Understanding the Relationship Between Crown Shape and Size and Structural Complexity of Individual Trees

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Abstract

Forest canopy structure is influenced by tree attributes and processes such as forest generation, growth, and mortality. Structural complexity of a tree or a stand has, however, been challenging to assess as comprehensive and quantitative measurements have practically been impossible to produce. Thus, we utilized 3D information provided by terrestrial laser scanning (TLS) in assessing structural complexity of individual Scots pine (Pinus sylvestris L.) trees to better understand of forest systems and especially relationships between structural complexity and crown shape and size. Additionally, we investigated the effects of forest management (i.e. thinning) on structural complexity of individual Scot pine trees. We applied fractal analysis (i.e. box dimension) to provide a measure for structural complexity of individual trees and investigated its relationship between crown dimensions (i.e. width, volume, and projection area). There was a positive relationship between crown characteristics and structural complexity indicating an increased structural complexity when crown shape and size increased. The strongest relationship (correlation coefficient of 0.4-0.7) was found between structural complexity and crown projection area and crown volume. The relationship between structural complexity and all crown attributes was stronger in denser forests (~900 stems/ha) with correlation coefficient 0.6-0.7 compared to sparse forests (~400 stems/ha) with correlation coefficient 0.6. Additionally, it was shown that structural complexity of individual Scots pine trees increased with forest management intensity. Crown characteristics can be considered as drivers of structural complexity of individual trees. Crown shape and size can be expected to characterize vitality of trees. Thus, this study provides an example how crown characteristics can be related to structural complexity of individual trees and how they can be quantitatively assessed. Furthermore, the study affirms the possibilities of TLS as a tool for characterizing forest canopy structure and dynamics.

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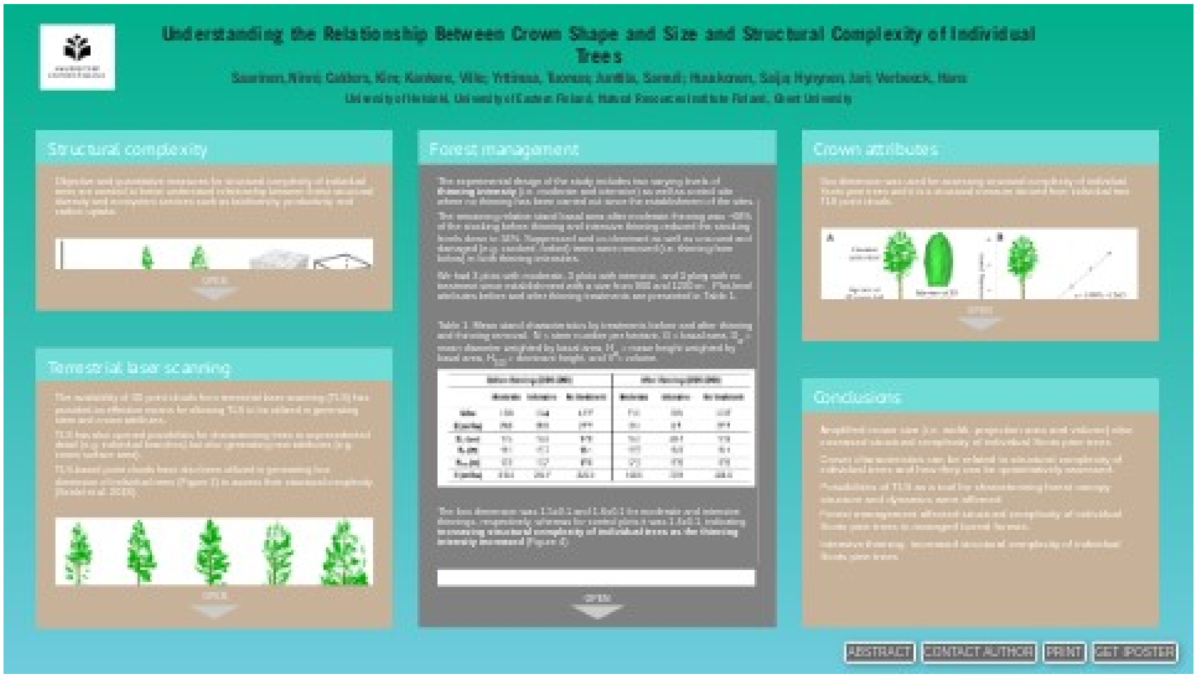

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STRUCTURAL COMPLEXITY

Objective and quantitative measures for structural complexity of individual trees are needed to better understand relationship between forest structural diversity and ecosystem services such as biodiversity, productivity, and carbon uptake.

