  

TRACKING AMERICAN WHITE OAK - *Quercus alba L.*

Current & Future Forecast in the Eastern Hardwood Region

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A SPECIAL THANKS to the 20+ university researchers and USDA Forest Service team members for taking the time to share knowledge, review data and discuss published, peer-reviewed research. Your dedication to the long-term research inherent in forestry knowledge is critically important, and we appreciate the insights you provided. We hope this report will help those who are seeking to understand more about the future of American white oak, including for cooperage, and encourage future communication to enhance engagement with the many stakeholders who care about this keystone species.

A note about the statistics included: numbers are presented in either the metric or imperial system according to how the data was originally published. While this is not consistent with choosing one system for all, it does seek to honor the original presentation of data by the researchers involved.

INTRODUCTION

Quercus alba L. has long been considered an outstanding tree species within its range in North America. This report is designed to review the current and future status of the species, especially as it pertains to cooperage. There is an abundance of data available on the topic; however, forest ecology remains a complex subject area that evolves over long periods of time, leading to a temptation to oversimplify or report data out of context. The information contained within this report has been gathered from many sources, including peer-reviewed research, with the goal of providing both a bird's eye view and detailed recap of what is currently being explored. It is recommended to update this report every five to seven years to account for the new data that will have been generated to best monitor ongoing trends, including those relevant to the cooperage industry.

References are cited throughout the report, presented as numbers within brackets, which correlate to the list in the References section at the end of the report. These references are separate from the footnotes, which are also included to clarify certain details on the same page.

UNDERSTANDING OAK

To best investigate *Quercus alba,* it is imperative to first understand the context of the oak genus.

DISTRIBUTION

Through history, the success of the oak genus is legendary. There are an estimated 435–600 total oak species distributed worldwide[1] with 90 of those species established in North America and approximately 30 species found in the Eastern United States. The success of the genus is often credited to oak's resilience, ability to hybridize and its lack of "overspecializing," allowing the oak category to grow in a wide range of habitats.

Quercus Oaks	up to 600 species (90 in North America)
Prunus Cherries	400 species
Salix Willows	350 species
Acer Maple	160 species
Pinus Pine	111 species
Betula Birch	30–60 species

Figure 1.1 Overview of the number of tree species for several key genera [1]

Considered a foundational genus, oaks help define many of the forests where they are found growing. *"Oaks are an important component of many forest associations in the Eastern United States, including northern hardwood conifer, maple–beech–basswood, mixed mesophytic, oak–hickory, oak–pine, and southern evergreen. Indeed, oak trees have dominated forests of the Eastern United States during the last 7,000-9,000 years."* [2]

Oaks are commonly found in combination with other trees, rarely growing in pure stands. [2]

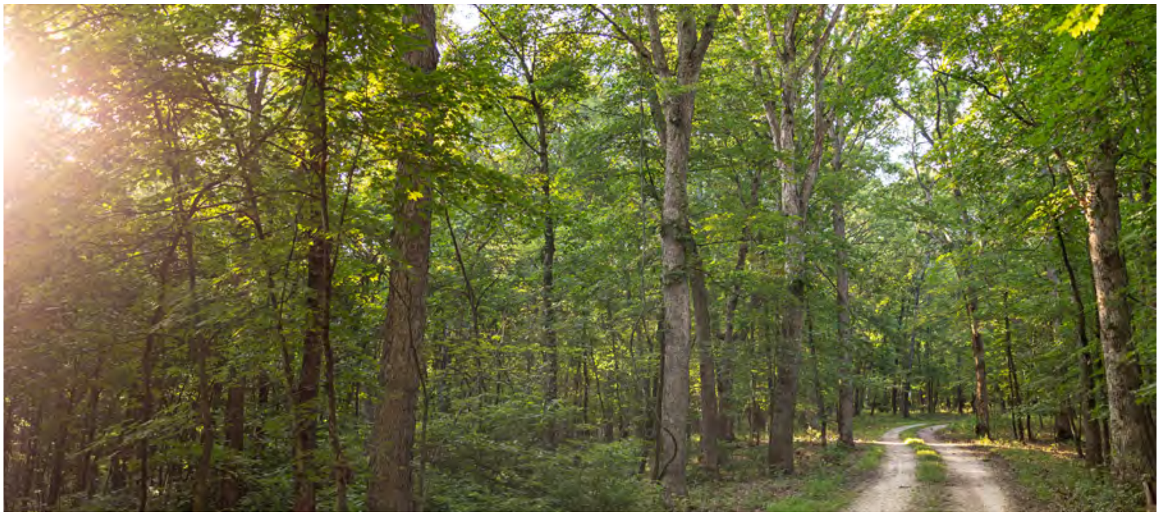
[1] There are at least 435 confirmed species of oak, but various sources estimate the number could be as high as 600 species since oaks cross-pollinate and hybrids are discovered regularly. Scientists have not agreed upon an exact number.

IMPORTANCE OF OAK

Given the distribution of oak species established for many centuries, it is not surprising that the stability of entire ecosystems can often be strongly linked to the oak trees found within those environments. An article published in the *Scientific American* summarized the important role oaks have played related to flora, fauna and human civilization: *"Oaks are keystone species, foundational to the functioning of the forest they form across the Northern Hemisphere. They foster diversity of organisms across the tree of life, from fungi to wasps, birds and mammals. They help clean the air, sequestering carbon dioxide and absorbing atmospheric pollutants. And they shaped human culture, feeding us with their acorns and providing wood to build our homes, furniture and ships. Indeed, oaks have proved so valuable to people that we have immortalized them in legends and myths for centuries."* [3]

In the modern era, oak forest and woodland continue to play a vital role, resulting in many stakeholders focused on the long-term success of the genus.

- **WILDLIFE & PLANTS**
  Oak trees continue to serve as an important habitat and a food source for a huge variety of living things. Squirrels and birds come to mind easily, but oaks are also essential to a huge number of insects as well as rodents, deer and even black bears.
- **A RENEWABLE RESOURCE UTILIZED BY THE FOREST PRODUCTS INDUSTRY**
  The durability of oak wood lends itself well to furniture, cabinetry and cooperage, to name just a few categories. A TedX Talk by Criswell Davis in 2019 [4] highlighted oak's importance as a hardwood to biophilic design, which centers on incorporating nature into building designs and indoor spaces for documented health and wellbeing benefits.
- **RECREATION & LAND STEWARDSHIP**
  Estimates maintain that 58–60% of the forested land in the United States is privately owned, although that percentage jumps to closer to 80% for forests east of the Mississippi. [5,6] Many landowners appreciate using the forest for recreation, including the privacy and inspiration living surrounded by nature can offer. Oaks are regarded as beautiful and long-lasting trees while often also benefiting a landowner's other goals, such as documenting wildlife, hunting, water quality and prevention of soil erosion.



THE "NATURAL" OAK FOREST – ROOTED IN CHANGE

Despite the prevalence of the oak species in the Eastern United States and beyond, history documents the success of oak associated with alternating periods of change and stability in the environment. This is the opposite of what many would think, preferring to believe the oak forests have thrived by being left alone. William Bryant Logan explains, *"Forests seem permanent and natural. Few are. For at least six thousand years, men and women have shaped the woods. The forests as we know them are products of craft."* [7]

Why is this especially true for oak? As will be discussed further in the How Oak Grows section of this report, oaks need sunlight at key intervals to thrive and growth "opportunity" created by disturbances in the understory and canopy. Native Americans in the pre-European Settlement era likely understood this through their use of fire as a management tool. It is not agreed upon if these groups understood how beneficial fire was specifically to the oak species. However, oaks provided an important food source, shelter, medicines, dyes and other useful products, and thus were certainly favored. [8]

In short, the wealth of oak trees available today is a testament to the opportunities oak trees have capitalized on historically, and continuing these opportunities is a key point to their continuing success that will be explored in this report.

CHANGES THROUGH HISTORY
Examples of management and disturbances that have shaped the oak forests we have now:

10,000 y. B.P.	Warmer/drier conditions associated with increased frequency of fire *Increase in oak dominance in the Eastern United States [9]*
Native Americans	Abundance of habitat, including drought-prone sites where oaks can still thrive Management benefiting oaks, often involving periodic fire [8,10] *Oaks grew slowly for long periods in uneven-age forest.* *Periodic "intermediate" level fire in the understory benefited the oaks by reducing competition with other tree species, preventing dominance of tree species not well suited to fire. This also maintained light conditions beneficial to strong recruitment of oaks into mid- and upper canopies.*
European Settlement	Increased use of fire to help clear land for lumber, fuel and agriculture. As settlements established, eventually there would be a decreased use of fire, often after 1–3 years. [8,10] *Areas that were clearcut and burned to provide fuel for forges, or sites that were later abandoned—white oak often able to grow back well.* *Oaks able to expand into prairies as they burned less frequently, giving more time between disturbances to allow oaks to establish, as well as allowing other tree species less fire tolerant than oak (such as elm and hackberry) to have increased opportunity. [9,11]* *"Q alba exhibited continuous recruitment into the tree size classes from 1700–1900." [12]*
EARLY 1900S Chestnut Blight	Blight affected the American Chestnut, and the relatively fast reduction in this tree species gave opportunity for *White Oak and Oaks in general to fill in* [8,10,12]
Significant game hunting	Decrease in populations of turkey, passenger pigeon and white-tailed deer [8,10] *Decreased acorn predation – more acorns available*
Exclusion of Fire (Smokey Bear era)	Established oaks continue to grow, but with less periodic disturbances to help younger oaks. [2,8,42]
1950s	Increase in population of shade-tolerant species starting to affect oak recruitment [2] as part of mesophication[2].
Increasing deer populations	More deer browsing—harder on oak seedlings [2,10]
Increasing invasives & new pathogens/pests	New dynamics to research and incorporate into forest management to minimize negative impacts on oak recruitment. [42]
2000s	Wealth of mature oak forest [10] *Research & management implementation to ensure continued opportunity for disturbances/opportunity for oak to thrive despite regeneration gaps in certain size classes. This includes a focus on resilience in the face of climate change, which is predicted to have some positive impacts for oak but also presents some challenges.*

[2] Mesophication is the name for the process that happens when fire is removed from the forest dynamics, causing forests to shift from more open, sun-loving and fire-tolerant forests to closed, shade-tolerant and fire sensitive.

WHITE OAK FOR COOPERAGE - *Quercus alba L.*

Only a few of the oak species distributed worldwide are used for cooperage. In the United States, the key species is *Quercus alba*, which is most often called white oak. It may also be called eastern white oak, forked-leaf white oak or "stave oak," inspired by its desirability for crafting barrel staves. [13]

Quercus alba is considered one of the most important species in the white oak group. It is distributed throughout the Eastern United States, with key concentrations in the Ozarks, Ohio Valley and Appalachian regions. Within this realm, the Central Hardwood Region is a key focus for cooperage companies seeking high-quality white oak thanks to the extensive habitat available and rich reserve of premier quality trees. On average, it is estimated the cooperage industry accounts for 3% of the total hardwoods harvested from the Eastern United States and utilizes 13% of the white oak harvest (based on data from the Hardwood Market Report and consumption estimates from cooperage companies).

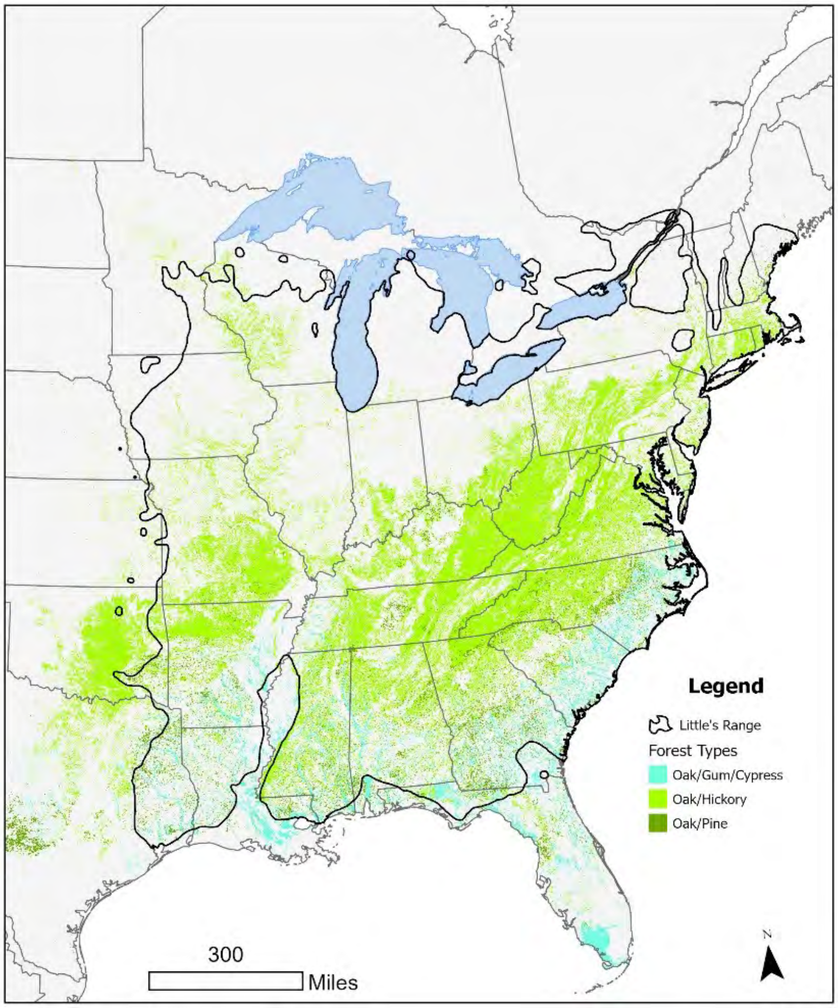
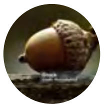


Figure 1.2 Range extent of white oak (*Quercus alba*) delineated by Little [14] and oak forest types classified using satellite imagery [15]. Figure by Matthew Peters, USDA Forest Service [16].

OVERVIEW OF *Quercus alba L.*

Classification	hardwood / broadleaf deciduous
Height	can grow up to 100 feet
Growth rate	slow
Light	loves sunlight. Intermediate tolerance to shading for the first part of its life, becoming less shade tolerant as it ages.
Leaves	smooth edges, but these edges are considered “highly variable” in terms of shape (more or less deeply lobed). Oak leaf litter is very important. Each fall, oak forest is estimated to shed about 23 million leaves per hectare, or 1 ton per acre. Within 9 months the litter will have completely decayed into fertile humus to maintain the woodland soil. Leaf litter is also key to many insects, fungi, microbes and even fire behavior.
Crown	wide spreading when grown in the open; in the forest, tall, straight trunks with a more compact canopy.
Roots	extensive root systems interlace under the soil, providing an excellent anchor and adding to soil stability. Rooting systems that extend from shallow to very deep soil profiles allow this tree greater adaptability to rain patterns, including drought.
Bark	thick, which helps white oak be more fire resistant than other tree species once they are old enough and reached sufficient size.
Wood	heartwood is very decay resistant, which protects the oak while it is living, and also yields an important forest product in the form of timber.
Mast (acorns)	a key food source for more than 100 animals, including squirrels, birds, rodents, deer and many others. This food source cannot be easily replaced due to the fat content acorns contain that is critical for helping wildlife build fat reserves.
Climate	adapted to a wide range of temperate conditions
Growing conditions	from dry upland slopes to well-drained loam in bottomlands. White oak can still grow and thrive in temperate zones with poor soil quality and low rainfall. Benefits from periodic disturbance in the environment.
Flora & fauna	supports a diverse community of plants and animals, including at least 895 caterpillar species. Able to sustain mycorrhizal associations with a large range of fungi.

[2,13,17,18,19,20,21,22]



HOW OAK GROWS

"…after their first year, a seedling oak may have up to 10 times more root mass than the biomass of leaves and shoots above ground. Oaks produce enormous root systems over their lifetimes, and these help make them champions when it comes to soil stabilization, carbon sequestration, and watershed management." [1]

White oak is a slow growing, long-lived hardwood tree that can thrive in a range of conditions. Adaptable to different nuances in climate within the temperate zone, white oak can also grow well in a range of soil types, topography and moisture levels. [13] It can live to 250+ years and is considered economically viable around 120 years. Research confirms the mortality rates for the white oak group is lower than the red oak group, as red oaks are cited as four to six times greater in mortality rate than white oaks. [23] White oaks are also notably decay resistant within the heartwood, which makes its wood long-lasting for a range of products. [24]

WHITE OAK HAS TWO NATURAL WAYS TO REGENERATE:

- **Production of mast, or acorns.** During the same growing season, flowers are pollinated and acorns will ripen by autumn and fall from the tree. (Red oak acorns won't ripen until the following year.) Acorns best germinate by falling to the forest floor and being covered in leaf litter or being buried in the soil by wildlife. Year to year, different levels of "mast" will be produced, which is still a source of research to determine all the factors that influence this fluctuation.

  Once germinated, a seedling will put most of its energy into its roots. Over time, it will begin to put more energy into its upward growth.

- **Stump sprouts (vegetative reproduction)** – a white oak may sprout from the stump when stems are cut, mechanically damaged, girdled or browsed, or fire results in the death or removal of the stem. The vast root system the white oak tree had established provides needed nutrition allowing stump sprouts to occur. Buds are located at the base, specifically the "root collar," which is typically an area protected from browsing and fire. The age and size of the tree, as well as timing within the growing season, can influence what percentage of stumps will sprout.

It is often assumed the next generation of oaks will come up near the "mother tree" as acorns fall or a stump resprouts. However, nature lends a hand in extending the distribution of acorns to a much larger range, with particular thanks to squirrels and blue jays.

- **Squirrels** – in addition to being iconic for their love of acorns, squirrels benefit the oak forest by detecting and selecting the acorns that will germinate. They do love white oak acorns, eating 85% of them upon selection, but the remainder are buried and thereby planted. [25] White oak germinates in the fall, leading to a seedling that can begin its development the same year. In this way, squirrels are important to maintaining and regenerating second-growth oak forests.

- **Blue jays** – these birds are especially significant at dispersing acorns, as they can carry them up to a kilometer from the parent tree [18], often burying them in the open, which expands the forest. A single jay can gather and bury up to 4,500 acorns each fall, and since only a quarter of them will be eaten through the winter, a jay may plant up to 3,360 oak trees each year. [1] It is also significant that jays prefer to select acorns that are healthy and more disease resistant, naturally spreading the best of the oak genome. Finally, the scattered dispersal pattern of blue jays helps maintain and expand oaks even where forests are highly fragmented. [11]

Oak forest may also be established or revitalized through artificial planting. This will typically involve:

- Direct planting of acorns
- Oak seedlings grown from collected acorns and then planted
- Rooting or grafting cuttings to create oak seedlings for planting

Today and historically, oak forest in the United States has been the product of natural regeneration with assistance from human management to further foster favorable growing conditions.

Competition among seedlings is fierce as they compete for resources, including sunlight. *"Oaks are widely perceived to be long-lived, but more than 99 percent of the natural oak population dies before it is 5 years old."* [26] This is one of the reasons it is important to consider multiple data points when evaluating how successfully oak is regenerating on a particular site.

A key point to oak regeneration is successful recruitment of oak seedlings and saplings into the mid- and eventually upper canopy. The goal is to have adequate numbers of the younger generation already large enough in size to then compete well when any surrounding mature trees are removed from the forest, whether that be a natural disturbance (such as tree old age, lighting, storms) or man-made (harvesting). Having ample acorns is a positive, especially for surrounding wildlife, but the acorns are not able to sprout and grow fast enough if seedlings from fast-growing tree species are present or the environment remains too shaded. The focus on having plenty of large seedlings and saplings available to compete well is called "advanced oak regeneration" and is a common focus of modern oak research.

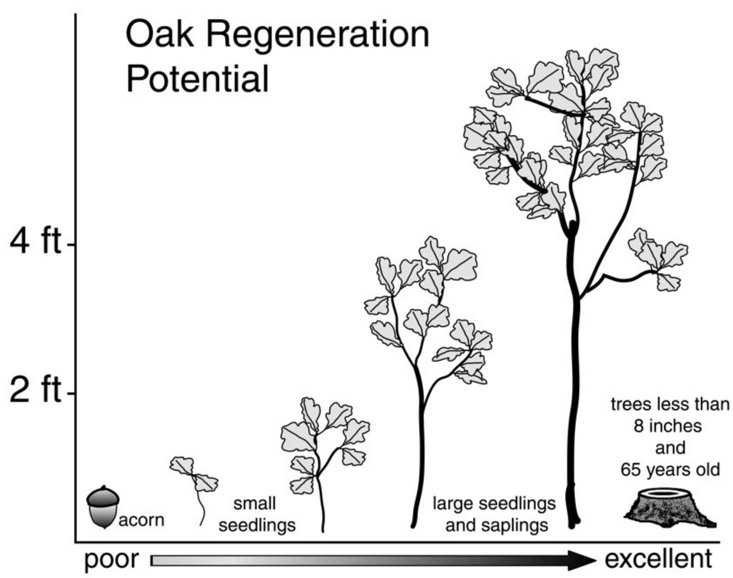


Figure 1.3 The likelihood of oak reproduction to develop into a canopy tree after an even-aged regeneration harvest. [27]

"Pioneering studies by Sander (1972, Sander and others 1976) suggest that advance reproduction of oak with sufficient numbers and size (generally ≥4 feet tall) is necessary to successfully regenerate oak. This advance oak reproduction should be present before the harvest cut. Otherwise, shade-tolerant species such as maple (Acer spp.) and beech (Fagus spp.) that are present in the understory and midstory and intolerant species from seed such as yellow-poplar (Liriodendron tulipifera) and cherry (Prunus spp.) will outgrow and supplant small oak reproduction…" [26]

SITE QUALITY

The quality of the particular site where oak is growing can influence how it grows, and also influence the growth of any other trees competing for natural resources on the same site. Interestingly, and to the benefit of white oak, *Quercus alba* can grow on poor-quality sites as it is tolerant of these conditions (drought, low fertility) and no longer needs to compete with as many other tree species. White oak has a competitive advantage compared to some other tree species that prefer more favorable conditions. This is especially beneficial to cooperage, which typically seeks slow-growing trees from the poorer sites due to the increased potential for flavorful extractives to be imparted to wine and spirits.

