CHAPTER 3

Do Forest Health Issues in Eastern Upland Oak Forests Affect Oak Regeneration and Recruitment?

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INTRODUCTION

Oaks (*Quercus* spp.) are an important genus in the Eastern United States, comprising 11 percent of all living trees and 16 percent of all standing dead trees, and occurring on over 187 million acres (Miles 2017). Prominent upland oak species in these communities may include white oak (*Q. alba*), northern red oak (*Q. rubra*), chestnut oak (*Q. prinus*), black oak (*Q. velutina*), post oak (*Q. stellata*), scarlet oak (*Q. coccinea*), bur oak (*Q. macrocarpa*), southern red oak (*Q. falcata*), chinquapin oak (*Q. muehlenbergii*), northern pin oak (*Q. ellipsoidalis*), and blackjack oak (*Q. marilandica*), among others. Maintaining species composition when regenerating upland oak forests is often difficult, potentially requiring decades of active forest management planning (Dey 2014, Johnson and others 2019, Loftis and McGee 1993). This is because upland oaks, in particular, are strongly reliant on competitive advance reproduction to regenerate, which is often scarce, and their recruitment into dominant canopy positions following canopy disturbance is usually commensurate with the abundance of competitive advance reproduction (Brose and others 2008, Sander 1971). Recent broad-scale studies have documented a lack of "regeneration-ready" mature oak stands in the Eastern United States, evidenced by a lack of sufficient advance reproduction (McEwan and others 2011, Miller and McGill 2019, Vickers and others 2019a). The transition of oak forests to non-oak species is a widespread concern that appears to be driven, at least in part, by disturbance regimes that do not favor oak regeneration and recruitment (Fei and others 2011, Larsen and Johnson 1998, McEwan and others 2011).

Recent studies have documented that mortality associated with forest pest invasions can lead to considerable loss of mature trees and reduced stand occupancy (Fei and others 2019). Throughout much of the Eastern United States, oak forest is relatively old, with at least 70 percent of the acreage approaching stages when regeneration considerations arise (Miles 2017, Shifley and others 2014). Untimely canopy mortality brought on by forest health issues may exacerbate regeneration difficulties and probably accelerates composition shifts (Appel 1995, Gottschalk 1993, Heitzman and others 2007). Recognizing that understory dynamics influence future forest composition, health, and sustainability, this project aimed to evaluate the influence of disturbance-induced oak canopy reductions on understory demographics in upland oak forests across the Eastern United States.

This study was an Evaluation Monitoring project funded under the U.S. Department of Agriculture (USDA), Forest Service, Forest Health Monitoring Program with an overarching goal to yield a better understanding of regeneration dynamics during disturbance-induced canopy reductions and help triage oak forests for regeneration risks. It proposed to examine seedling and sapling dynamics through time at broad spatial scales to examine whether forest health issues in eastern upland oak forests affect oak regeneration and recruitment by addressing two specific questions:

How to cite this chapter:

Vickers, Lance A.; Knapp, Benjamin O.; Dey, Daniel C.; Knapp, Lauren S.P. 2025. Do forest health issues in eastern upland oak forests affect oak regeneration and recruitment. In: Conkling, B.L.; Pandit, K., eds. Forest Health Monitoring: Evaluation Monitoring project summaries 2023. Gen. Tech. Rep. WO-105a. Washington, DC: U.S. Department of Agriculture, Forest Service. 17–24. Chapter 3. https://doi.org/10.2737/WO-GTR-105a-Chap3.

(1) Do forest health disturbances affect upland oak regeneration density (seedlings and saplings)?

(2) Do forest health disturbances affect upland oak sapling recruitment (sapling ingrowth)?

