IMPACTS OF FOREST MANAGEMENT ACTIVITIES ON SELECTED HARDWOOD WOOD QUALITY ATTRIBUTES: A REVIEW

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ABSTRACT

Hardwoods are increasingly being viewed as an important raw material component of the forest products industry, and this has spurred awareness of the impact of forest management on tree and wood quality. The impacts of various forest management activities on tree and wood quality in hardwoods are presented from the standpoint of the activities themselves rather than that of the wood properties. These silvicultural activities include genetic manipulation, intensive culture, fertilization and/or irrigation, pruning, thinning, weed control, and prescribed fire. A broad literature cited section is included as an aid to future scientists.

Keywords: Hardwoods, wood quality, forest management, silviculture.

In the past several decades, considerable attention has been devoted to measuring, manipulating, and improving wood quality in several softwoods, notably Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), the southern pines (Pinus spp.), and redwood (Sequoia sempervirens (D. Don) Endl.). However, the same level of attention has not been paid to hardwoods except perhaps for Populus and Eucalyptus on a global scale. At one time, the United States Forest Service North Central Forest Experiment Station had a major research effort in wood quality of fine hardwoods (white ash, white oak, and black walnut), but this was dropped in a reorganization. Purdue University is now the home of the Hardwood Tree
Improvement and Regeneration Center (HTIRC), a relatively new effort focusing on genetic improvement of fine hardwoods (Woeste and Michler 2000). The HTIRC is a partnership among state, federal, and private organizations and agencies.

The increased emphasis being placed on hardwood utilization requires that we focus on improving all aspects of hardwood growth and utilization. Luppold et al. (2002) noted that hardwood roundwood consumption has been increasing since the 1960s in all regions of the United States. In this paper we review efforts in wood quality improvement and manipulation in (primarily) North American hardwoods. While the majority of the research cited in this paper is post-1970, there were several pioneering studies predating this that deserve special notice. These include the efforts of Benson H. Paul, USDA Forest Service Silviculturist (Paul 1929 through 1963).

WOOD QUALITY

Wood quality is measured by several parameters whose importance varies from end-user to end-user. Briggs and Smith (1986) indicated that wood quality “is a measure of aptness of wood for a given use.” Larson (1969) views wood quality as a concept and further indicates that

... wood quality encompasses the whole of the wood, and when certain characteristics are segregated for measurement or evaluation, it must be recognized that the evaluation is arbitrary and the segregation artificial.

The characteristics or parameters Larson referred to might include cell length, density or specific gravity, growth rate, earlywood-latewood ratio, heartwood color, etc. They may also include such items as lumber grade where hardwood lumber is to be cut into smaller pieces to be remanufactured into furniture (as an example). Until recently, strength had usually not been a concern in hardwood utilization since the majority of the wood had been used for decorative veneers and furniture. Recent research has resulted in the inclusion of aspen, yellow-poplar, red oak, and maples in the National Design Specification (Blankenhorn et al. 1999).

The efforts in wood quality manipulation can be broadly defined as whatever actions the landowner undertakes that influence the growth of the trees and/or the stand. In forestry, this falls under the broad aegis of silviculture. Silviculture is both an art and a science and has been defined as the art of applying science to control forest stand quality (Nylund 2002). This includes no action as well since, as we will see, failure to control weeds or to remove diseased trees or to thin will influence the growth of the stand just as much as overt action does. One of the problems in looking at the effects of forest management activities on tree and wood quality is that all too often tree growth (diameter and/or height) is assumed to be a proxy for wood quality and specific measures of wood quality are left unmeasured.

A study of the literature indicated that the body of knowledge is lacking in many areas. While there have been many examples of guidebooks discussing hardwood stand management—USDA General Technical Report NC-38 by Schlesinger and Funk (1977) or UK Forestry Commission Handbook Number 9 by Kerr and Evans (1993) as examples—few, if any, of these discuss wood quality. The index in Johnson et al.’s recent book on oak ecology and silviculture lists neither tree nor wood quality (Johnson et al. 2002). There are some noteworthy exceptions to this, however. In the Fourth Black Walnut Symposium, Phelps (1989) addressed the tree growth-wood quality relationship from the wood properties perspective. Cutter et al. (1997) reviewed the impact of management activities on walnut growth and wood quality in the Fifth Black Walnut Symposium. Zhang et al. (1997) organized a workshop on timber management and wood quality/end product value. Nepveu (1999) led a workshop on modeling the relationships between silviculture and wood quality.