"Oaks, with their conservative growth strategy, regenerate well on lower quality, drier, more xeric upland sites where they do not compete with faster-growing species." [26]

The investment of white oak in the growth of its roots, along with its high sprouting capacity and drought tolerance, all help *Quercus alba* handle these more challenging sites.

IMPACT OF FIRE

Through the years, oaks have benefited from fire, whether set purposely as a management tool (records show Indigenous Peoples pre-European settlement used this technique for thousands of years) or through natural occurrences such as instigated by lightning. Oaks, including *Quercus alba*, can withstand fire to a much greater extent than many of the co-existing tree species, offering reduced competition after a fire and room to grow in sunlight. It is ideal for fires not to be too frequent, as oak needs opportunity to reach a certain threshold trunk diameter (caliper size) to best withstand the fire. Research into the use of fire for current management is ongoing—while it has offered advantages to oaks in the past, fire has to be managed well and results can depend on other factors of the site. The reality that fire will likely not be as relied upon today for management as it has been in past centuries is one of the factors influencing modern forest management to utilize other methods to benefit the oak genus for a thriving future. When fire is used, the variability in timing, number of fires and site quality have been key to promoting oak dominance. [2,9,11,12]

IMPORTANCE OF MANAGEMENT

Periodic disturbances, natural or manmade, have always been essential to oak success. Currently a variety of management techniques are employed to favor oaks: *"Prescribed fire, partial harvesting*[3], *herbicide application, and herbivore exclusion can all improve oak regeneration if applied at the right time, at the right place and at the right frequency and/or intensity (Brose and others 2008, Iverson and others 2017, Johnson and others 2009)."* [26]

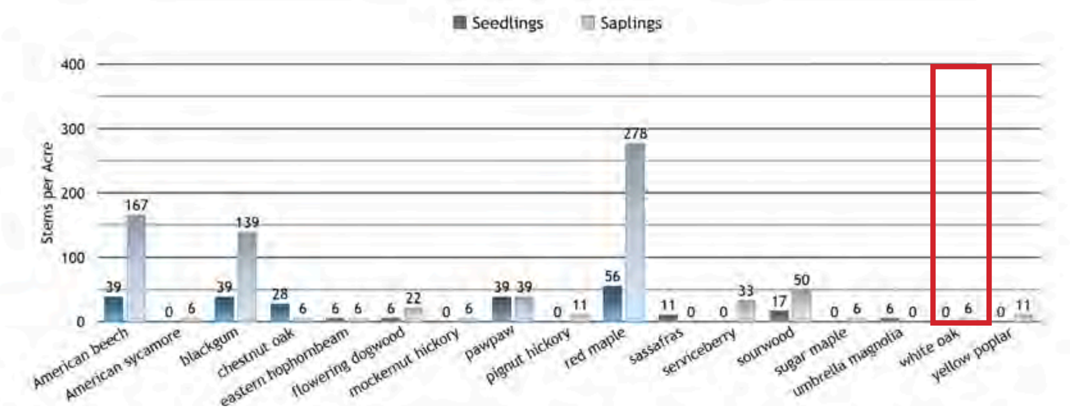


Figure 1.4 Populations of smaller trees in an unmanaged forest [28]

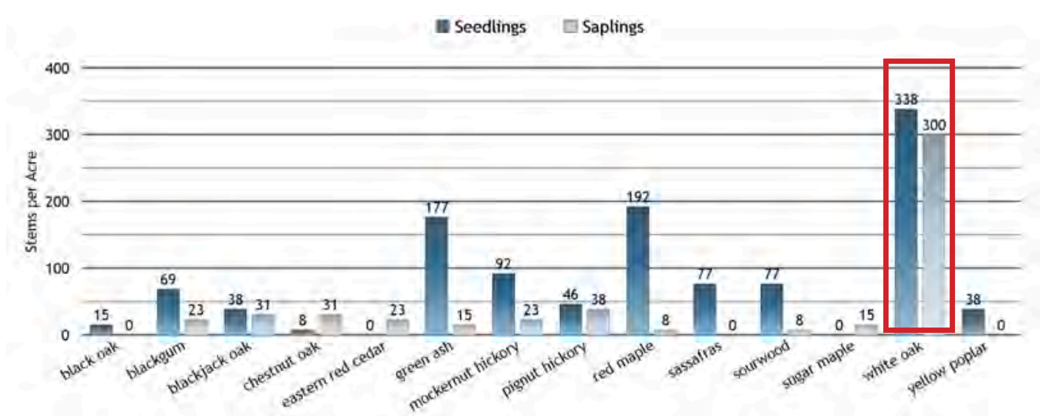


Figure 1.5 Populations of smaller trees in a managed forest [28]

White oak forests flourish with periodic disturbance regardless of location within North America. For example, Figures 1.4 and 1.5 demonstrate how management increases the quantity of young oaks based on presence or absence of periodic management. These two forests are located in eastern Kentucky less than 20 miles apart.

When little to no management occurs within oak forest, current trends show a succession pattern that favors shade-tolerant species, such as red/sugar maple and beech. If only harvesting is employed within these forests, there will be a "release" of the shade tolerant understory and mid-canopy trees that can risk accelerating succession away from oak. For this reason, management is a key focus to continue to maintain or improve the oak component within many forests.

[3] Partial harvesting: harvesting a selection of trees (as opposed to all of the trees) on a tract of land

TRACKING AMERICAN WHITE OAK - *Quercus alba L.*

Current Inventory

CURRENT INVENTORY

A variety of organizations track data related to American forests and oak species, which is a testament to the importance of oak to a variety of interests. For example, wildlife agencies track nut production as food for wildlife, while forestry experts track oak for its importance to forest ecosystems as well as its commercial use.

Two key sources of data include:

- **FOREST INVENTORY AND ANALYSIS (FIA) NATIONAL PROGRAM**
  This U.S. Forest Service program calls itself the "nation's forest census" and reports the status and trends of many tree species, including white oak. The program has been in continuous existence since 1930. FIA data is collected through established locations across the United States—each location comprises 6,000 acres, and actual measurement takes place on field sample sites within that location. State and regional reporting occurs every five years. Data is made available as a free resource online, available to any audience.

- **RESOURCES PLANNING ACT (RPA) ASSESSMENT**
  This congressionally mandated national report from the U.S. Forest Service examines the country's renewable resources on all forests and rangelands. While this reporting was established by the Forest and Rangeland Renewable Resources Planning Act of 1974, the U.S. Forest Service has been analyzing U.S. natural resources for more than a century. The report includes conditions and trends related to the past, present and future status of U.S. forests and is made available online. The report typically uses FIA data to estimate volume and species composition and aerial photography to determine the spatial extent of the forest cover. It is released every 10 years, with the first report in 1953 and most recent report in 2023.

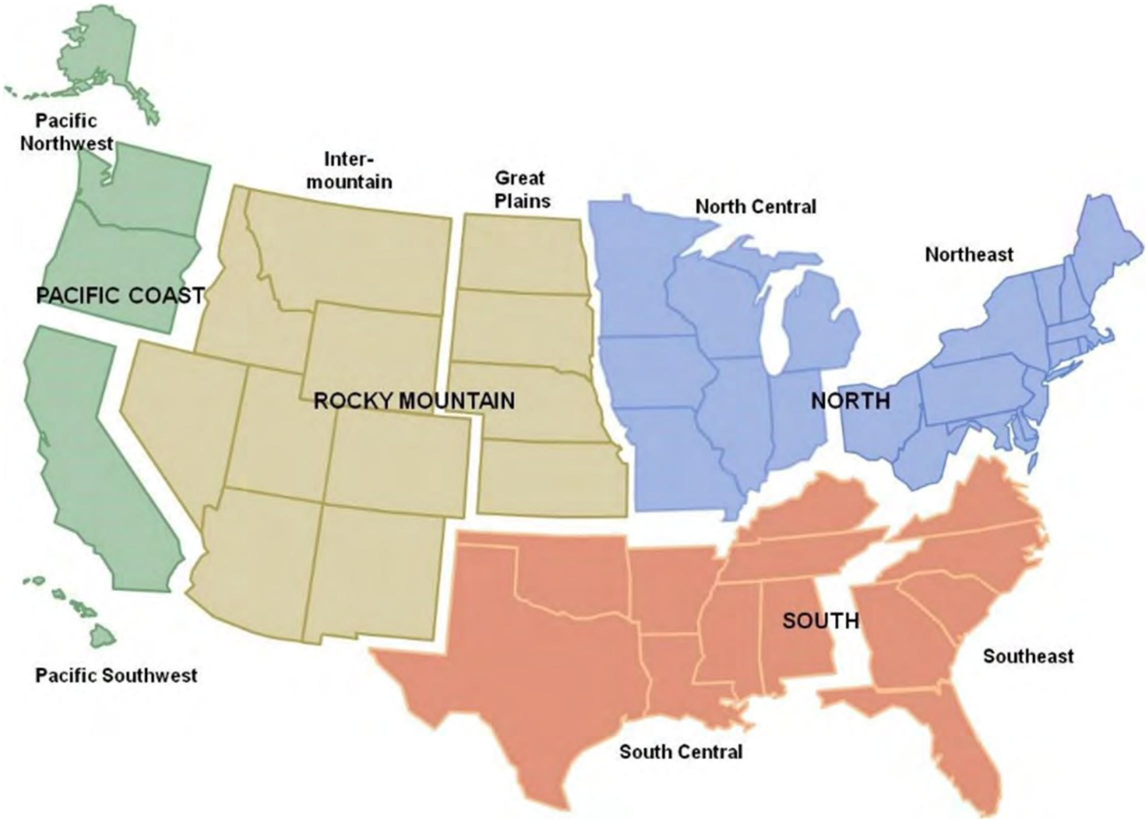


Figure 2.1 The RPA Assessment regions and subregions [6]

Many sources draw upon FIA data and RPA reports to supplement peer-reviewed research being conducted across the U.S. This report utilizes FIA and RPA data from the North and South regions (Figure2.1) that collectively comprise the Eastern United States. The cooperage industry most heavily procures white oak from the North Central, Northeast and South Central subregions.

AT A GLANCE

The current supply of white oak is well above the level of demand:

. More than 43 billion oak stems growing, representing 11 percent of the tree population
. White oak represents 19% of oak biomass, the most of all oaks
. White oak growing stock volume is increasing, and growth exceeds harvest in all major supplying states for cooperage
. Hardwood removals have decreased
. Mortality has increased over time, partially credited to the decrease in removal of mature trees
. Opportunity to increase oak abundance and better ensure younger trees are recruited into the mid and upper canopies

HARDWOOD INVENTORY

Since *Quercus alba* is a hardwood tree, this section highlights key statistics from RPA and FIA reports and data sets related to the hardwood inventory. It is clear the volume of growing stock on timberland in American forests is continuing to increase over time, outpacing reductions due to harvesting and tree mortality.

- **Hardwood growing stock[4] volume on timberland increased 39 percent between 1977 and 2017.**

  The largest increases are well above the national average and occurred in the RPA North and South Regions, which collectively make up the Eastern region that the cooperage industry targets for slow-growth white oak. [6]

  North Region – 107 billion cubic feet (65.7%) increase
  South Region – 95.7 billion cubic feet (42.8%) increase

  Furthermore, **hardwoods are cited as making up a large percentage of the increased growing stock volume.** [6]

  North Region – 90.3 billion cubic feet (84%) increase
  South Region – 55.6 billion cubic feet (58.1%) increase

  Next, Figure 2.2 shows the increasing hardwood growing stock primarily in the North and South regions between 1953 to 2017.

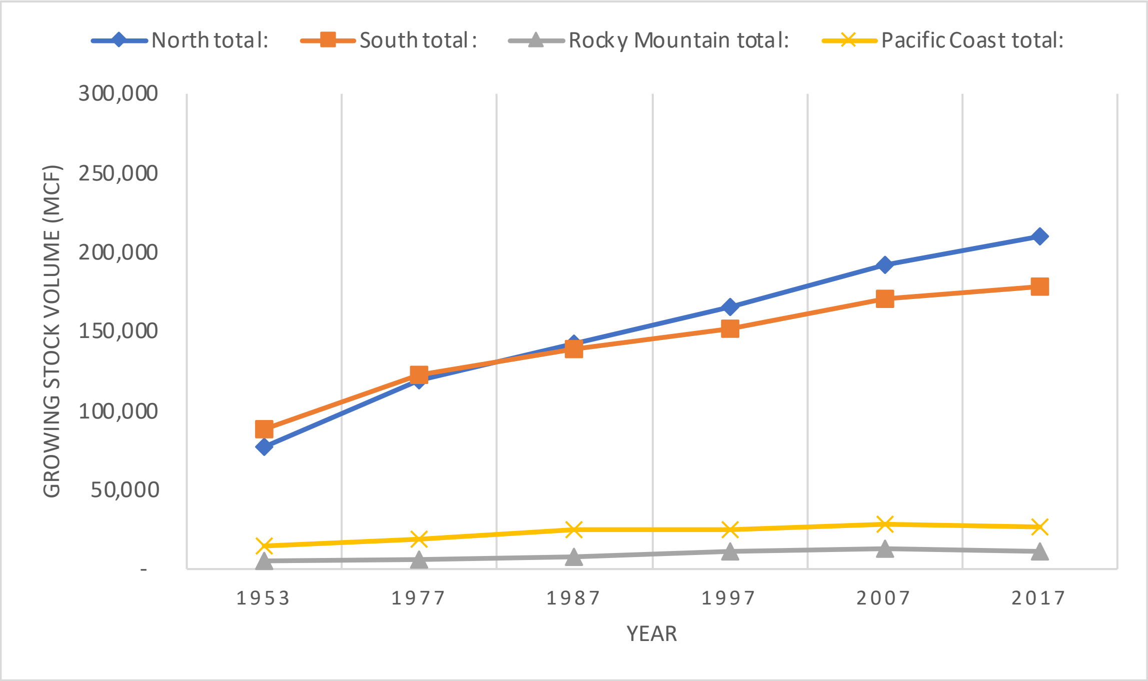


Figure 2.2 Hardwood growing stock volume by region, 1953–2017 in MCF (1,000 cubic feet) [5]

[4] The RPA defines growing stock as follows: All live trees 5.0 inches (12.7 centimeters) diameter at breast height or larger that meet (now or prospectively) regional merchantability requirements in terms of saw-log length, grade and cull deductions. Excludes rough and rotten cull trees.

- During the same time period as the 39% increase in growing stock volume, **average removals of hardwoods[5] has decreased in the North and South regions** as demonstrated in Figure 2.3.

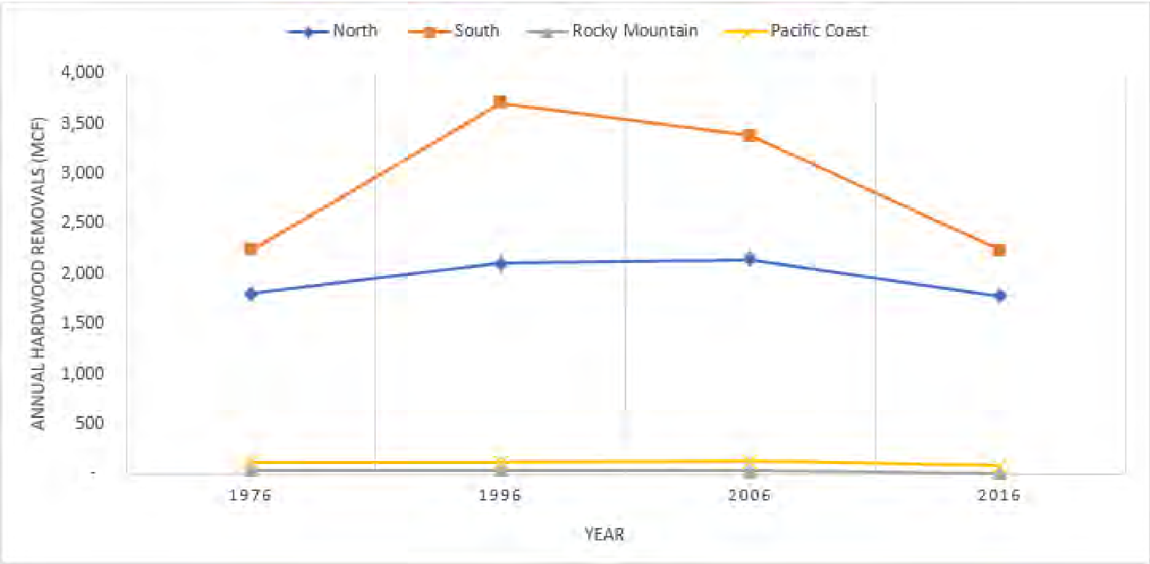


Figure 2.3 Average annual hardwood removals by region, 1976–2016 in MCF (1,000 cubic feet) [5]

- **Mortality has been increasing steadily from 1976 to 2016, which is partially credited to the decrease in removals of mature trees.** Tree pests, diseases and drought also contribute, with stressed trees as the most vulnerable.

"Yaussey et al. (2013) found that increased competition, due in part to a lack of removals, was increasing the mortality risk in eastern hardwood forests. In another study, conditions that resulted in slow growth increments were found to increase mortality in both red oak and white oak species (Quercus spp.), but red oak species were more affected (Shifley et al. 2006)." [30]

[5] This is based on removals of wood volume from timberland, which includes both harvested volume and volume that was "removed" from the timberland base because of reclassification into reserved land or another land use.

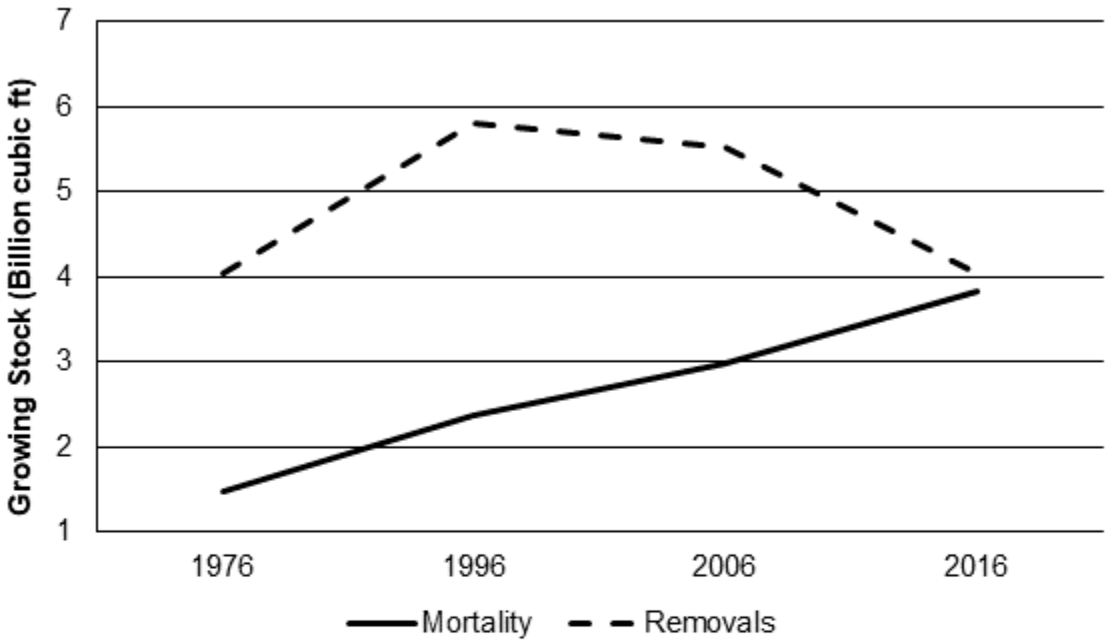


Figure 2.4 Annual average mortality and removals of Eastern hardwood growing stock in 1976, 1996, 2006 and 2016 (Oswalt et al. 2019) [30]

- **Forest cover in the Eastern region for several oak-related forest types is relatively stable**, showing a -1% change, which accounts for U.S. population growth and land development. [6]
- American hardwood forest is growing to the point that some argue it is being underutilized. **For every hardwood tree harvested, at least two trees take its place.** The Timber & Forestry Foundation cites between 2.2 to 2.4 trees depending on the year. [31]

  Since some trees are considered more desirable than others, ecologically or economically (or both), there is a focus on understanding which trees will be next in line within American forests to preserve the associated benefits of keystone species for the future.

  Related to this figure of tree replacement, there is a trend of Eastern U.S. forests exhibiting increased density, with two times more trees within forests now than was true historically. This is largely credited to fire suppression and human land use activity. [32]
- **There is an increasing focus on certified forests.** Approximately 19% of U.S. timberland area is certified for sustainable, responsible forest management. [33] Figure 2.5 shows the totals of certified land for three different certification programs: Sustainable Forestry Initiative (SFI), Forest Stewardship Council (FSC) and American Tree Farm System (ATFS).

