, P.; Buraczyk, W. *Variability of Annual Rings and Density of Scots Pine (*Pinus sylvestris *L.) Wood of Bolewice Origin from the Provenance Surface in Rogów*; Annals of Warsaw University of Life Sciences–SGGW; Forestry and Wood Technology: Warsaw, Poland, 2018; Volume 102, pp. 11–15.
19. Millers, M.; Magaznieks, J. Scots Pine (*Pinus sylvestris* L.) Stem Wood and Bark Moisture and Density Influencing Factors. In Proceedings of the Research for Rural Development, Annual 18th International Scientific Conference Proceedings, Jelgava, Latvia, 16–18 May 2012; Volume 2, pp. 91–96. Available online: https://www2.llu.lv/research_conf/Proceedings/18th_volume2.pdf (accessed on 20 January 2021).
20. Tomczak, A.; Jelonek, T. Green density of Scots pine (*Pinus sylvestris* L.) sapwood coming from selected stands north-western Poland. *For. Lett.* **2014**, *107*, 5–9. (In Polish)
21. Tomczak, A.; Wesołowski, P.; Jelonek, T.; Jakubowski, M. Weight loss and green density changes of Scots pine pulpwood harvested and stored during the summer. *Sylwan* **2016**, *160*, 619–626. (In Polish)
22. Tomczak, K.; Tomczak, A.; Jelonek, T. Effect of Natural Drying Methods on Moisture Content and Mass Change of Scots Pine Roundwood. *Forests* **2020**, *11*, 668. [CrossRef]
23. Polish Standardization Committee. Round Wood. In *Classification, Terminology and Symbols*; PN-93/D-02002; Polish Standardization Committee: Warsaw, Poland, 2002. (In Polish)
24. General Directorate of the State Forests. *Zarządzenie nr 51 Dyrektora Generalnego Lasów Państwowych z dnia 30.09.2019 r. Regulation No. 51 of the General Director of the State Forests of 30.09.2019*; General Directorate of the State Forests: Warsaw, Poland, 2019. Available online: http://drewno.zilp.lasy.gov.pl/drewno/Normy/1._podzia_terminologia_i_symbole_-_ujednolicono_wg_zarz_54-2020.pdf (accessed on 20 October 2020). (In Polish)
25. Moisture Content of a Piece of Sawn Timber—Part 2: Estimation by Electrical Resistance Method; EN 13183-2:2002; Comité Européen de Normalisation (CEN)): Brussels, Belgium. 2002. Available online: https://standards.iteh.ai/catalog/standards/cen/c04b1bc8-0dd6-4669-9ac6-4a1cc375369d/en-13183-2-2002 (accessed on 1 February 2010).
26. Wasilewska, E. *Statystyka Opisowa nie Tylko dla Socjologów. Teoria, Przykłady, Zadania (Descriptive Statistics not Only for Sociologists. Theory, Examples, Tasks)*; Warsaw University of Life Sciences—SGGW: Warszawa, Poland, 2008; ISBN 9788372449443. (In Polish)
27. *Moisture Content of a Piece of Sawn Timber—Part 1: Determination by Oven Dry Method*; EN 13183-1:2002; Comité Européen de Normalisation (CEN): : Brussels, Belgium, 2002. Available online: https://standards.iteh.ai/catalog/standards/cen/ebaf1b83-ed78-4bfe-838f-b02fef750459/en-13183-1-2002 (accessed on 1 February 2010).
28. Korzuchowski, K. *Klimat Polski. Climate of Poland*, 1st ed.; Polish Scientific Publishers PWN: Warsaw, Poland, 2011. (In Polish)
29. Wagenführ, R. *Holzatlas. Mit 890 Zum Teil Mehrfarbigen Bildern (Wooden Atlas. With 890 Partly Multicolored Pictures)*; VEB Fachbuchverlag Leipzig: Leipzig, Germany, 2007. (In German)
30. Shmulsky, R.; Jones, P.D. *Forest Products and Wood Science*, 6th ed.; Wiley-Blackwell: Chichester, UK; Ames, IA, USA, 2011; ISBN 978-0-8138-2074-3.
31. Kozakiewicz, P. Suszenie drewna okrągłego (Log drying). *Przemysł Drzewny* **2000**, *1*, 24–27. (In Polish)
32. Kolström, M.; Ruotsalainen, J.; Sikanen, L. Validation of Prediction Models for Estimating the Moisture Content of Small Diameter Stem Wood. *Croat. J. For. Eng. J. Theory Appl. For. Eng.* **2015**, *36*, 283–291. Available online: https://hrcak.srce.hr/151826 (accessed on 18 June 2021).
33. Lukason, O.; Ukrainski, K.; Varblane, U. Economic benefit of maximum truck weight regulation change for Estonian forest sektor (Veokite täismassi regulatsiooni muutmise majanduslikud mõjud eesti metsatööstuse sektorile). *Est. Discuss. Econ. Policy* **2011**, *19*. [CrossRef]
34. Liimatainen, H.; Nykänen, L. *Impacts of Increasing Maximum Truck Weight—Case Finland*; Transport Research Centre Verne: Brno, Czechia; Tampere University of Technology: Tampere, Finland, 2017. Available online: http://www.tut.fi/verne/aineisto/LiimatainenNyk%C3%A4nen.pdf (accessed on 10 January 2021).
35. Palander, T.; Kärhä, K. Potential traffic levels after increasing the maximum vehicle weight in environmentally efficient transportation system: The Case of Finland. *J. Sustain. Dev. Energy Water Environ. Syst.* **2017**, *5*, 417–429. [CrossRef]
36. Wilson, S. Permissible Maximum Weights of Lorries in Europe. Available online: https://www.itf-oecd.org/permissible-maximum-weights-lorries-europe (accessed on 26 January 2018).