In wood utilization texts, three general sources of variation in wood and wood prop-
erties are listed: genetics, tree (cambial) age, and environment (Panshin and de Zeeuw 1980; Bowyer et al. 2003). Environmental factors are typically thought of as climate, soil fertility, moisture, photoperiod, etc. However, forest management activities undertaken by the landowner constitute an environmental impact as well. Typical or traditional forest management activities—e.g., silvicultural activities—might include thinning, pruning, fertilization, irrigation, etc. Atypical activities might be agroforestry alleycropping where alleyways are used for rowcrops and grazing lanes (Garrett et al. 1991).

This paper is somewhat unusual in that we address primarily the effects of forest management activities on hardwood tree and wood quality rather than looking at specific wood quality measures. By no means should this paper be considered a complete and exhaustive compilation. We recognize that some citations will be overlooked. We will begin by briefly reviewing some of the literature on the other two sources of wood quality variation—genetics and tree age.

GENETICS

One of the glaring areas where noticeable effort has been lacking has been in the area of genetic improvement of hardwood quality. The establishment of the Hardwood Tree Improvement and Regeneration Center will address some of this. Several years ago there were efforts to improve sugar content in sugar maple for better syrup production (Kriebel 1967; Kriebel and Gabriel 1969). There has been considerable effort expended in poplar improvement by both the government and private industry beginning with Stout and Schreiner in the 1930s (Farmer 1972; Schreiner 1959, 1971; Smith 1967; Stout and Schreiner 1933) and continuing with private industry such as MeadWestvaco (Robison private communication). These efforts have been geared towards improved fiber production for pulp and paper usage and continue today. In recent years, willows (Salix spp.) have also received considerable attention because of their increased growth potential (Volk et al. 2001) as has river birch (Betula nigra L.) (Hicks et al. 1975).

When it comes to using hardwood for something other than a fiber or energy source, the efforts and results have been more modest. Farmer (1972) indicated that there were tree improvement efforts underway in yellow birch (Betula alleghaniensis Britton), northern red oak (Quercus rubra L.), sugar maple (Acer saccharum Marsh.), sweetgum (Liquidambar styraciflua L.), white ash (Fraxinus americana L.), sycamore (Platanus occidentalis L.), and yellow-poplar (Liriodendron tulipifera L.). Many of these early efforts were geared towards improvement in height and diameter growth and not necessarily wood quality parameters per se (Farmer et al. 1983).

In Europe, there have been several studies aimed at genetic improvement and breeding programs primarily in oaks and birches (Nepveu 1976, 1982; Nepveu et al. 1978; Sesbou and Nepveu 1978). Nepveu (1984) indicated that there was a high broad-sense heritability in several oaks (Quercus petraea (Matt) Liebl., Quercus robur L. and Q. rubra L.) for wood basic density, intermediate heritability for volumetric change, and low or insignificant heritability for growth and shrinkage anisotropy. Nepveu and Velling (1983) looked at genetic variability in Betula pendula and found that there was sufficient variation that selection for increased wood basic density was possible. Guilley et al. (1999) found that there was some degree of genetic control over spiral grain in Q. petraea. There has been some work done with evaluating genetic variation in Indian teak (Tectona grandis) as well (Varghese et al. 2000).

The one species where there have been concerted efforts in North America is eastern black walnut (Juglans nigra L.). Considerable time and effort have been expended over the
years in black walnut tree improvement programs with modest results (Beineke 1985; Bey 1973; Chenowerth 1995; Rink 1987; Rink and Phelps 1989; Rink et al. 1994a, b). Most of the work has been aimed at improving either growth and form or at increasing nut yield (Garrett et al. 1994; Jones et al. 1995). Rink et al. (1994a) evaluated wood quality in a thinning of plantation-grown walnut and found that selection for timber growth showed modest genetic advantage. Rink (1987) has also found low heritability for heartwood color in black walnut suggesting that environmental and/or management factors play a significant role in determining this important wood quality parameter. Woeste (2002) evaluated a 35-year-old walnut progeny test and found that there was significant opportunity for gain for heartwood area.

Chen et al. (1995) examined knots, pin knots, and pin knot clusters in black walnut boards cut from logs obtained from a precommercial thinning of a walnut-agroforestry plantation. They found no advantage over selection for either nut or timber characteristics with respect to knots, pin knots, or pin knot clusters. They suggested that retention of suppressed buds was controlled by environmental factors, not genetics.

While not actual genetic manipulation, there were early efforts to produce figured walnut by grafting (Lamb 1940). Walters (1951) reported that trees grafted had more figure in the outer section of the stem then the inner section. There have also been attempts to graft for birdseye grain in sugar maple, again with limited success (Kriebel and Gabriel 1969).