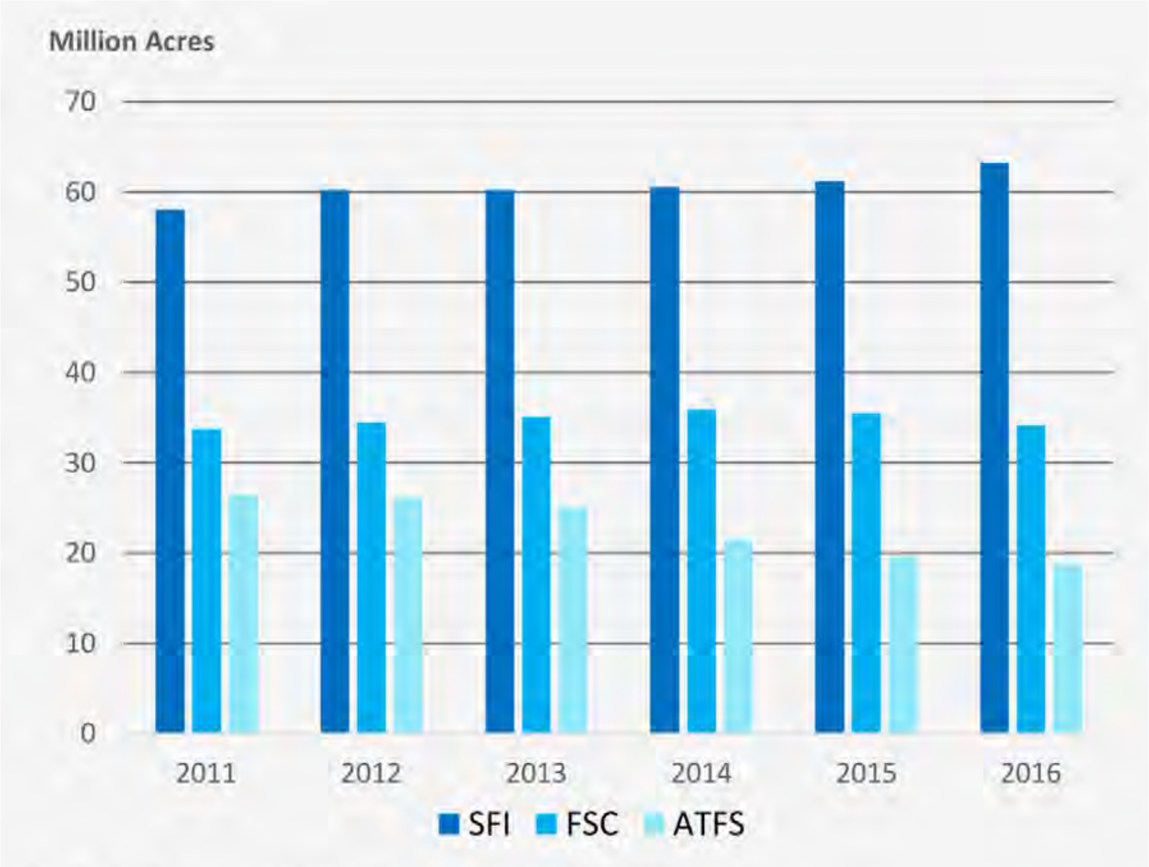


Figure 2.5 Certified U.S. forest area, by certification program, 2011-2016. [34]

Some acreage is certified by multiple programs. The net area without double counting totaled 95 million acres in 2017. [33]

Benefits of certified forest are numerous. One example explained by the Sustainable Forestry Initiative (SFI), the leading certification organization in the United States, reported those certified to the SFI Forest Management Standard harvest less than 1% and ensure the forest is regenerated after harvest. [35]

WHITE OAK IN AMERICA

Data confirms there is a large inventory of *Quercus alba* growing in the United States. This is made possible by its wide range across a variety of soil types as well as a large number of trees coming to maturity.

- There are an estimated **43 billion oak stems growing** across the United States that have achieved a 1-inch diameter at breast height (DBH). These oak stems represent about **11 percent of the total tree population.** [26]
- **In 2019, "white oak** *(Q. alba L.)* **represented 19 percent of all oak biomass, the most of all oaks,** while Oglethorpe oak (*Q. oglethorpensis Duncan*) represented the least (<0.001 percent of all oak biomass)." [26]
- **White oak represents 15.5% of the total U.S. growing stock**, with a total of 2.26 billion m^3. [36]
- **Growth of U.S. white oak currently exceeds harvest in all major supplying states:**

"*FIA data shows U.S. white oak growing stock is 2.26 billion m^3, 15.5% of total U.S. hardwood growing stock. American white oak is growing 40.1 million m^3 per year while the harvest is 20.1 million m^3 per year. The net volume (after harvest)* ***is increasing 20.0 million m^3 each year.***" [36]

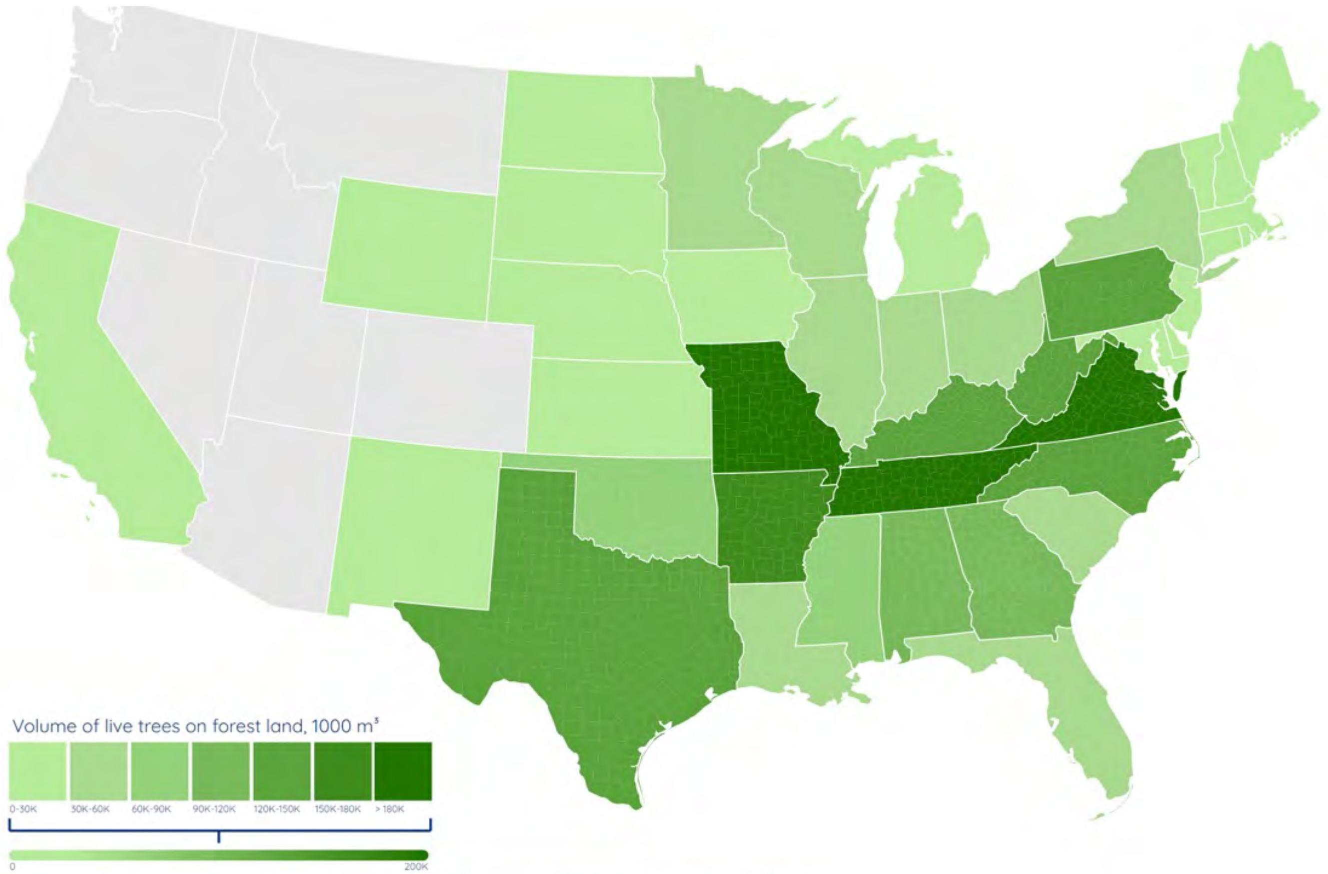


Figure 2.6 Volume of live trees on forest land; 1,000 m³ [36]

"Forest volume" refers to "Net volume of live trees on forest land" as defined by FIA[6]. FIA forest volume data is available for 49 U.S. states (Hawaii and Washington D.C. are omitted) with total commercially significant hardwood forest volume of 14.6 billion.

All data derives from The Forest Inventory and Analysis Database developed in 2001, a component of the U.S. Forest Service, Department of Agriculture. Data was compiled by AHEC in May 2020 using the most recent state inventory available (2018 for most states).

[6] Net volume in cubic feet—The gross volume in cubic feet less deductions for rot, roughness and poor form. Volume is computed for the central stem from a 1-foot stump to a minimum 4.0-inch top diameter outside bark, or to the point where the central stem breaks into limbs. [5]

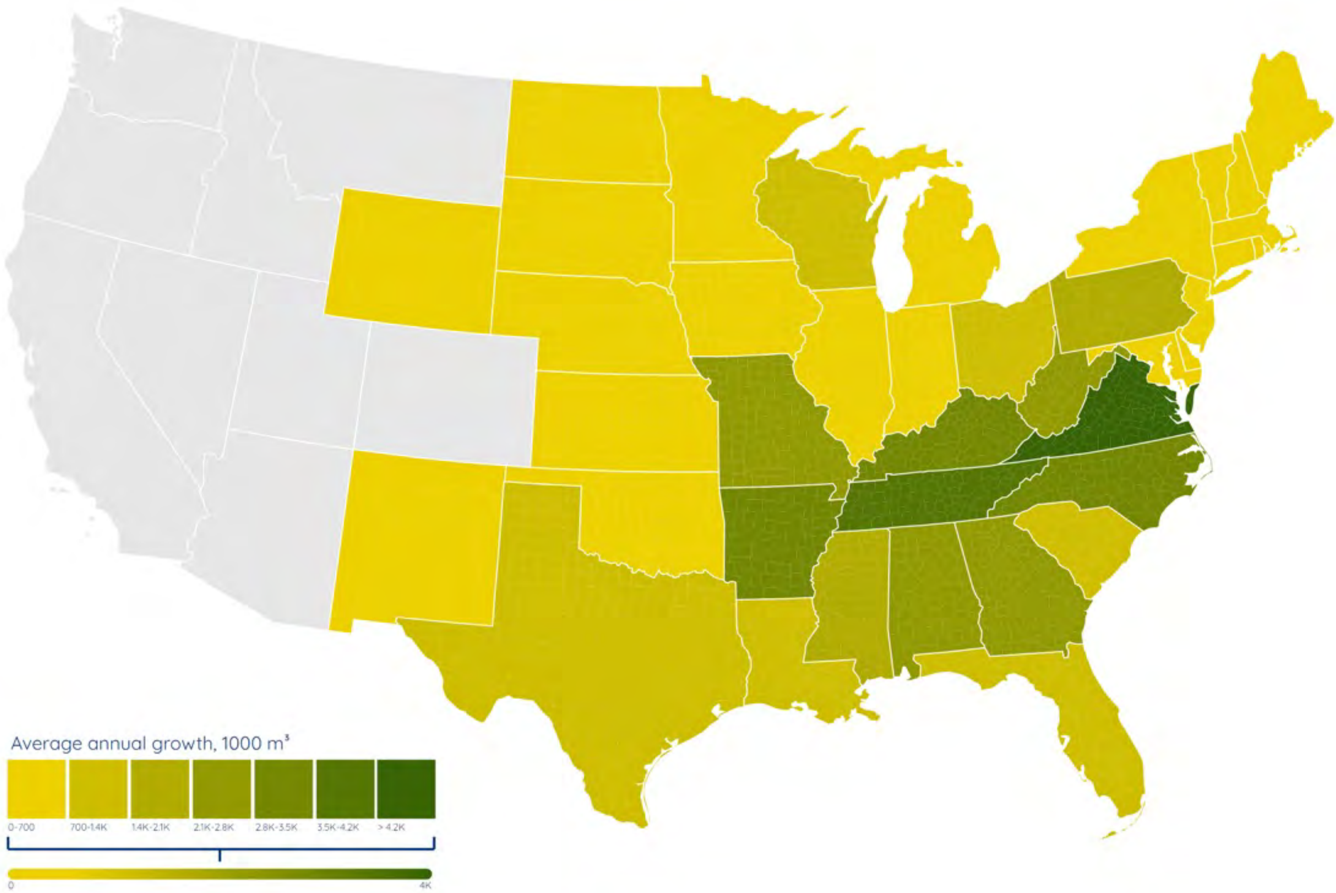


Figure 2.7 Average annual growth; 1,000 m³ [36]

"Growth" refers to "net annual growth of live trees on forest land" as defined by FIA[7]. FIA growth data is available for 45 U.S. states accounting for 97.9% of commercially significant hardwood forest volume.

All data derives from The Forest Inventory and Analysis Database developed in 2001, a component of the U.S. Forest Service, Department of Agriculture. Data was compiled by AHEC in May 2020 using the most recent state inventory available (2018 for most states).

[7] Net annual growth—The average annual net increase in the volume of trees during the period between inventories. Components include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year and minus the net volume of trees that became cull trees during the year. [5]

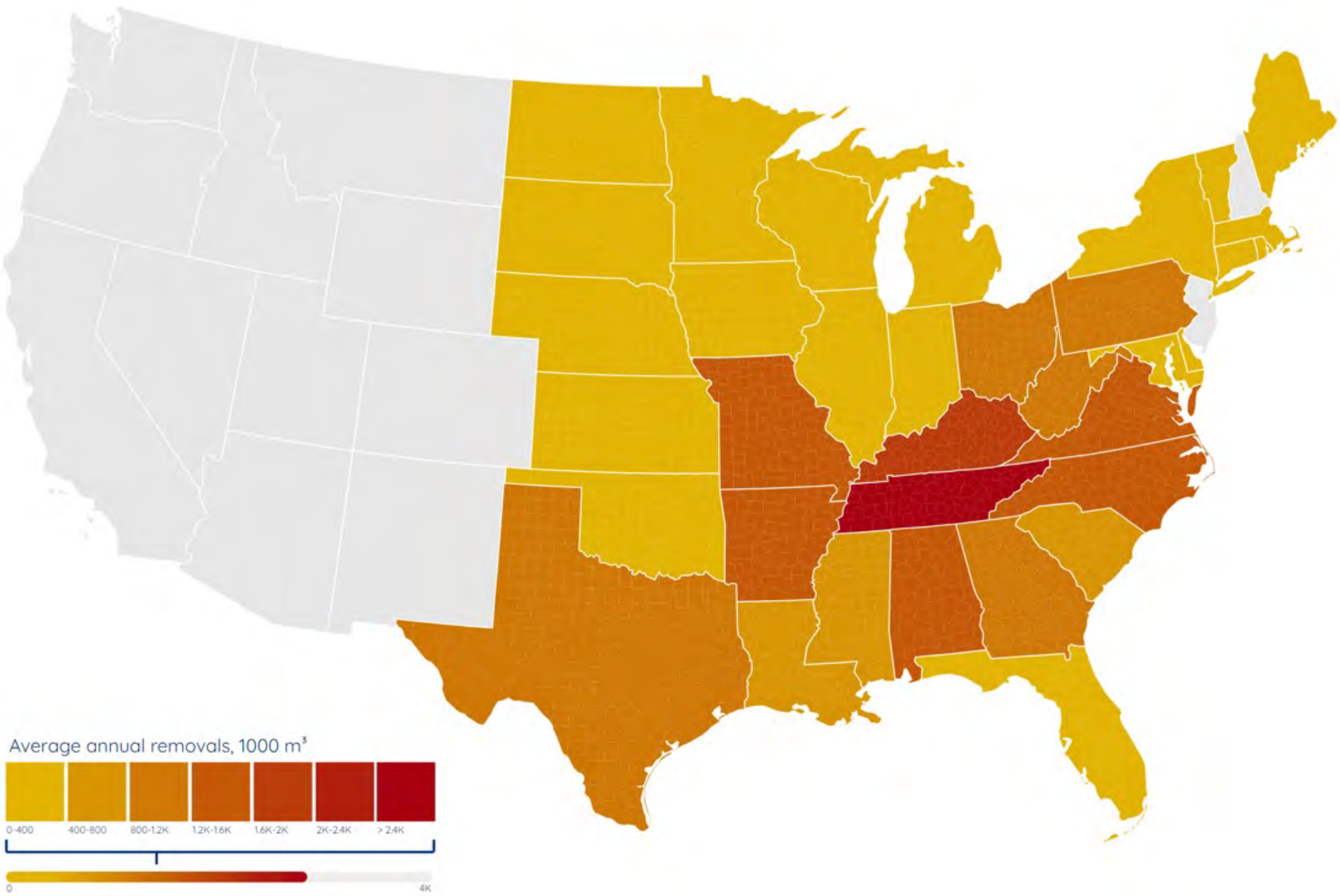


Figure 2.8 Average annual removals; 1,000 m³ [36]

"Removals" refers to "removals of live trees" as defined by FIA[8]. FIA removals data is available for 37 U.S. states accounting for 95.8% of commercially significant hardwood forest volume.

All data derives from The Forest Inventory and Analysis Database developed in 2001, a component of the U.S. Forest Service, Department of Agriculture. Data was compiled by AHEC in May 2020 using the most recent state inventory available (2018 for most states).

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[8] Removal of live tree volume from the forest land base including growing stock and nongrowing stock sources. The three main types are (1) harvested volume used for timber products, (2) logging residue (not used for a product), and (3) other removals arising from cultural treatments or land use change (sometimes used as a product.) [5]

- **Current estimates indicate approximately 12-13% of the white oak harvest is being utilized for cooperage, although a higher percentage than 13% would qualify as the desired quality for this craft.** [37]
- **Annual removal, or harvest, of white oak specifically has decreased by 9% since 1962.** [38]

Table 2.1: Total harvested 'Select White Oak' volume – Eastern region [38]

Year	North region harvested volume (MCF)	South region harvested volume (MCF)	Combined total harvested volume (MCF)	White Oak Share (MCF)	White Oak share (MMCF)
2016	734,966	654,309	1,389,275	128,691	129
2006	821,941	985,455	1,807,396	169,931	170
1996	943,145	958,900	1,902,045	170,420	170
1986	725,742	901,670	1,627,412	145,813	146
1976	699,612	667,403	1,367,015	129,002	129
1962	590,807	1,005,879	1,596,686	141,408	141

MCF – 1,000 cubic feet
MMCF – 1,000,000 cubic feet
White Oak Share – harvested volume specific to *Quercus alba*

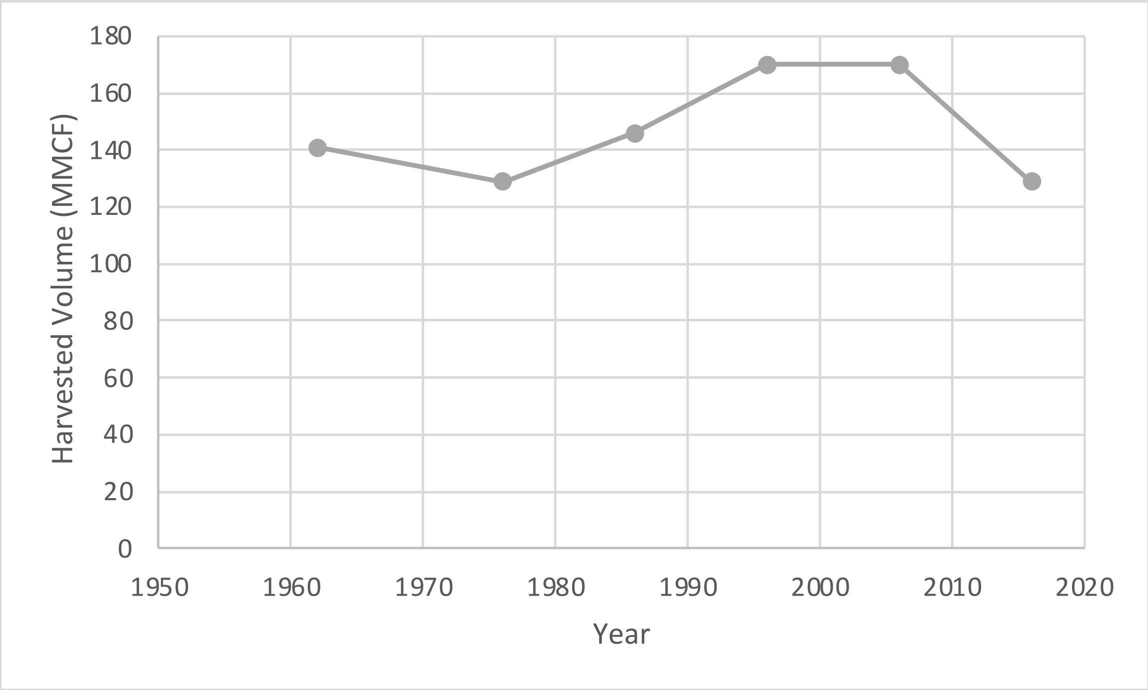


Figure 2.9 Total harvested volume of white oak – Eastern region, 1962–2016 [38]

- The American Hardwood Export Council estimates **it takes 1.57 seconds to grow 1 m³ of American white oak.** [36]

"The replacement rate is calculated from total U.S. annual increment of the specified hardwood species derived from the U.S. Forest Service Inventory and Analysis (FIA) program and assumes that 2 m³ of logs is harvested to produce 1 m³ of lumber (i.e. 50% conversion efficiency). The rapid rate of replacement is due to the very large volume of hardwood trees in U.S. forest." [36]

- American Cooperage Industries of America shared the following calculation in 2022 to relate this net growth to the cooperage industry's sourcing:

Based on 20.0 million cubic meters of net annual growth after harvests of U.S. white oak growing stocks (American Hardwood Export Council using FIA data), **it currently takes 14.8 seconds for the U.S. forests to generate one truckload of green, cooperage-quality white oak logs**, assuming 4,000 board feet per load.

WHITE OAK IN THE EASTERN REGION

The Eastern region of the United States is a key habitat for *Quercus alba*, which is why the cooperage industry focuses its sourcing in this area. White oak forest in this region is continuing to show strong growth in volume, providing an abundance of white oak timber in the forest and more than meeting supply needs for cooperage and other industries. The growth in white oak is largely credited to the mature oak forest in many regions, with large trees growing further in size over their long lifespan. There have also been some decreases in harvesting as some consumers switch away from hardwoods for cabinets and flooring in favor of alternative products, fewer sawmills due to decreased demand, and the general shortage of manual labor across all industries that was further accentuated during the Covid-19 pandemic.

