The Wood of Scots Pine (*Pinus sylvestris* L.) from Post-Agricultural Lands Has Suitable Properties for the Timber Industry

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Abstract: Scots pine (*Pinus sylvestris* L.) is a widespread species throughout Europe and at the same time is dominant in Polish forests and of key importance in the wood industry. Pine stands are subjected to numerous environmental stresses, and one of them is the different physico-chemical and biological properties of post-agricultural soils compared to forest soils, which may affect the properties of the resulting wood and its industrial suitability. The research material taken at the height of 1.3 m from tree trunks (breast height diameter, *dbh*) in the form of sections and discs was collected in an 80-year-old pine stand from four plots, representing former agricultural and ancient forest land, and two types of habitats: fresh coniferous forest and fresh mixed coniferous forest. The forest habitat trophy had a decisive impact on the dendrometric characteristics and properties of pine wood (density, modulus of elasticity, bending strength, and compressive strength along the tracheids). The history of soil use (post-agricultural or forestry) did not affect the analyzed pine wood properties. Regardless of the forest habitat type and soil type history, pine wood at the *dbh* height showed a variability of features typical of century-old cultivated stands. Individual pine trunks were characterized by significant individual variability.

Keywords: wood; conifer tree; density; modulus of elasticity; bending strength; compression strength

1. Introduction

The course of xylogenesis in trees as well as the properties of wood tissue resulting from this process are important issues in cognitive as well as practical aspects, in particular for forest management. Both the division activity of cambium underlying the entire process of secondary wood formation [1,2] as well as the subsequent stages of derivative cell differentiation are not only controlled genetically [3,4] but also epigenetically—i.e., regulated by internal and external factors acting in the environment [5,6]. Among the latter are factors basic for biogenesis, such as the temperature, light, water, soil, gravity, photoperiod, and climate factors, and occasionally such factors as wind, fires, frosts, flooding, defoliation, industrial pollution, pathogens, or breeding operations [7–9].
In this context, the question arises about the course of xylogenesis and the properties of wood originating from the stands growing on lands with an agricultural history that is not typical for forest production. The formation of forests on former agricultural land can arise through a natural secondary progression, but in recent times, especially in Europe, it is mainly the result of intentional afforestation [10–12]. This initiative was promoted by the European Economic Community’s (EEC) directive 2080/92, and later the EEC 1698/2005, which established a community aid scheme for forestry measures in agriculture, with the general aim of transforming agricultural lands into forested areas. Thus, soon, part of the wood raw material will come from forested post-agricultural areas, whose soils are characterized by different physico-chemical and biological properties compared to those of forest soils [13]. Studies on the flora of secondary forests and its comparisons with primary forests gave rise to the concept and separate category of the “ancient forest” [14–16]. Ancient forests are not necessarily old in the sense of the age of trees—it is their permanence in a given area that is meant. This criterion is met by primary forests and those secondary forests that have been growing for a long enough time, such as for several tree generations. These ancient forests include certain plant species that, although they possess the capability to colonize secondary forests—for example, former farmlands—the process is very slow and long-lasting.

The most frequently abandoned farmlands—mainly due to economic reasons—in the Polish lowlands are poor and mesotrophic. In most cases, the potential vegetation of these areas comprises forest stands dominated by pine; at the same time, this is also the most important economic species. For this and other historical and demographic reasons, Scots pine (*Pinus sylvestris* L.) dominated in the post-war afforestation on former farmlands [17]. Scots pine is a typical Euro-Siberian species that is characterized by a fairly wide range of occurrence, the largest of all species of the genus *Pinus* [18].

The issue of the appearance, development, and characteristics of groundcover in forests on former farmlands has been the subject of numerous studies in Europe and America—i.e., [19]—but studies on the characteristics of wood originating from such forests are still scarce, although from the timber production point of view they are very much needed, especially in the era of global warming, when the role of soil and forests in the global carbon budget has been incorporated in international treaties [20].

Determining the technical quality of wood raw material is mainly based on the study of its macrostructure—i.e., the width and share of sapwood and heartwood, annual wood increments, and the share of juvenile and mature wood. However, these factors do not fully reflect the quality of the produced wood tissue. Knowledge in this area is needed in the field of the breeding and use of wood. The discussion should include, first of all, the qualitative and quantitative features of wood formed in these conditions [21]. It seems justified to research the quality of wood from stands growing in those conditions that are atypical for forest production. Based on previous research, it can be assumed that forest habitat and its previous agricultural use can be a factor modifying wood tissue conditions related to the production of wood raw material on former agricultural lands [21]. It is known that wood density is correlated with some wood mechanical traits, such as the dynamic bending strength, modulus of elasticity, and compression strength [22]. The variation in wood density depends also on a range of intrinsic (it varies significantly from pith to bark) and environmental factors, and is often used in forest biomass and carbon dynamics [23]. Therefore, wood density is thought to guide the potential uses of an individual wood species, and it is important for guiding forest management activities.