**TREE AGE**

Tree age has become increasingly important with the emphasis on short-rotation forestry that surfaced during the 1970s. Again much of the emphasis has been either for fiber production (see Blankenhorn et al. 1988, 1992a, b; Holt and Murphey 1978; Murphey et al. 1979 for example) or biomass energy crops (Geyer 1981; Geyer and Walawender 1994, 1997, 1999; Geyer et al. 2000). In most tree species, the early years of growth produce wood that is variously termed “immature wood” or “juvenile wood” (Panshin and de Zeeuw 1980, Haygreen and Bowyer 1996). This wood has also been referred to as “crown-formed wood” since it is associated with the live crown section of the tree stem. Typically, this wood is characterized by shorter cells, steeper S2 cell-wall microfibril angles, and altered chemical composition. As a result of these changes, some physical and mechanical properties are altered as well—increased shrinkage, decreased density, decreased strength. Walnut does not appear to be an exception. Cutter and Garrett (1993) found that fiber length was increasing from pith to bark in a study of 15-year-old thinnings from an agroforestry plantation. Zhang et al. (1993, 1994a, b) looked at density variation in European oaks and were able to develop regression equations that related wood density and shrinkage to cambial age and ring width.

**FERTILIZATION AND/OR IRRIGATION**

As a rule, fertilization and irrigation increase ring width (Klem 1968). In hardwoods, most of this increase seems to occur in the latewood. Murphey et al. (1973b) found that red oak latewood growth increased significantly as a result of fertilization/irrigation with sewage effluent. This resulted in an overall increase in specific gravity. Mitchell (1971) found a slight increase in specific gravity following fertilization. Insofar as improving the growth and vigor of the trees, it is difficult to say that either of these practices would be detrimental to tree and/or wood quality. Certainly, based on the results from other species, one could infer that the results would likely be favorable (Murphey et al. 1973a, b; Scowcroft and Stein 1986). When fertilization is specifically discussed, it is usually with respect to the effect on nut yield (Jones et al. 1995).

There have been several studies conducted where nutrient levels were altered or controlled to determine what if any effect nutri-
tion had on wood anatomy and or quality. Foulger and Hacskaylo (1968) found that potassium-deficient *Populus deltoides* Bartr. seedlings had shorter, narrower fibers and narrower ring widths in their lower stems and narrower vessel elements in the upper stems. Foulger et al. (1971, 1972) stated that more information on specific nutrients was necessary. Cutter and Murphey (1978), Murphey and McAdoo (1969), and Murphey et al. (1962) all found that depriving seedling or cuttings of adequate potassium resulted in higher wood specific gravity.

**GRAZING**

While grazing is not what many people consider a recommended forest management practice, many times cattle are grazed in forests or woodlots. Some agencies explicitly recommend against grazing (Hershey 1991; Williams 1933). However, in many areas of the United States, forest grazing of cattle is a common practice (Lundgren et al. 1983). Much of the evidence cited against grazing appears to be either anecdotal or based on uncontrolled grazing of not only cattle, but hogs, sheep, goats, etc. and is related to soil erosion and watershed degradation (Patric and Helvey 1986). Cutter et al. (1996) found that controlled grazing with cattle had no influence on tree grade in slash pine. Lehmkuler et al. (1998) indicted that controlled grazing of cattle was not harmful to walnut over the short run. The emphasis in both studies was on control of the duration, intensity, and timing of the grazing.

**PRUNING**

Pruning is done for several reasons including the production of a clear stem, corrective pruning for tree form, and (in agroforestry alleycropping regimes) removal of low branches that might impede the access of agricultural equipment. While there have been numerous studies showing the proper way to prune to minimize bole damage (Armstrong et al. 1981; Shigo et al. 1978), it is important to remember that pruning is a deliberate wounding of the tree, regardless of the desirability of the end result. The general recommendation that may be made is that pruning should be done at an early age and limited to small-diameter branches (say less than 1-inch diameter). Early pruning will allow the production of the maximum amount of clear wood.

While pruning is frequently done to correct a misshapen stem, Reeves (1984) found that the tree will try to correct this on its own, and, if left alone, will do a very good job. The time of year that pruning occurs has been shown to play a role in both wound healing and scarring. Armstrong et al. (1981) and Smith (1980) found that fall pruning/wounding produced more scarring and discoloration in walnuts than did late winter–early spring pruning. Studies by Clark and several of his co-workers indicated that pruning, while stimulating growth, sometimes produced undesirable results including epicormic branching (Clark 1955, 1961; Clark and Seidel 1961). Indeed, even 25 years following pruning, the pruning wounds had not healed on some stems in one study (Shigo et al. 1978, 1979). Shigo and his numerous co-workers noted that dark bands of discolored heartwood were associated with pruning wounds. If the production of clear, uniform color wood is the desired result, this is clearly undesirable.