A recap follows with key trends:

- In the Eastern Region, "**oak-dominated forests represent 53 percent of the biomass and cover 47 percent of the forest area**…" [43]
- **White oak grows in most of the Eastern region and is estimated to be present in forests covering at least 104 million acres.** [39] Figure 2.10 shows a map of the growing range from the National Individual Tree Species Atlas published by the USDA Forest Service in 2015.

Within this growing region, *Quercus alba* is known to have its greatest abundance in the central part of the Eastern U.S. [41]

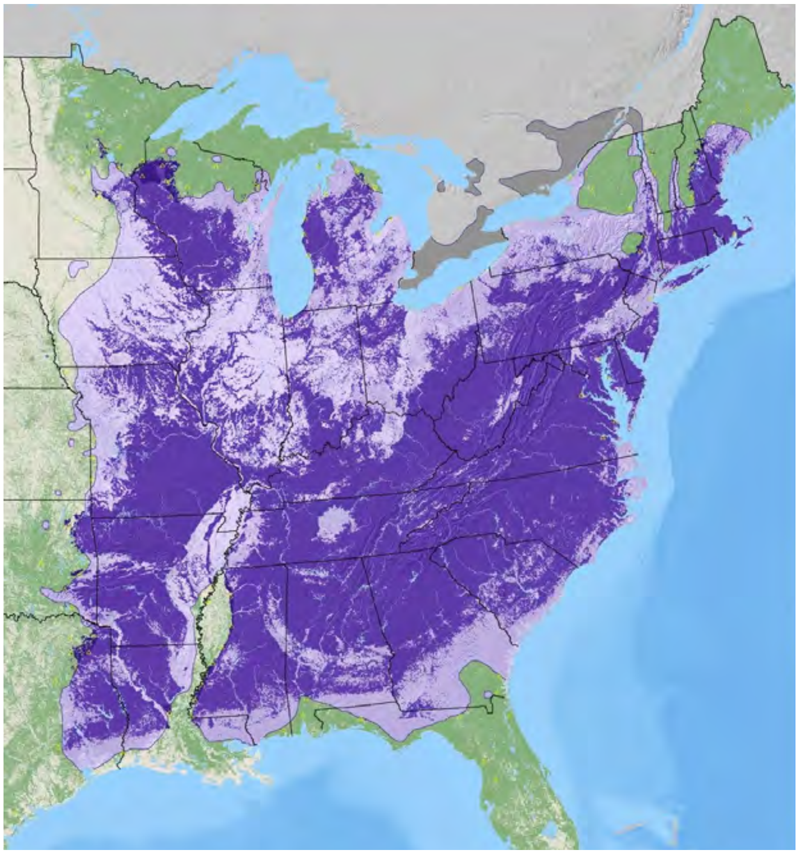


Figure 2.10
The distribution of white oak forests in the Eastern Region. Mapped Atlas is based on Little's estimated range [14], a historical map used for the past 50 years, while the Modeled Atlas is considered most accurate as it uses a combination of current data available to project the range. [40]

Mapped Atlas

Modeled Atlas

- In the Eastern region, **white oak is currently increasing in total population for the size classes that fall between 9.0 to 29.0+ inches in diameter** when measured 4.5 feet above the base. A comparison between the two decades shows a net increase in trees of 7.74%. **There were decreases in population for the 5.0-to-6.9 and 7.0-to-8.9-inch size classes,** which will be discussed further in this section of the report.

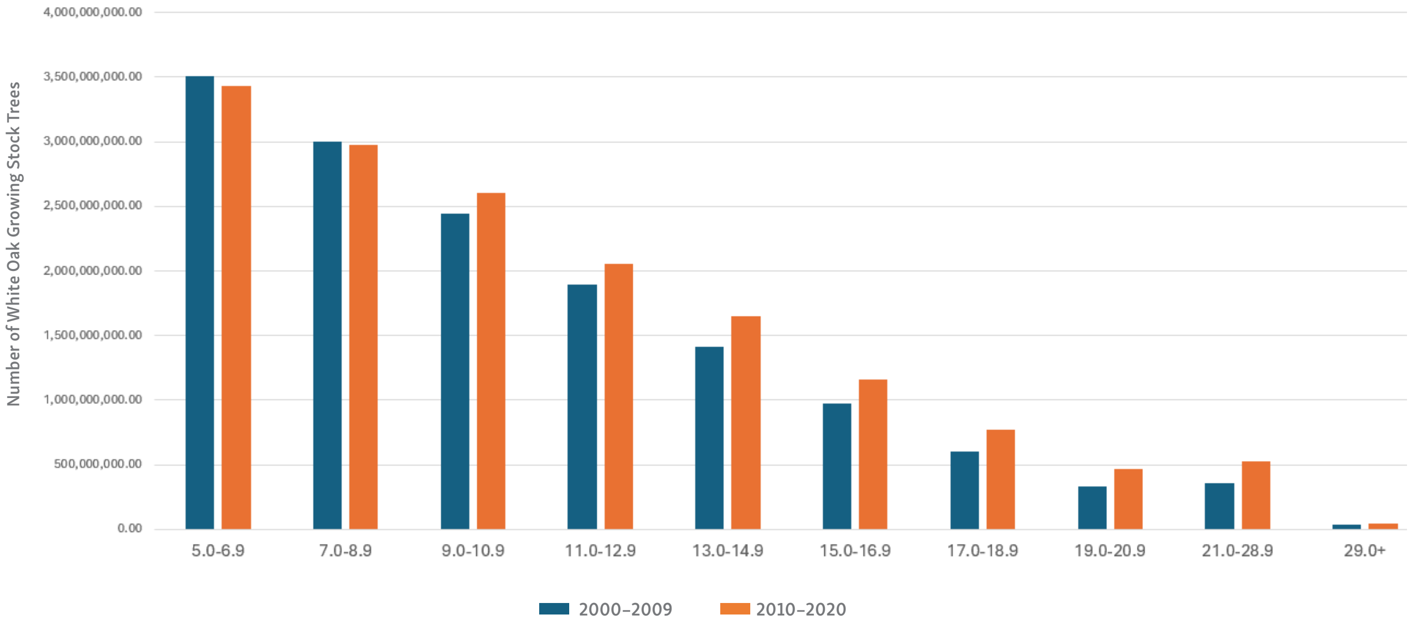


Figure 2.11 Number of white oak growing stock trees by size class in the Eastern U.S. by decade: 2000 to 2020. [29]

Note: the 2010–2020 block includes one more year of sampling data to best compare decades using the most similar sampling size/occurrences from FIA data. This was intentional to have a better comparison.

- **Many forests where white oak is growing are considered as coming into maturity or advancing in maturity.**

For the Eastern region, a 2014 report cited: *"A recent forest inventory and analysis report indicated that 67.8 percent of the oak-dominated forests in the eastern US were 40 to 99 years old."* [43]

The age distribution will vary by forest and region. For example, in the Northern region, approximately 60% of the forest is in the 40- to 80-year-old range; forests older than 100 years comprise only 5%. [64]

Related to this, **there is an increasing opportunity for acorns as trees continue maturing and producing increased levels of mast. Maintaining this long-term will be important, which is achieved by using management to have a balanced age and size class structure in Eastern oak forests.**

- Mirroring the national trends, **the net volume of white oak in the Eastern region is continuing to increase in current oak forests.** This measurement focuses on trees that meet regional requirements to be considered merchantable, now or in the future, and quantifies the total in terms of volume this would represent as saw logs in million cubic feet. The increase in net volume of white oak growing stock is credited in part to a large number of oak trees maturing in our Eastern forests, creating more and more board foot volume as the trees grow in size.

  Figure 2.12 demonstrates this trend from 1963 to 2017 based on the data presented for 'Select White Oaks' from Table 2.2. Select White Oak(s) is a class name that describes a group of species in the genus *Quercus* that includes white oak (*Quercus alba*) along with swamp white oak, bur oak, swamp chestnut oak and chinkapin oak.

Thanks to the abundant volume available, the current supply of white oak is well above the level of demand from the cooperage industry, which will be estimated later in this report.

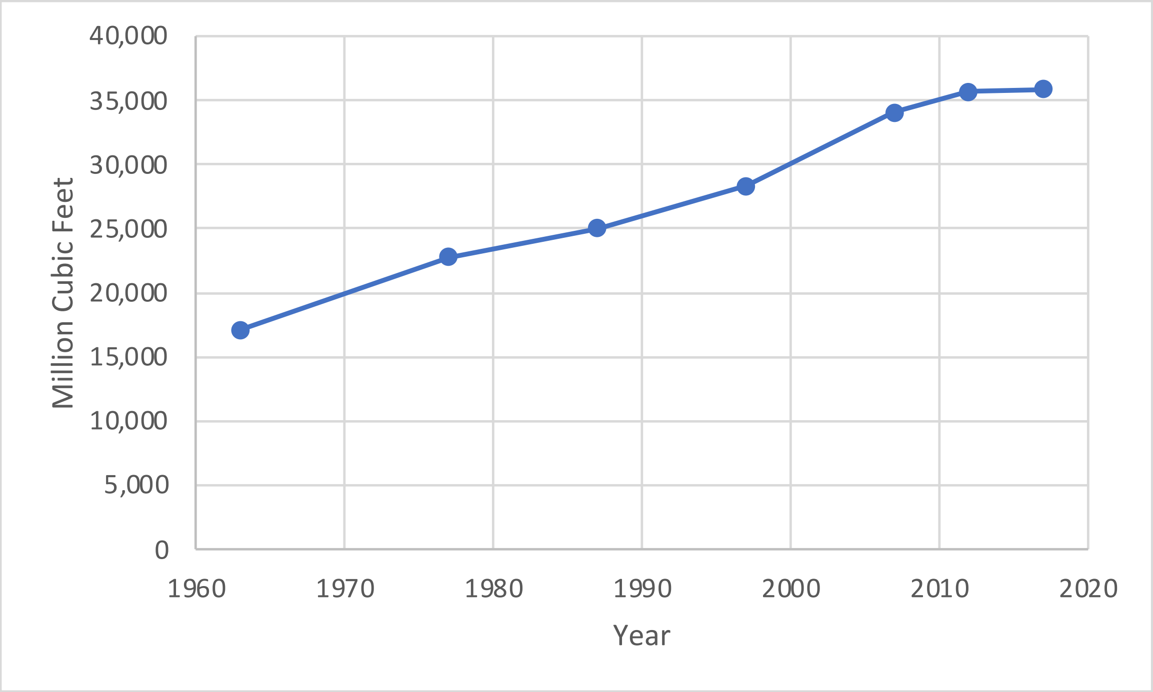


Figure 2.12 Net volume of select white oak growing stock on timberland in the Eastern United States [29]

Table 2.2 Net volume of growing stock on timberland in the Eastern United States by species, region and subregion, 1963-2017 [5]

Region and subregion	Year	Hardwoods									
		Total hardwoods	Select white oaks	Select red oaks	Other white oaks	Other red oaks	Hickory	Yellow birch	Hard maple	Soft maple	Beech
		Million cubic feet									
North											
Northeast	2017	115,672	5,885	12,064	5,670	6,047	4,146	3,778	13,899	22,095	4,921
	2012	115,634	5,962	11,591	5,461	6,051	4,029	3,910	14,029	22,220	5,376
	2007	103,329	5,396	9,775	4,786	5,142	3,501	3,354	12,697	20,418	4,922
	1997	90,234	4,437	8,625	4,271	4,932	2,846	3,062	11,533	16,741	5,466
	1987	80,524	4,384	8,137	4,928	5,405	2,791	2,987	10,104	13,544	4,685
	1977	67,320	4,721	7,616	4,589	4,890	2,563	2,452	7,755	10,645	3,807
	1963	52,835	3,402	6,536	3,709	2,550	1,810	3,791	5,883	6,515	3,973
North Central	2017	93,768	10,132	7,007	2,187	8,109	5,533	731	10,409	11,229	1,059
	2012	93,409	10,163	6,911	2,222	8,235	5,362	749	10,098	11,047	1,069
	2007	88,808	9,981	6,461	2,289	8,007	4,835	807	9,405	9,822	1,154
	1997	74,640	7,550	5,983	1,474	5,682	3,572	786	8,369	7,662	1,122
	1987	61,896	6,001	4,774	1,528	5,077	2,912	674	6,335	5,542	854
	1977	51,838	5,277	4,006	1,365	4,579	2,605	807	4,814	3,302	896
	1963	41,792	3,730	3,373	405	2,340	1,449	872	4,025	2,572	835
North total	2017	209,440	16,017	19,071	7,857	14,156	9,679	4,509	24,308	33,324	5,980
	2012	209,043	16,125	18,502	7,683	14,286	9,391	4,659	24,127	33,267	6,445
	2007	192,137	15,377	16,236	7,075	13,149	8,336	4,161	22,102	30,240	6,076
	1997	164,874	11,987	14,608	5,745	10,614	6,418	3,848	19,902	24,403	6,588
	1987	142,420	10,385	12,911	6,456	10,482	5,703	3,661	16,439	19,086	5,539
	1977	119,158	9,998	11,622	5,954	9,469	5,168	3,259	12,569	13,947	4,703
	1963	94,627	7,132	9,909	4,114	4,890	3,259	4,663	9,908	9,087	4,808
South											
Southeast	2017	75,063	7,680	3,489	5,659	11,746	3,896	72	531	5,266	922
	2012	72,812	7,417	3,362	5,704	11,792	3,765	81	504	5,148	888
	2007	70,025	7,056	3,191	5,300	11,338	3,591	57	471	5,149	770
	1997	71,124	7,167	3,126	6,008	12,307	3,593	83	467	5,712	1,000
	1987	68,154	6,639	3,074	5,563	11,826	3,641	62	402	5,221	942
	1977	60,691	6,152	2,650	5,009	10,841	3,680	61	299	3,845	805
	1963	46,998	4,753	1,966	3,886	7,837	3,314	39	158	2,555	561
South Central	2017	102,717	12,172	6,204	9,520	19,421	9,529	3	2,097	3,360	1,668
	2012	104,855	12,154	6,122	9,969	20,079	9,880	8	2,118	3,454	1,736
	2007	100,016	11,619	5,814	9,384	19,541	9,097	11	1,838	3,092	1,504
	1997	80,392	9,194	4,620	7,186	15,900	7,625	5	1,411	2,283	1,458
	1987	70,874	7,974	3,969	6,722	15,062	7,254	6	933	1,719	1,193
	1977	61,474	6,623	3,071	6,362	12,584	6,816	0	758	1,319	1,054
	1963	51,987	5,262	2,053	5,607	9,652	5,799	11	428	898	1,116
South total	2017	177,781	19,852	9,693	15,180	31,167	13,426	75	2,629	8,626	2,590
	2012	177,667	19,571	9,484	15,673	31,871	13,645	89	2,622	8,602	2,624
	2007	170,041	18,675	9,005	14,684	30,879	12,688	68	2,309	8,241	2,274
	1997	151,516	16,361	7,746	13,194	28,207	11,218	88	1,878	7,995	2,458
	1987	139,028	14,613	7,043	12,285	26,888	10,895	68	1,335	6,940	2,135
	1977	122,165	12,775	5,721	11,371	23,425	10,496	61	1,057	5,164	1,859
	1963	98,985	10,015	4,019	9,493	17,489	9,113	50	586	3,453	1,677
East total	2017	387,221	35,869	28,764	23,036	45,323	23,104	4,585	26,937	41,951	8,570
	2012	386,710	35,696	27,986	23,356	46,157	23,036	4,748	26,749	41,869	9,069
	2007	362,178	34,052	25,241	21,759	44,028	21,024	4,229	24,411	38,481	8,350
	1997	316,390	28,348	22,354	18,939	38,821	17,636	3,936	21,780	32,398	9,046
	1987	281,448	24,998	19,954	18,741	37,370	16,598	3,729	17,774	26,026	7,674
	1977	241,323	22,773	17,343	17,325	32,894	15,664	3,320	13,626	19,111	6,562
	1963	193,612	17,147	13,928	13,607	22,379	12,372	4,713	10,494	12,540	6,485

Note: Data may not add to totals because of rounding. Volume by State in this table may differ from volume by State in other tables because of rounding.

- **Analysis of net change in growing stock volume by diameter category reveals a current challenge for white oak, often referred to as the "oak bottleneck." A key goal is to improve the number of younger trees able to compete successfully to be recruited to the mid- and upper canopies.**

Table 2.3 summarizes net volume for a variety of species, including Select White Oak. The data shows positive net change in growing stock volume overall for Select White Oak and specifically the two upper class sizes. However, there is a decline in net volume shown for the 5 to 10.9 inches category. This type of data in the Eastern region is an indicator of needing to successfully recruit more of the younger trees to enter the next size categories as future generations of mature trees. [26]

Table 2.3 Net change in eastern hardwood growing stock volume by major species group and diameter category, 2002 to 2012, in million cubic feet.

Species group	Total net change	5 to 10.9 inches	11 to 16.9 inches	17 inches and larger
Total hardwood	59,018	-9,108	24,526	43,596
Select white oak	6,255	-1,334	2,365	5,224
Select red oak	5,186	-1,159	903	5,443
Other white oak	3,721	-1,036	2,072	2,687
Other red oak	5,636	-1,771	1,014	6,392
Hickory	4,517	-183	2,581	2,117
Hard maple	4,647	208	3,031	1,406
Soft maple	8,509	195	5,067	3,247
Sweetgum	1,792	-235	637	1,393
Ash	4,995	543	2,254	2,199
Yellow-poplar	9,194	347	1,786	7,058

Sources: Smith and others (2004), Oswalt and others (2014).

Note: these numbers were calculated as a comparison within the same size class.

"Recent data collected by the U.S. Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) project clearly illustrates the dramatic changes that have occurred in our forests and what that portends for the future. These FIA data show that the volume of oaks in the 5.0- to 6.9-inch stem diameter class decreased by more than 35% between 1987 and 2007. These oak saplings are needed to replace the aging oaks in the overstory." [2]

This topic has been a key focus area of peer-reviewed research for several decades, if not longer, exploring various factors that influence this decreasing recruitment in different areas of the Eastern region. Research efforts do take time, however, combining FIA and RPA data with other ongoing research projects has provided key insights to help increase recruitment through effective forest management and proactive efforts to help more of the younger trees be successful.

"In 2012, oak species (Quercus spp.) accounted for 34 percent of eastern hardwood growing stock (Oswalt and others 2014). This percentage has remained unchanged since 1992 (Powell and others 1993). What has changed is the proportional volume of oak poletimber [5 to 10.9 inches diameter at breast height (dbh)] which has declined from 27 percent in 1992 to 23 percent in 2012 (Oswalt and others 2014, Smith and others 2004). Nearly all this change has occurred since 2002. The decline in poletimber volume of oak species since 1992 is a precursor to reduced oak sawtimber volume in the coming decades. This decline has been predicted for decades, and management plans have been developed to prevent it but apparently not implemented on the scale necessary to avert it." [26]

Related to these volume changes in poletimber, there is concern that white oak saplings are caught in the bottleneck as well. Key to concerns about saplings and poles is how they are able to compete within the forest to keep progressing to the next size class. As discussed in the Understanding Oak section of this report, there is a current succession pattern that can favor shade-tolerant species, such as red/sugar maple and beech. These competitor species have also gained in numbers over the past century due to fire suppression and other changing dynamics within the forest. As such, when there is a 'release' in the forest—harvesting or natural tree mortality removes trees from the canopy—many of these shade-tolerant competitors can grow more quickly than oaks, so if too many are present on a site, they will outcompete the oak seedlings, saplings and poles by limiting the available sunlight and resources available for the oaks to keep progressing.

Seedlings, saplings and poles represent the future of the American white oak forest:

Seedlings	**under 4.5 ft tall** *FIA data: defined as live trees less than 1.0 inch dbh (dbh-diameter at breast height) and at least 1 foot in height*
Saplings	**4.5 feet tall to 4.9-inch dbh** *FIA data: defined as live trees that are 1.0 to 4.9 inch dbh*
Poles	**5.0-to-10.9-inch dbh**

The following set of figures explores FIA data for oak saplings and how they are faring in the forest in competition with one of the shade-tolerant competitors. The species included in the figures are as follows:

White oak (*Quercus alba*)	key species used for cooperage
Chinkapin oak (*Quercus muehlenbergii*)	also used for cooperage, but in a tiny percentage by comparison to *Quercus alba*
Red maple (*Acer rubrum*)	a shade-tolerant species very common in Eastern forests, and a key species in the "oak bottleneck"

The figures will either begin in 2004 or 2005, depending on when the FIA data became available.

Figure 2.13 presents the total saplings over a 13-year period in the Central Hardwood Region, a key area targeted by cooperage companies due to its abundance of quality white oak, stretching from Missouri to West Virginia, and Wisconsin to Alabama. White oak saplings are shown to have increased during this period, which is positive for the species, even as the number of red maple saplings has increased as well, and more than the white oaks.

It is notable that the total oak saplings in the Central Hardwood Region are not shown to be declining, even with increases for red maple saplings. This is likely related to 1) constructive management efforts underway and 2) the fact that many sites exist with an abundance of thriving saplings, whereas other sites are more problematic. We need to explore sub-regions and even by state to get a better idea of how oak saplings are faring in different areas; combining them together can only give an overall impression.

