APPLICATION OF HIGH FREQUENCY DENSITOMETRY TO DETERMINE WOOD DENSITY AND RING WIDTH OF BEECH TREES

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Abstract:
The variations of wood density and annual ring width were examined on different heights of beech trees. In total, 25 stem discs were collected from 5 beech trees, at 1,3m, 5m, 9m, 13m and 17m height from base of the tree. The wood density and ring width measurements were carried out via high frequency densitometry method, using the Lignostation system. The wood density showed variation within beech trees at different growth heights. There was a tendency for reduction of wood density with tree height, but this did not occur in all beech trees. The annual ring width varied within beech trees. In some beech trees, it gradually increased from the top of the tree to a maximum of around 9 m and then reduced to the base. The wood density showed a small variation between beech trees. There were not significant differences on the ring width of stem discs, between 4 beech trees, while the ring width of a beech tree was found to be the highest on every stem height. The results from this study suggest that the HF densitometry method is a promising technique to assess wood density and ring width. This method provides the variation of density and analyzes the ring width, within and in-between trees of the same species.

Key words: wood density; ring width; lignostation; beech; high frequency densitometry.

INTRODUCTION

Wood density is an important index of wood quality as it affects many wood properties (hydroscopicity, shrinkage and swelling, mechanical, thermal, electrical, etc.) related to the industrial processing of wood (Tsoumis 1991). Wood density is commonly used to describe the wood quality in the mechanical and chemical wood industry. There are many reasons for this interest in wood density as it is correlated with a number of wood quality properties (Repola 2006). Wood density and ring width are the most commonly used indicators of wood characteristics. Density is a complex of characteristic and is influenced by moisture, structure (width of growth rings, proportion of latewood), extractives and chemical composition. Even more, there is variation within a tree, between trees of the same species and between species (Tsoumis 1991). The average wood density of a stem is affected by a large number of factors such as tree species, geographical location and other environmental factors, site quality, position of the tree in a stand, tree age and size, growth rate and genetic factors (Repola 2006).

Density is determined by the gravimetric method or by other methods. The density of wood and its variability within growth rings may be determined by use of instruments (densitometers), which measure the absorbed radiation in different positions within a growth ring (Tsoumis 1991). High frequency densitometry is a new method, for measuring relative density variations along wood surfaces, utilizing the dielectric properties of wood. It is based on a simple measurement procedure, it allows extremely fast measurements of wood density variations and no protective arrangements are needed (Schinker et al. 2003).

Many studies into the application of high frequency densitometry method to obtain density and its variations on entire tree-rings as well as other parameters (tree-ring width, early and latewood width and density) along wood surfaces of stem discs and increment cores have been performed (Šilinskas et al. 2016, Matisons 2015, Shchupakivskyy et al. 2014, Clauder et al. 2012, Hochreuther et al. 2012, Linke and Beck 2012, Meinardus et al. 2012).

For instance, in a recent study of Shchupakivskyy et al. (2014) the High-Frequency densitometry method was proved to be applicable to localise the changes in density within an annual ring, in contrast to the gravimetric method. Furthermore, Clauder et al. (2012) found that, in contrast to the Gravimetric Method, the High-Frequency densitometry method allows to differentiate changes in earlywood and latewood density.

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OBJECTIVE

Similar research for the application of high frequency densitometry to detect changes on wood density and tree ring widths along wood surfaces, in Greece, is lacking. The objectives of this study were the potential use of high frequency densitometry to investigate the variations of wood density and tree ring width: a) within the stem of trees, b) between trees of the same species.

MATERIAL, METHOD, EQUIPMENT

Five standing beech trees (*Fagus sylvatica*) were chosen for our investigation, from the Aspropotamos forest district of Kalampaka, western-central Greece. Trees were felled during the harvesting operations on June 2016. Then, stem discs were cut on the breast height (1,3m) and on 4 different heights of the trees (5m, 9m, 13m and 17m from tree base). The experimental material in the present research consisted of 25 stem discs (Fir. 1.), five from each beech tree. Furthermore, 25 more stem discs were collected from the same heights as previous, for repeat testings in case of sample failure (discolouration, cracks, etc.).

