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Thinning treatments reduce severity of foliar pathogens in eastern white pine☆

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ABSTRACT

The foliar fungal pathogens associated with the disease complex known as White Pine Needle Damage (WPND) are causing widespread defoliation of eastern white pine (*Pinus strobus* L.) in the northeastern United States and Canada. Presently, there are no specific management recommendations for addressing declining stand health relating to WPND induced defoliations. This study aims to test the effects of thinning at two different residual stocking densities (14 and 25 $m^2\,ha^{-1}$) on mitigating the negative impacts of WPND within infected stands. To quantify the impacts of WPND on individual tree health, we generated a composite health index score using response variables measured in the field and weighted according to their association with observations of WPND severity. Post-thinning changes in disease severity were used to evaluate the effectiveness of stand thinning to reduce pathogen pressure and promote overall tree vigor. Results show that thinning had a rapid positive effect on overall tree health, with no significant difference between thinning treatment levels in the first two years following tree removal. Severity of WPND was reduced by 35% in low-density residual thinnings in the second year of the study. Our findings suggest that thinning as a silvicultural tool to reduce stocking densities within infected stands can effectively promote overall tree health and maintaining proper stocking densities is recommended for stands at risk of infection.

1. Introduction

Foliar pathogens of eastern white pine (*Pinus strobus* L.) in the northeastern US have been a recent cause of concern for land managers and timber producers in the region. Since ca. 2010, a complex of four native ascomycete fungi, termed White Pine Needle Damage (WPND), has induced widespread defoliation of mature needles in the summer months (Broders et al., 2015; Munck et al., 2012; Wyka et al., 2016). The incidence of WPND is ubiquitous throughout the northeastern US, with the presence of at least one of the associated pathogens confirmed at 93% of mature white pine stands sampled in a recent survey throughout Maine, New Hampshire, Vermont, and Massachusetts (Wyka et al., 2017a). Defoliation caused by WPND in the months of June and July have been shown to account for ~47% of the total annual foliar litterfall within infected stands, significantly altering the seasonal dynamics of litter deposition within diseased stands (McIntire et al., 2018, *this issue*). In turn, WPND has been shown to cause significant growth declines in stands subject to multiple years of defoliation stress, reducing mean annual basal area increment by 25–73% following the initial outbreaks in the region (McIntire et al., 2018, *this issue*).

Silvicultural practices have long been applied in white pine stands subject to insect and pathogen stress throughout its native range (Ostry et al., 2010). Historically, the greatest biotic threats to white pine health have been the native white pine weevil (*Pissodes strobi* Peck) and the introduced pathogen *Cronartium ribicola* Fisch, both of which have well established management recommendations (Major et al., 2009; Maloy, 1997; Ostrofsky, 1988; Stiell and Berry, 1985; Taylor and Cozens, 1994). Chemical control of foliar pathogens, while effective, is both expensive and time intensive, thus typically practiced in an urban forestry setting as opposed to landscape-level treatment. Presently, there are no specific silvicultural prescriptions that address the impacts of defoliating pathogens affecting white pine. To curb the impacts of WPND across a diversity of land management regimes, it is crucial to develop a treatment that can be applied on a large scale and ideally in conjunction with previously established management guidelines for white pine (Anderson et al., 2002; Lancaster, 1984; Lancaster and Leak,

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1978; Pinto, 1992; Robbins, 1984; Stiell, 1985). Therefore, the goal of this study was to test whether thinning treatments can be used to mitigate the negative impacts of WPND-induced defoliation in mature white pine stands. White pine has shown to respond well to thinning at virtually every age class, with increases in diameter increment on the order of 100%, 80% and 63% in age classes 19, 55, and 200+ years old respectively (Bebber et al., 2004; Burgess and Wetzel, 2000; Stiell, 1979; Stiell et al., 1994). A study involving thinning treatments in mature stands in Maine demonstrated that residual densities of 7.3 and 13.8 $m^2 ha^{-1}$ promoted growth, recovery, and regeneration of white pine seedlings in declining stands (Leak and Yamasaki, 2013).

The rationale behind applying a thinning treatment to reduce stand densities in WPND-infected stands is in large part due to the nature of spore dispersal of associated fungi. Needle chlorosis and defoliation have been found to be most severe in the lower portions of infected crowns, consistent with rain-splash dispersed foliar diseases (Broders et al., 2015). In a study of spore dispersal of *Lecanosticta acicola* Thümen, the most prevalent pathogen associated with WPND, Wyka et al. (2017b) found that abundance of spores was greatly reduced at distances > 3 m from the outer edge of lower branches compared with the area directly below infected crowns. We hypothesized that reducing stand densities will result in a decrease of foliar pathogen pressure while promoting growth, crown development, and recovery. Through application of thinning prescriptions, the distance between crowns will be increased, thus potentially limiting pathogen spread while exploiting the inherent benefits of increasing crown light exposure for tree health and vigor (Pacala et al., 1996). In this paper, we (1) determine the impacts of WPND on traditionally measured forest health traits, (2) generate a composite health index score used for monitoring change over time, and (3) assess the response of WPND-infected trees to reduced stand densities in the first two years following thinning treatment.