CENTRAL HARDWOOD REGION

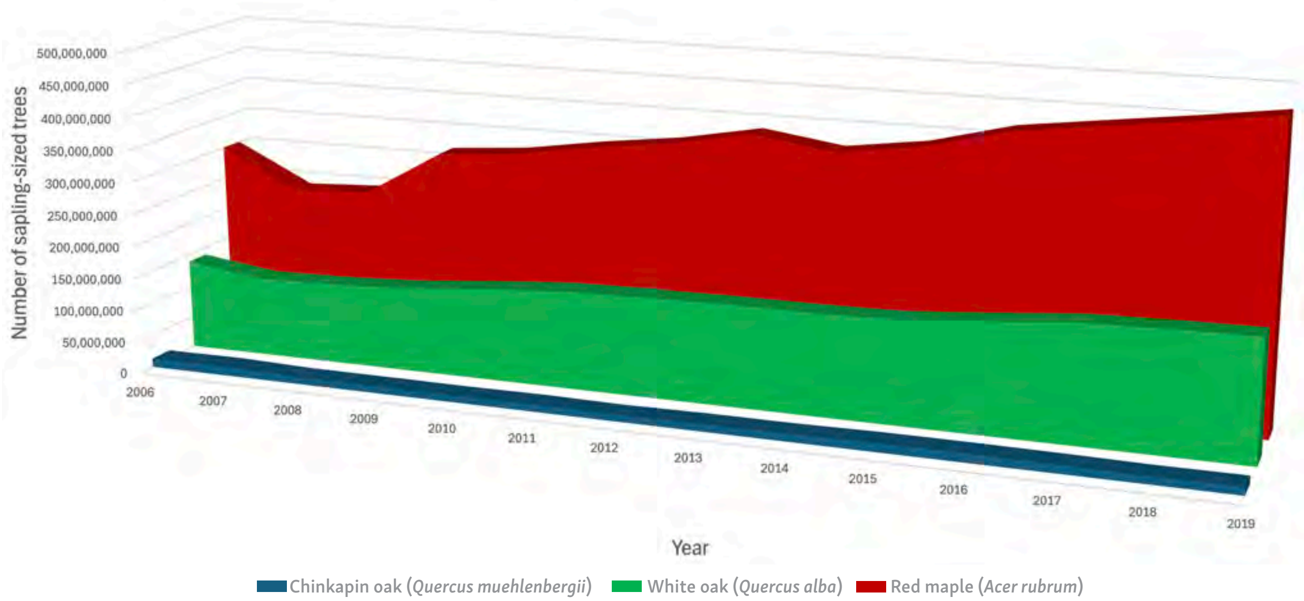


Figure 2.13 Saplings in the Central Hardwood Region based in FIA data: 2006 to 2019 [29]

COMPARISON OF TWO SUB-REGIONS

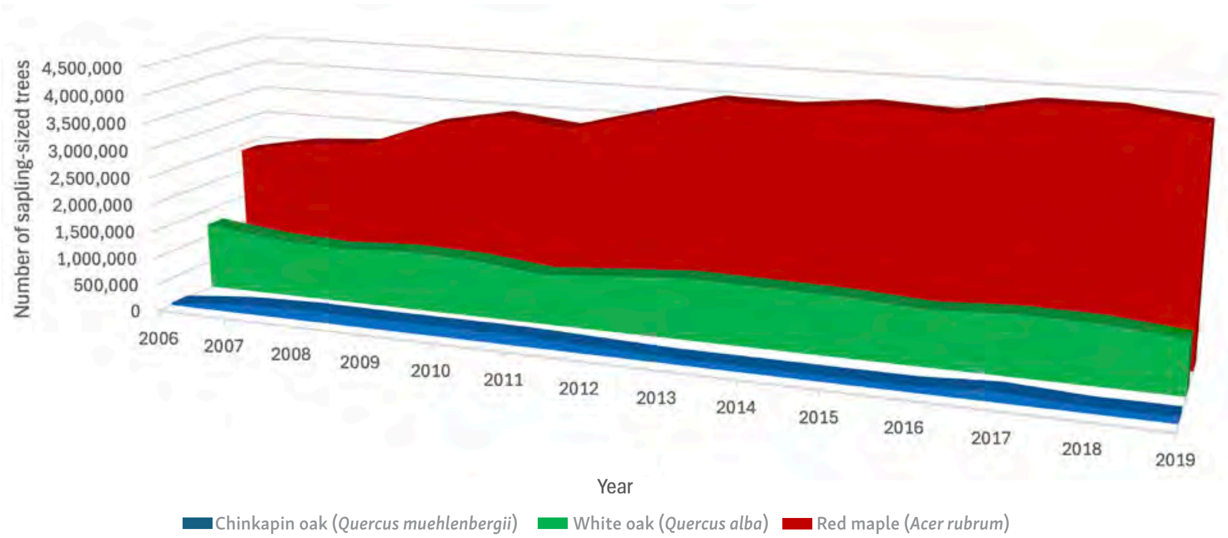


Figure 2.14 Saplings in Kentucky, Ohio and Tennessee based in FIA data: 2006 to 2019 [29]

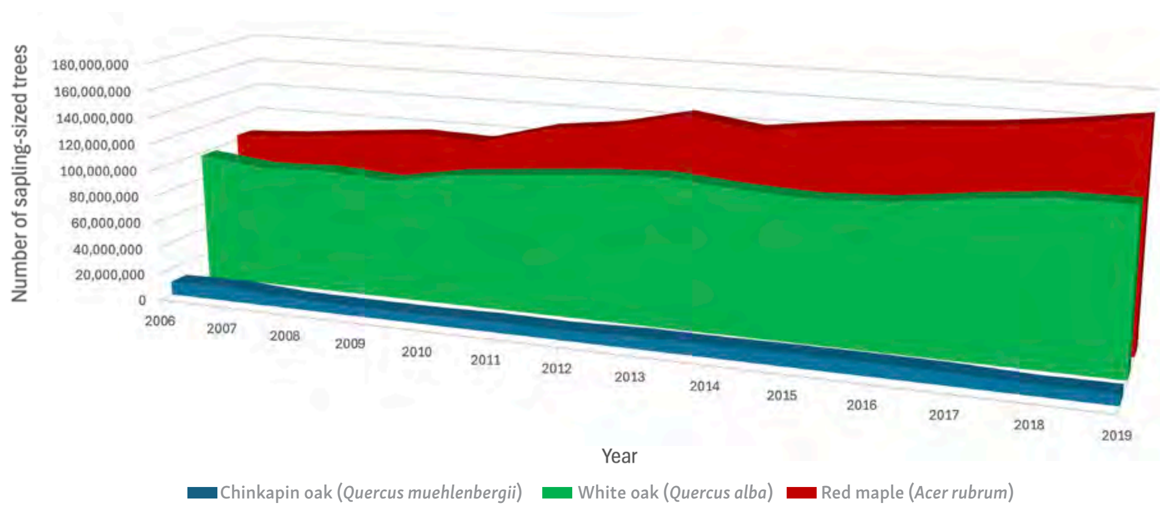


Figure 2.15 Saplings in the Arkansas, Illinois and Missouri based in FIA data: 2006 to 2019 [29]

Comparing Figure 2.14 to Figure 2.15 begins to tell a more complex story. In the combination of Kentucky, Ohio and Tennessee, white oak saplings seem to have some level of fluctuation, but without many gains as red maple continues to increase in higher proportion. Meanwhile, in Arkansas, Illinois and Missouri, the disparity between red maple and white oak saplings is much smaller, with white oak saplings seen to have increased in number between 2006 and 2019.

COMPARISON OF TWO STATES

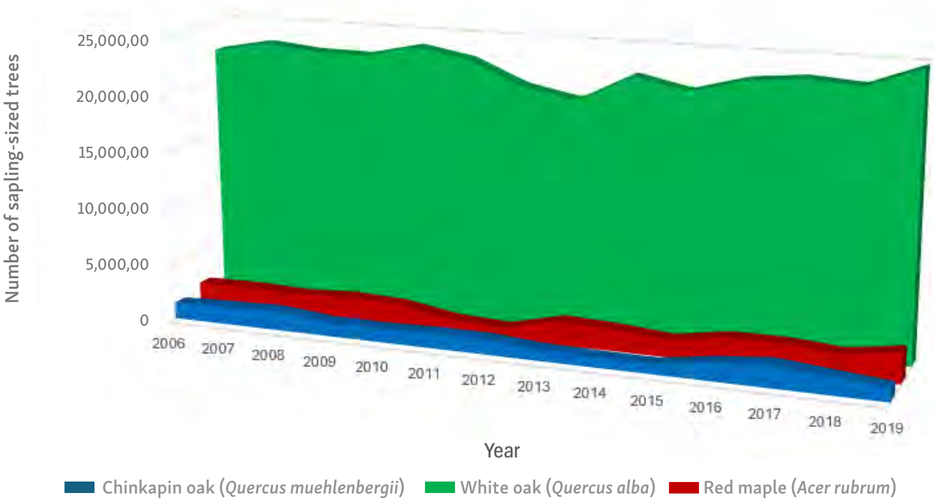


Figure 2.16 Saplings in Missouri based in FIA data: 2006 to 2019 [29]

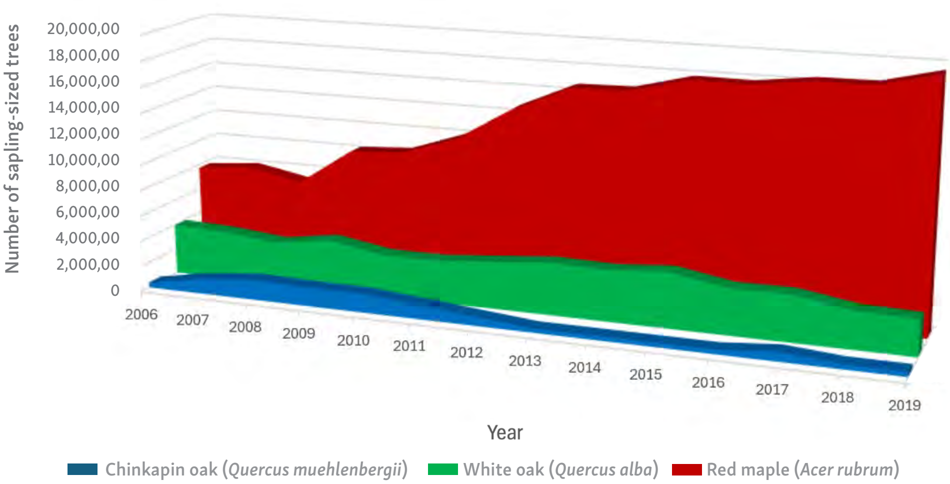


Figure 2.17 Saplings in Kentucky based in FIA data: 2006 to 2019 [29]

As we narrow in to the state level, we start to see even more differences. In Missouri, for example, which is known for its dry, sloping terrain in some of its forests, white oak saplings seem to be thriving overall, with red maple saplings existing but in a much lower percentage when compared to white oak (Figure 2.16). White oak's drought tolerance likely helps give it a competitive advantage in this area.

Meanwhile, in Figure 2.17 for Kentucky, red maple has continued to make important gains in numbers, while white oak saplings have at best maintained during the time period evaluated. Without effective management, there may be future decreases in white oak saplings in Kentucky —a key reason this state has often been cited in research calling for increased management, landowner education and resources to better ensure advanced regeneration.

Continuing to study the regional differences and promote management that is tailored to each forest site will be a key point moving forward.

- **Thankfully, despite competition in the forest, it is clear white oak is continuing to regenerate naturally—there are many areas where seedlings are present and mature trees are producing viable mast** (acorns). It is also of note that white oak seedlings are NOT considered to be caught in the bottleneck—that has been focused on the sapling and pole sizes.

"In addition to having the ability to mast, i.e., produce a tremendously large crop of acorns periodically, oaks have a secondary strategy for regeneration in the ability to accumulate advance reproduction. An abundance of large, competitive advance reproduction can act as a buffer against variations in acorn production by ensuring that seedlings are in place to take advantage of any disturbance that would initiate regeneration. The density of oak seedlings and seedling sprouts in the understory of mature forests may range from a few thousand to as many as 250,000 per ha (Johnson et al. 2009). In general, acorn production and seedling germination are considered sufficient in healthy mature oak forests, and they are not the bottleneck in the oak regeneration process (Lorimer 1993)." [10]

Of course, since all of the younger size classes need key opportunity over time to grow, such as disturbances creating better access to sunlight, seedlings should continue to be studied alongside the sapling and pole sizes. Seedling data can be tricky since the number of seedlings per site and per year can vary based on annual conditions. However, FIA data is available to help monitor overall trends.

Figures 2.18 and 2.19 compare the same two sub-regions previously used for the discussion of oak saplings, this time evaluating the inventory of seedlings recorded in FIA data. One figure begins in 2004 and the other in 2005 due to when the sampling data became available.

In Figure 2.18, white oak seedlings are maintaining in inventory on the forest floor and have increased in this region between the start and end points. Meanwhile, red maple seedlings have shown a downward trend between 2009 and 2020, which is encouraging for white oak…although as always, there will be further nuances by state and specific forest. Meanwhile in Figure 2.19, there is an expected abundance of oak seedlings on an increasing trend, while red maple has not made the same gains. It is considered very positive for white oak that seedlings remain in play in the beginning of the forest cycle, and with proper management, can grow into the forests of the future.

Continuing to monitor seedling trends is important, and ideally this would also take into account spatial density in addition to total population. Spatial density is often factored in when considering overall abundance, which will be discussed next.

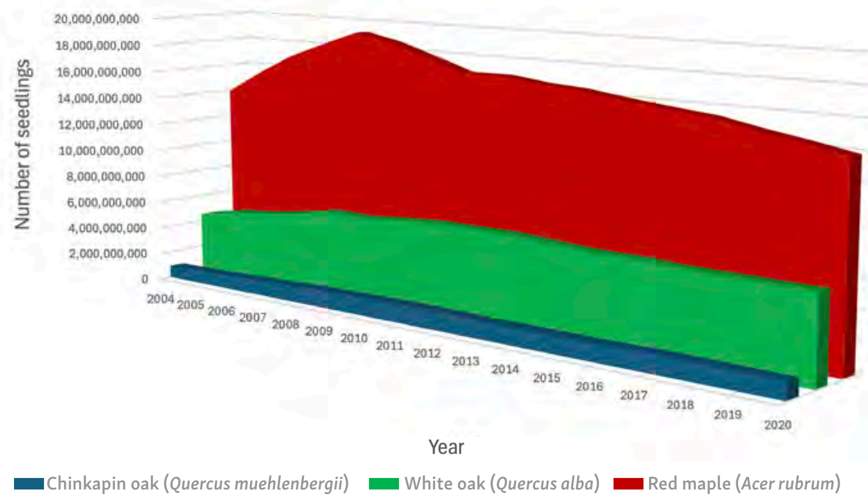


Figure 2.18 Seedlings in Kentucky, Ohio and Tennessee based in FIA data: 2006 to 2019 [29]

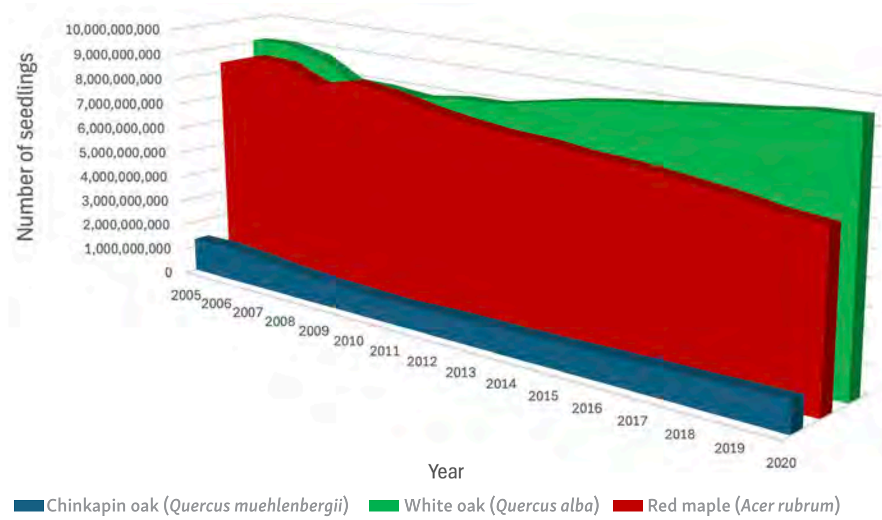


Figure 2.19 Seedlings in Arkansas, Illinois and Missouri based in FIA data: 2006 to 2019 [29]

- **Given various dynamics in play, there is opportunity to reinforce and increase oak abundance for the Eastern Region.** Some research has evaluated oak abundance by looking at a combination of density and volume to score "Importance Value." Defined this way, oak abundance looks to have decreased between 1980 and 2008 according to a study published in 2011 using FIA data. Details follow.

  Figure 2.20 from the 2011 study [41] shows the abundance of all oak species as well as two specific species, including *Quercus alba* (white oak).

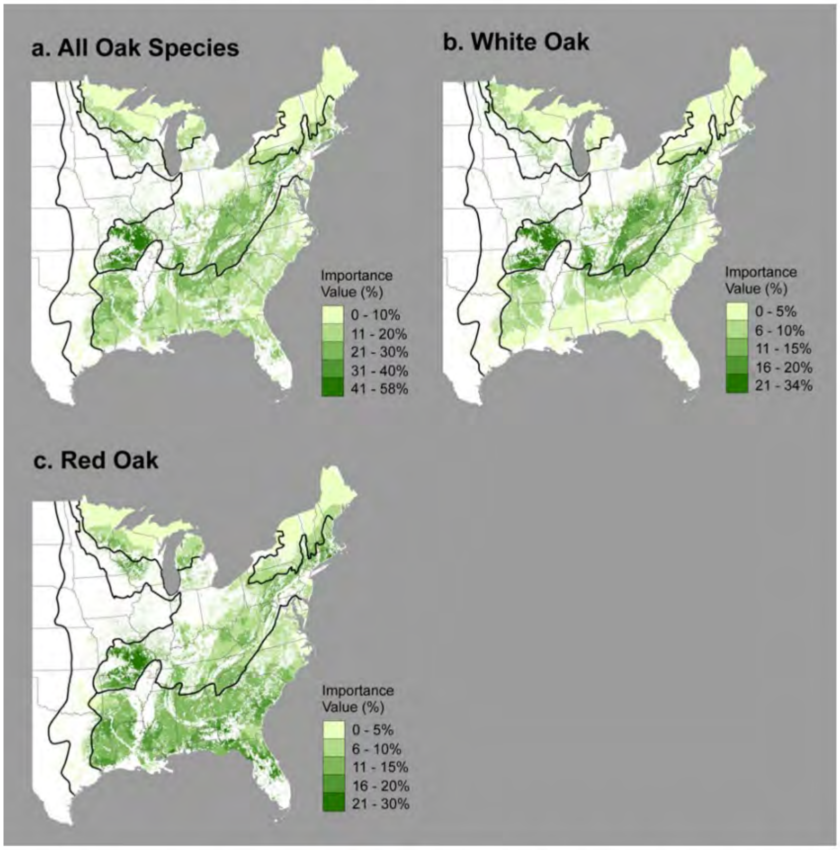


Figure 2.20 Current abundance, as measured by importance value, for a) all oak species, b) white oak species, and c) red oak species in the eastern U.S. forested areas. [41]

Relative Density: total number of oaks/total number of all live trees x 100
(for trees with a diameter of at least 2.54 inches)

Relative volume (or dominance): total growing stock volume of oak/total growing stock volume of all live trees x 100

Importance Value (IV) – the mean of Relative Density and Relative Volume

Next, Table 2.4 shows data by oak species. Over time, oak is shown as decreasing in relative density and volume, meaning that even though growing stock volume is increasing in the Eastern region, the density is decreasing and the relative increases in volume are slowing (based on a comparison of Importance Value).

Table 2.4 Changes in relative density, relative volume, and importance value (IV) in the eastern U.S. between the first (T_1) and second (T_2) inventory during the last two decades (No. of counties = the number of counties in which a given species was present in the inventory record) [41]

Species	No. of counties	Rel. dens. (%)		Rel. vol. (%)		IV (%)	
		T_1	T_2	T_1	T_2	T_1	T_2
White oak (*Q. alba*)	1739	3.4	2.8**	8.2	8.1**	5.8	5.4**
Post oak (*Q. stellata*)	1026	2.7	1.8**	3.7	3.1	3.2	2.5**
Chestnut oak (*Q. montana*)	636	3.0	2.8**	7.3	7.8	5.2	5.3
Bur oak (*Q. macrocarpa*)	623	4.2	4.4	9.9	11.9*	7.0	8.2
Chinkapin oak (*Q. muehlenbergii*)	594	1.1	1.3	2.2	2.4	1.7	1.9
Swamp chestnut oak (*Q. michauxii*)	466	0.4	0.3*	0.8	1.0*	0.6	0.7
Swamp white oak (*Q. bicolor*)	393	0.6	0.5	2.1	1.8	1.3	1.2
Overcup oak (*Q. lyrata*)	391	0.7	0.6*	1.7	2.1*	1.2	1.3
All white oaks (section *Quercus*)	**2033**	**6.7**	**5.5****	**14.7**	**14.4**	**10.7**	**9.9****
Northern red oak (*Q. rubra*)	1593	2.0	1.8**	6.4	5.7**	4.2	3.8**
Black oak (*Q. velutina*)	1487	2.1	1.8**	5.4	4.5**	3.8	3.2**
Scarlet oak (*Q. coccinea*)	959	1.2	1.0**	3.1	3.2	2.2	2.1*
Southern red oak (*Q. falcata*)	929	1.7	1.6*	2.8	3.0	2.2	2.3
Water oak (*Q. nigra*)	689	4.5	5.7**	3.9	4.7**	4.2	5.2**
Willow oak (*Q. phellos*)	592	1.1	1.0	2.2	2.1	1.6	1.6
Cherrybark oak (*Q.pagoda*)	522	0.6	0.6	2.0	2.4	1.3	1.5
Blackjack oak (*Q. marilandica*)	507	1.5	0.8**	1.1	0.6**	1.3	0.7**
Laurel oak (*Q. laurifolia*)	444	3.1	3.4	3.2	3.4	3.1	3.4
Pin oak (*Q. palustris*)	412	0.9	1.1	3.0	4.2	2.0	2.6
Shumard oak (*Q. shumardii*)	394	0.2	0.3	0.7	1.2	0.5	0.8
Shingle oak (*Q. imbricaria*)	279	1.7	2.2	2.0	2.8*	1.8	2.5*
Northern pin oak (*Q. ellipsoidalis*)	231	1.1	1.2	2.6	2.7	1.8	1.9
Nuttall oak (*Q. nuttallii*)	162	0.7	1.0	2.4	2.8	1.6	1.9
Live oak (*Q. virginiana*)	161	3.0	3.7	4.0	5.1	3.5	4.4
Turkey oak (*Q. laevis*)	146	3.9	2.3**	0.5	0.5	2.2	1.4**
Bluejack oak (*Q. incana*)	130	1.8	0.5**	0.4	0.1*	1.1	0.3**
All red oaks (section *Lobatae*)	**1998**	**8.1**	**7.8****	**15.8**	**15.0****	**12.0**	**11.4****

Bold indicates the sub-total statistics of all species in this section.
* Change during the study period is significant at $p < 0.05$.
** Change is significant at $p < 0.01$.

