CHAPTER 9.

Impact of Southern Pine Beetle on Forest Structure and Fuel Loading in a Wildfire-prone Landscape

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INTRODUCTION

Southern pine beetle (SPB; *Dendroctonus frontalis*) is the most destructive forest insect in the Southeastern United States, with greatest damage occurring in high-density pine stands with basal area above approximately 18 m^2 ha^{-1} (Aoki and others 2016, Ayres and others 2011, Nowak and others 2015). As SPB migrates northward, it is impacting pine-dominated forests throughout much of the Mid-Atlantic region. In the New Jersey Pinelands National Reserve (PNR), Forest Inventory and Analysis (FIA) data indicate that approximately 65 percent of the stands dominated by pitch pine (*Pinus rigida*) and shortleaf pine (*P. echinata*) are at or above the density at which SPB can cause significant pine mortality (Crocker 2014, 2015). Since 2001, SPB damage has been detected in southern New Jersey, with over 500 SPB locations identified and ground-truthed on public lands alone (New Jersey Agricultural Experiment Station 2017, Weed and others 2013). Extensive mortality in pitch and shortleaf pine-dominated stands of the PNR could dramatically alter forest structure, future species composition, and wildfire risk in impacted stands. Although FIA field sampling efforts have been accelerated in New Jersey and enhanced FIA forest census protocols are appropriate for quantifying changes to understory vegetation, fine fuels, and coarse woody debris on the forest floor, we currently have little information on the regeneration phase following extensive overstory mortality driven by SPB in naturally regenerated pitch and shortleaf pine stands. However, this phase has significant implications for wildfire activity in the PNR, especially if it resembles early successional pine- and scrub oak-dominated forests of the early 1900s, which were characterized by extremely large, destructive wildfires (Clark and others 2014a, 2014b). Any potential impacts on wildfire occurrence and intensity are especially important on the Mid-Atlantic Coastal Plain, where high human population densities, high-value property, and air quality concerns in the adjacent large urban areas are significant issues.

In this project, we addressed how SPB damage and predominant management options alter forest structure, species composition, and canopy fuel loading using FIA forest census protocols in pairs of control and impacted stands. We focused on three major treatments employed by the New Jersey Department of Environmental Protection (NJ DEP) and contractors: (1) “natural” or no treatment: (2) “cut and leave,” where infested pines and a buffer are cut and stems are left in place: and (3) “cut and chip,” where infested pines and buffers are cut, bunched, chipped, and occasionally hauled offsite. We then used forest census data to inform a canopy energy balance and hydrology model to evaluate potential changes to hazardous fuel loading and wildfire risk in this fire-adapted ecosystem. Specific questions addressed in this project were:

- How are stand structure and composition altered by SPB-driven mortality of overstory pines? Are treated (e.g., cut and leave, cut and chip) plots different from natural plots in terms of retained trees and saplings?
- How will mortality (and removal) of overstory pines potentially affect the long-term forest structure and composition of stands impacted by SPB?
- To what extent are canopy and understory fuels altered by SPB? Using a multi-level energy exchange and hydrologic model informed using comparative forest census data, how do changes in overstory canopy cover and altered fuel loads affect fuel moisture dynamics compared to intact stands?

METHODS

We used aerial and ground-based surveys conducted by NJ DEP and Dartmouth College researchers to locate impacted stands. We then installed paired field census plots to quantify trees, saplings, seedlings, and understory composition and structure in control and impacted areas using U.S. Department of Agriculture (USDA) Forest Service FIA forest census protocols (www.fia.gov) during 2014 and 2015. All stands were located on public lands (primarily State forests and wildlife management areas) and encompassed the range of treatment strategies: natural (n = 12), cut and leave (n = 27), and cut and chip (n = 12) treatments. Impacted areas in sampled stands ranged from approximately 0.5 to 35.0 ha. All live and dead trees and saplings were censused for species, diameter at breast height (d.b.h.), height, and crown condition: canopy cover was estimated for each 168-m^2 subplot. Understory height, species composition, and cover by species (including tree seedlings) were recorded for each subplot. Pine seedlings were tallied by height class in each subplot when present. We used recently developed allometric equations for pines based on destructive harvests and LiDAR to estimate total aboveground biomass and biomass of available fuel for crown fires, defined as all live and dead needles and live and dead twigs < 0.635 cm diameter, for pine trees and saplings in each subplot (Clark and others 2013).

We collected understory meteorological data in defoliated (n = 3 to 5 towers) and control stands, in addition to meteorological data collected from seven above-canopy towers throughout the Pinelands in conjunction with New Jersey State Climatologist's Office (Clark and others 2012; http://climate.rutgers.edu/usfs/monitoring.php). Information on the immediate and longer term effects of SPB on complex fuel beds was integrated with a multi-level model of fuel moisture dynamics to assess fire danger and wildfire risk.