2. Methods

2.1. Study sites

We conducted thinning trials within two white pine dominated stands, separated by approximately 100 km, located in central and southern New Hampshire, USA. The first stand is located on the Bear Camp River property in the town of West Ossipee (OSP) and is owned and maintained by the University of New Hampshire. This property is composed of 12.7 ha of forested area, of which 63% is nearly pure white pine and 83% features white pine as a dominant component. The white pine dominated compartments in which the thinnings were conducted are approximately 8.1 ha. The symptoms and presence of WPND fungi were observed to be ubiquitous throughout the stand during an initial survey in June of 2015. Other species present within this site include eastern hemlock (*Tsuga canadensis* (L.) Carrière), northern red oak (*Quercus rubra* L.), American beech (*Fagus grandifolia* Ehrh.), red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marshall), and silver maple (*Acer saccharinum* L.). Soils at this site are excessively drained and largely classified as Colton gravelly loamy fine sand. The approximate date of establishment for the mature white pine is 1928. White pine saw timber and pulpwood were harvested from OSP in 1976 and 1989, respectively totaling 236.8 and 353.1 m^3 of volume removed. An additional 9.4 m^3 of white pine was salvaged from blowdowns at this site in 1980. A second stand is located within the 585 ha Caroline A. Fox Research and Demonstration Forest in Hillsborough, NH (FOX) and is under the management of the state of New Hampshire Department of Resources and Economic Development. FOX is included within a permanent network of plots throughout the northeastern United States that have been monitored for WPND incidence and severity since 2012 by the US Forest Service and state forest health cooperators. Severity of symptoms associated with WPND have generally increased annually at this site since monitoring began. The majority of mature trees at this site established following a severe hurricane in 1938, which felled over 3776 m^3 of standing timber (Allen and Seaboyer, 2017). The compartment in which the thinning was conducted established later, following abandonment of agricultural land in 1959. White pine and eastern hemlock are the most abundant species at FOX, followed by northern red oak, red maple, and several other northern hardwood species. Soils within the thinned stand are stony and generally classified as a Marlow fine sandy loam. Pre-thinning stocking levels and additional site characteristics for OSP and FOX are shown in Table 1.

Table 1
Initial conditions of the two naturally established eastern white pine stands in New Hampshire measured in 2015.

		OSP	FOX
Site description	Latitude	43.810	43.129
	Longitude	−71.186	−71.923
	Elevation (m)	160	240
	Mean annual temperature (°C)	7.0	7.5
	Mean maximum temperature (°C)	13.6	13.6
	Mean minimum temperature (°C)	0.3	1.5
	Mean annual sum precipitation (mm)	1216	1205
Initial conditions	Year of initiation	1928	1960
	Stand age (yr)	89	57
	Basal area ($m^2 ha^{-1}$)[*]	40.3 ± 2.4	42.3 ± 1.9
	Stem density (ha^{-1})[*]	447 ± 49	646 ± 18
	Quadratic mean diameter (cm)[*]	33.9	28.9
	Stand density index[a]	710.1	794.2
	Relative density[b]	0.457	0.791
	Site index[c]	71.1	83.5
	Percent *P. strobus* (% BA)	91.8	84.0

* Mean and standard error.
[a] VanderSchaaf (2013).
[b] Ducey and Knapp (2010).
[c] Parresol and Vissage (1998).

2.2. Experimental design

We implemented a blocked experimental design on a 2.4 ha area within each study site. Each block (n = 4) consisted of three 4047 m^2 (1 acre) treatment plots, composed of two thinning variants and a single control plot. To accommodate the constraints of the white pine dominated portions of each stand the dimensions and subsampling of the plots differed between sites, but total area was conserved (Fig. 1). We conducted two thinning trials at each field site that aimed for a residual basal area of 25 and 14 $m^2 ha^{-1}$, henceforth referred to as the high-density residual (HD) and low-density residual (LD) thinning treatments, respectively. The high-density stocking level was selected to simulate a traditional white pine precommercial thinning, targeting the area between the managed B- and C-line according to the Leak and Lamson (1999) stocking guide for eastern white pine. The low-density thinning treatment was a more intensive tree removal, simulating what would be most commonly referred to as a crop tree release, placing these plots well below the managed C-line of the stocking chart. Low-density thinnings have previously been advocated for rapid growth of individual trees in white pine (Seymour, 2007). Individual trees were selected for trait measurements using variable radius (prism) subplots. A preliminary cruise of each stand was conducted to determine the mean diameter at breast height (DBH, 1.3 m above ground level) in order to estimate the mean expected inclusion zone radius for spacing prism points. Within each treatment plot, three permanent prism points (BAF 4.6 $m^2 ha^{-1}$) were established, oriented to maximize distance from each other to avoid double-sampling large trees while also allowing for a buffer of at least 18 m from the subplot center point to the edge of the plot (Fig. 1). Block and plot boundaries were adjoined at each site. A pre-thinning inventory was conducted for each stand in June of 2015, during which each tree selected for measurements was