This visual from the study (Figure 2.21) shows the mean annual change in "Importance Value" for some highly valued oak species. For *Quercus alba*, the map shows a mix of areas where oak is continuing to be just as abundant or increasing, as well as areas where regeneration is likely affecting oak abundance more strongly.

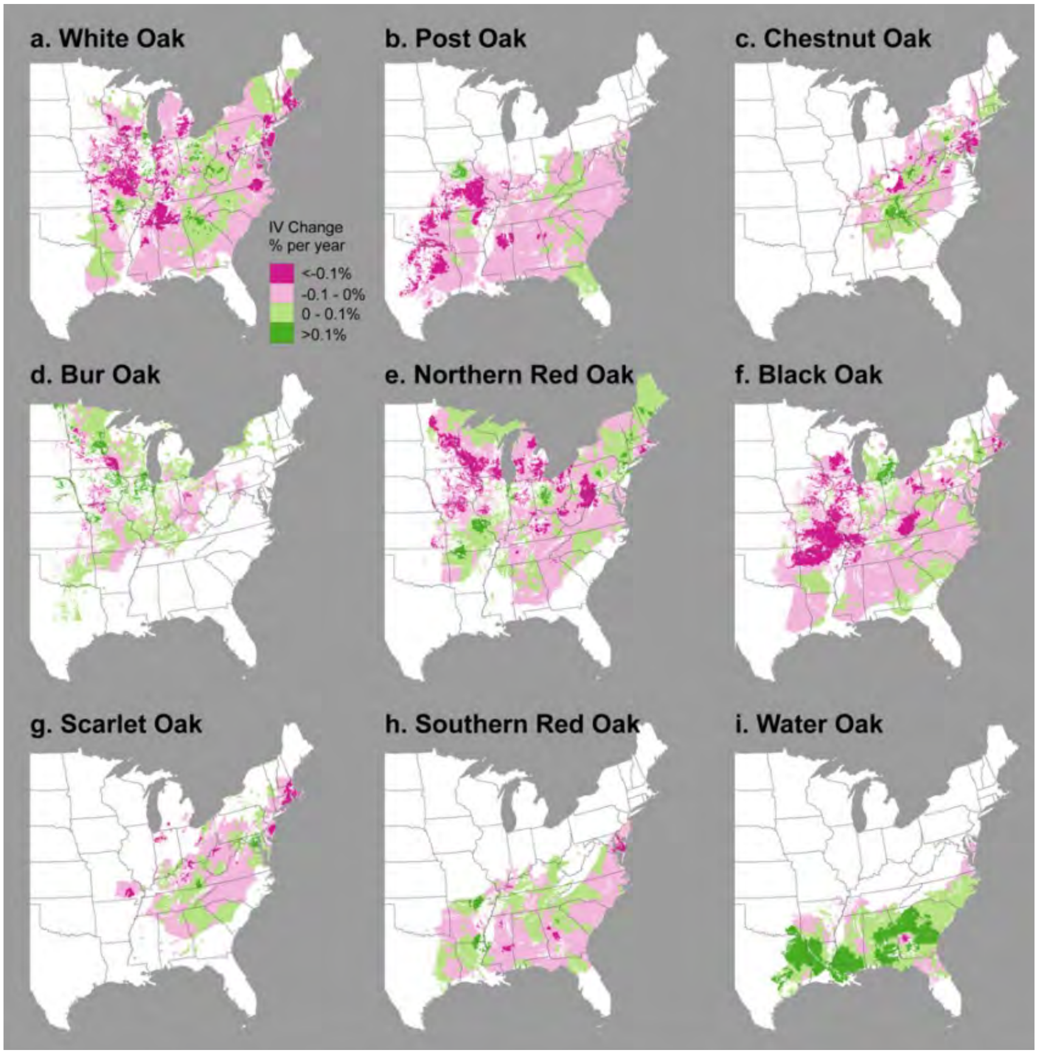


Figure 2.21 Mean annual change in IV for nine key oak species, including white oak. [41]

A follow-up study to this research published in 2018 (7 years later), confirmed a continuing trend of decrease in Importance Value in Eastern forests, this time for the *Quercus* genus, which would include white oak but many other oak species as well.

"Forests around the eastern U.S. have seen dramatic changes over the past three decades. We found that four genera (Acer, Fraxinus, Pinus, and Prunus) increased in importance over the last three decades, four other genera (Carya, Nyssa, Quercus and Ulmus) decreased in importance, and two genera (Betula and Populus) were relatively stable over time." [44]

TRACKING AMERICAN WHITE OAK - *Quercus alba L.*

‘Near Future’ Forecast

‘NEAR FUTURE’ FORECAST

TRENDS

While many data points are available to tell us what has been happening over the past 50 years, there is less information focused on predicting the future. However, the combination of 1) past data that establishes ongoing trends and 2) how slowly the forest grows allows researchers to provide insights with a fair amount of certainty for the upcoming decades. This report focuses on the “near future” as the next 50+ years. A summary of current predictions is available in this section, which provides a relatively positive outlook for the cooperage industry and other hardwood-related industries, balanced with key opportunities to improve future sustainability as research continues to track trends and pursue solutions to the challenges.

AT A GLANCE

TRENDS

- Cooperage supply remains strong
- Eastern forests are projected to “age” 14 years in 50 years
- Volume of growing stock is projected to increase, both for timberland and specifically hardwoods
- Removals of hardwoods may increase, although this is debated as the logging industry continues to recover from setbacks
- White oak forest is predicted to continue slowly shifting its range to the Northeast
- Total U.S. forest is projected to decrease slightly, largely due to development
- Barrel production can continue to grow and still represent a tiny percentage of the current white oak stock, which is growing
- The white oak “bottleneck” is expected to continue

OPPORTUNITIES

- Monitor trends every 5-7 years
- Increase the advanced oak regeneration in our forests
- Tailor forest management by region and localized factors
- Develop management that accounts for diverse goals society cares about, from forest products to wildlife, carbon to recreation
- Educate the public on the importance of harvesting and forest renewal
- Increase participation in forest certification programs
- Support long-term strategies even when there aren’t short-term results
- Share research
- Engage more investors in long-term research programs

- **Cooperage supply of *Quercus alba* remains strong.** Furthermore, sawmills have greatly increased the utilization and efficiencies for every log processed. This optimization has not been "necessary" to the sustainability of the forest but is nevertheless an important factor that will help make the most of our resources moving forward. Most if not all the advancements in the milling sector are thanks to development of new technologies and refinements in engineering.

  Furthermore, a 2023 study called *Critical Market Tipping Points for High-Grade White Oak Inventory Decline in the Central Hardwood Region of the United States* used a model to analyze white oak future inventory for high-grade timber using key ecological, climactic and economic interrelationships. [42]

  Key scenarios identified predicted:

  1) If demand growth remains below 1.5% per year, the supply will continue climbing until at least 2100.
  2) There was not evidence of a tipping point in inventory over the projection period, which extended to 2500.

Photo courtesy of Dr. Scott Schlarbaum, University of Tennessee:
Acorns prior to collection for research

Two excerpts from the published results:

"As expected, we do not find evidence of tipping point in inventory over the projection period through 2500. This is because current annual growth removals constitute a very small proportion of the available growing stock." [42]

"Our simulations show that with a scheduled lower annual rate of rising demand for high-grade white oak, a more adaptive demand-price response provides added sustainability of the growing stock inventory, as it delays the time before inventory begins to decline and tends to raise the volume of inventory by that time. However, our simulations suggest that the sustainability of the white oak growing stock across the CHR is unlikely to be threatened, as it would require annually compounding increases in demand to draw upon and eventually deplete the growing stock inventories of high-grade roundwood."* [42]

- **Eastern forests are projected to "age" 14 years between 2020 and 2070.** To understand this statement, it is important to comprehend that forest aging is not considered to be a uniquely linear process. If it were linear, all forest land would age the same number of years as the projection period (in the case of the chart, 50 years). However, the RPA explains, *"forest management, disturbance, and succession generally reduce the age of forests."* [6]

  The RPA report continues: *"In the East, all projections suggest an increase in proportion of forest 80+ years old and a decrease in the proportion of forest less than 80 years old by 2070. However, the amount of forest management driven by timber prices associated with the LM and HH scenarios leads to less 80+ year old forest by 2070 than the other scenarios, as well as young forests (0 to 9 years old) having a similar areal extent to the forests of 2020."* [6]

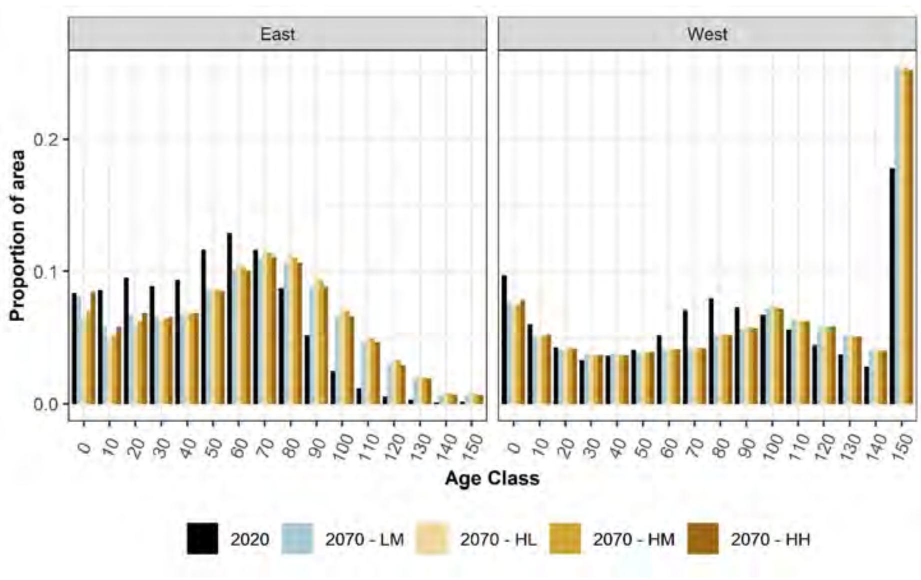


Figure 3.1 Forest age distribution in 2020 and projected forest age distribution by 2070 for the Eastern and Western Conterminous United States [45]

150-year age class represents age classes 150 years and older
LM – lower warming/moderate U.S. growth
HL – high warming/low U.S. growth
HM – high warming/moderate U.S. growth
HH – high warming/high U.S. growth

*CHR - Central Hardwood Region

- The 2020 RPA Assessment states the **volume of United States timberland growing stock is projected to increase through 2050**. [6]
- **Growing stock volume for hardwoods specifically is projected to increase over the 2020 to 2070 projection period,** while softwood growing stock volume is projected to decrease after 2050. [6]

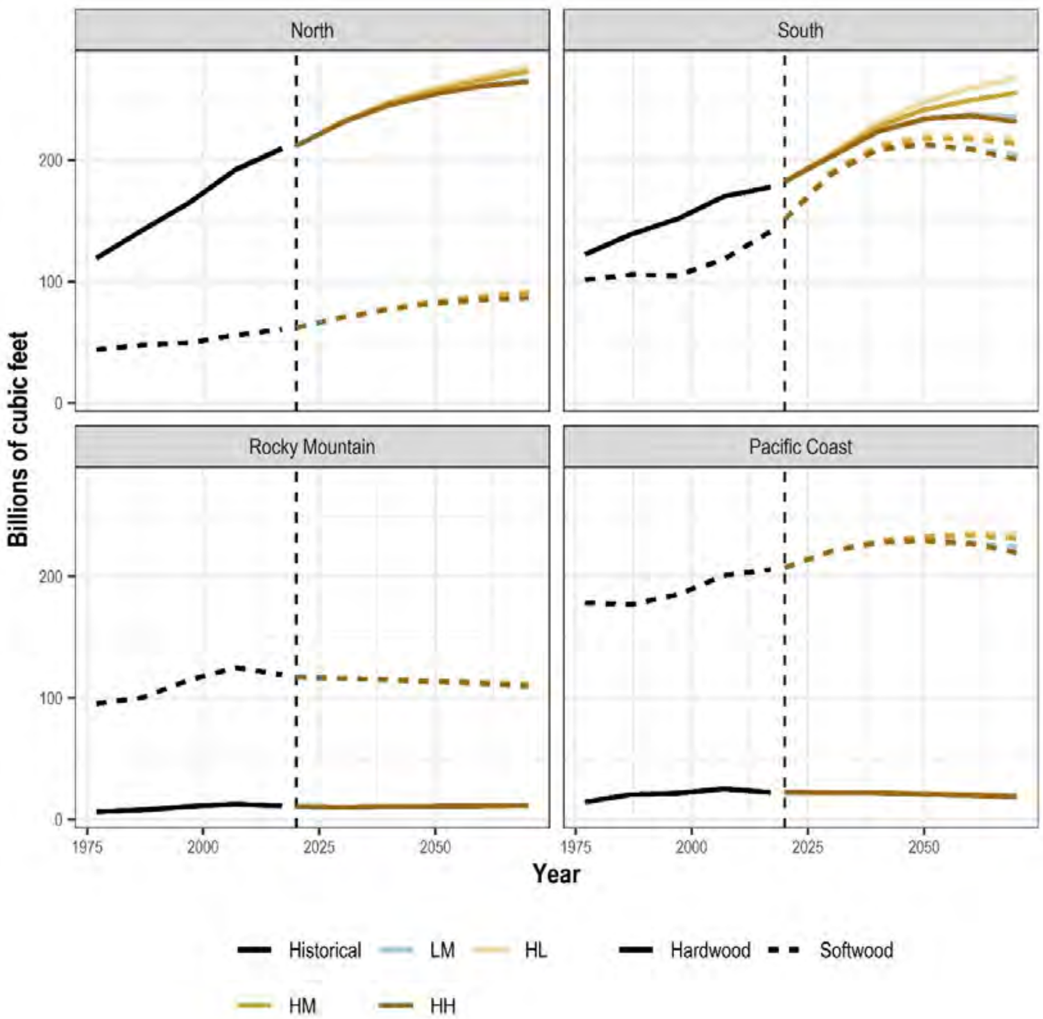


Figure 3.2 Historic and projected growing stock volume for hardwood/softwood by RPA scenario and RPA region [45]

Notes:
LM – lower warming/moderate U.S. growth
HL – high warming/low U.S. growth
HM – high warming/moderate U.S. growth
HH – high warming/high U.S. growth
Projected growing stock volume is based on averaging decadal projection results across climate projections within each RPA scenario, RPA region and species group.

- **Removal of hardwoods is expected to increase over time between now and 2070.** This is partially credited to assuming recovery from the lower rates of harvesting that occurred in the 2000s in each region. [6]
  - **South region – removals are expected to return to pre-2000s levels**
  - **North region – "…projections vary from 1.88 billion cubic feet per year by 2070** under the HL scenario (5.0 percent above 2020 levels) **to 2.54 billion cubic feet per year** under the HH scenario (41.9 percent above 2020 levels), as driven by the economic growth assumptions inherent in these RPA scenarios and to a lesser extent by land use choices."

by RPA Scenario and RPA Region

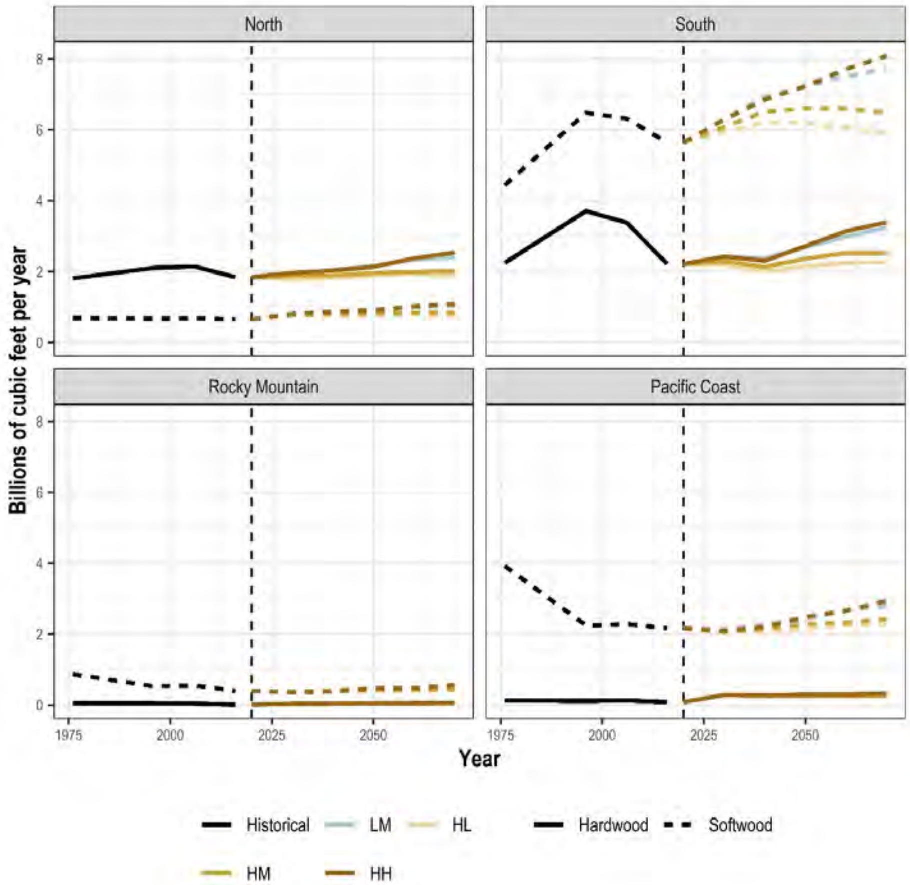


Figure 3.3 Historic and projected removal volume on timberland for hardwood/softwood [45]

Notes:
LM – lower warming/moderate U.S. growth
HL – high warming/low U.S. growth
HM – high warming/moderate U.S. growth
HH – high warming/high U.S. growth
Projected removal volume is based on averaging decadal projection results across climate projections within each RPA scenario, RPA region and species group.

Not all industry participants agree with the RPA's prediction for hardwood removals. Predicting future markets can be difficult as it involves a complex set of factors that can swing different ways. A key challenge to achieving continued increases in harvesting involves having sufficient labor available to carry this out. Previous setbacks to the logging industry have led to some workers to permanently redirect to other careers. In positive news for the industry, there are programs evolving to help with this. A key example is Forestry Works, an organization dedicated to increasing awareness of forestry jobs starting in elementary school and providing training to job seekers, including at the high school level, to increase opportunity for adults entering the job market to find viable and sustaining careers in forestry. [46]

- **White oak forest is predicted to continue slowly shifting Northeast based on the current and continuing shifts in climate.** Research that evaluated shifts in forest communities over three decades confirmed "Oak-hickory" forest is slowly, but measurably, moving to the northeast. [47]

Table 3.1 Shifts in forest communities over three decades [47]

Community	Latitude shift (km/decade)	Longitude shift (km/decade)	Observed direction	Predicted direction	Distance shift (km/decade)	Area change (km²/decade)
1. Cherry–oak	−2.3	2.8*	South-east	North-west	3.6*	4,578* (+7.1%)
2. Central woodlot	6.9**	−23.2***	North-west	North-east	24.2***	175 (+.2%)
3. Conifer–birch	.2	21.2***	North-east	North-west	21.2***	1,259 (+2.5%)
4. Pine–tupelo–oak	18.3***	11.3***	**North-east**	**North-east**	21.5***	−11506*** (−18.5%)
5. Oak–hickory	5.8***	2.5*	**North-east**	**North-east**	6.3***	−17089*** (−15.6%)
6. Beech–maple	−6.9***	−11.4***	South-west	North-east	13.3***	−205 (−.2%)
7. Pine–sweetgum	8.6***	−3.1	North-west	North-east	9.1***	1,830 (+1.8%)
8. Yellow poplar–oak	−4.2**	3.7*	South-east	South-west	5.6***	2,878 (+5.0%)
9. Red maple	−1.7	−6.7***	South-west	North-west	6.9***	3,423* (+5.1%)
10. Poplar–aspen	−6.4***	+0.0	South-east	North-east	6.4***	−2005 (−4.7%)
11. Southern lowland	−21.4***	−12.2***	**South-west**	**South-west**	24.6***	13,759*** (+26.7%)
12. Spruce–tamarack	−2.3	−6.4***	South-west	North-west	6.8***	2,903** (+7.7%)

Note: Shifts were measured by the movement of the community centroid and changes in community spatial coverage. Positive values of latitude and longitude shift represent northward and eastward movement, respectively; conversely, negative values represent southward and westward movement. The predicted direction was based on expected shifts owing to climate change (communities shown in bold had the same observed and predicted direction of shift). The percentage change in the area is in parentheses. Asterisks indicate significant Benjamini–Hochberg-adjusted *p*-values (P_{BH}) when tested by randomization tests.

*P_{BH} ≤ .05; **P_{BH} ≤ .01; ***P_{BH} ≤ .001.