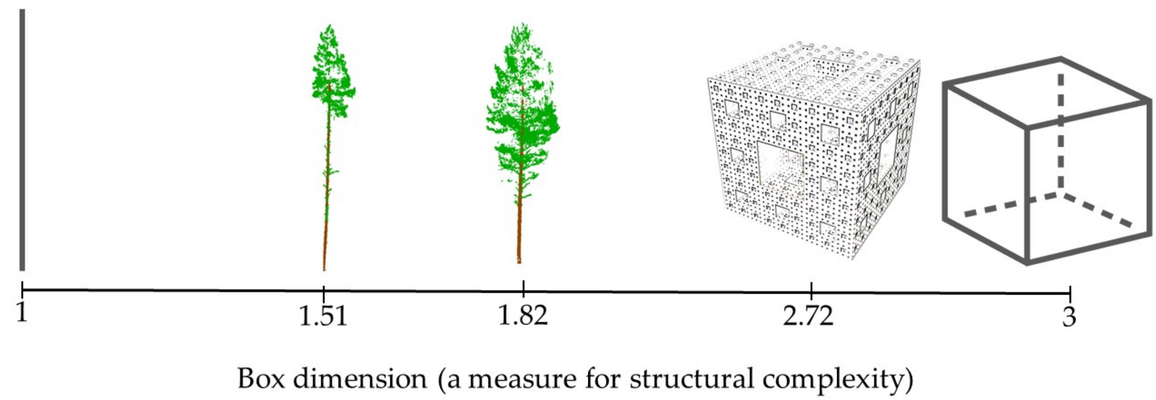

Figure 1. Examples of objects with box dimension ranging from one (cylindrical pole) to three (solid cube) in between two real-life trees and a Menger sponge (i.e. infinite surface area with zero volume; box dimension = 2.72).

Tree structure can be characterized by using morphological measures such as crown dimension (e.g. volume, surface area) and stem attributes (e.g. diameter at breast height (DBH), height, height of crown base).

Fractal analysis can provide an approximation of natural forms for characterizing structural complexity of individual trees.

The so-called box dimension is based in fractal analysis and determined as a relationship between the number of primitives of varying size needed to enclose a tree and the inverse of the primitive size (Figure 1).

TERRESTRIAL LASER SCANNING

The availability of 3D point clouds from terrestrial laser scanning (TLS) has provided an effective means for allowing TLS to be utilized in generating stem and crown attributes.

TLS has also opened possibilites for characterizing trees in unprecedented detail (e.g. individual branches) but also generating new attributes (e.g. crown surface area).

TLS-based point clouds have also been utilized in generating box dimension of individual trees (Figure 2) to assess their structural complexity (Seidel et al. 2018).