The diameter of the discs ranged between 15cm to 50cm, as the maximum length of the measurement machine was 50cm. All discs were transferred indoors for storage and were air-dried for three months to a moisture content of 12% (Fig. 2.). Furthermore, the sample discs were covered with wood dust to prevent discs from cracking, due to moisture content reduction.

The moisture content of the discs was checked with an electronic moisture meter. Furthermore, moisture content was estimated by the following equation:

- $$MC(\%) = \frac{M_{wet} - M_{dry}}{M_{dry}} * 100$$ (1)

where: M_{wet} is the initial weight;
M_{dry} the oven dry mass of the stem discs.

Fig. 1.
View of the collected beech stem discs.

Fig. 2.
Storage of stem discs for indoor air-dry.

The relative density measurements were carried out via high frequency densitometry. The method is based on the propagation of continuous electromagnetic waves in a high-frequency (HF) transmitter-receiver link of an extremely small electrode system, which is in direct contact with the wood surface investigated (Schinker et al. 2003).

For our experiment, we used the measuring system LignoStation (Fig 3.). LignoStation is used to determine information about relative radial density variances of dry wood samples (stem disks or increment cores) using high-frequency scanning of a probe with a very thin tip. The HF-probe measures the di-electric constant of wood, which is proportional to the spatial density (Rinntech 2006).

Before scanning, the sample surface had to be smooth and plain. This was done with LignoTrim, a milling tool with fly-cutter (Fig. 4.). Then, the scan-path had to be scanned optically with LignoScop, a microscope camera. After this step, density variations were measured along the smoothed surfaces, using the high frequency dielectric scanner (Fir. 5.).

Fig. 3.
The Lignostation machine based in the School of Forestry and Natural Environment, Aristotle University of Thessaloniki, Greece.

Fig. 4.
Disc surface milling with the fly cutter.

Fig. 5.
Disc surface scanning with the high frequency probe.

Prior to density measurements, the measuring system (probe-transmitter-receiver) of the machine was calibrated with a set of standards for wood samples. Next step was to set the milling parameters of the machine. After several trial cuttings, the milling speed, depth and number of paths, were adjusted. The HF probe measurement was highly depended on the wood milling surface quality. It was found that samples of low milling surface quality gave lower values of density measurement, than that of better surface quality. The measurements of the discs were carried out from bark to pith. When any abnormalities in wood surfaces appeared, like knots, cracks, and checks, the milling path was corrected and set again in surfaces without defects.

RESULTS AND DISCUSSION

Table 1 shows the density and moisture content mean values of the selected stem discs calculated from the lignostation system and the oven-dry density values calculated with the gravimetric method.

Table 1

Mean values of density and calculated oven dry density values

Beech trees	Mean density (kgr/m^3)	Moisture content (%)	Oven-dry density (kgr/m^3)
	529,0	12,0	690,5

Certain differences on density values were found to exist among high-frequency densitometry and gravimetric method. These differences may be attributed to the milling surface quality of the stem discs. It was observed that a milling surface of bad quality affects the density measurement with the HF probe, giving lower values of density than the surface of better quality. This variance on density values could be also due to the appearance of defects on the stem discs surface or on the existence of reaction wood. Tsoumis (1991) stated that the density of tension wood can be 2-20% higher than normal wood.

Although proportion of earlywood and latewood, earlywood and latewood density, minimum and maximum density were also determined for every stem disc, only mean stem density values and annual ring width were analyzed in this study. The density and ring width analysis of a beech stem disc, as carried out