METHODS

Data Source

This project relied on data collected as part of the Forest Service's Forest Inventory and Analysis Program (FIA; https://www.fia.fs.usda.gov/). FIA collects data on permanent sample plots at known locations that are systematically distributed across all forested lands around the country such that each sample plot generally represents about 6,000 acres, though certain areas such as national forests are sampled with higher intensity. At each FIA sample location, one or more conditions—which include information on land/water, forest/nonforest, reserved/not reserved, stand type, ownership, and accessibility—are recorded. The tree data collected for all trees with diameter at breast height (d.b.h.) ≥5.0 inches include species, mapped location on the plot, d.b.h., status as live or dead, whether a dead stem is to be counted as a harvest removal or other mortality, the likely cause of death, and several other attributes on a cluster of nested subplots at each sample location (Bechtold and Patterson 2005). For saplings (d.b.h. = 1.0–4.9 inches), species, d.b.h., and location are consistently collected for live stems only (the fates of dead or harvested stems of this size are not tracked). Seedlings (d.b.h. <1.0 inch and height ≥6.0 inches for softwoods or ≥12.0 inches for hardwoods) are simply tallied by species. In addition to various tree-centric measures, inventories record several site attributes such as ownership group, forest type, stand size/maturity, visible signs of disturbances including forest health and harvesting operations, and more ancillary site attributes to help describe the condition (Burrill and others 2018).

Data Filtering

FIA has a long history of data collection and is administered at the State level. Around 2000, FIA adopted a nationalized and annualized inventory protocol in every State in which the inventory was continuous, i.e., a fixed percentage of inventory plots is measured every year in every State such that plots are remeasured every 5–7 years and, after the initial cycle, statewide inventories are updated yearly as the oldest data are replaced by the remeasured data. At the time of data acquisition, complete inventories were available from ca. 2000 through 2018 across the Eastern U.S. study region (forest land portions of 37 States east of 100° W longitude). Analyses were limited to inventories that included a complete seedling count, which was not consistent across the Eastern United States before ca. 2005; thus, the actual timeframe of these analyses within the approximate 2000–2018 temporal window varies slightly by State within the study region. Within this timeframe, this study collated the first three inventories (t1–3) with full seedling counts for each plot location. Any plot locations without at least three consecutive inventories recorded were discarded.

Locations with mature, upland oak characteristics that did not show signs of recent disturbance during the first of the three consecutive inventories (hereafter, t1) were identified. Mature characteristics included the following plot-level characteristics: a preponderance of large or medium tree diameters (STDSZCD = 1 or 2), an average (quadratic) tree diameter ≥7 inches, and a recorded stand age ≥50 years old (STDAGE). Upland oak characteristics included plots that had at least 10 percent of living plot-level stocking (sensu Gingrich 1967) comprising upland oak species (as defined in Introduction) but were not located on hydric sites or floodplains/bottomlands (PHYSCLCD = 11–23, 29). Evidence of recent disturbance included: disturbances or treatments recorded (DSTRBCD1 >0 or TRTCD1 >0), artificial regeneration recorded (STDORGCD = 1), canopy stocking <60 percent, and a standing-dead basal area more than one standard deviation greater than the average across all mature upland oak plots in the study region.

The second of these consecutive inventories (hereafter, t2) categorized the previously undisturbed, mature upland oak plot locations based on which tree-level cause of death (AGENTCD), if any, affected the most basal area since t1 (the previous measurement, ≈5–7 years earlier). Analyses were limited to plot locations that fell into one of the following four disturbance categories: insect, disease, harvesting, or undisturbed. Plot locations that experienced multiple types of disturbance were discarded. A total of 3,302 plot locations within the data available for the period of interest met all the t1 criteria above, of which 97 were categorized as insect disturbances at t2, 335 were categorized as diseased, 326 were categorized as harvested, and 549 were categorized as undisturbed. This same dataset was used to address the two research questions stated above. Data were retrieved via the rFIA package for R statistical software (Stanke and others 2020), and all analyses were conducted with R statistical software (R Core Team 2020).