The present work is part of the research on the trunk wood structure and properties of Scots pines from stands on former farmlands or ancient forests within two habitats: fresh coniferous forest and fresh mixed coniferous forest. The research presented here concerns the characteristics of differences in Scots pine wood properties, such as the density, modulus of elasticity, bending strength, and compressive strength along the tracheids. This study aimed to determine the influence of forest habitat conditions on the investigated properties of Scots pine wood. We expected less dense wood and an increased density from pith to bark in more fertile stands.
2. Materials and Methods

Wood samples from a total of 40 Scots pines (*Pinus sylvestris* L.) aged 66 to 99 years growing in the Chojnów Forest District were taken for tests. Only trees with no visible damage or disease symptoms that were present in the main layer of the stand were selected. The trees were from four plots, representing former farmland and ancient forest and two habitat types: fresh coniferous forest and fresh mixed coniferous forest. The plots and stands were selected in the Chojnów Forest District using site inspection preceded by interviews with local forest management staff and an analysis of the history of stands taken from the forest management plans. Basic data on the plots are given in Table 1. Four plots near each other gave the opportunity to reduce the variability in environmental factors. The analysis of the research plots in terms of flora and vegetation was the subject of separate studies [24,25]. In short, the study confirms the difference between plots on agricultural land and old forests, as well as differences in trophy between fresh and fresh mixed coniferous forest habitats, which is in line with the expectations and methodological assumptions of the study—i.e., that the studied plots were diversified in terms of both land-use history and fertility.

Table 1. The location and basic data of four experimental plots in the Chojnów Forest District.

| Planting Sites                                | Country     | Latitude   | Longitude   | Habitat Type of Forest | Prior Land Use |
|-----------------------------------------------|-------------|------------|-------------|------------------------|----------------|
| Sekocin Forest Administration Region, compartment 406 | Poland      | 20°53′10″ E | 52°06′40″ N | fresh coniferous forest | ancient forest |
| Sekocin Forest Administration Region, compartment 56a | Poland      | 20°53′10″ E | 52°06′40″ N | fresh coniferous forest | former farmland |
| Uwieliny Forest Administration Region, compartment 214g | Poland      | 21°02′49″ E | 51°58′15″ N | fresh mixed coniferous forest | ancient forest |
| Bogatki Forest Administration Region, compartment 447 | Poland      | 20°57′43″ E | 52°00′37″ N | fresh mixed coniferous forest | former farmland |

Chojnów Forest District is located in the central part of Poland in the Masovian Voivodeship on the left bank of the Vistula River, in the vicinity of Warsaw. According to the physico-geographical regionalization, the Chojnów Forest District is located in the Central Polish Lowland within the North European Plain. The Central Polish Lowland is dominated by glacial uplands with no lakes, though it also includes depressions, basins, valleys, and water accumulation plains and is partially covered with dunes [26,27]. According to the geobotanical division of Poland [28], the Chojnów Forest District is located in the Lowland-Upland Central European Province within the Baltic Sector in the Masovian Region, and encompasses two districts: the Rawa district and the Warsaw district.

For each tree, its diameter at a height of 1.3 m from the ground (breast height diameter, *dbh*), the total height of the tree, and the length of the trunk from the ground to the location of the living crown were measured. From each tree, a roller about 50 cm long and a cross-section disk about 10 cm thick from the part below the *dbh* were taken for the tests. The places of collecting the research material along the trunk are shown in Figure 1. That part was chosen according to other research findings [29,30] that the wood density and other parameters determined from the wood at *dbh* represent average values for all the log.
The samples collected in this way were used to determine the wood density (according to [31]) and mechanical properties—i.e., bending strength (according to [32]) and static modulus of elasticity (according to [33]). After the bending strength test, the ends of the samples were cut and the compressive strength along the tracheids tests were performed (according to [34]). The parallel control of wood moisture was conducted (according to [35]). Standard laboratory equipment with the required measurement accuracy and an INSTRON testing machine (Instron®—ITW company, Norwood, MA, USA) equipped with specialized IX-SERIES computer software for recording and analyzing the measurement results were used for the tests. The test procedures listed above should be considered as compliant with the current requirements of the international ISO standards [36–41].