with the Lignostation software, are shown in Fig. 6. The upper part of the graph indicates the variation of density values of the stem disc from bark to pith, as measured by the HF probe. While, the lower part of the graph depicts the ring width measurement of the disc from pith to bark. On the right part of Fig. 6, the milling and scanning paths of the stem disc are shown.
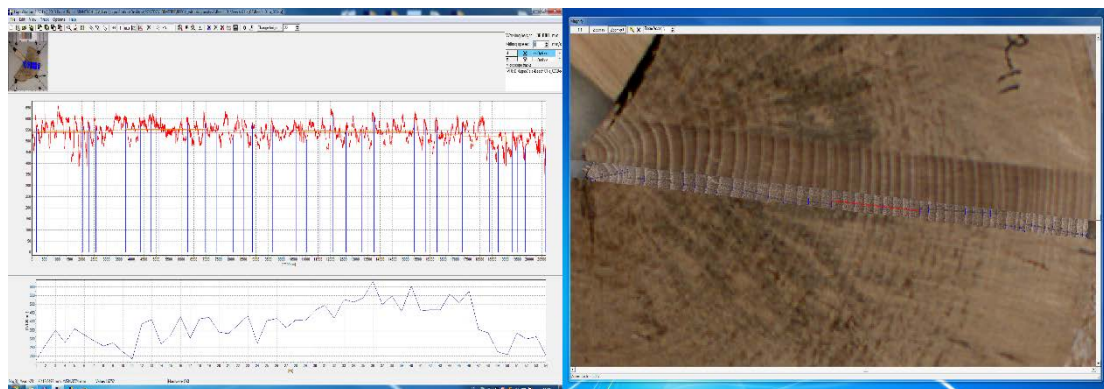

Fig. 6.
The density and ring width analysis on beech stem disc with Lignostation software.

Variation of the wood density and the annual ring width within beech trees
The variation in wood density at different heights are shown in Fig. 7. From the base to the top, the highest average wood density for all beech trees was found at breast height (1,3m). There was a tendency for reduction of density with tree height, but this did not occur in all cases. For instance, beech tree 3 showed a constant decrease in density from base to top of the tree. While, beech trees 1, 2 and 4 indicated a reduction in density from the breast height to 9m long height of the tree, then slightly increased with stem height and finally beech trees 1 and 4 declined. Beech tree 5, with the highest density, showed a decline in wood density below 5m stem height. Overall, the average wood density presented a decreasing trend with stem height.
This reduction may be attributed to mechanical factors. Under the influence of weight, wind, and snow on the crown, greater stresses develop at the base of the trunk, resulting in local formation of wood of higher density. Furthermore, greater density at the base of a tree is contributed by the formation of heartwood, as the proportion of heartwood is higher at the base (Tsoumis 1991).
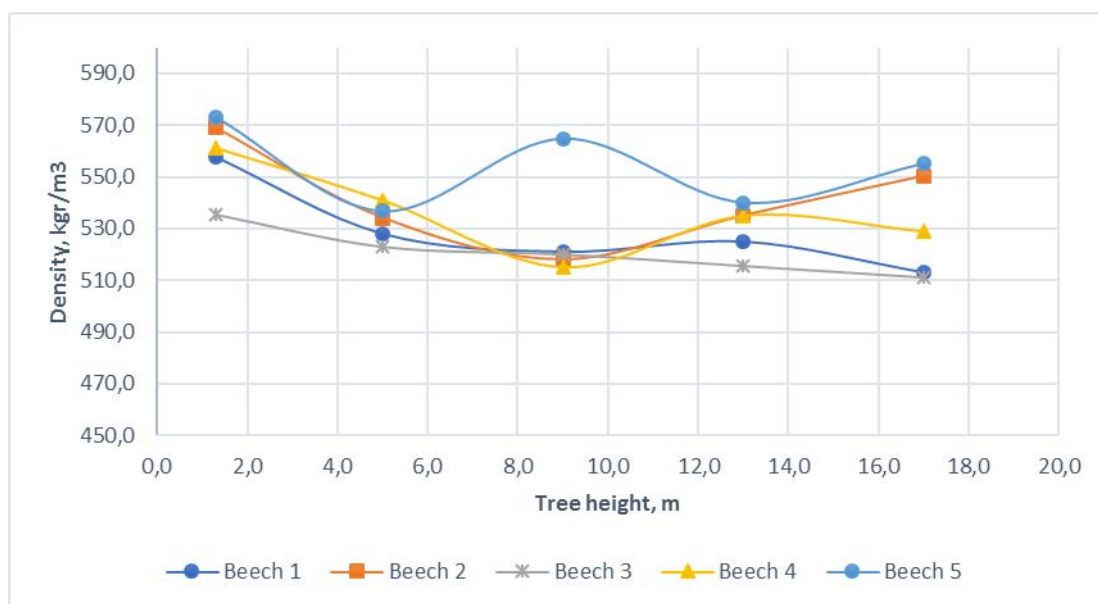

Fig. 7.
Variation of the wood density in beech trees.