Data Analyses

The data selection process described above enabled a "natural experiment" approach in analyzing this observational data where all plot locations began the series as undisturbed mature upland oak forests (t1), encountered one of the disturbance types by the second inventory (t2), and were examined for their responses to those disturbances at the third inventory (t3). Because of variation in State-level sampling schedules, the time since disturbance can range from 5–14 years or be ongoing in the case of a single disturbance type that continued from t2 to t3.

To address the first question (Do forest health disturbances affect upland oak regeneration density?), a negative binomial generalized linear model compared the combined density of upland oak seedlings and saplings at t3 between all disturbance categories with the harvesting and undisturbed categories serving as disturbed and undisturbed "controls," respectively. To address the second question (Do forest health disturbances affect upland oak sapling recruitment?), a negative binomial generalized linear model compared the combined density of post-disturbance sapling ingrowth (t2 + t3) between all disturbance categories with the harvesting and undisturbed categories serving as disturbed and undisturbed "controls," respectively.

RESULTS

This study found little evidence of direct effects from forest health disturbances on upland oak regeneration and recruitment. On average, more upland oak seedlings and saplings regenerated following harvesting than other types of disturbance ($p = 0.0043$), while the densities of upland oak regeneration following insect, disease, and undisturbed categories were statistically indistinguishable (fig. 3.1A). No statistical differences ($p = 0.6917$) were found in new sapling ingrowth following any of the disturbance types examined (fig. 3.1B). Upland oaks (fig. 3.1A) comprised 10–15 percent of all combined seedlings and saplings across species regardless of disturbance category, while upland oak sapling ingrowth (fig. 3.1B) comprised 5–10 percent of sapling ingrowth.

DISCUSSION

Forest health issues often create a canopy disturbance that releases understory trees. In oak stands where oaks are absent or sparse in the understory, untimely disturbance or canopy disruption may initiate composition shifts by releasing non-oaks. Many times, focused silviculture based on timely release of existing advance reproduction is advocated to improve this condition (Brose and others 2008, Johnson and others 2019, Loftis 2004). Broad-scale studies have highlighted potential oak regeneration problems given current understory conditions across vast acreages (Miller and McGill 2019, Vickers and others 2019a), but this landscape-scale concern is not regarded as a conventional forest health issue. Collectively, the results of these analyses suggest that forest health-related disturbances, in broad terms, resulted in about as many new upland oak saplings several years following disturbance as did harvesting or no disturbance. However, the 15–25 new upland oak saplings per acre that developed in this study, regardless of disturbance category (fig. 3.1B), fall short of even the lowest estimates of sapling recruitment required to plausibly avoid composition shifts in upland oak forests (86–130 per acre; Vickers and others 2019b, 2019b) as well as the 60–70 saplings per acre estimated as necessary to simply maintain the economic viability of the oak component in such stands (Brose and others 2008, Miller and others 2007, Ward 2009). Moreover, the 5–10-percent average upland oak component of sapling ingrowth by t3 regardless of disturbance category represents a considerable regeneration debt (sensu Miller and McGill 2019) compared to the nearly 50-percent average upland oak component in the upper canopy of these plots at maturity prior to disturbance (t1). Thus, forest health disturbances appear to be forcing an untimely initiation of the regeneration process in stands that are not poised for successful oak regeneration. This, in turn, accelerates the widespread phenomena of composition shifts in oak stands, not by negatively impacting oak seedling and sapling