- **The total forest area in the conterminous United States is projected to decrease from 634 million acres to between 619-627 million acres by 2070**, largely due to development. While a reduction, this does not currently represent a key threat to *Quercus alba* and many other species. [6]
- Annual white oak barrel production consumes approximately 250 million board feet or 12% of the current removals, or 0.1% of the total white oak stock. **If barrel production grows at 7.5% compound annual growth rate (CAGR) for the next 10 years, it would only represent 0.2% of the current white oak stock, which is growing.** (Information based on production estimates shared by the cooperage industry)

- **The white oak "bottleneck" is expected to continue** as more work needs to be done to ensure more younger oak stems, including the 5 to 10.9 inch diameter at breast height class size, need to be able to progress to the next stage. Resolving this issue is expected to take time.
  - Natural and managed disturbances can create positive change and vigor for oak regeneration seen within five years.
  - More often changes will take more time, and how quickly oak recruitment can be adjusted will depend on the specific situation, so the methods employed should be customized to the site in question.
  - Educating and empowering landowners to carry out management benefiting oaks is an ongoing key goal, representing a significant outreach focus shared by foresters and forest product related industry professionals.

"Oaks are disturbance-dependent and advance growth-dependent. Regenerating oak is a process and not an event. Growth of competing species often displaces the development of oak (bottleneck effect) before oaks are able to emerge into the overstory." [26]

- White oak is not identified as currently threatened by climate change, and oak-hickory forest is one of the forest type groups projected to increase in area across RPA's different climate models from 2020 to 2070.

"Of the 16 major forest type groups based on 2020 areal extent, only the loblolly/shortleaf, oak/hickory, and white/red/jack pine groups are projected to increase in area." [6]

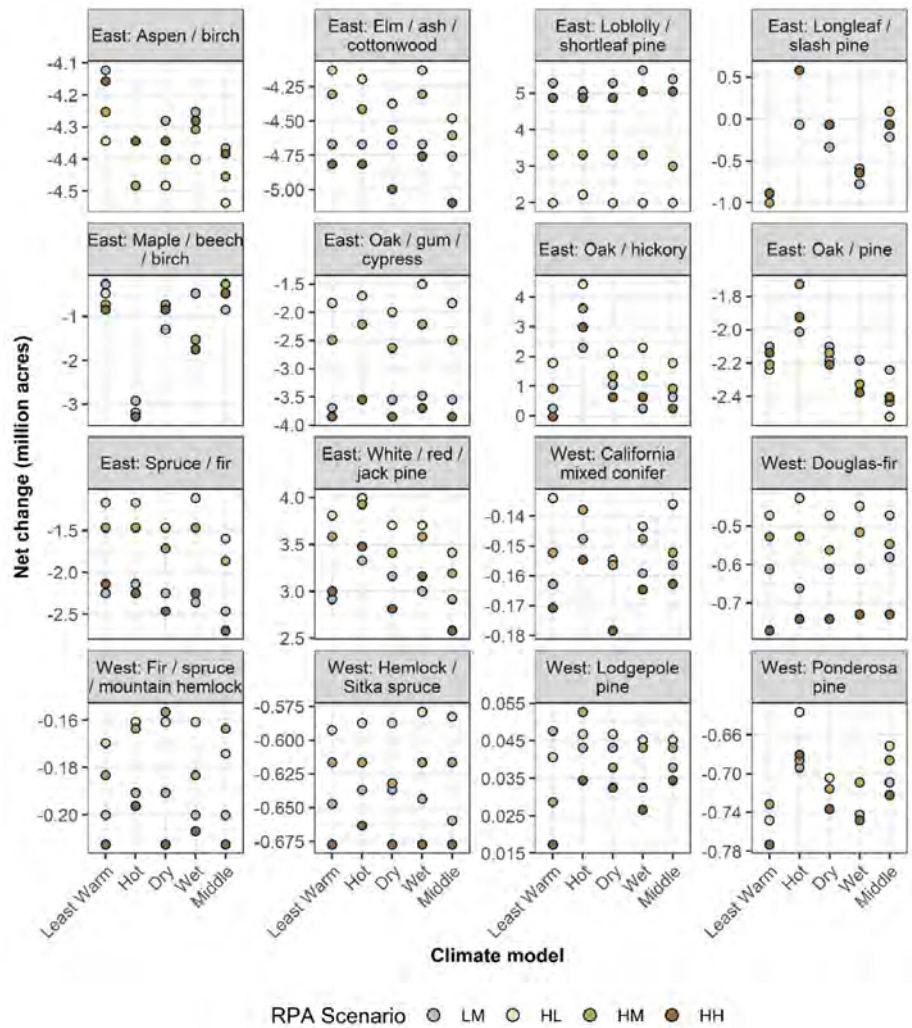


Figure 3.4 Projected net change in timberland area from 2020 to 2070 for the forest type groups with the largest areal extent in 2020 by RPA scenario-climate future. Net change is based on averaging projection results for each RPA scenario-climate future by forest type group. [45]

Notes:
LM – lower warming/moderate U.S. growth
HL – high warming/low U.S. growth
HM – high warming/moderate U.S. growth
HH – high warming/high U.S. growth
Net change is based on averaging projection results for each RPA scenario-climate future by forest type group.

Since climate change will also affect disease and pest interference with any tree, including *Quercus alba*, research is ongoing to continue predicting how a complex set of factors may play out related to climate change. A particular focus on understanding the effect of drought may prove very useful. Tree improvement programs are also being pursued to address threats from key diseases, pests and climate change.

OPPORTUNITIES

Based on predictions and established trends from the past, there is opportunity to increase the focus on oak trees, including *Quercus alba*, as keystone species in their established environments. This report recommends the following:

- **Review FIA/RPA data every 5-7 years to watch for trends and determine continued status of white oak growth in the Eastern Hardwood region.** Also review any updates presented at the next International Oak Symposium in October 2024 in Knoxville, TN.

- **Support efforts to improve advanced regeneration of *Quercus alba* through effective management.** Key stakeholders should follow and monitor this trend to verify progress every 5-7 years.

  There is a large inventory of mature trees and many non-competitive oak seedlings, but we need to ensure these small seedlings can recruit into 'advanced reproduction', defined as seedlings that are relatively large (typically defined as > 0.5 inches at the ground-level diameter, or > 3–4 feet in height). Advance reproduction has a better probability of recruiting into mid-canopy following a disturbance instead of being caught in a "bottleneck" competing with other species.

  Each year, there will be fluctuation in new oak seedlings as it is well established forests will have fluctuating levels of mast over time, which is considered normal and natural, and the weather patterns will further influence some years to have high germination and other years to be lower.

  This report recommends closely monitoring and supporting efforts to:
  1) Continue to maintain or increase the number of *Quercus alba* seedlings
  2) Increase the population of advance reproduction in mature stands that are ready to be regenerated.

  This is supported by information presented at the 2017 International Oak Symposium:
  "*The portions of the timber base that appear to have the greatest investment opportunity in the next 25 years are mid-size trees and poletimber.*" [26]

  Successful case studies in oak habitat, including on problematic sites, will be a great resource moving forward. Citations for three examples include [48,49,65].

- **Tailor forest management to the specific locations of oak forest.** Oak grows over a wide range of habitat in constantly evolving forests. Forest management benefiting oaks will involve some key principals, however a one-size-fits-all approach will not be viable across different ecosystems. Thankfully research being conducted across numerous oak forest locations has helped establish and continue developing solutions to known challenges.
  - Ongoing research has and will continue to identify what can be done in different regions to mitigate problems and improve advanced regeneration.
  - Carrying out effective management is a partnership between foresters, landowners and industry stakeholders. **Increasing education and support of these groups is key moving forward.**
  - Some specific locations of oak forest have been identified as of higher concern, and the key will be effective forest management to reestablish successful regeneration.

- **Continue developing management strategies to balance different needs – not only focused on the forest products industry.** It is clearly established that the oak genus, and *Quercus alba* as a key species within the genus, are highly desirable to many stakeholders. Forest management can continue to become increasingly sophisticated in its approach, moving away from a "leave it alone" strategy or "take only the best" strategy to account for current forest trends, including challenges, and achieve more goals across different areas of interest. For example, more research is not just focusing on how to grow trees well, but also the interconnected benefits to wildlife, carbon cycles, water quality and more.

"Whereas more traditional objectives associated with thinning are related to timber production, today thinning treatments are designed and implemented to achieve numerous objectives including the creation and maintenance of wildlife habitat, wildfire hazard reduction, and ecosystem restoration, with benefits to timber production often considered a positive byproduct." [50]

- **As more stakeholders and even consumers are interested in oak, capitalize on the opportunity to educate and increase support for effective forest management—without fear of harvesting** (or other methods such as herbicides/fire/grazing).

It appears that more and more people are becoming aware of oaks again and very interested in sustaining them:

"Oaks provide a plethora of ecosystem services, so that sustaining the biodiversity, cultural, aesthetic, and economic services provided by oaks is highly desired by society." [26]

It is important to educate these interested parties that a solution to the long-term regeneration gap of white oak is more active and intensive management, not abstinence from harvesting or other forest tending/site preparation methods. Harvesting applied correctly, and coupled with other treatments such as fire or herbicide, helps renew the forest, increasing diversity and making way for the younger generations of trees. Opening the canopy to allow more sunlight to the forest floor often creates a response of vegetative growth that is beneficial to wildlife as part of the forest cycle. Furthermore, mortality increases in oak forests without removals and active regeneration.

Several key audiences:

. General public – enjoyment of forest and utilization of forest products can work hand in hand.
. Outreach & education for landowners – effectively managing for oaks alongside other goals
. Support & education for loggers – encouraging best management practices

Another source further explains the connection to forest management: *"Simply 'letting nature take its course' will result in 'unnatural' forests. Oak forests developed with frequent disturbance that we control. Using science-based management practices, you can secure the future of oak forests on your land. You must move beyond focusing on the mature overstory trees and look down. The next oak forest lies at your feet."* [2]

- **Promote and support certification programs, which while increasing, currently represent an under-utilized sustainability strategy.**

"Successful oak regeneration could be promoted as a part of hardwood sustainability certification, thereby transferring the management costs to the current customers of hardwood products." [26]

Certification programs are established in all the regions where white oak is growing and the cooperage industry targets. The amount of certified wood is projected to increase over the coming years given current momentum from related stakeholders.

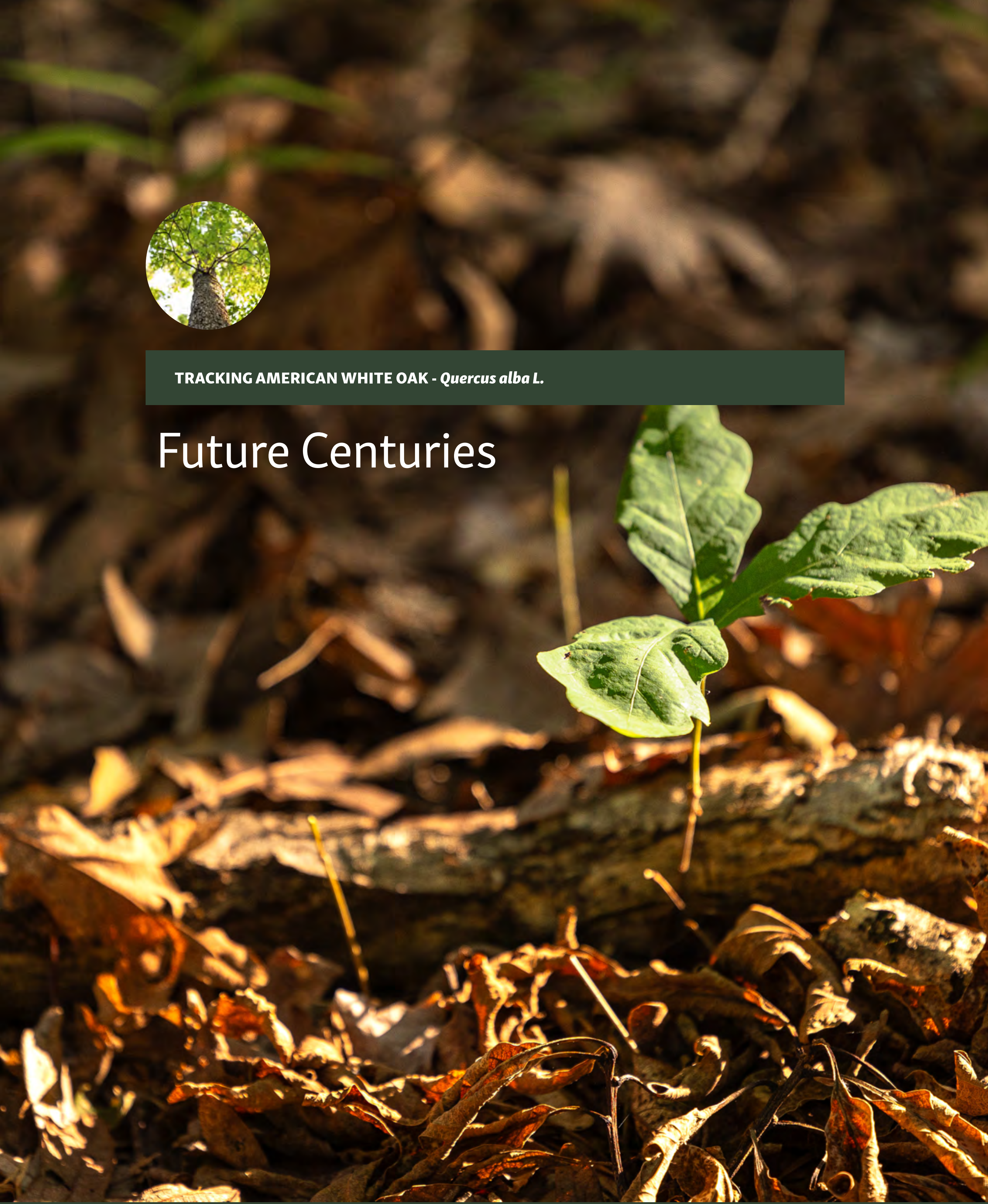
- **Support long-term strategies even when there aren't immediate (short-term) results.** Forests grow slowly and so long-term planning needs to influence everything from strategic planning, reporting on long-term research projects (any project involving trees takes much longer than shorter cycle plants and animals) and both testing and then applying management strategies to a larger percentage of oak forest.
    - **Opportunity for industry to get more involved in research and oak-related conferences to continue sharing information and supporting ongoing efforts.**
    - **Support "Tree Improvement" programs** seeking to protect and develop white oak trees that are demonstrably more resistant to key stressors and understand overall diversity across the oak genus. Ideally this support would come from public entities and even involve legislation increasing funding to support the efforts.

"Restoring and sustaining oak forests require active management and long-term commitment. *Climate change, deer populations, invasive species, and social constraints can complicate oak management.* ***Despite these challenges, we have sufficient knowledge to be successful in our efforts despite an uncertain future."*** [10]

- **Continue to share research across the USA regions where white oak is growing.** Much is being learned, and this is especially important since oaks are cited as not always easily understood in their responses to different types of management. Continued investment in and reporting of research helps evolve the conversation more efficiently.

- **Increase funding when possible for oak research—more money is needed given the cost associated with such long-term projects.** A number of cooperage and distillery related companies are already engaged in this effort.

"The greatest barrier to hardwood management appears to be the opportunity cost of the money required to finance forestry activities if that money were invested in other, higher yielding endeavors which is associated with the time value of money." [26]



TRACKING AMERICAN WHITE OAK - *Quercus alba L.*

Future Centuries

FUTURE CENTURIES

While the next 50 years are more defined in scope, the future centuries are yet to be determined. Much can be accomplished over the next half-century with motivated stakeholders to improve oak regeneration as forest management is increased and refined to the benefit of *Quercus alba* and other keystone species.

Predicting further out is a challenge because there are so many complex factors, and forests are always changing. However, there are several topics predicted to have long-term influence as we look ahead by century blocks of time: climate change, carbon sequestration, and development of technology.

CLIMATE CHANGE

Forests are predicted to experience change due to shifts in climate patterns. This is not a new issue when we consider the history of our world:

"America's forested lands will respond to climate change much as they responded to continental glaciation events over the last 2.5 million years—through contractions and expansions of their ranges. However, forests do not respond to environmental change as a whole. Instead, species (including pests) respond individually." [51]

It is therefore important to consider predictions focused by tree species. **Thankfully, oaks have had incredible success in distribution and longevity over many centuries, in part because they are adaptable.** [3] White oak's ability to be drought tolerant and other traits helping it to persist through disturbances will lend the species a competitive advantage in a number of places in the future.

> *"**Those species projected most favorably under these analyses include white oak,** black oak, mockernut hickory, chestnut oak, post oak, northern red oak, and, gauging for the future, southern red oak; **each of these species scored as viable species capable of coping with the hotter and physiologically drier future climate.**"* [26]

Models for what may happen to forests as a result of climate change do exist, showing updates for forests as a whole and predictions by tree species.

- The "Conservation Gap Analysis of Native U.S. Oaks" published in 2019 by The Morton Arboretum and partners **listed *Quercus alba* in the lowest vulnerability class across all categories** evaluated, one of which included a climate change vulnerability study. [52] See Table 4.1.

Table 4.1 Excerpt of vulnerability study including *Quercus alba* [52]

Species name	Concern score	IUCN Red List	NatureServe	Potter *et al.*, 2017	2017 *ex situ* survey results	
		Threat category	Global conservation status ranking	Vulnerability class	Number of individuals in *ex situ*	Number of *ex situ* institutions
Quercus imbricaria	1	LC	G5	C	595	73
Quercus incana	1	LC	G5	B	126	22
Quercus laevis	1	LC	G5	B	80	14
Quercus lyrata	1	LC	G5	C	372	61
Quercus michauxii	1	LC	G5	D	295	61
Quercus mohriana	1	LC	G4		24	11
Quercus montana (prinus)	1	LC	G5	B	702	75
Quercus muehlenbergii	1	LC	G5	C	733	76
Quercus oblongifolia	1	LC	G5	D	31	13
Quercus pagoda	1	LC	G5	C	123	32
Quercus palustris	1	LC	G5	C	5758	97
Quercus polymorpha	1	LC	G5	B	120	28
Quercus prinoides	1	LC	G5	C	335	44
Quercus pungens	1	LC	GNR		54	17
Quercus shumardii	1	LC	G5	C	745	85
Quercus vacciniifolia	1	LC	G4G5		35	16
Quercus vaseyana	1	LC	G4G5		23	14
Quercus virginiana	1	LC	G5	D	420	60
Quercus agrifolia	0	LC	G5	E	1760	43
Quercus alba	0	LC	G5	E	3180	101
Quercus berberidifolia	0	LC	G5		246	20
Quercus buckleyi	0	LC	G5		73	26
Quercus chrysolepis	0	LC	G5	E	228	39
Quercus coccinea	0	LC	G5	E	976	88
Quercus falcata	0	LC	G5	E	489	56
Quercus fusiformis	0	LC	G5		61	19
Quercus gambelii	0	LC	G5	E	262	32
Quercus garryana	0	LC	G5	E	350	36
Quercus geminata	0	LC	G5		124	19
Quercus hemisphaerica	0	LC	G5		100	28
Quercus hypoleucoides	0	LC	G5	E	65	22
Quercus kelloggii	0	LC	G5	E	158	30
Quercus laurifolia	0	LC	G5	E	125	38
Quercus macrocarpa	0	LC	G5	E	2472	108
Quercus marilandica	0	LC	G5	E	208	56
Quercus minima	0	LC	G5	E	43	12
Quercus myrtifolia	0	LC	G5		56	17
Quercus nigra	0	LC	G5	E	211	57
Quercus phellos	0	LC	G5	E	743	81
Quercus rubra	0	LC	G5	E	4003	115
Quercus stellata	0	LC	G5	E	727	65
Quercus turbinella	0	LC	G5		214	34
Quercus velutina	0	LC	G5	E	1323	83
Quercus wislizeni	0	LC	G5	E	239	22

*Not included in final species of concern list because less than 10% of the species' distribution is within the U.S.

Explanation of metrics used for scoring

IUCN Red List	CR = 5 points, EN = 4 points, VU = 3 points, NT = 2 points, DD = 1 point, LC = 0 points
NatureServe	G1 = 5 points, G2 = 3 points, G3 = 2 points, G4 = 1 point, G5 = 0 points; if two ranks are given (e.g. G3G5) the score reflects the more severe threat level; other indicators (i.e., Q = Questionable Taxonomy, ? = Inexact Numeric Rank) are not taken into account for scoring
Potter *et al.*, 2017	A = high vulnerability, little adaptation or persistence potential (2 points), B = high vulnerabiliy, potential adaptation (1 point), C = high vulnerability, potential persistence (1 point), D = Potential high future vulnerability (1 point), E = Low current vulnerability (0 points); blank cells represent species that were not included in the study
***Ex situ* survey**	Number of individuals in *ex situ* collections ≤ 20 = 1 point; number of *ex situ* institutions ≤ 10 = 1 point; values outside these thresholds = 0 points

- **Climate change models predict *Quercus alba* to experience an expansion of its range, including moving northward.** [53]
    - In the Eastern region: USDA Forest Service's "Climate Change Atlas" has created models to estimate "suitable habitat" in the future for at least 125 tree species factoring in changes to the climate.

      Quercus alba is shown to have an expanded range, and it is given an adaptability score of 6.1, which is the highest category of adaptability:
      low (<3.4)
      medium (3.4-5.1)
      high (>5.1)

      A further explanation from the atlas, which is available to anyone online to explore:
      "The DISTRIB-II and the SHIFT models cannot take into account the multitude of biological and disturbance factors affecting species distribution (insect outbreaks, fire, etc). We therefore use a scoring system based on the available literature to account for these 'modification factors'. Our scoring system gauges the effect of 9 biological and 12 disturbance components in modifying the interpretations of the species response outcomes; combining these forms the basis of an Adaptability score. Higher relative biological and disturbance scores yield higher adaptability."