RESULTS

SPB damage in infested portions of all stands resulted in significant mortality of pitch, shortleaf, and Virginia pine (*P. virginiana*) trees, averaging 95 percent and 98 percent of pine tree basal area and aboveground biomass, respectively (fig. 9.1; table 9.1). Pine sapling basal area and aboveground biomass were similar in control and natural stands, but much lower in treated stands (fig. 9.2). In contrast to their response following wildfires, resprouting from epichormic meristems or root crowns of impacted pine trees or saplings was rarely observed following SPB attack. Pine seedlings were abundant only in cut and chip stands, where extensive disturbance of the forest floor had occurred because of vehicle and equipment use, exposing bare sand. Primarily oaks in the upland stands and other hardwood trees and saplings in lowland stands were present to abundant in natural plots, and many were retained in treated plots, with basal areas as high as in non-impacted stands (figs. 9.1 and 9.2).

Total canopy cover was reduced in natural and treated stands compared to control stands, with canopy reduction occurring in the order natural stands < cut and leave stands < cut and chip stands (table 9.1). In contrast, understory cover and height remained nearly unchanged in natural and cut and leave stands, and there was a trend towards increased understory cover in cut and chip stands sampled 2 to 4 years following treatment (table 9.1). Canopy fuels

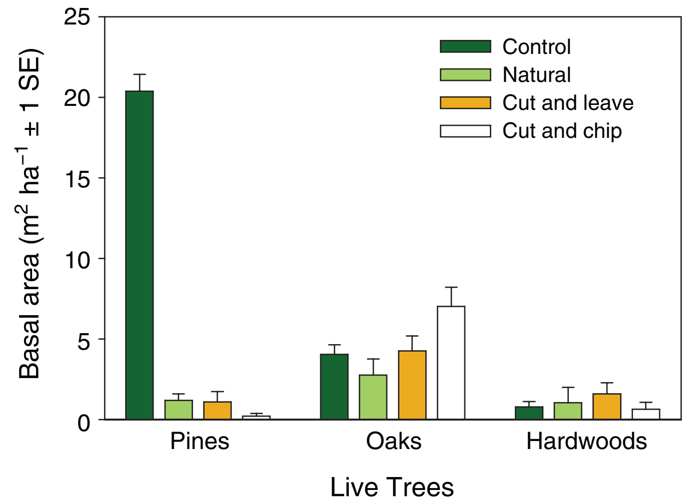

Figure 9.1—Basal area of live trees separated into pines (Pinus rigida, P. echinata, P. virginiana), *oaks* (Quercus alba, Q. prinus, Q. marlandica, Q. velutina, Q. stellata, Q. falcata, Q. bicolor), *and other hardwoods* (Acer rubra, Nyssa sylvatica, Carya glabra, Magnolia virginiana, Sassafras albidum) *in control, natural, and treated plots.*

Table 9.1—Structural characteristics of canopy and understory in control, natural infested, and treated plots

Characteristic	Control	Natural	Cut and leave	Cut and chip	Significance
Canopy					
Height (m)	15.2 ± 0.3[a]	10.1 ± 1.0[b]	10.4 ± 1.0[b]	12.0 ± 1.5[b]	F = 12.1, P < 0.01
Cover (%)	61.9 ± 2.4[a]	30.8 ± 6.0[b]	20.2 ± 4.8[b]	16.6 ± 6.1[b]	F = 29.5, P < 0.01
Understory					
Height (m)	0.7 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.5 ± 0.1	F = 0.9, P = NS
Cover (%)	71.6 ± 4.6	71.3 ± 8.3	72.0 ± 5.5	88.7 ± 1.0	F = 1.7, P = NS
Aboveground pine biomass (tons ha^{-1})					
Trees	74.18 ± 4.18[a]	2.59 ± 0.88[b]	0.33 ± 0.21[b]	0.71 ± 0.40[b]	F = 57.1, P < 0.01
Saplings	3.96 ± 0.84[a]	3.93 ± 1.27[a]	0.08 ± 0.06[b]	0.02 ± 0.01[b]	F = 3.0, P < 0.05
Available fuels (tons ha^{-1})					
Canopy	8.04 ± 0.47[a]	0.28 ± 0.09[b]	0.04 ± 0.04[b]	0.08 ± 0.04[b]	F = 53.0, P < 0.001
Sub-canopy	0.71 ± 0.15[a]	0.80 ± 0.24[a]	0.01 ± 0.01[b]	0.01 ± 0.01[b]	F = 3.1, P < 0.05

Available fuels were defined as live and dead pine needles, and live and dead stems with a diameter of up to 0.635 cm. Estimates were based on destructive sampling and LiDAR data described in Clark and others (2013).