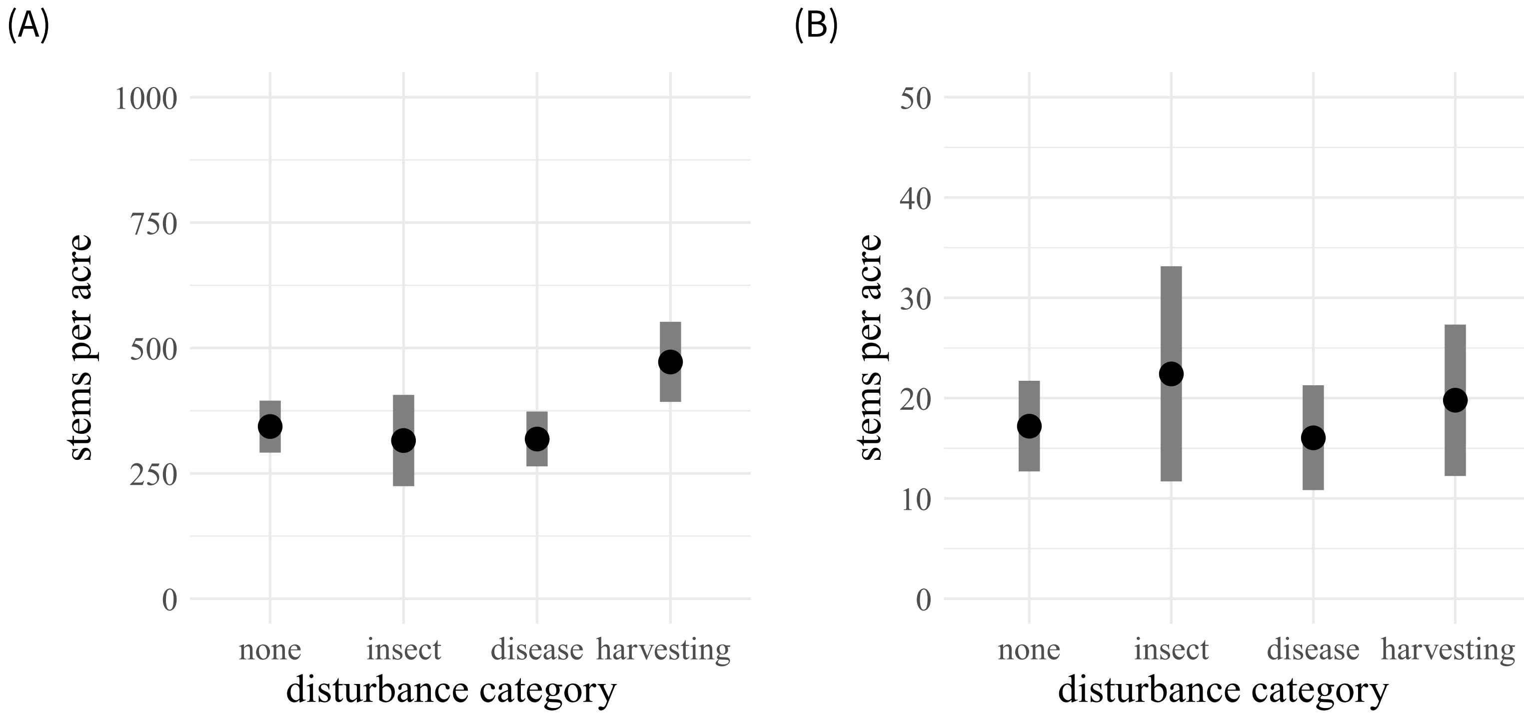

Figure 3.1 —Density of post-disturbance upland oak seedling and sapling regeneration (A) and upland oak sapling ingrowth (B) by disturbance category across 37 Eastern U.S. States. Points depict average values and error bars depict 95-percent confidence intervals.

populations more so than any other kind of disturbance examined in this study, but instead by releasing competing species in the understory in stands without adequate upland oak advance reproduction.

One weakness of this study is that it could only examine forest health issues as detected by new tree deaths recorded in the inventory record. There are likely instances where canopy trees do not exhibit widespread mortality but nonetheless are experiencing forest health-related disturbances that alter canopy health, which subsequently influences understory populations either directly or indirectly through altered light levels and other ways. While FIA does record certain aspects of tree and canopy health on a subset of plots (Schomaker and others 2007), the sample sizes are relatively sparse (Randolph and others 2010) and the attributes collected and protocols used have changed through time (Burrill and others 2017, Woudenberg and others 2010), which may complicate potential inferences that may be attainable from such data. Future research directions would ideally include longer data timeframes and better attribution of disturbance including specific types of pests. This will become increasingly possible as the latest FIA protocols are implemented and plots are remeasured (Burrill and others 2017). The potential incorporation of data from USDA Animal and Plant Health Inspection Service (APHIS) and possibly other datasets that document the range, prevalence, and occurrence of various pest outbreaks, often at the county level, is another potential research avenue to explore.