The annual rings were analyzed on the transverse wood discs from pine stems. The analysis of the annual growth rings was performed using WINDENDRO™ (Ver. 2002a, Regent Instruments Inc., Quebec, Canada)—semi-automatic image-analysis software—and a high-definition optical scanner was used to measure the tree ring width and density variables (based on [42]). WINDENDRO™ is an image analysis system for tree-ring analysis. For the ring-width measurements, sanded discs were scanned (600 dpi resolution) and the images were saved as tagged information file format (TIFF) files. The WINDENDRO™ software measures the selected tree-ring parameters using a line of sensors traced along with the imported image profile. The measurement paths were selected to detect each ring boundary at right angles (four measurement paths were appointed for each wooden disc).

The results were analyzed using the program STATISTICA 10.0 PL (TIBCO Software Inc., Palo Alto, CA, USA), descriptive statistics, and the two-factor variance analysis ANOVA. All the tests were carried out for a significance level of \( p < 0.05 \).

3. Results and Discussion

3.1. Dimensional Features

Scots pine trees from the fresh forest were characterized by smaller diameters at \( dbh \) compared to the trees from the fresh mixed forest. Within the same habitat type, the pines grown on former agricultural lands showed smaller diameters compared to the pines grown in ancient forest land. Additionally, pine trees from mixed forests, regardless of the type of soil (post-agricultural or forestry), were characterized by a significantly greater width of the sapwood zone (Table 2). The ANOVA confirmed the impact of the habitat and soil use history (forestry and post-agricultural) on the dimensional features (Table 3).
Table 2. Dimensional features of pine trunks at breast height diameter, dbh (standard deviation is given in parentheses).

| Feature                        | Fresh Coniferous Forest on Post-Agricultural Soil | Mixed Forest on Post-Agricultural Soil | Fresh Coniferous Forest in the Ancient Forest | Mixed Forest in the Ancient Forest |
|--------------------------------|--------------------------------------------------|---------------------------------------|----------------------------------------------|-----------------------------------|
| Diameter with bark [mm]       | 202 (22)                                         | 221 (24)                              | 217 (24)                                     | 301 (43)                          |
| Diameter without bark [mm]    | 187 (22)                                         | 204 (23)                              | 198 (22)                                     | 274 (39)                          |
| Heartwood diameter [mm]       | 75 (12)                                          | 104 (11)                              | 73 (16)                                      | 149 (33)                          |
| Bark thickness [mm]           | 8 (2)                                            | 8 (3)                                 | 10 (3)                                       | 13 (4)                            |
| Width of heartwood [mm]       | 56 (11)                                          | 50 (7)                                | 63 (10)                                      | 63 (18)                           |
| Width of sapwood [mm]         | 37 (6)                                           | 52 (6)                                | 36 (8)                                       | 74 (16)                           |

Table 3. Values of ANOVA for pine trunk dimensional features depending on the forest habitat and previous land use.

| Feature                        | Factor                               | SS         | DF  | MS         | F            | p         |
|--------------------------------|--------------------------------------|------------|-----|------------|--------------|-----------|
|                                 | Intercept                            | 2,217,468  | 1   | 2,217,468  | 2536.391     | 0.000000  |
|                                 | Forest Habitat Type (1)              | 26,010     | 1   | 26,010     | 29.751       | 0.000004  |
|                                 | Land use (2)                         | 22,468     | 1   | 22,468     | 25.699       | 0.000012  |
|                                 | 1 * 2                                | 10,433     | 1   | 10,433     | 11.933       | 0.001429  |
|                                 | Error                                | 31,473     | 36  | 874        | -            | -         |
|                                 | Intercept                            | 1,864,944  | 1   | 1,864,944  | 2490.309     | 0.000000  |
|                                 | 1                                    | 21,856     | 1   | 21,856     | 29.184       | 0.000004  |
|                                 | 2                                    | 16,524     | 1   | 16,524     | 22.065       | 0.000038  |
|                                 | 1 * 2                                | 8497       | 1   | 8497       | 11.347       | 0.001813  |
|                                 | Error                                | 26,960     | 36  | 749        | -            | -         |
|                                 | Intercept                            | 402,804.9  | 1   | 402,804.9  | 1001.379     | 0.000000  |
|                                 | 1                                    | 27,984.1   | 1   | 27,984.1   | 69.569       | 0.000000  |
|                                 | 2                                    | 4494.4     | 1   | 4494.4     | 11.173       | 0.001946  |
|                                 | 1 * 2                                | 5475.6     | 1   | 5475.6     | 13.612       | 0.000738  |
|                                 | Error                                | 14,481.0   | 36  | 402.3      | -            | -         |
|                                 | Intercept                            | 3900.625   | 1   | 3900.625   | 449.352      | 0.000000  |
|                                 | 1                                    | 50.625     | 1   | 50.625     | 5.832        | 0.020943  |
|                                 | 2                                    | 112.225    | 1   | 112.225    | 12.928       | 0.000963  |
|                                 | 1 * 2                                | 21.025     | 1   | 21.025     | 2.422        | 0.128385  |
|                                 | Error                                | 312.500    | 36  | 8.681      | -            | -         |
|                                 | Intercept                            | 133,980.6  | 1   | 133,980.6  | 877.2352     | 0.000000  |
|                                 | 1                                    | 93.0       | 1   | 93.0       | 0.6901      | 0.440236  |
|                                 | 2                                    | 990.0      | 1   | 990.0      | 6.4822      | 0.015320  |
|                                 | 1 * 2                                | 87.0       | 1   | 87.0       | 0.5698      | 0.455251  |
|                                 | Error                                | 5498.3     | 36  | 152.7      | -            | -         |
|                                 | Intercept                            | 100,902.0  | 1   | 100,902.0  | 1030.343     | 0.000000  |
|                                 | 1                                    | 6943.2     | 1   | 6943.2     | 70.899       | 0.000000  |
|                                 | 2                                    | 1134.2     | 1   | 1134.2     | 11.582      | 0.001647  |
|                                 | 1 * 2                                | 1334.0     | 1   | 1334.0     | 13.622      | 0.000735  |
|                                 | Error                                | 3525.5     | 36  | 97.9       | -            | -         |