Data are shown for control stands averaged together (n = 51), and natural (n = 12), cut and leave (n = 27), and cut and chip (n = 12) stands. Values are means ± 1 SE. Significance levels were tested using ANOVAs and Tukey's MSD tests. Values indicated with different superscripts among plot types are significantly different.

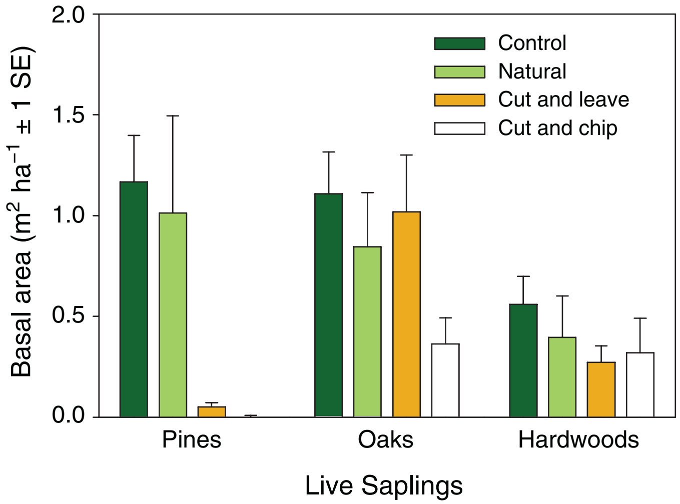

Figure 9.2—Basal area of live saplings separated into pines (Pinus rigida, P. echinata, P. virginiana), *oaks* (Quercus alba, Q. prinus, Q. marlandica, Q. velutina, Q. stellata, Q. falcata, Q. bicolor), *and other hardwoods* (Acer rubra, Nyssa sylvatica, Carya glabra, Magnolia virginiana, Sassafras albidum) *in control, natural, and treated plots.*

were reduced rapidly in impacted stands because the "red needle" phase is short in pitch and shortleaf pines. Available fuels in the canopy of control plots totaled 8.8 ± 0.5 tons ha^{-1} (mean ± 1 standard error), while they were only 1.1 ± 0.3, 0.1 ± 0.1, and 0.1 ± 0.1 tons ha^{-1} in plots in natural, cut and leave, and cut and chip treatments, respectively (table 9.1). Impacted stands initially had greater needle mass, and 1-hour + 10-hour woody fuels on the forest floor compared to control stands, estimated to range from 5.5 ± 0.8 to 8.6 ± 0.7 tons ha^{-1}. In the years following pine mortality, reduced litterfall inputs and litter decomposition resulted in reduced forest floor mass compared to undisturbed control plots. Coarse wood mass totaled up to 105 ± 12 tons ha^{-1} in cut and leave stands, was highly variable in natural stands due to a large proportion of standing dead trees in some stands, and was minimal in some of the cut and chip treatments.

Meteorological conditions in larger cleared areas driven by insect damage were more similar to above-canopy conditions for wind speed and relative humidity, while mid-day air temperatures near the forest floor were greater than those above canopy or within unimpacted stands with greater canopy cover (table 9.1). Fuel moisture model simulations indicated that larger, treated stands experienced greater amplitudes in moisture dynamics of fine and woody fuels on the forest floor compared to unimpacted stands with intact canopies.

DISCUSSION

The extensive mortality of pines in infested portions of stands with an average tree and sapling basal area of 21.5 m^{-2} ha^{-1} reported here is consistent with SPB impacts in southern pine-dominated forests (Nowak and others 2015, 2016). Many of the stands that we sampled in the PNR have regenerated naturally following the cessation of intensive forest management and intense wildfires in the Pinelands, and pines averaged 77 ± 24 years old (Aoki and others 2017). However, our field observations indicate that the impacts of SPB differ significantly from wildfire or wind damage because they cause mortality and not solely damage to crowns or aboveground portions of stems of mature pitch and shortleaf pines. Contrary to our initial hypothesis, we encountered very few pine seedlings in natural or cut and leave plots. Pine regeneration from seedlings is occurring only in areas where the litter layer and soil has been disturbed significantly, such as in cut and chip stands and in areas associated with the use of vehicles in treated plots, or in areas that had experienced previous disturbance, such as following a summer wildfire in 2010 in Bass River State Forest. Advance regeneration of oak and hardwood saplings in natural stands, and retained trees and saplings in treated stands suggest that many of these stands will become hardwood-dominated in the near future. In the absence of wildfire, oaks in upland stands and other hardwoods in lowland stands will eventually replace pitch and shortleaf pines (La Puma and others 2013). Thus, SPB is accelerating successional sequences in the Pineland, and without forest management intervention, impacted areas will likely not return to pine-dominated stands.

