Crown shape and size of Scots pine affected by thinning?

N Saarinen[1], T. Yrttimaa[1], V. Kankare[1], V. Luoma[2], J. Pyörälä[2], S. Bianchi[3], S. Huuskonen[3], J. Hynynen[3], M. Holopainen[2], J. Hyyppä[4], M. Vastaranta[1]

[1]School of Forest Sciences, University of Eastern Finland, P.O. Box 111, 80101 Joensuu, Finland
Email: {ninni.saarinen; tuomas.yrttimaa; ville.kankare; mikko.vastaranta}@uef.fi

[2]Department of Forest Sciences, University of Helsinki, P.O. Box 27, 00014 University of Helsinki, Finland
Email: {ville.luoma; jiri.pyorala; markus.holopainen}@helsinki.fi

[3]Natural Resources Institute Finland, Latokartanonkaari 9, 00790 Helsinki, Finland
Email: {simone.bianchi; saija.huuskonen; jari.hynynen}@luke.fi

[4]Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute, National Land Survey of Finland, Geodeetinrinne 2, FI-02430 Masala, Finland
Email: juha.hyyppa@nls.fi

1. Introduction

Trees adapt to their growing conditions by regulating size of their parts and their relationships. For example, removal or death of adjacent trees increases the amount of light to the remaining trees and their crown can expand. Trees of different species require differing amount of growing space; for example, Scots pine (*Pinus sylvestris* L.) is more demanding for space than Norway spruce (*Picea abies* (H. Karst) L.) (Aaltonen 1925).

In dense forests, lower branches die due to the limited amount of light (Heikinheimo 1953, Flower-Ellis et al. 1976, Kellomäki 1980). Live-crown ratio (proportion of live crown from tree height) is used in assessing vitality of trees. Removal or death of trees enhances the light regime and photosynthesis for the remaining trees, and this is particularly evident in near the lowest limit of live crown where changes in the amount of light increases considerably more compared to the top of a tree.

There is also a relationship between tree size and growing conditions that can be assessed through the light regime. Removal or death of trees increases the light for various parts of and below crown of remaining trees. According to Oker-Blom & Kellomäki (1982), self-shading is greater for large trees compared to medium or small trees.

Thinning is aimed at improving growing conditions of remaining trees and maximize their economic value. Thinning decreases the shadowing leaf mass, increases the amount of light, and thus enhances the growth of the remaining trees (White 1980). Thinning intensity affects the number of removed trees, whereas thinning type defines what kind of trees are removed, and thus left to grow. Intermediate and suppressed as well as overgrown trees are removed with thinning from below, whereas dominant and overgrown trees are removed with thinning from below.

Although, forest growth and yield research have a long history in studying effects of forest management, measuring tree crown has mainly been limited to live-crown proportion that can easily be measured together with tree height. Terrestrial laser scanning (TLS) offers a means for characterizing individual trees with a detail (Calders et al. 2020, Liang et al. 2018).

Thus, the aim of the study was to investigate how crown size and shape of individual Scots pine trees generated from TLS data differed between thinning intensity and type. Furthermore, we studied how thinning affected crown size and shape of dominant trees (i.e., the 100 thickest trees per hectare) only.

2. Data and Methods

2.1 Study area and data acquisition

The study area is located in southern boreal forest zone in Finland and consists of three study sites with relatively flat terrain (elevation above sea level ~137 m±17 m) in mesic heath forest dominated by Scots pine. The study sites were established in 2005 and 2006 when nine rectangular sample plots (sized 1000-1200 m^2) were placed on each study site (27 plots in total). At the same time, first in situ measurements were carried out and the plots were also thinned according to the experimental study design that included two levels of thinning intensity (i.e., moderate and intensive) and three thinning types (i.e., from below,

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from above, and systematic) resulting in six different thinning treatments: moderate thinning from below (3 plots), moderate thinning from above (4 plots), moderate systematic thinning (5 plots), intensive thinning from below (3 plots), intensive thinning from above (5 plots), and intensive systematic thinning (5 plots).

One plot at each study site was left as a control plot where no thinning has been carried out since the establishment of the sites. Suppressed and co-dominant trees were removed with thinning from below, whereas dominant trees were mainly removed with thinning from above. Additionally, unsound and damaged trees (e.g., crooked, forked) were removed. With intensive thinning, the remaining basal area was ~50% lower compared to moderate thinning. Stem density per hectare varied between 1160 and 1390 before thinning and between 290 and 1030 after thinning (see more information on plot structure before and after thinning in Saarinen et al. 2020).

