# Choice of Silvicultural System Influences Internal Wood Characteristics of Sugar Maple

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Quality is an important determinant of the end use of wood, and therefore its value. Silviculture and growing environment can influence wood characteristics of softwood species (Barnett and Jeronimidis 2003, Shmulsky and Jones 2011, Zobel and Van Buijtenen 1989); however, less is known about these influences in hardwoods (Dickinson et al. 2019). A number of tree species typical of northern hardwood forests such as sugar maple have been conventionally utilized primarily for aesthetic applications and are therefore graded visually. However, the recent expansion of engineered wood products has created new potential uses for hardwoods (Ross and Erickson 2005, 2020), and a greater understanding of wood quality is needed to allow continued development of these engineered wood products.

The objective of this study was to investigate the influence of silviculture on the fundamental physical and mechanical properties of sugar maple, a dominant northern hardwood species. We investigated the influence of silvicultural system on internal wood characteristics of sugar maple, primarily wood density, in a long-term silvicultural experiment utilizing nondestructive acoustic testing.

Transverse and longitudinal stress wave velocity at breast height, tree age, green moisture content, and oven-dry wood density were measured for 30 randomly selected live trees managed under each of seven silvicultural systems at the Dukes Experimental Forest (DEF), Hiawatha National Forest, Michigan (46.34236, -87.14078). Stress wave velocity is the speed which an acoustic wave takes to travel through a material and is known to have a strong relationship with a range of wood quality characteristics including wood density (Wang and Carter 2015). Furthermore, the stress wave velocity horizontally through the trunk of a tree in the transverse direction (across the wood grain), and vertically along the trunk in the longitudinal direction (along the wood grain) differ.

The study area is characterized by continental climate, although it is in close proximity (18 km) to a large body of water, Lake Superior. The average annual temperature is about 5 °C, the average snowfall about 355 cm, and the growing season length is 110 days. The soils are moderately to somewhat poorly drained sandy loams (Sheopac-Trenary and Reade silt loams) with site indices (at age 50) up to 20 m for sugar maple (NRCS 2007). The Partial Cuttings Study was established on the DEF in 1926 (Eyre and Zillgitt 1953). Prior to study establishment, the forest was in a late-successional stage of development and was dominated by large diameter sugar maple (*Acer saccharum* Marshall). Density of large trees >46 cm diameter at breast height (d.b.h.) was 64 trees/ha, while total stand basal area varied between 27 and 32 $m^2$/ha. Minor species (<10 percent of tree density) were primarily yellow birch (*Betula alleghaniesis* Britton) with lesser amounts of American elm (*Ulmus americana* L.), eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Kock) and balsam fir (*Abies balsamea* (L.) Mill.).

While some of the experimental treatments included common practices of the time focusing on removing large trees (i.e., diameter-limit cutting), other treatments approaches tested were new

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to the forest type, such as improvement cuttings and selection systems. In the current study we revisited the 30 cm (12 inch) diameter limit, 55 cm (22 inch) diameter limit, 70 percent selection, clearcut, single-tree selection (originally called overmature and defective No. 1) and group selection treatments. Treatments were applied in stands (experimental units) 2 to 13 ha in size. Replication of treatments was uncommon in forestry research at the time and, consequently, the treatments were applied once (N = 1). The treatments were initiated between 1926 and 1932 and the most recent harvest occurred over winter 2008–2009. In addition, we utilized the nearby Dukes Research Natural Area (RNA) (https://www.fs.usda.gov/research/nrs/rnas/usingrna) as an old-growth, reference condition (control) to compare and contrast with the silvicultural treatments. This RNA is an area of uncut, old-growth forest and therefore trees within this area provide a good representation of the wood characteristics of trees grown without silvicultural treatments.

Transverse and longitudinal stress wave velocity were measured using the time-of-flight method. Two sensor probes (transmit probe and receiver probe) were inserted into the sapwood and acoustic energy introduced into the tree through a hammer impact on the transmit probe. The time taken for the stress wave to travel between the two probes was measured, and the speed of travel calculated. During this study, the probes were inserted into the tree trunk (through bark and cambium to extend into the sapwood) and aligned within a vertical plane on the same face. The lower probe was placed about 40 to 60 cm above the ground. The span between the probes were determined from a practical standpoint, typically in the range 1.0 to 1.2 m. In addition, acoustic wave velocity was measured in the transverse direction at d.b.h. The two probes were placed either side of the tree, and measurements recorded as above.

Green moisture content, oven-dry wood density, and tree age were measured using a pith-to-bark increment core collected at breast height. The core volume and weight were recorded in the field immediately after collection, and again after being oven dried at 100 °C to a consistent weight. The moisture content and wood density were then calculated. Each core was mounted and sanded, and tree rings counted under a microscope.

We used multiple linear regression to statistically test whether longitudinal and transverse stress wave, respectively, were predictive of oven-dry wood density. Moisture content is known to influence stress wave velocity; therefore, green moisture content of the increment core from each tree was included as a covariate. Furthermore, age was included as a covariate as it also potentially influences wood characteristics. All assumptions of multiple linear regression were examined and satisfied. Where the covariates were not significant ($\alpha = 0.05$), they were removed from the final analysis model. We also used ANOVA to statistically test whether longitudinal and transverse stress wave velocities, and wood density, respectively, vary among the six silvicultural treatments and control treatment. Similarly, moisture content and age were initially included as covariates, but removed where not significant. All assumptions of ANOVA were examined and satisfied. Where the ANOVA was significant, follow-up *ad hoc* Tukey tests were used to identify which of the treatments had statistically significantly different stress wave velocities. All analyses were undertaken using R version 4.0.3 (R Core Team 2019).

