CONSIDERATIONS IN THE UTILIZATION OF OAK

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Abstract—The commercial groupings of red and white oak make up the majority of timber in the central hardwood region. Getting the highest value during utilization is important for the management of forests, forest landowners, and the regional economy; therefore, understanding the limitations of the raw material and proper handling and processing is critical. This paper focuses on a description of material limitations, such as: mineral stain, bacterial infection, and why differences in price exist for the "same" material. Utilization considerations, such as reducing log yard degrade, phytosanitation requirements for log shipments overseas, longer drying times, drying methods used, and difficulty with checking will also be discussed.

INTRODUCTION

In the central hardwood region, the commercial groupings of red and white oak make up the majority of timber, and getting the highest value during utilization is important for the management of forests, forest landowners, and the regional economy. Nationwide, it is estimated that red and white oak account for 41 percent of all hardwood lumber produced (U.S. Census Bureau 2011). The oaks are a preferred species for products ranging from furniture, cabinets, millwork, caskets, and flooring to industrial products such as railroad ties, mine timbers, pallets, blocking, and industrial and truck flooring. Both species are well suited to secondary products as they tend to machine well, process well, and glue, stain, and finish well. They are typically straight grained and steam bend well (Cassens 2007).

Achieving the highest value requires an understanding of the limitations of the raw material, proper handling methods, and processing. Raw material variability and processing inconsistencies can limit the value recovered. Examples of raw material variability include: density/specific gravity, anatomy, and growth site and location. Taking a closer look at the two groupings of oak will help to understand some of the variability of the species.

DEFINING OAK AND LIMITATIONS

In the forest industry, oaks are commonly classified into two categories: red oak and white oak. These classifications are commercial classifications based on similarity of the anatomical properties of the tree and wood. Multiple species fall into each commercial category, for example, there are 17 species considered in the red oak commercial classification. An example of eight red oak species and their properties are listed in table 1. The variability is reflected in stumpage prices paid for timber sales that have higher proportions of one or another of the species in a species group. For example, for a given log size, diameter, and number of clear faces, scarlet oak often is valued lower than other species in the red oak grouping. In the white oak grouping, chestnut oak is not accepted for barrel stave production due to its lack of consistent tyloses. Interestingly, once sawn, scarlet oak will be mixed with the lumber produced from other species and sold as red oak lumber, and chestnut oak will be sold intermixed with white oak lumber.

The variability within each of the two species groups is further exemplified by the differences in the value given to the lumber based on the location where it was grown which can influence average growth rates (Shmulsky and Jones 2011), species composition, and perceived quality. The value of lumber for the same commercial grouping is shown in price reports to vary by its production region; three common price categories for lumber produced for red and white oak are Appalachian, Northern, and Southern (Hardwood Market Report 2017).

Other material limitations for the red oak group include the presence/absence and percentage of material that includes mineral stain or bacterial infection. Both of these defects reduce the value of the raw material and the quality of the lumber produced. They can also influence the quality of the lumber when it is processed through drying operations.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

Mineral Stain

Mineral streak/stain in red oak is a common visual defect. The dark discolorations of undetermined origin may be present in a portion of a growth ring or in small patchy clusters either within the sapwood, heartwood, or both. These areas reduce the value of both logs and lumber. Log buyers often deduct a log with mineral stain by one log grade, and veneer buyers will often entirely avoid logs with mineral stain, even when all four faces are clear of knots and other defects. While mineral streak is not considered a lumber grade defect in National Hardwood Lumber grading rules, it is often considered a defect by the purchaser. Many purchasers will specify that mineral stain is to be considered a defect in the purchase order. Mineral stain is also commonly considered a defect in export markets. This defect is associated with increased tool wear when machining and increased checking when drying (Sachs and others 1966). Mineral stain in the finished product is often considered undesirable and of lower quality and value. In one study, approximately 25 percent of #1 Common and 33 percent of #2 Common oak flooring was determined to be downgraded because of mineral stains and streaks (Bulgrin 1965).