ACKNOWLEDGMENTS

This project falls under task agreement 18-JV-11242311-084 within master joint venture agreement 18-JV-11242311-093. The study authors appreciate the U.S. Department of Agriculture, Forest Service, Forest Health Monitoring Program for funding this work and Dennis McDougall for helping initiate the project. They also appreciate the efforts of the Forest Service's Forest Inventory and Analysis (FIA) Program in collecting and curating the data analyzed here.

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LITERATURE CITED

Appel, D.N. 1995. The oak wilt enigma: perspectives from the Texas epidemic. Annual Review of Phytopathology. 33: 103–118. https://doi.org/10.1146/annurev.phyto.33.1.103.

Bechtold, W.A.; Patterson, P.L. 2005. The enhanced Forest Inventory and Analysis Program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 85 p. https://doi.org/10.2737/SRS-GTR-80.

Brose, O.H.; Gottschalk, K.W.; Horsely, S.B. [and others]. 2008. Prescribing regeneration treatments for mixed-oak forests in the Mid-Atlantic region. Gen. Tech. Rep. NRS-33. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 100 p. https://doi.org/10.2737/NRS-GTR-33.

Burrill, E.A.; Wilson, A.M.; Turner, J.A. [and others]. 2017. The Forest Inventory and Analysis Database: database description and user guide version 7.2 for Phase 2. Washington, DC: U.S. Department of Agriculture, Forest Service. 946 p. https://usfs-public.box.com/v/FIA-FIADB-UserGuides. [Date accessed: Unknown].

Burrill, E.A.; Wilson, A.M.; Turner, J.A. [and others]. 2018. The Forest Inventory and Analysis Database: database description and user guide version 8.0 for Phase 2. Washington, DC: U.S. Department of Agriculture, Forest Service. 946 p. https://usfs-public.box.com/v/FIA-FIADB-UserGuides. [Date accessed: Unknown].

Dey, D.C. 2014. Sustaining oak forests in eastern North America: regeneration and recruitment, the pillars of sustainability. Forest Science. 60: 926–942. https://doi.org/10.5849/forsci.13-114.

Fei, S.; Kong, N.; Steiner, K.C. [and others]. 2011. Change in oak abundance in the eastern United States from 1980–2008. Forest Ecology and Management. 262: 1370–1377. https://doi.org/10.1016/j.foreco.2011.06.030.

Fei, S.; Morin, R.S.; Oswalt, C.M.; Liebhold, A.M. 2019. Biomass losses resulting from insect and disease invasions in US forests. Proceedings of the National Academy of Sciences. 116(35): 17371–17376. https://doi.org/10.1073/pnas.1820601116.

Gingrich, S.F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. Forest Science. 13: 38–52.

Gottschalk, K.W. 1993. Silvicultural guidelines for forest stands threatened by the gypsy moth. Gen. Tech. Rep. NE-171. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. https://doi.org/10.2737/NE-GTR-171.

Heitzman, E.; Grell, A.; Spetich, M.; Starkey, D. 2007. Changes in forest structure associated with oak decline in severely impacted areas of northern Arkansas. Southern Journal of Applied Forestry. 31: 17–22. https://doi.org/10.1093/sjaf/31.1.17.

Johnson, P.S.; Shifley, S.R.; Rogers, R. [and others]. 2019. The ecology and silviculture of oaks. 3d ed. Boston, MA: CABI. 612 p. https://doi.org/10.1079/9781780647081.0000.

Larsen, D.R.; Johnson, P. 1998. Linking the ecology of natural oak regeneration to silviculture. Forest and Ecology Management. 106(1): 1–7. https://doi.org/10.1016/S0378-1127(97)00233-8.