Minckler (1967) indicated that pruning and thinning could improve stem quality in white oak, but no direct measure of wood quality was examined. Dwyer and Lowell (1988) and Lowell and Dwyer (1988) showed that, while pruning may appear to improve log grade and therefore lumber quality, the time and effort may not be economically worthwhile over the rotation cycle. This was a study of black and scarlet oak (*Quercus velutina* Lam. and *Q. coccinea* Muench, respectively) growing on an upland site in the Missouri Ozarks. DeBell et al. (2002) found that pruning had no significant impact on wood quality in nine-year old *Populus* stems.
THINNING

Typically, thinning is thought of as removal of poorly formed trees, low vigor trees, diseased trees, etc. From a traditional forest management standpoint, thinning is either pre-commercial (i.e. the cut trees are left on the ground) or commercial (the removed trees are large enough for product recovery—also known as harvesting or logging). In either event, the result is increased water and nutrient availability for the residual stand. In some instances, there have been reports of increased levels of limb-related defects associated with heavily thinned hardwood stands (Sonderman 1986). It is well recognized that thinned stands have a tendency towards epicormic branch proliferation. In another study, gum spots were found in the wood of black cherry (Prunus serotina Ehrh.) following a partial harvest (Rexrode and Smith 1990). There has also been some indication in the literature that thinnings increased the tendency towards sun scald and frost cracks in certain climates, although mechanical injury from equipment could not be ruled out (Phelps 1976).

It should be obvious that there is some damage to the residual stand as a result of thinnings. The damage can occur either from the falling trees damaging limbs or stems of the residual stand or basal damage from skidding, or—more insidious—root damage from soil compaction, which may translate to stem damage.

Cutter et al. (1991) indicated that there was a differential response to thinning between black oak and scarlet oak in the Missouri Ozarks. The black oak responded immediately to the release, while the scarlet oaks lagged some six to seven years behind.

Paul (1943) reported that open-grown black walnut had higher density than did forest-grown walnut. Open-grown was defined at that time as “trees growing singly or in small scattered groups in pastures and relatively open farm woodlots.” This might be analogous to stand densities seen in many agroforestry configurations. In a latter paper, Paul (1963) recommended that management practices producing conditions similar to those where open-grown walnut occurs be followed. On the other hand, Landt and Phares (1973) suggested that open-grown walnut would tend to be forked and limby while forest-grown walnut would have a straight, clear stem. According to them, the forest-grown stems would have a dark-colored heartwood with a narrow sapwood band while open-grown trees would have lighter heartwood and wider sapwood rings.

Phelps and Chen (1989) found that—while plantation-grown black walnut grew faster—lumber quality was lower in logs from the plantation-grown trees. They attributed this to the presence of numerous knots in the boards. Phelps and Workman (1992) compared vessel element area in naturally-grown walnut against plantation-grown walnut trees. They found that the faster-growing plantation trees had wider growth rings, which in turn have wider latewood zones. This results in a reduction in vessel area in the cross-section, which results in poorer wood texture. On the other hand, stand management favors a more uniform wood texture.

Phelps and Chen (1991) examined wood and drying properties in white oak (Quercus alba L.) lumber from thinned and unthinned stands. They found that tree size had a greater influence on lumber grade than any other variable. There were no significant differences in amounts of heartwood, specific gravity, and board width shrinkage. There was a significant difference in thickness shrinkage between thinned and unthinned wood.

Other literature suggests that trees growing in a crowded stand may have greater height: diameter ratios. In a study of the effect of stand density, Holbrook and Putz (1989) found that sweetgum (Liquidambar styraciflua L.), which like walnut is a light-demanding tree, apparently allocated more wood to height growth than to diameter when grown in dense stands.

Zhang et al. (1993) studied wood density in two European oaks (Q. petraea (Matt) Liebl.
and Q. robur L.) and developed a model that allowed prediction of wood density based on cambial age and ring width. They suggested that application of (what they termed) dynamic silviculture might result in denser and more uniform oak than did conventional silviculture.

Bragg et al. (1997) suggested that management activities—such as thinning—may reduce the occurrence of “birdseye” figure in sugar maple.