A tool to help foresters predict where mineral stain would occur in red oak would allow for better value estimation of timber stands. Work to develop such a tool was conducted in the Appalachian Mountains of Virginia and West Virginia. Researchers focused on geographic and growth site factors selected through a literature search and a survey of foresters who purchased stands for harvesting. Then, the presence and severity of mineral stain in red oak were sampled at eight locations and correlated to growth site variables collected in the field and derived from spatial datasets (table 2). A statistical model was developed to predict mineral stain presence, which determined that elevation, slope angle, solar radiation, flow accumulation (hydrologic analyses), and cardinal direction contributed the most to the presence or absence of mineral stain in red oak for the sites studied. The values of the model coefficients suggested that the probability of staining was highest when the tree is on a relatively flat part of the ground, which receives more water and little sunlight to evaporate the moisture. Although the model did explain a large amount of the variation in the presence/absence of mineral stain, it was clear that some important variables were not included or that some variables measured did not contain enough contrast to provide a clearer picture of their contribution (Bond and Resler 2012).

Table 1—An example of eight species considered in the red oak commercial classification and four important properties (specific gravity, modulus of rupture, modulus of elasticity, hardness) (Ross 2010)

	SG[a]	MOR[b]	MOE[c]	Hardness
		lb/in^2	*x 106 lb/in*^{2}	*lbs*
Black	0.61	13,900	13.7	1,210
Cherrybark	0.68	18,100	18.3	1,480
Laurel	0.63	12,600	11.8	1,210
Northern red	0.63	14,300	14.5	1,290
Pin	0.63	14,000	14.8	1,510
Scarlet	0.67	17,400	20.5	1,400
Southern red	0.59	10,900	9.4	1,060
Water	0.63	15,400	21.5	1,190

[a] SG = specific gravity.

[b] MOR = modulus of rupture.

[c] MOE = modulus of elasticity.

Bacterial Infection

Another site-related defect that can reduce the quality and value of red oaks is the presence of bacterial infection. An anaerobic bacterium known as *Clostridium* spp. can enter the living tree through the roots, slowly moving up the log over time (Ward and Groom 1983).

The bacteria are most commonly found in the butt log of a tree, the log which usually has the highest volume, quality, and value wood material. Wood that is

Table 2—Field and GIS-derived variables measured in Bond and Resler's (2012) study of mineral stain in red oak (variables written in bold font were found to be significant)

Field- or GIS-derived	Variable
Field	Longitude/latitude
Field (GPS)	**Elevation**
Field	Visual damage
GIS	**Cardinal direction**
Field	Age of tree
Field	Calcium (Ca)
Field	pH
Field	Potassium (K)
Field	Phosphorus (P)
Field	Zinc (Zn)
Field	Magnesium (Mg)
Field	Copper (Cu)
Field	Iron (Fe)
Field	**Slope angle**
GIS	**Flow accumulation**
GIS	**Solar radiation**

bacterially infected often contains large amounts of ring shake thus reducing the value of logs and lumber. When lumber containing the bacterial infection is processed, if often has a higher incidence of honey comb, surface checks, and pockets of wood with higher moisture contents (Ward and Groom 1983). While there are methods that can identify the presence of bacterially infected wood, none are commercially practical for the commercial forester or wood processor to use in a production environment. The techniques that have shown promise for bacterial infection detection include stress wave analysis, near-infrared spectroscopy (NIR), and laser fluorescence (Murdoch 1992). Extremely high moisture content, strong odor, and the presence of ring shake have been associated with bacterial infection but have not proven effective for commercial sorting of infected material.

Export Limitations

A large volume of oak is exported in log form (table 3), and understanding the limitations for exporting this material is also important for its utilization. Red and white oak logs are required to be sterilized/fumigated at the port of exit to prevent the transport of insects or other biological organisms. The most common method of sterilization/fumigation is the treatment of containers with methyl bromide at the port of exit. Methyl bromide is considered an ozone-depleting substance, and the Environmental Protection Agency has established site-specific usage restrictions and is providing incentives to develop alternatives to its use. The long-term goal is to eliminate its use (EPA 2017). Sterilization/fumigation requirements have been developed by the U.S. Department of Agriculture and are available in the Treatment Manual (USDA 2016). The standards vary for different species and types of biological organisms being addressed. The problem with fumigation as the currently accepted method for sterilization is that the cost of methyl bromide is increasing as its allowable uses are scaled back. Also, the treatment times are typically long (72 hours) and limited by temperature (must be above 4.44 °C).