SS—the sum of squares; DF—degrees of freedom; MS—mean sum of squares; F—Fisher’s F-test; p—significance level; *—significant at the 0.05 level; NS—not significant.

A characteristic feature recurring in all the analyzed trunks was wide annual increments next to the pith (first 8–10 increments), gradually transforming with the age of the tree into narrow ones. This arrangement is typical due to the widespread phenomenon of the formation of juvenile wood, but it is particularly strongly pronounced in trees grown in pine stands from artificial plantings [43]. Irrespective of the type of habitat, the average ring width of the heartwood was greater than the average width of the annual growth increments in the sapwood zone. In the case of Scots pine trees grown in mixed forests, the average width of the annual heartwood growth was on average over 2 mm,
while in the case of trees growing in fresh coniferous forests it was on average below 2 mm (Table 4). Notwithstanding the above, the average width of annual increments for the cross-section of the whole trunk at breast height was similar everywhere and amounted to approx. 1.5 mm. In individual trees, the described features indicated significant variability, which was indicated by the high coefficients of variation within each group, even in the order of 30%. The ANOVA confirmed the impact of habitat on the width of the annual rings (Table 5). Based on previous studies [44–46], the width of the annual rings affects in a significant way the physical and mechanical properties of coniferous wood species, and those properties determine the suitability of the wood.

Table 4. Width of the annual rings in pine trunks from four experimental plots in the Chojnów Forest District (standard deviation is given in parentheses).

| Feature                          | Fresh Coniferous Forest on Post-Agricultural Soil | Mixed Forest on Post-Agricultural Soil | Fresh Coniferous Forest in the Ancient Forest | Mixed Forest in the Ancient Forest |
|----------------------------------|--------------------------------------------------|---------------------------------------|----------------------------------------------|-----------------------------------|
| Width of annual rings in mature | 1.28 (0.27)                                      | 1.2 (0.23)                            | 1.33 (0.25)                                  | 0.98 (0.30)                       |
| wood zone [mm]                  |                                                  |                                       |                                              |                                   |
| Width of annual rings in juvenile| 1.90 (0.34)                                      | 2.16 (0.35)                          | 1.69 (0.41)                                  | 2.59 (0.76)                       |
| wood zone [mm]                  |                                                  |                                       |                                              |                                   |
| Average width of annual rings   | 1.46 (0.17)                                      | 1.53 (0.17)                          | 1.43 (0.18)                                  | 1.47 (0.28)                       |
| [mm]                            |                                                  |                                       |                                              |                                   |

Table 5. Values of ANOVA for annual ring widths in trunks of pine trees depending on the forest habitat and previous land use.