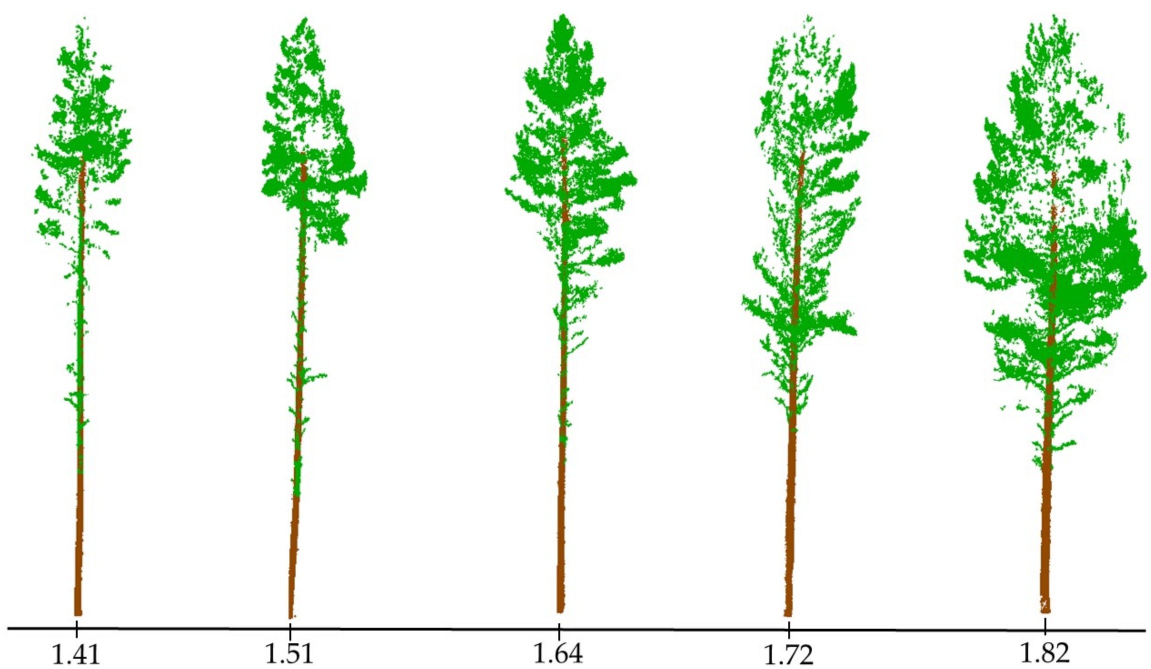

Figure 2. Terrestrial laser scanning point clouds from example trees with varying structural complexity (i.e. box dimension).

Previous work (Seidel et al. 2018, 2019a, b) demonstrated the potential of box dimension as a meaningful measure for structural complexity of individual trees. However, how this measure can be used to quantify tree structure of conifers and how it can expand our understanding about effects of anthropogenic activities (e.g. forest management) on tree structure is largely unexplored.

First, plot-level TLS point clouds were segmented to identify points from individual trees. Then, classification of stem and non-stem points was carried out based on an assumption that stem points have more planar, vertical, and cylindrical characteristics compared to non-stem points representing branches and foliage (Liang et al. 2012, Yrttimaa et al. 2020). The result of this step was classified 3D point clouds for each individual tree (n=741) (Figure 3A).

FOREST MANAGEMENT

The experimental design of the study includes two varying levels of **thinning intensity** (i.e. moderate and intensive) as well as control site where no thinning has been carried out since the establishment of the sites.

The remaining relative stand basal area after moderate thinning was ~68% of the stocking before thinning and intensive thinning reduced the stocking levels down to 34%. Suppressed and co-dominant as well as unsound and damaged (e.g. crooked, forked) trees were removed (i.e. thinning from below) in both thinning intensities. See more information on thinning treatments in Saarinen et al. (2020).

We had 3 plots with moderate, 3 plots with intensive, and 3 plots with no treatment since establishment with a size from 900 and 1200 m^2. Plot-level attributes before and after thinning treatments are presented in Table 1.

Table 1. Mean stand characteristics by treatments before and after thinning and thinning removal. N = stem number per hectare, G = basal area, D_w = mean diameter weighted by basal area, H_w = mean height weighted by basal area, H_{100} = dominant height, and V = volume.

	Before thinning (2005-2006)			After thinning (2005-2006)		
	Moderate	Intensive	No treatment	Moderate	Intensive	No treatment
N/ha	1269	1244	1337	716	289	1337
G (m^2/ha)	26.5	26.5	27.7	18.1	8.7	27.7
D_w (cm)	17.5	18.0	17.8	18.7	20.4	17.8
H_w (m)	16.1	16.3	16.1	16.5	16.9	16.1
H_{100} (m)	17.3	17.7	17.5	17.3	17.5	17.5
V (m^3/ha)	213.4	215.7	224.0	148.3	72.9	224.0

The box dimension was 1.5±0.1 and 1.6±0.1 for moderate and intensive thinnings, respectively, whereas for control plots it was 1.4±0.1, indicating **increasing structural complexity of individual trees as the thinning intensity increased** (Figure 4).