Loftis, D.L. 2004. Upland oak regeneration and management. In: Spetich, M.A., ed. Gen. Tech. Rep. SRS-73. Asheville, N.C: U.S. Department of Agriculture, Forest Service, Southern Research Station: 163–167. https://www.fs.usda.gov/research/treesearch/6532. [Date accessed: December 10, 2024].

Loftis, D.L.; McGee, C.E. 1993. Oak regeneration: serious problems, practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 319 p. https://doi.org/10.2737/SE-GTR-84.

McEwan, R.W.; Dyer, J.M.; Pederson, N. 2011. Multiple interacting ecosystem drivers: toward an encompassing hypothesis of oak forest dynamics across eastern North America. Ecography. 34: 244–256. https://doi.org/10.1111/j.1600-0587.2010.06390.x.

Miles, P.D. 2017. Forest Inventory EVALIDator web-application version 1.6.0.03. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northern Research Station. http://apps.fs.fed.us/Evalidator/evalidator.jsp. [Date accessed: Unknown].

Miller, G.W.; Stringer, J.W.; Mercker, D.C. 2007. Technical guide to crop tree release in hardwood forests. Publication PB1774. Knoxville, TN: University of Tennessee Cooperative Extension [published with the University of Kentucky Cooperative Extension and Southern Regional Extension Forestry]. 24 p.

Miller, K.M.; McGill, B.J. 2019. Compounding human stressors cause major regeneration debt in over half of eastern US forests. Journal of Applied Ecology. 56(6): 1355–1366. https://doi.org/10.1111/1365-2664.13375.

R Core Team. 2020. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/. [Date accessed: March 12, 2024].

Randolph, K.C.; Morin, R.S.; Steinman, J. 2010. Descriptive statistics of tree crown condition in the North Central United States. Gen. Tech. Rep. SRS-125. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 21 p. https://doi.org/10.2737/SRS-GTR-125.

Sander, I.L. 1971. Height growth of new oak sprouts depends on size of advance reproduction. Journal of Forestry. 69: 809–811.

Schomaker, M.E.; Zarnoch, S.J.; Bechtold, W.A. [and others]. 2007. Crown-condition classification: a guide to data collection and analysis. Gen. Tech. Rep. SRS-102. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 78 p. https://doi.org/10.2737/SRS-GTR-102.

Shifley, S.R.; Moser, W.K.; Nowak, D.J. [and others]. 2014. Five anthropogenic factors that will radically alter forest conditions and management needs in the Northern United States. Forest Science. 60(5): 914–925. https://doi.org/10.5849/forsci.13-153.

Shifley, S.R.; Moser, W.K.; Nowak, D.J. [and others]. 2019. Using a tree-seedling mortality budget as an indicator of landscape-scale forest regeneration security. Ecological Indicators. 96(1): 718–727. https://doi.org/10.1016/j.ecolind.2018.06.028.

Vickers, L.A.; McWilliams, W.H.; Knapp, B.O. [and others]. 2019a. Are current seedling demographics poised to regenerate northern US forests? Journal of Forestry. 117: 592–612. https://doi.org/10.1093/jofore/fvz046.

Vickers, L.A.; McWilliams, W.H.; Knapp, B.O. [and others]. 2019b. Using a tree-seedling mortality budget as an indicator of landscape-scale forest regeneration security. Ecological Indicators. 96(1): 718–727. https://doi.org/10.1016/j.ecolind.2018.06.028.

Ward, J.S. 2009. Intensity of precommercial crop tree release increases diameter growth and survival of upland oak. Canadian Journal of Forest Research. 39: 118–130. https://doi.org/10.1139/x08-165.

Woudenberg, S.W.; Conkling, B.L.; O'Connell, B.M. [and others]. 2010. The Forest Inventory and Analysis Database: database description and users manual version 4.0 for Phase 2. Gen. Tech. Rep. RMRS-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 336 p. https://doi.org/10.2737/RMRS-GTR-245.