| Feature                          | Factor                  | SS (DF, MS) | F | p   |
|----------------------------------|-------------------------|-------------|---|-----|
| Width of annual rings in mature  | Intercept              | 57.69604 (1, 848.457) | 848.457 | 0.000000 * |
| wood zone                        | Forest Habitat Type (1) | 0.44944 (1, 6.609)    | 6.609  | 0.014425 * |
|                                 | Soil Type (2)           | 0.07744 (1, 1.139)    | 1.139  | 0.293009 NS |
|                                 | 1 + 2                   | 0.19044 (1, 2.806)    | 2.806  | 0.102901 NS |
|                                 | Error                   | 2.44804 (36, 0.06800) | -     | -    |
| Width of annual rings in juvenile| Intercept              | 174.1393 (1, 710.824) | 710.824| 0.000000 * |
| wood zone                        | Forest Habitat Type (1) | 3.4223 (1, 13.969)    | 13.969 | 0.000643 * |
|                                 | Soil Type (2)           | 0.1188 (1, 0.485)     | 0.485  | 0.490650 NS |
|                                 | 1 + 2                   | 1.0433 (1, 4.259)     | 4.259  | 0.046317 * |
|                                 | Error                   | 8.8194 (36, 0.2450)   | -     | -    |
| Average width of annual rings    | Intercept              | 86.99550 (1, 2087.989) | 2087.989| 0.000000 * |
|                                 | Forest Habitat Type (1) | 0.03192 (1, 0.766)    | 0.766  | 0.387206 NS |
|                                 | Soil Type (2)           | 0.02352 (1, 0.565)    | 0.565  | 0.457310 NS |
|                                 | 1 + 2                   | 0.00182 (1, 0.044)    | 0.044  | 0.835513 NS |
|                                 | Error                   | 1.49993 (36, 0.04166) | -     | -    |

SS—the sum of squares; DF—degrees of freedom; MS—mean sum of squares; F—Fisher’s F-test; p—significance level; *—significant at the 0.05 level; NS—not significant.

3.2. Density and Selected Mechanical Properties

The average values of the wood density and selected mechanical properties of wood from trees grown in four different stands are given in Table 6. Regardless of the habitat type of the stand and the type of previous land use (ancient forest, post-agricultural forest), the juvenile wood of Scots pine trees (including several of the oldest in-season annual rings) was characterized by a lower density (from 500 to 600 kg/m³) compared to the density of mature wood (from 570 to 630 kg/m³). The density values were affected randomly by the locally and irregularly occurring higher content of resin wood in the selected trunks. Within such an area, the density was higher. These results are in line with the literature data, as the density of the wood varies significantly from pith to bark and is affected by other intrinsic factors [23].
Table 6. Density and selected mechanical properties of wood from trees from four plots of the Chojnów Forest District (standard deviation is given in parentheses).

| Feature                          | Fresh Coniferous Forest on Post-Agricultural Soil | Mixed Forest on Post-Agricultural Soil | Fresh Coniferous Forest in the Ancient Forest | Mixed Forest in the Ancient Forest |
|----------------------------------|--------------------------------------------------|---------------------------------------|-----------------------------------------------|-------------------------------------|
| Density [kg/m³]                  | 591 (32)                                         | 563 (32)                              | 597 (43)                                     | 556 (36)                            |
| Compressive strength along tracheids [MPa] | 69.4 (5.4)                                      | 62.3 (7.8)                            | 67.5 (9.7)                                   | 57.3 (5.6)                          |
| Modulus of elasticity [GPa]      | 11.98 (0.87)                                     | 11.00 (1.56)                          | 11.96 (1.83)                                 | 9.71 (1.25)                         |
| Bending strength [MPa]           | 117 (11)                                         | 104 (16)                              | 112 (23)                                     | 99 (13)                             |

The analyzed strength characteristics also showed significant variability depending on the tested trunk. Sometimes the test results were significantly affected by defects present, such as an eccentrically arranged core (pith), flattening, scleroderma, and curvatures, as well as the related non-rectilinear course of the tracheids. The presence of resin was another disturbing factor. Wood zones oversaturated with resin were denser, but this did not cause an increase in the compressive and bending strength or the modulus of elasticity. On average, the wood obtained from former agricultural lands slightly differed in terms of its density and mechanical properties from the wood of pine trees from ancient forest land. Wood from fresh coniferous forests, while maintaining practically the same average density and compressive and bending strength, was characterized by the slightly reduced modulus of elasticity for forest soils (with this feature showing a high variability). For Scots pines wood from mixed forests, slightly higher average density and technical parameters are obtained in the case of wood from former agricultural land compared to the wood from forest land.

The density and mechanical properties of wood were more influenced by the forest habitat type than the history of soil use (post-agricultural or ancient forestry). Scots pine wood from fresh coniferous forest was characterized by higher mechanical parameters, which was confirmed by the ANOVA (Table 7). Therefore, from a practical point of view, the history of the soil (post-agricultural or forestry) does not matter in the case of the above-analyzed wood parameters. Slightly similar results were obtained during the study of Scots pine originating from the north part of Poland [21]. According to those results, the wood of pines growing on post-agricultural land in the fresh mixed coniferous forest had a higher basic density but lower compression strength along the tracheids. The performed analyses pointed to differences in the properties of wood tissues between pines growing on post-agricultural land and pines growing on typical forest soils [21]. Therefore, more verification studies need to be carried out on wood from different habitats.