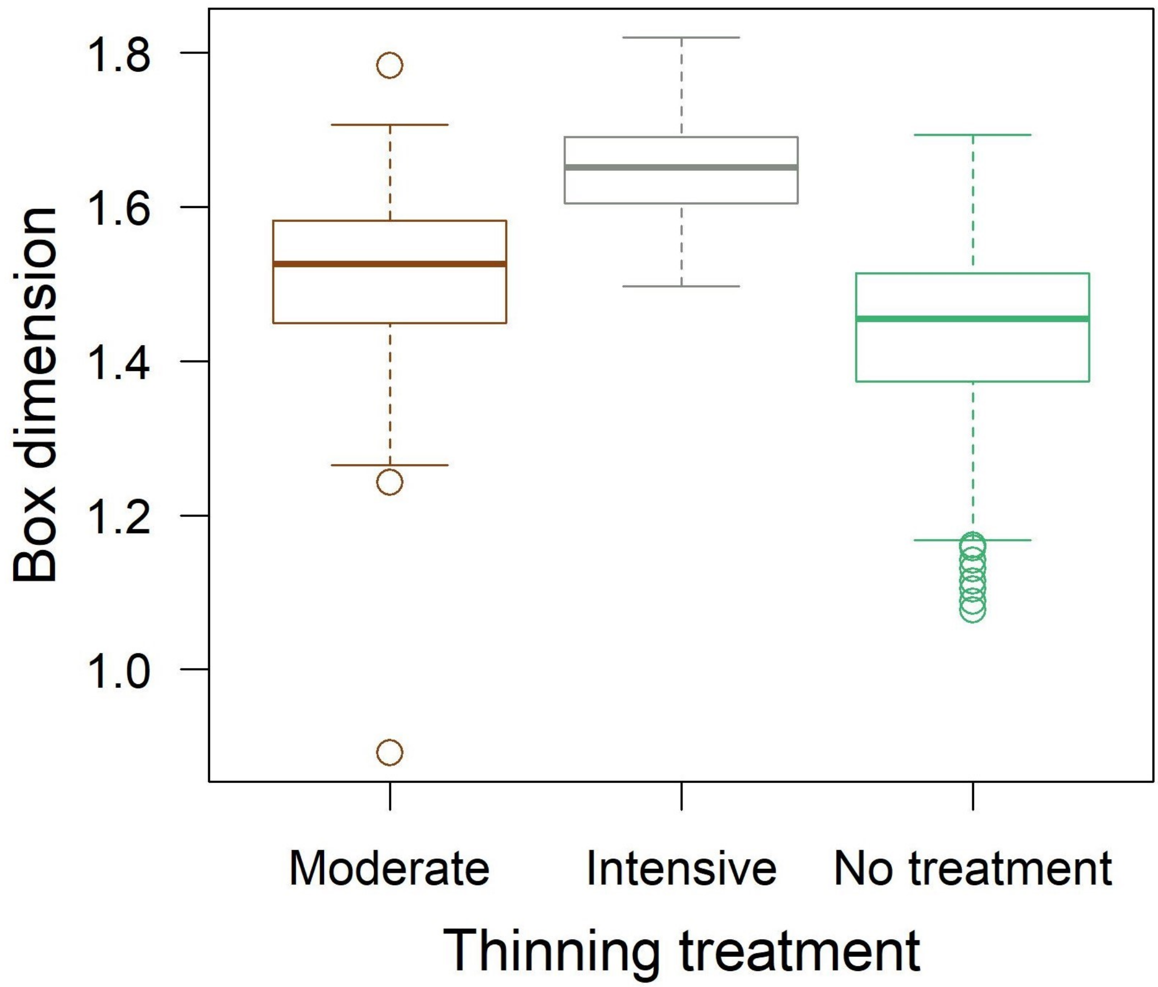

Figure 4. Variation in box dimension between moderate and intensive thinning as well as without thinning (no treatment).

Pearson's correlation coefficient was >0.5 between box dimension and crown projection area and crown volume with moderate no thinning (Table 2). Additionally, the **correlation was significant (p<0.001) between box dimension and all crow attributes with all thinning treatments**.

Table 2. Pearson's correlation coefficients between box dimension and crown attributes grouped by thinning treatment. Correlation coefficients >0.50 are bolded and * denotes statistical significance (p<0.001).

	Moderate	Intensive	No treatment
		Box dimension	
Crown width (m)	**0.55***	0.36*	**0.56***
Crown projection area (m^2)	**0.69***	0.43*	**0.62***
Crown volume (m^3)	**0.67***	0.37*	**0.57***

All crown attributes were significant ($p<0.05$) drivers for structural complexity and coefficient of determination between structural complexity and crown projection area and volume was 0.5 for moderately thinned Scots pine plots (Figure 5).