In contrast to the effects of mountain pine beetle (*Dendroctonus ponderosae)* in western forests, needle abscission occurs quickly following mortality in pitch and shortleaf pines, thus the "red needle" phase is relatively short-lived (Jenkins and others 2014, Page and others 2015), reducing the potential for crowning fire behavior in impacted stands. We expected that increased fuel loading on the forest floor would likely significantly alter fuel beds, and that the more open canopies would alter the meteorological conditions on the forest floor, contributing to higher fire danger in impacted stands. Fuel loads on the forest floor were initially high, with an increase of up to 170 percent from pine needles and twigs, but then reduced litterfall inputs and high rates of decomposition reduced fuel loads on the forest floor. High decomposition rates reflected the relatively high nitrogen and phosphorus content of pine needles when they fell following tree mortality, and may also be related to higher temperatures on the forest floor due to reduced canopy cover. The analogous "grey phase" has been characterized by lower wildfire danger in western forests, but does allow for greater penetration of wind and incident radiation, potentially driving greater fuel moisture dynamics in impacted stands (Jenkins and others 2014, Page and others 2015). Coarse wood on the forest floor was much greater in cut and leave and to a lesser extent natural stands in the Pinelands, but these fuels are usually not consumed during the relatively fast-moving spring wildfires that typically occur in the Pinelands. Our hydrologic simulations indicated an initial increase in fuel moisture dynamics in impacted stands, but when canopy closure occurs these will be reduced. In the long term, decreased available fuels in the canopy and a shift from pine to hardwood litter on the forest floor will very likely reduce wildfire risk in stands impacted by SPB.

To date, management of SPB in the Pinelands has been highly reactive; extensive outbreaks were detected primarily by aerial surveys conducted by NJ DEP, ground-truthed, and then either not treated, infested trees and buffers were cut and left, or infested trees were cut, bunched, and then chipped. Proactive management should be considered in the future because both thinning of dense stands and higher intensity prescribed fires that reduce basal area and increase tree spacing have been effective in limiting SPB outbreaks in other pine-dominated forests (Nowak and others 2015). To address the long-term impacts of SPB outbreaks and management options, we are now coupling a forest dynamics model (LANDIS II) to predict changes to forest structure and composition in the PNR and surrounding areas.

CONCLUSIONS

Southern Pine Beetle outbreaks are causing > 90-percent mortality of mature pine trees in infested stands in southern New Jersey. While pine saplings are present in natural stands, regeneration is very low in cut and leave treatments, and pine seedlings were encountered only in the most disturbed treatment (cut and chip), where the forest floor and shrub layer were disturbed. Oaks (upland stands) and other hardwoods (lowland stands) were present to abundant in all natural and treated stands, indicating that impacted stands would become oak- or hardwood-dominated in the future. Canopy fuels were reduced rapidly in impacted stands because needles abscised soon after mortality and the "red needle" phase was short. Fuel loading on the forest floor was initially enhanced in the order cut and leave > natural > cut and chip, but then reduced litterfall and litter decomposition following overstory mortality resulted in lower fuel loading on the forest floor with time since SPB outbreaks.

CONTACT INFORMATION

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The annual national report of the Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, presents forest health status and trends from a national or multi-State regional perspective using a variety of sources, introduces new techniques for analyzing forest health data, and summarizes results of recently completed Evaluation Monitoring projects funded through the FHM national program. In this 16th edition in a series of annual reports, survey data are used to identify geographic patterns of insect and disease activity. Satellite data are employed to detect geographic patterns of forest fire occurrence. Recent drought and moisture surplus conditions are compared across the conterminous United States. Data collected by the Forest Inventory and Analysis (FIA) Program are employed to detect regional differences in tree mortality. Change over time in the understory Vegetation Diversity and Structure Indicator is assessed on more than 500 FIA plots in the North Central and Northeastern States. Remeasured vegetation data across several Northern States are used to assess change over time in plant species diversity, occupancy and constancy. A new Regeneration Indicator, which includes a suite of tree-seedling and browse impact measurements, is described. The general magnitude of tree mortality predicted by the National Insect and Disease Risk Map was compared to FIA estimates of mortality. Six recently completed Evaluation Monitoring projects are summarized, addressing forest health concerns at smaller scales.

Keywords—Change detection, drought, fire, forest health, forest insects and disease, regeneration, tree mortality.

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