The existence of a vertical variation of structural characteristics should be expected, since at different height levels wood is composed of growth rings of different structure. The ring width increases from the top of the tree to a maximum near the lower part of the crown, and then slowly decreases to the base

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(Tsoumis 1991). Fig. 8. shows the results of the ring width variation from base to top of the tree. A vertical variation was observed, as the ring width of beech trees increased from the top of the tree to a maximum of around 9m, for trees 1, 3 and 4 and then reduced to the base. The same trend was observed in beech tree 5, where the maximum ring width appeared at 5m. For beech tree 2, the ring width declined from the top of the tree, but the highest ring width was found near stem base.
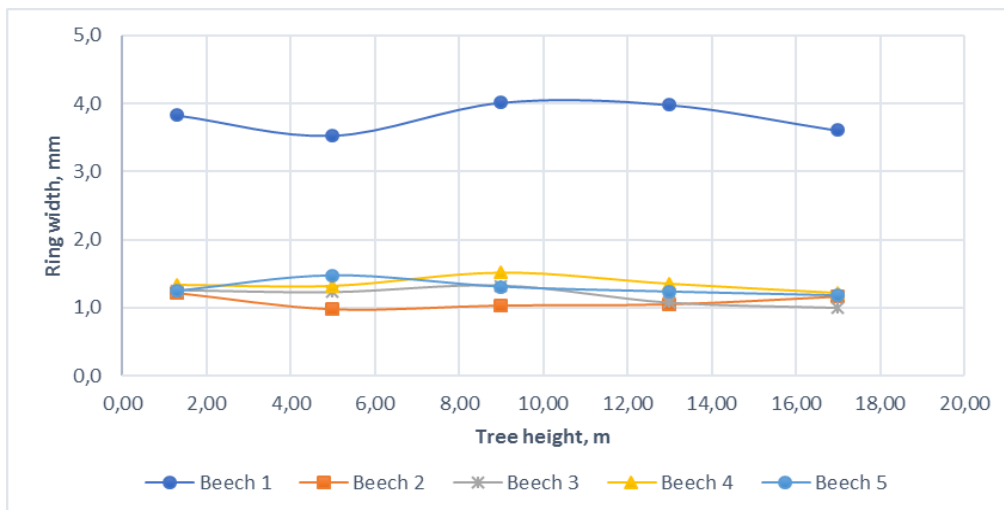

Fig. 8.
Variation of the annual ring width in beech trees.

Variation of the wood density and the annual ring width between beech trees
Based on the results of Fig. 7., there was a small variation on wood density between beech trees. For instance, the density values between beech trees 1, 2 and 4 were found quite similar near the base (1,3m) and on 5m, 9m and 13m height from the base. It was also recorded that the wood density for beech tree 3 was lower on every stem height, except from the height of 9m, were the density was quite the same as trees 1, 2 and 4. The wood density of beech tree 5 was the same as other beech trees on the lower parts of the stem (1,3m and 5m). As shown in Fig. 8, there were not significant differences on the ring width of different heights of stem discs, between beech trees 2, 3, 4 and 5. While, the ring width of beech tree 1 was found to be the highest on every stem height.
According to Tsoumis (1991), variation of density and ring width between trees of the same species exists and is influenced by environmental conditions (soil, climate, tree spacing) and heredity. This effect of environment is basically expressed through changes of ring width and proportion of latewood and as a result, adjacent tree may differ in pattern of ring width and ring structure.

CONCLUSIONS
The results obtained from this study suggest that the HF densitometry method is a promising technique to assess the density and ring width on stem discs. This method provides the variation of density and analyzes the ring width within trees and in-between trees of the same species. The results of this work indicate that the HF densitometry method allows to measure the density variation on every part of a stem disc, from pith to bark and to differentiate changes in earlywood and latewood density. On the contrary, the gravimetric method calculates the wood density on small parts of the disc or separately for earlywood and latewood. Furthermore, the HF densitometry method is based on a simple measurement procedure, it is extremely fast than the traditional methods and thus it could become widely used for measuring wood density and ring width variations. However, it should be noted that the application of HF densitometry via Lignostation machine to measure wood density variations on stem discs, is highly depended on the milling surface quality and on any abnormalities appeared in wood surfaces of stem discs.

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