Table 7. Values of ANOVA for selected wood density mechanical properties depending on the forest type and soil.

| Feature                          | Factor                        | SS        | DF | MS       | F          | p         |
|----------------------------------|-------------------------------|-----------|----|----------|------------|-----------|
| Density                          | Intercept                     | 13,401,781| 1  | 13,401,781| 13,690.18  | 0.000000 *|
|                                 | Forest Habitat Type (1)       | 8716      | 1  | 8716     | 8.90       | 0.005086 *|
|                                 | Land use (2)                  | 8         | 1  | 8        | 0.01       | NS        |
|                                 | 1 * 2                         | 22        | 1  | 22       | 0.02       | 0.881597 NS|
|                                 | Error                         | 35,242    | 36 | 979      | -          | -         |
| Compressive strength along tracheids | Intercept                   | 170,046.1| 1  | 170,046.1| 2783.004   | 0.000000 *|
|                                 | 1                             | 815.0     | 1  | 815.0    | 13,339     | 0.000820 *|
|                                 | 2                             | 68.2      | 1  | 68.2     | 1.116      | 0.297658 NS|
|                                 | 1 * 2                         | 29.7      | 1  | 29.7     | 0.486      | 0.490304 NS|
|                                 | Error                         | 2199.7    | 36 | 61.1     | -          | -         |
| Modulus of elasticity           | Intercept                     | 5209.409  | 1  | 5209.409 | 1335.168   | 0.000000 *|
|                                 | 1                             | 26,929    | 1  | 26,929   | 6.902      | 0.012571 *|
|                                 | 2                             | 1.484     | 1  | 1.484    | 0.380      | 0.541273 NS|
|                                 | 1 * 2                         | 5.021     | 1  | 5.021    | 1.287      | 0.264136 NS|
|                                 | Error                         | 140.461   | 36 | 3.902    | -          | -         |
4. Conclusions

The present work is a part of wider research on the trunk wood structure and properties of Scots pines from stands on former farmlands or ancient forests within two habitats: fresh coniferous forest and fresh mixed coniferous forest. Scots pine trunks from fresh coniferous forest were characterized by smaller diameters at the breast height and a smaller proportion of sapwood compared to the trunks of pine trees from the moist mixed forest. Based on the presented research, it was stated that the forest habitat type had a decisive impact on the dendrometric characteristics and properties of the tested Scots pine wood (density, modulus of elasticity, bending strength, and compressive strength along the tracheids). The history of soil use (post-agricultural or forestry) did not affect the properties of the analyzed pine wood. Pine wood from stands grown on forest land was characterized by a higher technical quality in terms of the parameters analyzed in this work.

The obtained research results allow for a statement that the wood of Scots pine from post-agricultural lands has suitable properties for the timber industry, which is extremely important from a practical point of view. The acquired knowledge can be used in planning the location of tree plantations for the needs of the wood industry.

