Forest Ecology and Management 424 (2018) 355–366

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Spatial modeling and inventories for prioritizing investment into oak-hickory restoration

Louis R. Iverson[a,*], Matthew P. Peters[a], Jarel L. Bartig[b], Joanne Rebbeck[a], Todd F. Hutchinson[a], Stephen N. Matthews[a,c], Susan Stout[d]

[a] *USDA Forest Service, Northern Research Station, 359 Main Road, Delaware, OH 43066 USA*
[b] *USDA Forest Service, Wayne National Forest, 13700 U.S. Highway 33, Nelsonville, OH 45764 USA*
[c] *The Ohio State University, School of Environment and Natural Resources, 2021 Coffey Road, Columbus, OH 43210 USA*
[d] *USDA Forest Service, Northern Research Station, 335 National Forge Road, Irvine, PA 16329 USA*

ARTICLE INFO

Keywords:
Ecological classification and mapping
Oak-hickory forests
Moisture modeling
Prescribed fire
Silviculture
Maple
Zones of investment

ABSTRACT

Oak (*Quercus* spp.) and hickory (*Carya* spp.) forests in the eastern United States provide a host of ecosystem services as their mast are prized by wildlife, the timber is a valued commodity, and they are generally more tolerant of extreme weather events under a changing climate. They are, however, undergoing a severe decline in prominence throughout the region, yielding to more mesic and shade-tolerant species, largely red maple (*Acer rubrum*). Two decades of research in Ohio have shown that silviculture and/or natural disturbances that reduce understory shade during seedling establishment and early growth, followed by canopy opening and competition management through prescribed fire and partial cutting, can encourage oak and hickory regeneration, most successfully on drier ridges and south- and southwest-facing slopes. We employed an ecological classification and mapping approach to prioritize areas across a 17-county region (~22,000 km^2) that may be more receptive, and thus more cost effective, to successful oak regeneration following silvicultural treatment. The ecomapping effort was comprised of two parts; a GIS model of the terrain, and a stand inventory of current vegetation condition coupled with the SILVAH decision-support system to recommend needed silvicultural treatments. The GIS model is based primarily on topography as vegetation patterns in the project area are largely driven by landscape position and soil moisture regimes. It uses transformed aspect, slope angle, topographic position index, and slope position as inputs to define six classes of landtype phases: ridge, southwest upper slopes, southwest lower slopes, northeast upper slopes, northeast lower slopes, and bottomland. The first three and following two classes, respectively, were hierarchically nested to form Dry Oak Forest and Dry-mesic Mixed Oak Hardwood Forest classes at the landtype level. Dry Oak Forests require the least silvicultural intervention to sustain or restore oak, while the other two landtypes normally require serious intervention to sustain oak into the future. To determine whether sufficient stocking is present for adequate regeneration, we use forest inventory data to represent current vegetation conditions including both overstory and understory stocking. Overall, these tools allow managers to identify 'zones of investment', i.e., those stands with the bulk of the area in the Dry Oak Forest landtype and with some level of advance oak regeneration, which will have a greater likelihood of growing into oak-dominated stands with minimal investment of scarce funding resources.

1. Introduction

1.1. Background

Oaks (genus *Quercus* L.) of eastern North America are a foundational species in our forests (Hanberry and Nowacki, 2016). Forests dominated by oaks are important ecosystems for many faunal assemblages, from birds and small mammals, to species such as white-tailed deer (*Odocoileus virginianus*) and black bear (*Ursus americanus*) (McShea and Healy, 2002; Dey et al., 2010). The importance of oaks goes much beyond acorn production, as numerous organisms directly or indirectly use other live and dead materials of the tree. For example, birds have been found to be more abundant and diverse in oak-dominated stands than in maple-dominated stands, most likely as a result of the presence of mast and differences in the arthropod prey, growth form, and leaf architecture that facilitates the way in which birds perceive, maneuver,

---

[*] Corresponding author.
E-mail address: liverson@fs.fed.us (L.R. Iverson).