**PRESCRIBED FIRE OR WILDFIRE**

While wildfire is not a management tool, prescribed fire is—and it is becoming more common in some areas (Van Lear 2000). In either event, fire may impact tree growth and therefore wood quality. In a prescription (or prescribed) fire, the impact on tree growth and wood quality may be minimized by proper burning techniques. Wendel and Smith (1986) indicated that a single prescribed fire in a central Appalachian oak-hickory stand resulted in a major reduction in butt log quality. The basal scars that result from fire damage are the result of the cambium being heated for a known length of time to a lethal temperature—typically cited as 60°C (140°F) for 30 s or 64°C (147°F) for instantaneous cambial death (Brown and Davis 1973). Obviously this is a function of bark thickness as well and many hardwood species are (relatively) thin-barked. Paulsell (1957) noted that post oak (Quercus stellata Wangenh.) and hickory (Carya spp.) had thicker bark than more desirable species and therefore were more resistant to basal scarring. Many times the scar is only part way around the tree because of fuel loadings and wind currents (Hare 1965; Gill 1973). Loomis (1973, 1977) and Wendel and Smith (1986) indicated that the chance of tree mortality was a function of tree diameter as well. In the case of wildfires, the damage may include complete destruction of the tree. There is some indication in the fire literature (Van Lear and Waldrop 1989, for example) that seasonal timing of the fire may have a major impact on the likelihood of basal scarring which is of most interest to the forest products community.

**WEED CONTROL**

This could also be termed “competing vegetation control” since, under some scenarios, the competing vegetation that landowners need to control may be rowcrops or other tree species. Numerous papers have shown that vegetation control during establishment phases of walnut stands is necessary for optimum growth response (Schlesinger and Van Sambeek 1986; Van Sambeek et al. 1989). What many do not realize is that the competition for available nutrients and water continues once the tree is into the sapling or pole stage. If the competing vegetation is other trees, be they walnut or some other species, then vegetation control is termed thinning. If the competing vegetation is an annual (such as corn or soybeans) or a perennial (such as clover or lespideza), then the tree line may need to be kept vegetation-free in order for the tree to successfully compete for water and nutrients. This could be done through either chemical or mechanical means (Jones et al. 1990). Cutter and Garrett (1993) indicated that declining growth in an agroforestry plantation on an exceptional site (SI = 90+) was coincident with conversion of the alleyways to a perennial cover crop. SI refers to site index, commonly defined as the height of the dominant and co-dominant trees at age 50.

**OTHER ASPECTS OF WOOD QUALITY**

By focusing this review on the impacts of management on tree and wood quality, we have neglected some important hardwood quality issues. One that immediately comes to mind is tension wood and its development (Scurfield 1973). Tension wood in hardwoods has been the subject of numerous studies (Isebrands and Bensend 1972; Isebrands and Parham 1974; Schumann and Pillow 1969, for example). In many species, the amount of tension wood present in a stem has been linked directly to the degree of lean in a tree while
in other species, tension wood develops regardless of lean (Reeves 1984). In either event, tension wood is not considered a desirable trait in many products!

Color has been examined in a number of studies to attempt to describe the quality of wood from that perspective. Wood color is an elusive trait, primarily because the importance of it (from a quality standpoint) varies from species to species and from market to market (Bistline 1981; Blomgren 1965). There are differences within a species as well. Anecdotally, there are reputed to be black walnut buyers who claim that walnut from certain regions has a reddish hue in color and is therefore less desirable. As previously noted, Rink (1987) suggested that environmental/management factors play a significant role in determining this important wood quality parameter.

In the early 1990s, Phelps and colleagues conducted a series of studies to evaluate the potential for using color-measuring instruments in matching colors in white oak panels destined for the kitchen door market. The color value for lightness (L*) was found to be the most influential in determining color separation between dimension parts in a door panel (Phelps et al. 1994). Little difference was found within individual panel parts, leading to the observation that very few measurements per part were necessary. In a subsequent study (Stokke et al. 1995), the distribution of lightness values within dimension parts was found to be statistically normal, suggesting that there may be an opportunity to examine the source of the raw material for selection of panel dimension parts. The third study in this series examined the potential for pre-sorting dimension parts prior to assembly (Pugel et al. 1995). The pre-sort was shown to have potential for improving the quality and value of the final panel product, but there were increased costs due to the added step in processing.

Obviously there is considerable interest in producing high quality hardwoods. This interest has been spurred by indications that hardwoods are going to play an increased role in providing fiber for the 21st century and beyond. As a closing note, the literature section of this paper is labeled as a “Partial Bibliography.” We recognize that not all references on the broad subject we have attempted to review will be included in this section. By the same token, many of the references listed in this section are not cited in this paper but are included to facilitate future use. The relative ease of searching electronic databases and accessing online journals has on one hand simplified life but has also complicated it. However, we have attempted to include a broad cross-section of new as well as older literature to facilitate the efforts of future researchers.

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