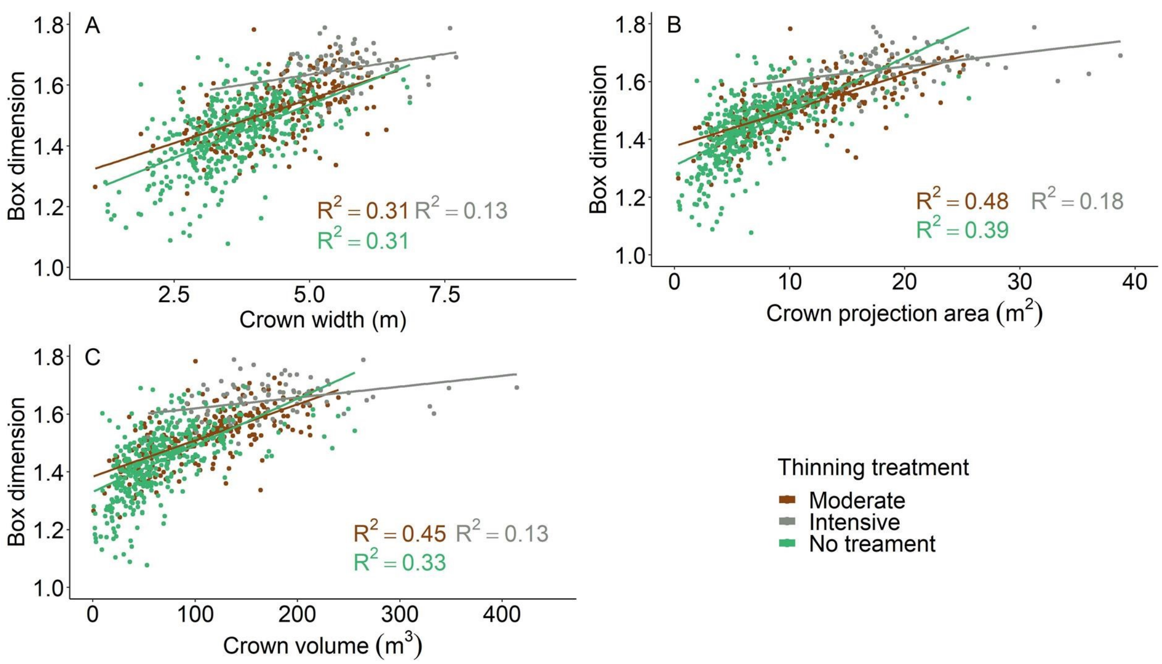

Figure 5. Relationship between box dimension (i.e. structural complexity) and crown width (A), crown projection area (B), and crown volume (C) grouped by thinning treatment.

CROWN ATTRIBUTES

Box dimension was used for assessing structural complexity of individual Scots pine trees and it is a structural measure derived from individual tree TLS point clouds.