https://doi.org/10.1016/j.foreco.2018.05.018
Received 22 February 2018; Received in revised form 7 May 2018; Accepted 8 May 2018

0378-1127/ Published by Elsevier B.V.

and obtain food in forest habitats (Rodewald and Abrams, 2002; Wood et al., 2012). Tallamy and Shropshire (2009) found that oaks supported the greatest Lepidopteran richness (more than 500 species in the mid-Atlantic region of USA), an important food source for birds (Robinson and Holmes, 1982). Oak litter decays slowly and may provide more cover and increased prey availability, which is important for ground-foraging species (Fox et al., 2010) such as birds and amphibians. Oaks also provide vital economic resources via the timber industry, and is the species most removed from eastern US forests. For example in one typical hardwood state, Ohio's timber industry creates thousands of jobs, and in 2012 contributed $287 million in products (Coronado et al., 2014), with much of the value coming from oak-hickory forests (Coronado et al., 2014; Duval et al., 2014).

Because oak-hickory forests have been shown to be ecologically and economically important, the "oak regeneration problem" is one of the most important issues in the Eastern Deciduous Forest (Sutherland and Hutchinson, 2003; Johnson et al., 2009; Dey, 2014). Failure of oaks to regenerate after a canopy disturbance is primarily caused by a lack of larger and thus more competitive oak seedlings and saplings relative to other species in the understory, or failure to provide timely release of competitive seedlings when they exist (Loftis, 2004). This condition of oak (and hickory) being overstory dominants but poorly represented in the understory is evident in current Forest Inventory and Analysis (FIA) plot data for a 17-county region in southeastern Ohio (Fig. 1). Currently oak-hickory comprises 33.6% of stems > 15" DBH, but only 7.5% of stems 1' tall to < 3" DBH, the latter a classic signature of the sapling bottleneck incurred by oak in shaded conditions (Nowacki and Abrams, 2008). Under competition for light, many small saplings and especially seedlings < 1' tall linger and eventually die. Further, FIA data for Ohio between 1968 and 2011 show a decline of the oak proportion of the timber resource from 38 to 22 percent (Widmann et al., 2014). Maples and other shade-tolerant species currently dominate the smaller size classes (Fig. 1), and are increasing at a rate that is nearly four times their harvest rate, while white oak (*Quercus alba*) is being harvested at a rate exceeding growth (Widmann et al. 2014).

Silvicultural interventions are often needed to increase the competitiveness of existing oak seedlings, or create conditions in which new seedlings can establish strong root systems without being overwhelmed by aboveground growth of competitors (Brose et al., 1999). There is now a robust body of research that identifies effective silvicultural treatments to increase the probability of successful oak regeneration. Two decades of research in Ohio have shown that silviculture treatments that reduce understory shade during seedling establishment and early growth, followed by canopy opening and competition management through prescribed fire and partial cutting, can encourage oak and hickory regeneration, most successfully on drier ridges and south- and southwest-facing slopes (Iverson et al., 1997, 2008, 2017a; Hutchinson et al., 2005b, 2012). Prescribed fire, partial harvesting, 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 et al., 2008; Johnson et al., 2009; Iverson et al., 2017a). When appropriate conditions are met (e.g., drier positions with advance oak regeneration), these 'zones of investment' for prioritizing silvicultural treatments have been shown to increase the regeneration capacity for oaks. In contrast, areas not meeting criteria for the 'zones of investment' (e.g., mesic sites with little or no oak advance regeneration) are ill suited for silvicultural treatments aimed at oak regeneration based on limited available resources.

