Impacts of a Hickory Decline Event and Implications for Bitternut Hickory

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Abstract.—Between 2010 and 2016, rapid and extensive mortality of bitternut hickory (i.e., 35 percent year^{-1}) was observed within a long-term experimental site in Wisconsin. The purpose of this study was to document and quantify the mortality, investigate stem-density impacts on mortality, and assess remaining hickory regeneration. Similar mortality has been reported in the midwest and northeast United States, and a pathogenic fungus (*Ceratocystis smalleyi* Johnson and Harrington) and hickory bark beetle (*Scolytus quadrispinosus* Say) were identified as the causal agents, herein investigated via a post hoc analysis. Larger hickory stems (i.e., $\geq$20 cm d.b.h.) experienced higher mortality rates than smaller stems (i.e., 10 to <20 cm d.b.h.). Density (i.e., percent hickory), crown class, and diameter were statistically important in predicting hickory mortality. Maintaining this species is increasingly important, especially as other dominant species, such as ash, are also decreasing. Management actions such as selective thinning will be important in mitigating these rapid hickory declines.

INTRODUCTION

Bitternut hickory (*Carya cordiformis* [Wangenh.] K. Koch) is an important component of many hardwood forests, including sugar maple-basswood forests in northern Wisconsin. The range extends from Quebec to Minnesota, and south to Georgia and Texas. Periodic and severe mortality has occurred historically throughout its range, and more recently within the northeast and midwest United States. Mortality was attributed to the hickory bark beetle (*Scolytus quadrispinosus* Say) and an associated canker pathogen (*Ceratocystis smalleyi* J.A. Johnson and Harrington) (Park et al. 2010, 2013; Park and Juzwik 2014). Extensive mortality of bitternut hickory occurred between 2010 and 2016 within a long-term research site in the Flambeau River State Forest in northern Wisconsin. The objectives of this study were to (1) quantify and characterize the bitternut hickory tree mortality, (2) investigate impacts of stem density on mortality patterns, and (3) assess hickory-regeneration persistence. Post hoc sampling for the hickory bark beetle and *C. smalleyi* was conducted to support the hypothesis that hickory decline was the cause of the extensive mortality.

METHODS

Site Description

The long-term experimental study site is in a second-growth northern hardwood forest dominated by sugar maple, in the southern edge of the Flambeau River State Forest in northern Wisconsin. The "Flambeau Experiment" includes thirty-five 80 × 80 m (i.e., 0.64 ha) permanent plots to test

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seven treatment levels, with five replicates. Treatments are woody debris addition, gap creation, gap creation and woody debris addition, gap creation with deer exclusion, deer exclusion, mechanical disturbance from harvest equipment, and control (Forrester et al. 2013).

Stem Inventory

All trees (stems $\geq$10 cm diameter at breast height [d.b.h.]) in plots were tagged, identified, and mapped. D.b.h., crown class, and status (i.e., live or dead) were measured annually in fall from 2005 to 2010 and in 2016. Saplings (i.e., 0.5 to <10 cm, d.b.h. >1.4 m in height) were measured (i.e., height and d.b.h.) in subplots in 2005, 2010, 2013, and 2016. Woody understory plants were measured in 2010, 2013, and 2016. Species and counts were recorded by height class.

Statistical Analysis

Mortality rates were calculated for the trees in 5 cm diameter classes with the following equation (from Lorimer et al. 2001):

$$mortality = \left(1 - \left(\frac{N_t}{N_o}\right)^{\left(\frac{1}{t}\right)}\right) \cdot 100 \qquad (1)$$

Where

N_o = number of trees at first measurement,

N_t = number of surviving trees at next measurement, and

t = time between measurements.

An analysis of variance (ANOVA) with a Tukey's test was used to test for difference in mortality rates by diameter class. Hickory regeneration was assessed with an ANOVA followed by least squares means comparisons to test the significance of the interaction of year by height class.

Using geographic information systems (GIS), four circular areas (i.e., 4, 8, 11, 25 m radii) were delineated around each mapped hickory tree to estimate if density influenced mortality and at what scale. Stem density (percentage hickory) was calculated for each area. Logistic regression was used to model the likelihood of hickory stem mortality testing predictor variables including d.b.h., crown class (canopy or subcanopy), and percentage hickory. All statistical analyses were completed in Statistical Analysis System (SAS) statistical software (i.e., SAS version 9.0, SAS institute, Cary, NC), and significance was determined using an $\alpha \leq 0.05$.

Biotic Agent Identification

In July 2019, three actively dying hickory trees were felled, surveyed, and sampled for biotic agent confirmation. Wood samples were cut and brought back to the laboratory for pathogen identification confirmation using DNA sequencing.