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References
1. Wodzicki, T.J. Mechanism of xylem differentiation in Pinus sylvestris L. J. Exp. Bot. 1971, 22, 670–687. [CrossRef]
2. Tulik, M.; Kłosińska, T.; Iqbal, M.; Grochowina, A. Figures of the wood of Khaya ivorensis and Millettia laurentii. Wood Res. 2011, 56, 613–620.
3. Zobel, B.J.; Jett, J.B. Genetics of Wood Production; Springer Series of Wood Science: Berlin, Germany, 1995.
4. Plomion, C.; Leprovost, G.; Stokes, A. Wood formation in trees. Plant Physiol. 2011, 127, 1513–1523. [CrossRef]
5. Larson, P.R. The vascular cambium. In Development and Structure; Barnett, J.R., Ed.; Castle House Publications LTD: Tunbridge Wells, UK, 1981; pp. 236–255.
6. Denne, M.P.; Dodd, R. Environmental control of xylem differentiation. In Xylem Cell Development; Barnett, J.R., Ed.; Castle House Publications LTD: Tunbridge Wells, UK, 1981; pp. 236–255.
7. Wodzicki, T.J. Natural factors affecting wood structure. Wood Sci. Technol. 2001, 35, 5–26. [CrossRef]
8. Tulik, M.; Yaman, B.; Köse, N. Comparative tree-ring anatomy of Fraxinus excelsior with Chalara dieback. J. For. Res. 2018, 29, 1741–1749. [CrossRef] [PubMed]
10. Mather, A. *Afforestation. Policies, Planning and Progress*; Belhaven Press: London, UK, 1993.
11. Szwagrzyk, J. Sukcesja leśna na gruntach porolnych; stan obecny, prognozy i wątpliwości (Forest succession on former agricultural land; current state, forecasts and doubts). *Sylwan* 2004, 148, 53–59.
12. Vadell, E.; de-Miguel, S.; Pemán, J. Large-scale reforestation and afforestation policy in Spain: A historical review of its underlying ecological, socioeconomic and political dynamics. *Land Use Policy* 2016, 55, 37-48. [CrossRef]
13. Meyer, F.H. Distribution of ectomycorrhizae in native and man-made forest. In *Ectomycorrhizae—Their Ecology and Physiology*; Marks, G.C., Kozlowski, T.T., Eds.; Academic Press: London, UK; New York, NY, USA, 1973; pp. 79–105.
14. Peterken, G.F. A method for assessing woodland flora for conservation using indicator species. *Biol. Conserv.* 1974, 6, 239–245. [CrossRef]
15. Peterken, G.F. Habitat conservation priorities in British and European woodlands. *Biol. Conserv.* 1977, 11, 223–236. [CrossRef]
16. Rackham, O. *Ancient Woodland, Its History, Vegetation and Uses in England*; Edward Arnold: London, UK, 1980; p. 402.
17. Smykała, J. Historia, rozmiar i rozmieszczenie zalesień gruntów porolnych w Polsce w latach 1945–1987 (History, size and distribution of afforestation of former agricultural land in Poland in 1945–1987). *Sylwan* 1990, 134, 1–7.
18. Bialobok, S.; Boratyński, A.; Bugała, W. Biologia sosny zwyczajnej. In *Polska Akademia Nauk; Instytut Dendrologiczny* Poznań-Kórnik, Poland, 1993.
19. Honnay, O.; Bossuyt, B.; Verheyen, K.; Butaye, J.; Jacquemyn, H. Ecological perspectives for the restoration of plant communities in European temperate forests. *Biodivers. Conserv.* 2002, 11, 213–242. [CrossRef]
20. Tochi, E.C. Carbon sequestration: How much can forestry sequester CO₂? *For. Res. Eng. Int. J.* 2018, 2, 148–150. [CrossRef]
21. Jelonek, T.; Pazdrowski, W.; Tomczak, A. Właściwości drewna sosny zwyczajnej (*Pinus sylvestris L.*) na gruntach porolnych w północnej Polsce (Properties of Scots pine (*Pinus sylvestris L.*) on former agricultural lands in northern Poland). *Leśne Prace Badaw.* 2009, 70, 277–286.
22. Machado, J.S.; Louzada, J.L.; Santos, A.J.A.; Nunes, L.; Anjos, O.; Rodrigues, J.; Simões, R.M.S.; Pereira, H. Variation of wood density and mechanical properties of blackwood (*Acacia Melanoxylon*, R. Br.). *Mater. Des.* 2014, 56, 975–980. [CrossRef]
23. De Mil, T.; Tarelkin, Y.; Hahn, S.; Hubau, W.; Deklerck, V.; Debeir, O.; Van Acker, J.; De Cannière, C.; Beeckman, H.; Van den Bulcke, J. Wood Density Profiles and Their Corresponding Tissue Fractions in Tropical Angiosperm Trees. *Foressts* 2018, 9, 763. [CrossRef]
24. Ciurzycki, W.; Marciszewska, K. Flora of pine forests on former farmlands and in ancient forests in the Chojnów Forest District. *Ann. WULS–SGGW For. Wood Technol.* 2016, 93, 30–36.
25. Ciurzycki, W.; Marciszewska, K. Vegetation of pine forests on former farmlands and in ancient forests in the Chojnów Forest District. *Ann. WULS–SGGW For. Wood Technol.* 2016, 93, 37–43.
26. Kondracki, J. *Geografía Polski. Mezoregiony Fizyczno-Geograficzne* (Polish Geography. Physico-Geographical Mesoregions); PWN: Warsaw, Poland, 1994.
27. Kondracki, J.; Richling, A. Regiony fizycznogeograficzne. In *Atlas Rzeczypospolitej Polskiej. Główny Geodeta Kraju* (Atlas of the Republic of Poland. Chief Land Surveyor); Poznań Świat: Warsaw, Poland, 1994.
28. Szafer, W.; Zarzycki, K. *Szaty Roślinne Polski T. II* (Plant cover in Poland Vol. II); PWN: Warsaw, Poland, 1977; p. 347.
29. Niedzielska, B. Zmiennaść gęstości oraz podstawowych cech makroskopowej struktury drewna jodły (*Abies alba* Mill.) w granicach jej naturalnego występowania w Polsce (Variability of density and basic features of the macroscopic structure of fir wood (*Abies alba* Mill.) within its natural occurrence in Poland). In *Zeszyty Naukowe Akademii Rolniczej im. H. Kolłątaja w Krakowie* (Scientific Notebooks of the Agricultural University of H. Kolłątaja in Krakow); Uniwersytet Rolniczy w Krakowie: Kraków, Poland, 1995; Volume 198.
30. Pazdrowski, W. Wartość techniczna drewna sosny zwyczajnej (*Pinus sylvestris L.*) w zależności od jakości pni drzew w drzewostanach ręcznych (Technical value of Scots pine (*Pinus sylvestris L.*) wood depending on the quality of tree trunks in forest stands). In *Rocznik Akademii Rolniczej w Poznaniu, Rozprawy Naukowe* (Yearbook of the Agricultural University in Poznań, Scientific Dissertations); Uniwersytet Przyrodniczy w Poznaniu: Kraków, Poland, 1988; Volume 170.
31. PN-D-04101:1979 Drewno. Oznaczanie Gęstości. (Wood. Determination of Density); Polski Komitet Normalizacyjny: Warszawa, Poland, 1979.