TLS data acquisition was carried out with Trimble TX5 3D laser scanner between September and October 2018. Eights scans were acquired from each plot, and they were co-registered into a single, aligned coordinate system with mean distance error of 2.9±1.2 mm (more description in Saarinen et al. 2020).

Points originated from a crown of individual Scots pine trees with diameter at breast height varying between 7.6 cm and 36.4 cm were identified by utilizing a fully automatic method developed by Yrttimaa et al. (2019, 2020). The methodology includes point cloud normalization, tree segmentation, and point cloud classification. Points representing planar, vertical, and cylindrical surfaces were assumed to have originated from stem and rest of the tree-level points were classified as crown points.

Table 1. Crown attributes.

Attribute	Definition/calculation
Crown volume	Volume of the 3D convex hull
Surface area	Surface area of the 3D convex hull
Maximum diameter	Crown points were divided in height percentiles (i.e., slices) of 10% starting from the lowest part and their diameter was calculated using 2D convex hull -> maximum
Projection area	Area of the maximum crown diameter
Live crown base height	Height of the maximum crown diameter; Defined from the crown slices
Mean diameter	Mean diameter of the crown slices
Live-crown ratio	Proportion of live crown (i.e., length between live crown base height and tree height) from the tree height

2.2 Crown attributes and statistical analyses

Attributes characterizing tree crowns were generated from the classified point originated from individual tree crown. A 3D convex hull was fitted to envelope the crown points of each tree of which crown volume and surface area were derived (Table 1). Crown points were divided in slices based on height by utilizing 10% percentiles and a 2D convex hull was fitted to all these slices to obtain maximum and mean crown diameter. Crown projection area was defined at the height of the maximum crown diameter. Similarly, the height of the maximum crown diameter was defined as the live crown base height, which was used, together with tree height, to define live-crown ratio.

A nested- two-level linear mixed-effects model was utilized to find possible statistically significant differences in crown attributes between different thinning treatments (including the control plots). The analyses were carried out with i) all Scots pines within the sample plots (n=1919), and ii) with dominant trees only (n=290). Dominant trees from each sample plot were defined based on their diameter at breast height, in other words the trees representing the 100 thickest trees per hectare that would have been used for calculating top height.

3. Results and Discussion

When all Scots pine trees were considered, crown volume, projection area, maximum and mean diameter, live-crown ratio, and diameter at 10-80 crown height percentiles were statistically significantly larger ($p<0.05$) due to intensive thinning from below compared with moderate thinning from below. Between moderate and intensive thinning from above, live crown base height, live-crown ratio, and diameter at 10-30 crown height percentiles increased significantly ($p < 0.05$). Crown volume, surface area, projection area, and maximum diameter increased when thinning from below was compared with other thinning types, however, there was statistically significant difference ($p<0.05$) only within intensive thinnings.

When only dominant trees were included in the analyses, crown volume, projection area, maximum diameter, and diameter of 10-70 crown height percentiles increased statistically significantly ($p<0.05$) between moderate and intensive thinning from below. With thinning from above, only diameter of 10-20 crown percentile heights of the dominant trees increased statistically significantly between moderate and intensive thinning. Similarly to all Scots pine trees, crown volume and surface area of dominant trees were statistically significantly larger between thinning from below and other thinning types, but only within intensive thinnings.

The crown attributes generated here from TLS have been challenging to obtain with traditional means. Here, diameter of crown height percentiles, for example, that characterize crown shape has not been possible to measure before the utilizations of TLS. Only maximum diameter has been measured, when needed, with a measuring tape on the ground underneath a tree crown. Thus, it is challenging to assess the accuracy of the presented crown attributes based on TLS.

There are no studies on the effects of thinning on conifers but there is an increasing body of literature studying European beech (*Fagus* sylvestris) trees. Juchheim et al. (2017), for example, found that increasing thinning intensity increased crown surface area and crown length.

This study contributed to understanding how Scots pine trees adapt to their increased growing space due to management activities by investigating their crown shape and size.

4. Conclusions

Thinning intensity increased crown shape and size of individual Scots pine trees, whereas thinning type mainly increased crown size. The results were similar when the largest trees by their diameter at breast height (i.e., dominant trees) were considered. Thus, it can be concluded that thinning intensity increased both crown shape and size of Scots pine trees of different sizes.

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