RESULTS

There was an 84 percent reduction of bitternut hickory trees (i.e., $\geq$10 cm d.b.h.) from 2010 to 2016. Mortality rates were higher for hickory compared to other important species (i.e., sugar maple [*Acer saccharum*], American basswood [*Tilia americana*], and ash species [*Fraxinus* spp.]) at the site, at 35 percent year^{-1} vs. 1 percent year^{-1}. Bitternut hickory trees declined in all size classes, and mortality rates were higher in larger stems compared to smaller stems (Fig. 1).

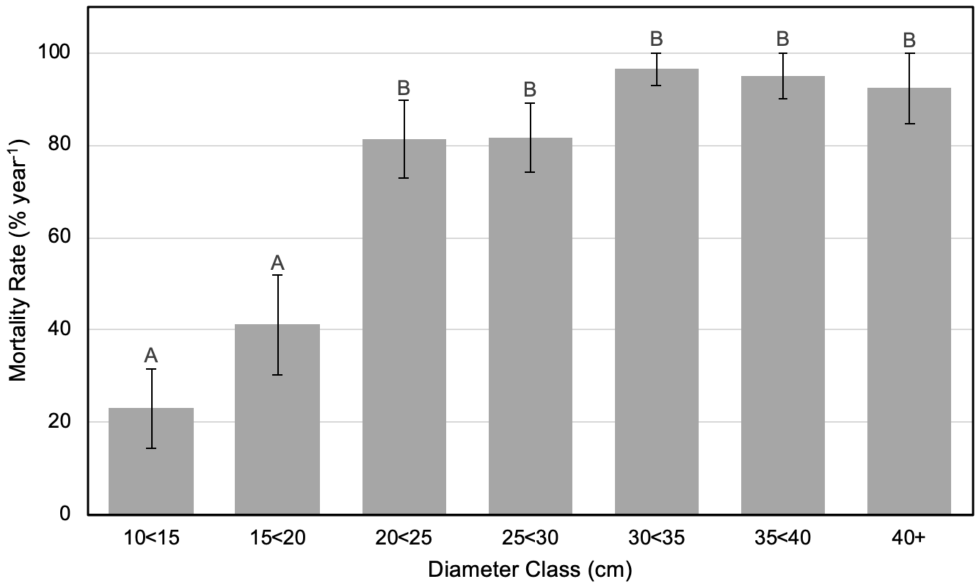

Figure 1.—Mean hickory tree mortality rates from 2010 to 2016. The analysis of variance (ANOVA) of mortality by diameter class resulted in a p < .0001, F-value = 15.79, and letters A and B indicate results from a Tukey's test to compare diameter classes (α = 0.05 level). Error bars indicate ±1 standard error.

Table 1.—Logistic regression model equation and parameter estimates for predicting mortality of individual hickory stems using four differently sized circular buffers. Parameter estimate significance from Wald's chi-squared tests denoted using * (α = 0.05) and ** (α = 0.01). M is log-odds of the probability of mortality, β_i are coefficient estimates, X_1 is crown class (Canopy (D) = 1; Subcanopy (S) = –1); X_2 is percent hickory; and X_3 is d.b.h. (cm).

Model: $M = \ln(m/[1-m]) = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$

Buffer size (radius)	β_o	β_1 (crown class)	β_2 (percent hickory)	β_3 (d.b.h.)	LR ChiSq	H-L (df = 8)	P > ChiSq for H-L
4 m	-1.1018	0.7813**	0.0176**	0.0920**	105.91	4.5695	0.8024
8 m	-1.2583*	0.8040**	0.0367**	0.0875**	112.09	11.2861	0.1860
11 m	-1.1695*	0.7821**	0.0345**	0.0862**	105.85	7.4211	0.4919
25 m	-1.4728**	0.7902**	0.0554**	0.0903**	110.14	5.7647	0.6736

LR ChiSq = Likelihood ratio chi-square statistic, H-L = Hosmer and Lemeshow statistic for testing model goodness of fit (P > ChiSq is statistical significance)

All variables in the logistic regression used to predict likelihood of mortality were significant for each radius modeled (Table 1). All models show that likelihood of mortality increases with increasing d.b.h., a higher (i.e., canopy) crown class, and higher percentage of hickory stems near to the host-hickory stem.

Hickory regeneration density in the <30 cm height class decreased significantly from 2010 to 2016 (i.e., p = .0012, F-value = 10.86). Investigation of densities from earlier years revealed that density has been extremely variable, so the decrease cannot be attributed to the same decrease in overstory tree density.

Debarking of sampled hickory trees confirmed the presence of the hickory bark beetle, based on entrance holes and larval galleries. Presence of *C. smalleyi* was confirmed with DNA sequencing.