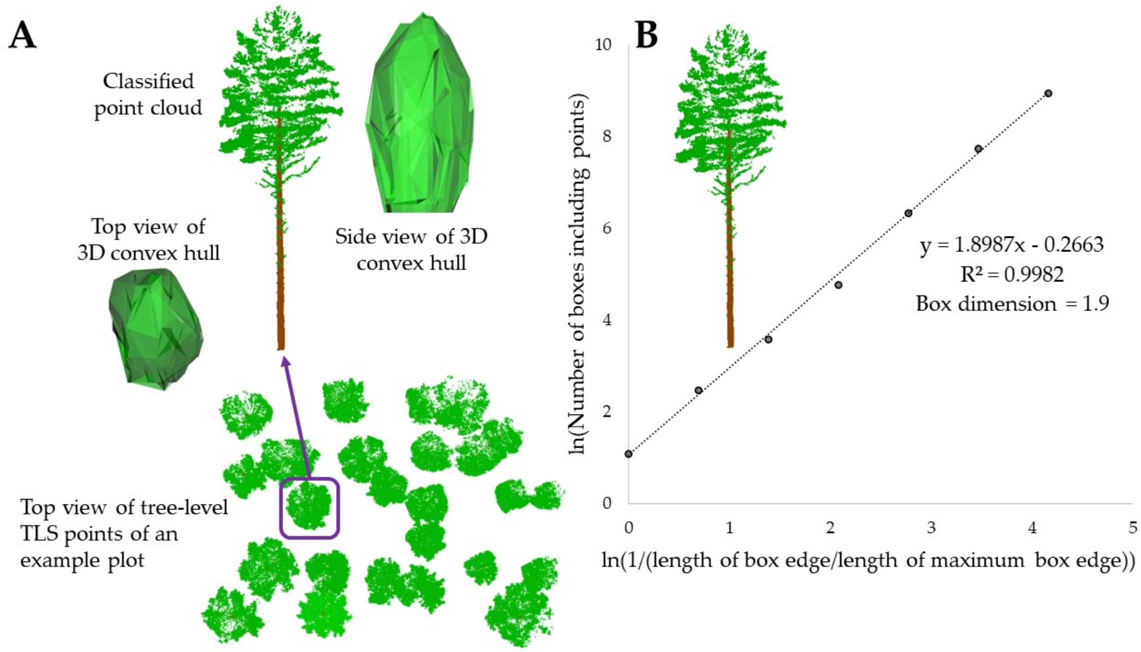

Figure 3. Crown-segmented point clouds of individual Scots pine trees (A bottom) and an example of classified point clouds representing a Scots pine tree (A top center) with the fitted 3D convex hull enveloping the crown points, viewed from the top (A top left) and side (A top right). The definition for the box dimension for the same Scots pine (B), the slope of the fitted straight line (1.90) equals the box dimension whereas the intercept (-0.27) is a measure of tree size and coefficient of determination (R^2=1.0) self-similarity.

First, one box including all TLS points of a single tree was fitted (i.e. initial box) in which the edge length of the box was tree height and then boxes of different sizes (i.e. tree height/2, tree height/4, tree height/8, tree height/16, tree height/32, tree height/64, tree height/128) were fitted to point clouds of each tree and the number of fitted boxes of each size was saved. Finally, the box dimension for each tree was defined as a slope between natural logarithm of 1/(box edge length of certain size/edge length of initial box) and natural logarithm of number of boxes including boxes of certain size (Figure 3B).

Crown attributes were generated from TLS points originating from branches and foliage (i.e. crown points). A 2D convex hull was fitted to envelope the crown points of each tree of which **crown projection area** was derived whereas **crown volume** was calculated from a 3D convex hull. **Crown width**, on the other hand, was defined as the distance between the two most outer points in xy-space.

CONCLUSIONS

Amplified crown size (i.e. width, projection area and volume) also increased structural complexity of individual Scots pine trees

Crown characteristics can be related to structural complexity of individual trees and how they can be quantitatively assessed.

Possibilities of TLS as a tool for characterizing forest canopy structure and dynamics were affirmed

Forest management affected structural complexity of individual Scots pine trees in managed boreal forests.

Intensive thinning increased structural complexity of individual Scots pine trees

ABSTRACT

Forest canopy structure is influenced by tree attributes and processes such as forest generation, growth, and mortality. Structural complexity of a tree or a stand has, however, been challenging to assess as comprehensive and quantitative measurements have practically been impossible to produce. Thus, we utilized 3D information provided by terrestrial laser scanning (TLS) in assessing structural complexity of individual Scots pine (*Pinus sylvestris* L.) trees to better understand of forest systems and especially relationships between structural complexity and crown shape and size. Additionally, we investigated the effects of forest management (i.e. thinning) on structural complexity of individual Scot pine trees.

We applied fractal analysis (i.e. box dimension) to provide a measure for structural complexity of individual trees and investigated its relationship between crown dimensions (i.e. width, volume, and projection area).

There was a positive relationship between crown characteristics and structural complexity indicating an increased structural complexity when crown shape and size increased. The strongest relationship (correlation coefficient of 0.4-0.7) was found between structural complexity and crown projection area and crown volume. The relationship between structural complexity and all crown attributes was stronger in denser forests (~900 stems/ha) with correlation coefficient 0.6-0.7 compared to sparse forests (~400 stems/ha) with correlation coefficient 0.6. Additionally, it was shown that structural complexity of individual Scots pine trees increased with forest management intensity.

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