We found that transverse stress wave velocity is a statistically significant predictor of measured wood density ($P < 0.001$) suggesting that it may be used to indicate internal wood quality of standing sugar maple trees; however, this relationship is influenced by tree age ($P = 0.017$; Fig. 1). Oven dry wood density increases with increased transverse stress wave velocity and tree age. In contrast, longitudinal stress wave velocity is not a statistically significant predictor of measured wood density ($P = 0.977$) and cannot be used to indicate internal wood quality of live sugar maple.

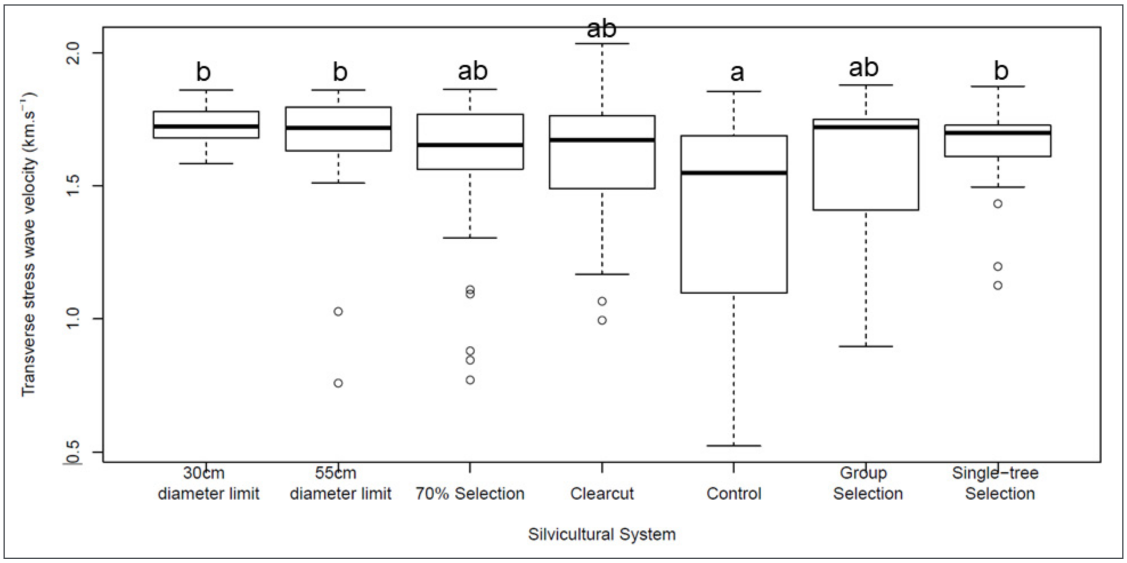


Figure 2. —Transverse stress wave velocity varies significantly among silvicultural systems. Letters indicate statistically significant differences.

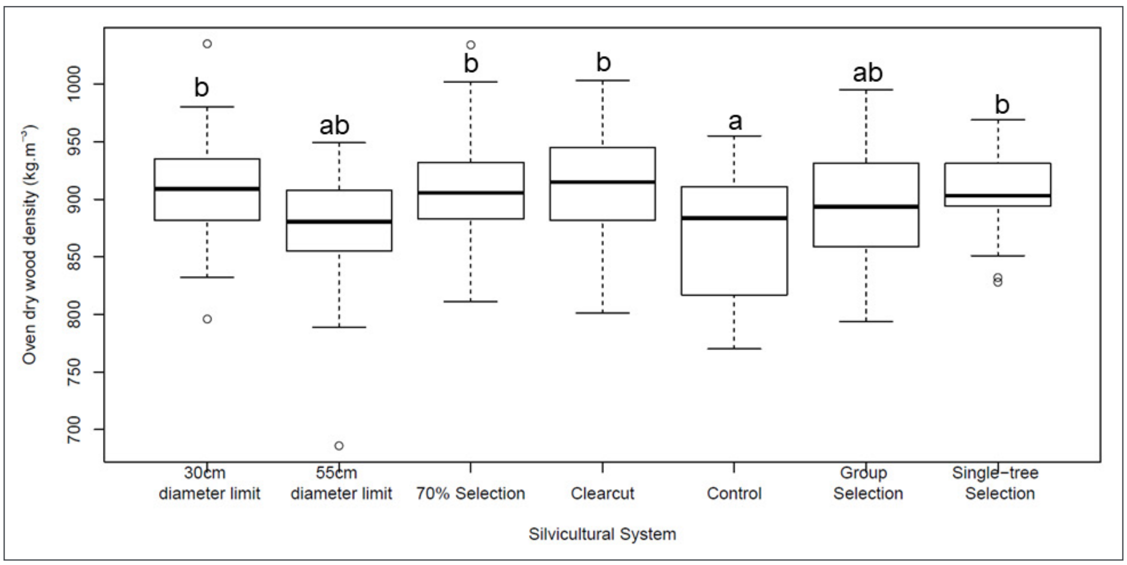


Figure 3. —Oven dry wood density varies significantly among silvicultural systems. Letters indicate statistically significant differences.

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