CONCLUSION

Rapid crown decline of hickory is the likely cause of the bitternut hickory mortality, which is supported by the presence of the biotic decline agents and the consistency of the observed-mortality patterns with other reports in the midwest and northeast United States in the same period. *C. smalleyi* is commonly associated with the hickory bark beetle and has been associated with beetle galleries (Juzwik et al. 2013), although the function of the beetle as a vector has not been proven. Mortality is ultimately caused by vascular dysfunction from multiple beetle attacks, and multiple stem cankers. Drought is known to be an inciting factor in decline diseases and was also observed in the area prior to this mortality event.

Bitternut hickory stems in dominant and codominant canopy positions were almost eliminated from the site following the mortality event, and only 20 percent of stems $\geq$10 cm d.b.h. survived. The likelihood of mortality increased with higher percentages of bitternut hickory within a defined area of a host hickory tree, the host tree d.b.h., and a higher crown class. Stem density is known as a stressor of trees, often increasing susceptibility to insect attacks. In this case, stem density did indeed increase that susceptibility. Hickory regeneration was variable through time, so the decrease in population cannot be attributed to the rapid crown decline of hickory. These results suggest that regeneration does persist shortly following overstory mortality.

Low mortality of the regeneration layer and surviving stems in the mature stem cohort suggest that bitternut hickory can be maintained at the site. The potential for more frequent and intense droughts with climate change could incite mortality events like this to occur more frequently. The loss of even a single species reduces the resilience of a site, especially if other species are under threat as well, such as ash trees facing future emerald ash borer (*Agrilus planipennis* Fairmaire) attack. Managing forests to reduce stress on trees and encourage resilience to insects and pathogens is important to address decline diseases because stressed trees are more likely to succumb to other inciting and contributing factors. The logistic regression model developed here can guide management to reduce stem density, which would minimize the effect of density as a predisposing factor. Mortality is likely in all diameter sizes and canopy positions; however smaller, subcanopy hickory stems are less susceptible to mortality when hickory is in lower proportions. Thinning or selective harvesting techniques can reduce stem density and the proportion of hickory trees, while also increasing biodiversity and heterogeneity in stand species and structure. This further reduces bark beetle populations and the potential for subsequent attacks (Fettig 2012, Knops et al. 1999).

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LITERATURE CITED

Fettig, C.J. 2012. **Forest health and bark beetles**. In: North, M., ed. Managing Sierra Nevada forests. Gen. Tech. Rep. PSW-GTR-237. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 13–22. [Chapter 2].

Forrester, J.A.; Mladenoff, D.J.; Gower, S.T. 2013. **Experimental manipulation of forest structure: near-term effects on gap and stand scale C dynamics.** Ecosystems. 16: 1455–1472. https://doi.org/10.1007/s10021-013-9695-7.

Juzwik, J.; Park, J.-H.; Banik, M.T.; Haugen, L. 2013. **Biotic agents responsible for rapid crown decline and mortality of hickory in northeastern and north central USA.** In: Miller, G.W.; Schuler, T.M.; Gottschalk, K.W. [et al.], eds. Proceedings, 18th Central Hardwood Forest Conference; 2012 March 26-28; Morgantown, WV; Gen. Tech. Rep. NRS-P-117. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 152–168.

Knops, J.M.H.; Tilman, D.; Haddad, N.M.; Naeem, S.; Mitchell, C.E. [et al.]. 1999. **Effects of plant species richness on invasion dynamics, disease outbreaks, insect abundances and diversity.** Ecology Letters. 2(5): 286–293. https://doi.org/10.1046/j.1461-0248.1999.00083.x.

Lorimer, C.G.; Dahir, S.E.; Nordheim, E.V. 2001. **Tree mortality rates and longevity in mature and old-growth hemlock-hardwood forests.** Journal of Ecology. 89(6): 960–971. https://doi.org/10.1111/j.1365-2745.2001.00619.x.

Park, J.-H.; Juzwik, J. 2014. ***Ceratocystis smalleyi* colonization of bitternut hickory and host responses in the xylem.** Forest Pathology. 44(4): 282–292. https://doi.org/10.1111/efp.12098.

Park, J.-H.; Juzwik, J.; Cavender-Bares, J. 2013. **Multiple *Ceratocystis smalleyi* infections associated with reduced stem water transport in bitternut hickory.** Phytopathology. 103(6): 565–574. https://doi.org/10.1094/PHYTO-10-12-0272-R.

Park, J.-H.; Juzwik, J.; Haugen, L.M. 2010. ***Ceratocystis* canker of bitternut hickory caused by *Ceratocystis smalleyi* in the north-central and northeastern United States.** Plant Disease. 94(2): 277–277. https://doi.org/10.1094/PDIS-94-2-0277B.

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