Meanwhile, prospects for oak regeneration may be changing as the climate warms (Wuebbles et al., 2017), and fire and drought frequency and intensity increase (Clark et al., 2016; Wehner et al., 2017). The climate is changing in a way that could be more favorable for oak-hickory forests and less so for mesic species, and therefore it is important to maintain oak-hickory stands to take advantage of those changes when they come. Even though many of the climate models show an increase in precipitation over the next decades in the eastern US, the additional precipitation trends so far, and expected in the future, are primarily expressed through more intense events and more concentrated in later winter and spring (Wuebbles et al., 2017). Simultaneously, the dramatic increase in heat (see Heat Index, Matthews et al., 2018), with its influence on the monthly Palmer Drought Severity Index (PDSI), creates a very large increase in the Cumulative Drought Severity Index (CDSI, based on 30 years of monthly PDSI) by century's end, especially under a scenario of continued high emissions (see CDSI, Matthews et al., 2018). For example, much of Ohio could have 80–100 *additional* days of maximum temperature exceeding 30 °C by 2100 under the high emissions scenario. These conditions would substantially increase the frequency and intensity of droughts according to

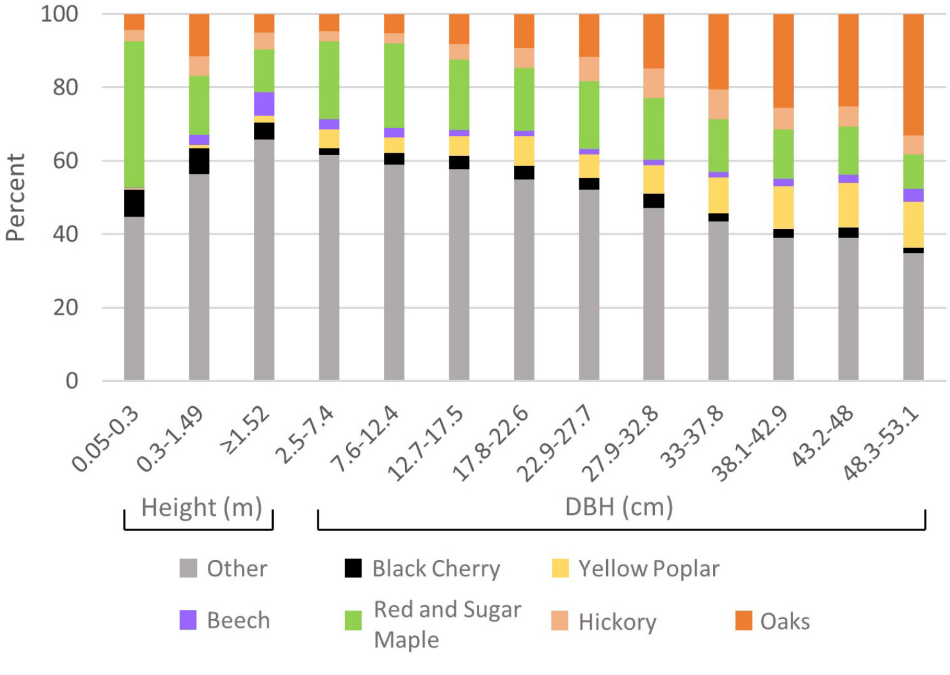

Fig. 1. Species prominence by size class.. Percent of total number of seedlings, live saplings, and dominant/codominant growing-stock trees (adults) for select taxa in the 17-county region of southeast Ohio, 2007–2016. The first three bars represent heights and remaining bars are dbh in cm. Seedling estimates are based on forested Phase 2-plus sample plots for 2012–2016. Sapling and tree estimates are based on forested Phase 2 plots for 2007–2011. Select taxa are those with the most above-ground biomass for all trees. Sampling errors are high because of relatively small numbers of samples. Besides oaks (*Quercus* spp.), yellow poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), red maple (*Acer rubrum*), sugar maple (*A. saccharum*), beech (*Fagus americana*), and hickory (*Carya* spp.), and 'other' species are graphed. The 'other' class is made up of 63 species including, in decreasing importance of basal area: white ash (*Fraxinus americana*), American elm (*Ulmus americana*), sassafras (*Sassafras albidum*), bigtooth aspen (*Populus grandidentata*), eastern white pine (*Pinus strobus*), Virginia pine (*P. virginiana*), American sycamore (*Platanus occidentalis*), black locust (*Robinia pseudoacacia*), slippery elm (*U. rubra*), and black walnut (*Juglans nigra*). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)