While heat treatment standards exist as an alternative, the time period required to heat a log to the required temperatures are excessive with standard conventional heating methods, which use convection to apply heat to the log surface. There are currently no commercial applications of heat sterilization of logs. However, a method using vacuum/steam heating has recently been developed and can treat logs effectively, meeting the current standards in less than a 24-hour time period. Treatment times are dependent on the size of the log, the species, and the treatment standard required. The vacuum/steam treatment has been shown to be effective meeting the 56 °C/30-minute sterilization requirement for logs 46 to 53 cm (small-end diameter) using an initial vacuum of 200 mmHg, with a temperature of 90 °C applied over 24 hours; no adverse effect on the quality or yield of veneer produced occurred (Chen and others 2017). The same equipment has demonstrated its effectiveness on oak wilt, meeting the 56 °C/30-minute treatment standard and the 60 °C/60-minute standard at 2-inch depth with an initial vacuum of 100 mmHG. The average treatment time to 56 °C/30 minutes was 6.4 hours, and the average treatment time to 60 °C/60 minutes was 8.2 hours (White and Chen 2016). This new treatment method creates an opportunity for not only lower cost treatment of oak logs for export but also shorter treatment times.

Drying

Oak lumber must be dried before use in secondary products. Both red and white oak are relatively dense and have wide wood rays. These two characteristics require a slower drying process with a reduced rate of moisture content loss per day relative to other North American hardwood species. Drying too fast results in high drying stresses due to the large moisture content gradient that can form as a result of slow moisture transfer, in part, due to its high density. The wide wood rays result in lower strength perpendicular to grain in the tangential plane of reference. The combination results in a propensity to split on the ends and to surface check, at the wood ray, when dried at too high a rate. Therefore, oak must be dried slowly, resulting in higher cost of drying. Kiln drying times for 4/4 red oak lumber that is put into the kiln directly after being sawn are commonly 28–35 days (table 4) (Denig and others 2000). The kiln drying times can be shortened by air drying or pre-drying, both of which still require that large inventories be carried to fill the kilns as they cycle, adding to the cost of drying.

A potential solution to overcome the longer drying times for the oaks is the use of vacuum drying. Vacuum drying can significantly reduce the drying time, drying costs, and potential for defects. Depending on the vacuum technology used, drying times for 4/4 red oak can be reduced from 28–35 days to 3 to 9 days (Brenes-Angulo

Table 3—Log exports from the United States in 2011 (Luppold and Bumgardner 2013)

Species	Volume	Number of logs	Number of 40-foot containers
Red oak	223,000 m^3	300,000	6,700
White oak	229,000 m^3	305,000	6,700

Table 4—Drying times for 4/4 and 8/4 red oak using conventional drying methods versus vacuum

Species and thickness	Conventional kiln drying time (green condition)	Vacuum (dependent on technology)
Red oak 4/4	28–35 days	3–9 days
Red oak 8/4	46–53 days	4–6 days

and others 2015). One of the drawbacks to industry acceptance of vacuum kilns is the high cost of the kiln and limited capacity compared to conventional dry kilns. However, research based on the use of this technology in flooring production has demonstrated the high initial capital cost can be offset by a lumber drying inventory reduction, from 52 to 58 percent. The work-in-process inventory could also be reduced up to 50 percent. Most importantly, a company's lead time, the time from the placement of an order to shipment, could be reduced 78–90 percent (Brenes-Angulo and others 2015). The operational costs of drying were estimated to not be significantly different between vacuum and conventional drying technology (Brenes-Angulo and others 2017). It should be noted that the conventional drying technology compared was air drying for 30 days and then kiln drying to the target moisture content. Not only has research demonstrated the ability of vacuum drying to be used on a large commercial scale for 4/4 hardwood lumber, but as of 2017 two large commercial secondary processing operations, a large national flooring company and a cabinet company, have begun to implement the technology to meet specific species production requirements.

SUMMARY

Understanding the limitations of a particular species is important to understanding the value of the material and the markets that utilize the material. In this paper, I have tried to demonstrate how variations in red and white oak influence their value and processing. While difficulties associated with their utilization exist, I have also tried to present some technologies that have been or are being developed to overcome these limitations and thus assure a bright future for oaks' continued utilization and value.

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