      The model includes maps of potential suitable future habitat with supporting analysis:
      *"White oak is widely distributed (28.6% of area, fourth behind red maple, black cherry, and American elm), dense, high IV, and abundant (fifth in FIAsum behind loblolly pine, red maple, sweetgum, and sugar maple) throughout much of the eastern US, with a medium reliable model predicting a small increase in suitable habitat, throughout most of the eastern US and up past the Canadian border (RCP 8.5), by century's end. However, the SHIFT model largely limits those northern locations from being naturally colonized within 100 years, though **a fairly large northward expansion has some possibility. While it is susceptible to some insects and diseases, it is tolerant of drought and rates a high adaptability rating. Thus, its overall rating for capability is very good, and SHIFT identifies it as a very good species for infilling as well."***

    - An updated model released in 2022 studied forest type (as opposed to specific species), focusing on "departure scores" that represent to what extent it is believed habitat suitability and climate pressure will shift the forests we see today. This is presented in Figure 4.1. It is a complex figure to understand, but nevertheless it is important that researchers continue to use a variety of data points to track and predict how tree species may respond in environments known to be changing.

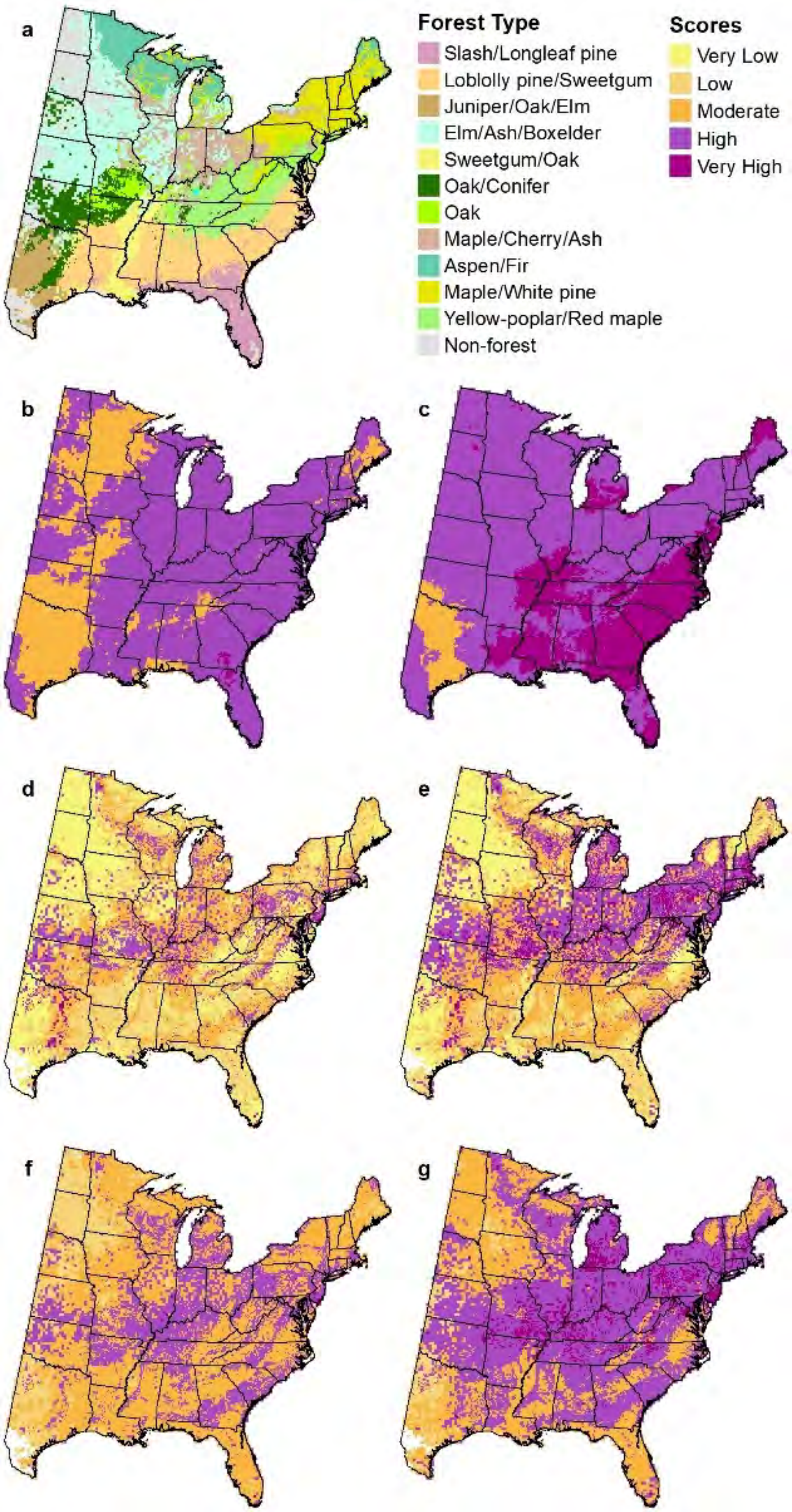


Figure 4.1
Maps of (a) forest types modeled by latent Dirichlet allocation under current (1981–2010) climate conditions, climate pressure scores under future (2070–2099) scenario (b) RCP 4.5 and (c) RCP 8.5, habitat suitability scores under (d) RCP 4.5 and (e) RCP 8.5, and the potential departure scores under (f) RCP 4.5 and (g) RCP 8.5 which combines the climate pressure and habitat suitability scores. [54]

- **Regionally, shifts for *Quercus alba* are shown to be both positive and negative according to the specific area, as a shift in habitat would bring about some long-term change.** Models that have been localized to states or sub-regions show an impact of *Quercus alba* increasing as a result in many areas, whether high or low climate change impact (ex: the Central Appalachians), and some potential decreases in some states (ex: Illinois). ***However, the overall analysis is Quercus alba will fare well.*** [55]

- Meanwhile, the 2020 RPA Assessment cites factors such as population and income trends influencing demand for forest products to be a stronger influencer in the near future than changes from climatic shifts. What will happen in the coming centuries? We don't know exactly, but ***there seems to be positive opportunity for white oak with the opportunity these climate shifts may provide.***

  "It is possible that some disturbances promoted by climate change may open the canopy sufficiently to enhance the probability of oak regeneration. *Additional research on this topic is needed."* [56]

- **"Assisted migration" is also being explored, which would involve planting and prioritizing white oak trees with genetics believed to help it be most successful in a localized (and changing) environment.** A study published in 2023 and carried out over 40 years evaluated the response of white oak trees sourced from different climatic conditions in the Eastern United States:

  "Climate adaptation appears to be closely tied to genetic adaptation to the local environment prior to anthropogenic climate change. These results are critical for understanding the impact of climate change on forest tree species. For forest managers and tree breeders, this study provides essential insights into selecting and managing white oak provenances. This knowledge is crucial for developing effective reforestation and tree improvement programs that can mitigate the adverse effects of climate change and ensure the sustainability of future white oak forest ecosystems." [57]

- **Management carrying into future centuries is recommended to look closely at vulnerabilities of key tree species to help adjust into the changing environments:**

  "Future climate change has the potential to significantly impact disturbance dynamics and species response of oak forests. Historical and dendrochronological records indicate a strong relationship between drought years and oak decline (Dwyer and others 1995, Jenkins and Pallardy 1995). As droughts are projected to increase in duration and aerial extent (Mishra and others 2010), oak decline could become an even larger problem for species in the red oak group across the Missouri Ozarks, especially for older trees on marginal sites. Oak decline could be exacerbated by other stressors: insect defoliation may increase with rising temperatures, and red oak species may already be stressed due to a decline in habitat suitability as projected by tree species models. As these species decline, ***new opportunities could open up for other species that are better adapted to projected climate, such as pine and white oak species (Brandt and others 2014). Utilizing ecosystem vulnerability information will be key to promoting resilient ecosystems into the future, with the ASCC study potentially informing climate-adaptive management decisions."*** [26]

A research paper released in January 2024 has identified **key traits likely to be influential to white oak's adaptive response to climate change** [20]:

. Root growth and ability to source water at different soil depths
. Reproduction, including flowering, pollination, masting and seed germination
. Seedling growth control, including seedling size and genetic potential
. Impact/shifts in native and non-native pests and pathogens. A particular focus on oak wilt and oak decline are likely to be most focused on since they currently represent the most important negative influence.

- **White oak also could be a beneficial tree species to prioritize during any efforts to decrease forest density** and thus better position forests to navigate continued climate shifts, as white oak is considered both drought tolerant and resilient:

"…restoration of lower density forests composed of drought-tolerant tree species should translate to management for changing climate." [58]

CARBON SEQUESTRATION

Another complex topic of relevance today and for future centuries relates to the much-discussed topic of carbon. Current efforts to reduce carbon emissions utilize the forest to offset these emissions as trees effectively store carbon. However, it is of note that trees and forests store carbon as they are growing and renewing (not as they are degrading), and also in the form of long-lasting hardwood products. More constructive discussion is needed to evolve the conversation beyond a "leave it forever" strategy to a long-term look at the role of healthy, growing forest that includes renewal and harvesting.

- **In a growing state, oak forests are highly capable of storing carbon:**

"One acre of healthy oak woodland takes two tons of carbon from the atmosphere each year." [7]

Oaks help us with this effort by storing carbon as biomass. It is estimated that half the dry weight of the bole (trunk) of an oak tree is carbon. [59] This has a very beneficial effect:

"Forests sequester more carbon from the atmosphere than they require for their own growth and respiration, so forests are carbon sinks (accumulators of carbon)...Nationally, growth of forests plus the accumulation of harvested wood products annually sequester and store the equivalent of 14 percent of total U.S. CO2 emissions." [59]

However, there is a cycle to forest carbon that still includes release, typically through decaying trees, tree mortality and fire. The last option (fire) can be used to manage forests effectively, especially when used in a mild to intermediate level (as opposed to severe fire). The key in any ecosystem is balance and may often be referred to as carbon stewardship.

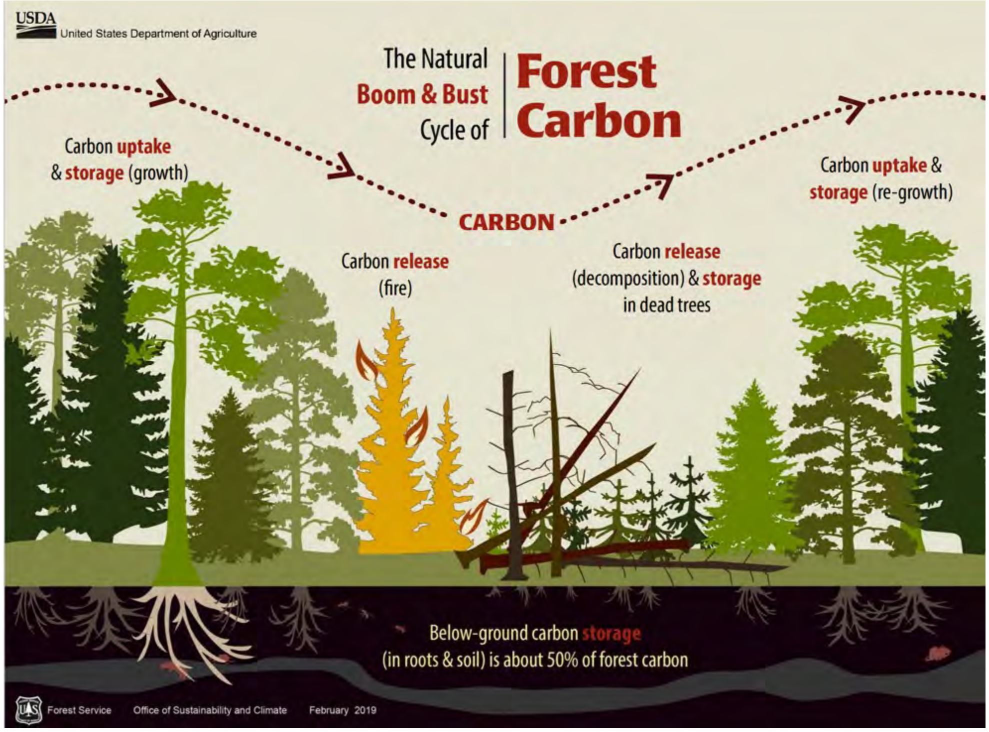


Figure 4.2 Forest carbon cycle. Many people do not realize an estimated 50% of forest carbon is stored below ground. [60]

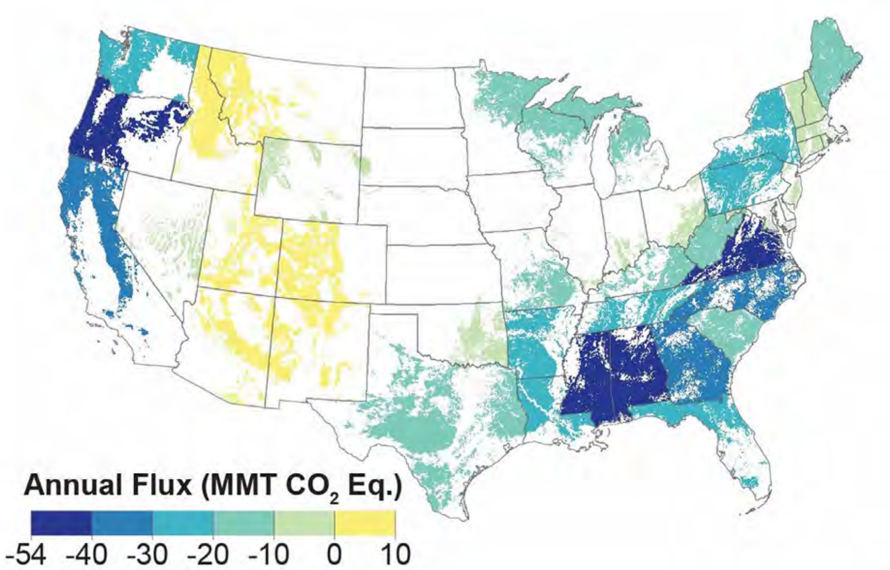


Figure 4.3 Estimated greenhouse gas emissions and carbon removals (i.e. sequestration) on forest land by U.S. state in 2018. Negative estimates indicate carbon sequestration to forests from the atmosphere. MMT CO_2 Eq. = million metric tons of carbon dioxide equivalent. [61]

- **Harvesting does not need to be a 'threat' to carbon sequestration thanks to how long hardwood products can be used:**

"Timber harvesting removes carbon from forest land, but much of that carbon is stored in long-lived HWPs (hardwood products)." [5]

In fact, the USDA Forest Service reported that forest ecosystems in the United States contained just under 60 gigatonnes of carbon in 2019, with 95% stored in the "forest ecosystem pool" (includes biomass above ground and storage in the soils) and the remainder as harvested wood products. [62]

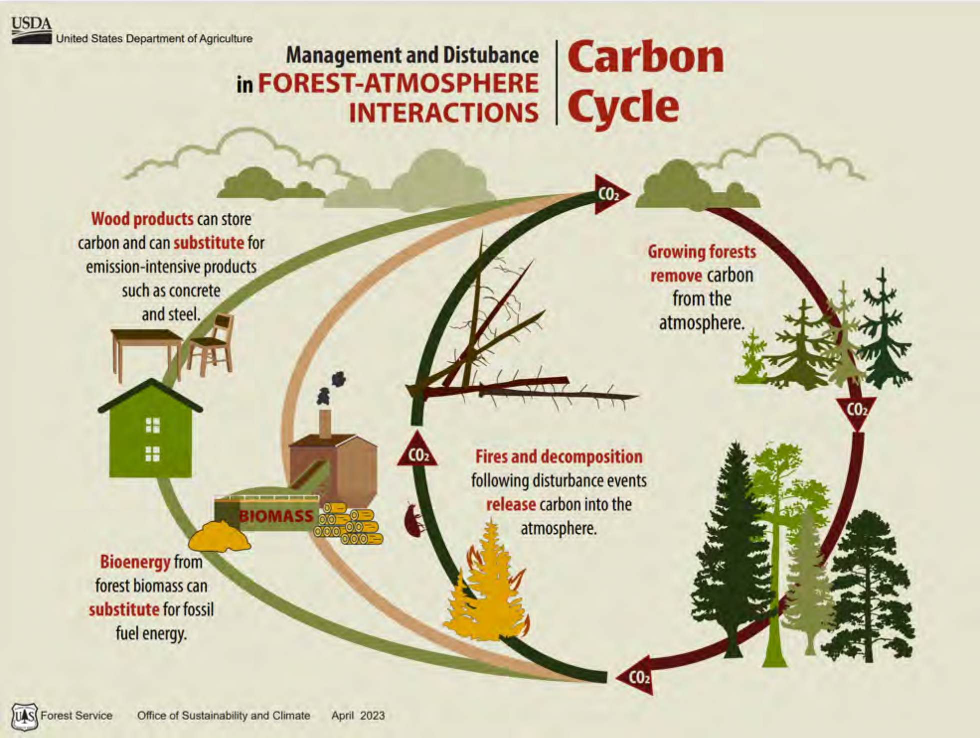


Figure 4.4 A simple overview of the carbon cycle.
Note: carbon management for climate mitigation is a complex topic, and further research is needed to better understand how to make long-term management decisions. [60]

Managing forests to mitigate increasing density is also relevant to carbon sequestration:
"In many forests, stocking levels have been increasing to a point that compromises forest health, and biomass removal (such as through mechanical thinning and/or prescribed burning) may be required to restore forest health and promote stable to increasing carbon sequestration rates (see Criterion 2)." [61]

- **In the United States, the combination of forests, wood products and urban trees are estimated to offset annual carbon emissions by roughly 10–15%.** There are varying models and estimates for how long into the future our forests will offset emissions as "carbon sinks." It's a complex area, and there is need for a comprehensive, long-term life cycle analysis of carbon in different ecosystems and under different types of management to keep evolving the conversation further.
- **Continuing to protect the forest and invest in its renewal, which includes regeneration, harvesting, and protecting a diverse mix of species, will help the forest continue to be an important factor in carbon sequestration.**

"Forest health and conditions, management practices, disturbances such as fire, and wood harvesting and use all influence how much carbon is stored and released from forests over time (referred to as "carbon flux"). Tracking these dynamic processes over vast landscapes is crucially important for understanding and harnessing the power of forests to curb our greenhouse gas footprint." [62]

This includes:

- **Protecting forest to remain forest.**
- **Protecting tree diversity, which is considered crucial to long-term sustainability.** When forests become more homogenous in structure, they are increasingly at risk to catastrophic mortality (from drought, wildlife, insects and disease). **This is an incentive across many interest groups to continue protecting the oak component of forests for the future.**

TECHNOLOGY

A sometimes-overlooked factor that will influence decisions into coming centuries is the use of technology, which has absolutely transformed forest management relatively recently, especially if we think in terms of the very long history of our forests. Technology has revolutionized what is possible in the world of forestry and will undoubtedly continue to do so. This is a quick recap of what has happened and possibilities we are seeing for the future:

- **DNA:** Mendelian genetics rediscovered in the 1900s, and further work to understand DNA eventually led to the birth of "forest genetics," which by the 1950s became a key strategy. For a long time, the focus of forest geneticists centered on tree improvement—using the genetics to benefit the health and productivity of commercially-relevant tree species. Over time the focus shifted to include ecosystem management, and today also includes a strong focus on how to protect trees from pests and diseases, including foreign pests that arrive in the USA due to increased shipping and global exchange. [63]

  Genome sequencing and creation of oak genetic maps are continuing to be researched, and have been most explored for the oak species *Quercus robur* and *Quercus petraea*. Opportunity exists to expand to more species and create a central repository to foster synergy between research teams.

  For white oak:

  "*To address the paucity of genomics research in Q. alba, recent private/public partnerships (White Oak Genomics Working group, UKY; White Oak Genetics Improvement Initiative, UKY) are focusing on building Q. alba genetics/genomics research infrastructure, integrated with a Q. alba breeding and improvement program. This group has recently completed a high-quality, haplotype resolved genome sequence for Q. alba that will underpin much of the future white oak genetics/genomics and tree improvement research (Staton personal communication).*" [20]

- **Computers & Internet:** analyzing and sharing data has become much more efficient and widespread in our modern age. Further investment in computer programs and apps that can support forest research will be a benefit moving forward, not only for research but also education.

- **Drone sensing & robots:** capturing data sets will still be carried out involving the human eye. However drones are already benefiting foresters and researchers to capture data above and below canopy more efficiently and through larger tracts of land, increasing the quantity and even accuracy of information available. Use of drones and new robotic technologies developed will likely be critically important, regardless if resources for human effort are increased over time, to best support research needs. AI is also being utilized as part of this effort. "Digital Forestry" using a synergy of technologies will be an increasing trend in the future.

- **Engineering:** designing and building equipment has been transformative to increasing efficiency when milling wood. While it is hard to see how this can be further optimized moving forward, it's clear future centuries will bring about new opportunities we cannot yet see as we all seek to increase the sustainability of our collective natural resources.

CONCLUSION

The length of this report is a reflection of the complexity of the topic. Thankfully, it is clear *Quercus alba* is an incredibly resilient tree with many stakeholders dedicated to its continued success. There is a building movement to increase effective management across more oak forests to boost successful recruitment of oaks into the canopy, and also to help consumers see the value of the resource that may be growing in their backyard. It is extremely positive that oak is continuing to regenerate throughout the United States and likely stands to gain habitat moving forward with forecasted shifts in the climate. Continued research is vital, including tracking ongoing trends, as is partnering closely with the many private landowners who, given representing such a high percentage of forest land ownership, are key stewards of our white oak. **This North American tree is iconic: from the wildlife it supports to aging America's bourbons and whiskeys, it's a valuable resource we should all aim to do our part to protect.**

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[28] Graphs courtesy of Jeffrey Lewis, former USDA Forest Service & current employee of Independent Stave Company, from data collected in 2023.

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