32. PN-D-04103:1968 Fizyczne i Mechaniczne Własności Drewna. Oznaczanie Wytrzymałości na Zginanie Statyczne. (Physical and Mechanical Properties of Wood. Determination of Static Bending Strength); Polski Komitet Normalizacyjny: Warszawa, Poland, 1968.

33. PN-D-04117:1963 Fizyczne i Mechaniczne Własności Drewna. Oznaczanie Współczynnika Sprężystości Przy Zginaniu Statycznym. (Physical and Mechanical Properties of Wood. Determination of the Modulus of Elasticity in Static Bending); Polski Komitet Normalizacyjny: Warszawa, Poland, 1963.

34. PN-D-04102:1979 Drewno. Oznaczanie Wytrzymałości na Sciskanie Wzdłuż Włókien. (Wood. Determination of Compressive Strength Along Fibers); Polski Komitet Normalizacyjny: Warszawa, Poland, 1979.

35. PN-D-04100:1977 Drewno. Oznaczanie Wilgotności. (Wood. Determination of Moisture Content); Polski Komitet Normalizacyjny: Warszawa, Poland, 1977.

36. ISO 4471:1982 Wood. Sampling Sample Trees and Logs for Determination of Physical and Mechanical Properties of Wood in Homogeneous Stands; International Organization for Standardization: Geneva, Switzerland, 1982.

37. ISO 13061-1:2014 Physical and Mechanical Properties of Wood. Test Methods for small Clear Wood Specimens. Part 1: Determination of Moisture Content for Physical and Mechanical Tests; International Organization for Standardization: Geneva, Switzerland, 2014.

38. ISO 13061-2:2014 Physical and Mechanical Properties of Wood. Test methods for small Clear Wood Specimens. Part 2: Determination of Density for Physical and Mechanical Tests; International Organization for Standardization: Geneva, Switzerland, 2014.

39. ISO 13061-3:2014 Physical and Mechanical Properties of Wood. Test Methods for Small Clear Wood Specimens. Part 3: Determination of Ultimate Strength in Static Bending; International Organization for Standardization: Geneva, Switzerland, 2014.

40. ISO 13061-4:2014 Physical and Mechanical Properties of Wood. Test Methods for small clear wood Specimens. Part 4: Determination of Modulus of Elasticity in Static Bending; International Organization for Standardization: Geneva, Switzerland, 2014.

41. ISO/DIS 13061-17:2014 Physical and Mechanical Properties of Wood. Test Methods for Small Clear Wood Specimens. Part 17: Determination of Ultimate Stress in Compression Parallel to Grain; International Organization for Standardization: Geneva, Switzerland, 2014.

42. Campbell, R.; McCarroll, D.; Robertson, I.; Loader, N.J.; Grudd, H.; Gunnarson, B. Blue intensity in Pinus sylvestris tree rings: A manual for a new palaeoclimate proxy. Tree Ring Res. 2011, 67, 127–134. [CrossRef]

43. Zobel, B.J.; Sprague, J.R. Juvenile Wood in Forest Trees; Springer Science & Business Media: Berlin, Germany, 2012; p. 304.

44. Kollmann, F. Technologie des Holzes und der Holzwerkstoffe; Springer: Berlin-Göttingen-Heidelberg, Germany, 1951.

45. Dzberński, W. Jakościowa klasyfikacja iglastej tarcicy obrzynanej w świetle wymagań stawianych konstrukcjom drewnianym (Qualitative classification of softwood timber edged in light of the requirements for wooden constructions). Przemysł Drzewny 1970, 4, 1–7.

46. Krzysik, F. Nauka o Drewnie, 1st ed.; PWN: Warsaw, Poland, 1957; pp. 615–623.