Long-Term Impact of Shoot Blight Disease on Red Pine Saplings

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ABSTRACT

Damage from *Sirococcus* and *Diplodia* shoot blights of red pine is widespread and periodically severe in the Lake States. An outbreak of shoot blight occurred in red pine sapling plantations across northern Wisconsin, northern Minnesota, and the Upper Peninsula of Michigan in 1993. We established monitoring plots in red pine sapling plantations severely affected by shoot blight in Michigan and Wisconsin to assess the influence of residual overstory red pine and the presence of *Sirococcus* and *Diplodia* shoot blights on disease severity and their long-term impact on tree survival and growth. Fourteen years after the initial outbreak, many red pine saplings had recovered from serious damage ($>$ 1/3 of new shoots affected) that had occurred in a single outbreak year followed by lower levels of disease in subsequent years. However, the most severely affected trees sustained higher mortality and reduced growth. Forking or development of crooks of the main stem was common if terminal leaders were killed by shoot blight. Results from this study suggest that the impact of a shoot blight outbreak on red pine saplings largely depends on the presence or absence of an inoculum source in residual overstory trees, the species of pathogen present in the stand, and the initial disease severity.

Keywords: *Pinus resinosa*, plantations, *Diplodia pinea*, *Sirococcus conigenus*, multicohort stands

The fungal pathogens *Sirococcus conigenus* and *Diplodia pinea* can be highly damaging to red pine (*Pinus resinosa*), often killing seedlings and young trees during episodic outbreaks (Nicholls and Ostry 1990, Ostry et al. 1990, Bronson and Stanosz 2006, Oblinger et al. 2013). First reported in Wisconsin in 1959, *S. conigenus* infects young needles then grows into and kills current-year shoots, reducing the live crowns of affected trees (O'Brien 1973). *Sirococcus* shoot blight is favored by cool, wet weather and low light conditions (Nicholls and Robbins 1984). *Diplodia pinea* was first reported killing seedlings in a Wisconsin nursery in 1975 (Palmer et al. 1988) and since has become widespread in the Lake States on red pine, causing a collar rot of seedlings, shoot blight, and branch and stem cankers. Trees under drought stress and wounded by hail, heavy snow, and various insects are highly susceptible to infection by *D. pinea* (Peterson 1981, Nicholls and Ostry 1990, Feci et al. 2003).

Shoot blights have not been a problem in even-aged red pine stands. Infected overstory trees and logging slash are inoculum reservoirs for *S. conigenus* and *D. pinea*. Rain-splashed and windblown spores can be carried a significant distance, as evidenced by red pine seedlings in a nursery that became infected from inoculum produced in infected windbreak red pine nearly 600 ft away (Palmer et al. 1988). Trees growing under or near infected overstory red pine are particularly vulnerable to extensive damage (Ostry et al. 2002, 2012). Cones and logging debris infected by *D. pinea* are sources of inoculum that can infect planted or natural red pine seedlings, even in the absence of an overstory (Munck and Stanosz 2010, Oblinger et al. 2011). Although numerous studies have been done on the impact and control of shoot blight diseases caused by *S. conigenus* and *D. pinea* on red pine seedlings in nurseries and plantations, we are not aware of any studies on the long-term impact of shoot blights on the survival and growth of established red pine saplings that are subjected to a disease outbreak.

Weather in spring of 1993 was particularly conducive to shoot blight diseases, with measurable rainfall every week during the infection period from May through early July. High incidences of severe shoot blight damage in red pine sapling plantations were reported across northern Wisconsin, northern Minnesota, and the Upper Peninsula of Michigan. To provide guidance to managers on the expected long-term impact of shoot blights in affected plantations we monitored the fate of the most highly impacted saplings on four sites in Wisconsin and Michigan for 14 years. Our objectives were to (1) document the persistent impact of shoot blight diseases on survival and form of red pine saplings; (2) verify the effects of residual, infected red pine overstories on the incidence and severity of shoot blight diseases on sapling red pine; and (3) compare the impact of *Diplodia* and *Sirococcus* shoot blights individually and together on affected trees. Unique to this study was the opportunity to compare long-term impacts under varying factors, including effects from either one or both shoot blight pathogens and whether saplings were growing with or without neighboring, infected residual overstory red pine.

Materials and Methods

To determine the long-term impact of shoot blight on survival and growth of red pine saplings, in 1994 we established permanent monitoring plots in severely affected plantations on four comparable pine sites. Trees in these plantations ranged in age from 12 to 18

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Table 1. Description of red pine shoot blight impact monitoring plots.

Location	Stand age and trees per acre (in 1994)	Number of trees and plots	Presence or absence of overstory	Pathogen present	Mean shoot blight severity rating (0–6) in 1994
Kenton, MI	13 460 tpa[a]	46, 4 plots	No residual trees	*Sirococcus*	2.7
Washburn, WI	18 590 tpa	59, 4 plots	Residual trees influencing all plots	*Sirococcus* on all 4, *Diplodia* on 2	5.4
Watersmeet, MI	18 312 tpa	39, 5 plots	Residual trees influencing 2 plots	*Sirococcus*	3.9
Northern Highlands, WI	12 625 tpa	25, 2 plots	Residual trees influencing all plots	*Sirococcus* and *Diplodia*	6.0

[a] Red pine trees per acre (tpa). Pines greater than 0.4-m tall were included in the tally.

years at time of plot establishment. The plantations were on the Kenton Ranger District of the Ottawa National Forest, Michigan; on the Watersmeet Ranger District of the Ottawa National Forest, Michigan; on the Washburn Ranger District of the Chequamegon National Forest, Wisconsin; and on the Northern Highlands-American Legion State Forest in Wisconsin (Table 1).

A transect survey was conducted in each stand to determine the distribution and impact of disease, then the plots were established in locations that had sustained the greatest incidence and severity of shoot blight, as evidenced by the presence of shoots killed in 1993. Fixed radius 1/40 acre plots were established on the national forest sites in June 1994, and 1/50 acre plots were established on the state forest site in November 1994. Individual and groups of large red pine reserve trees remained scattered over portions of some of the plantations, or along the periphery of the plantations. The plots were not located directly under residual overstory trees, but some plots were near enough to these residual trees to potentially be affected by disease inoculum that may have been present in their crowns. The presence of residual red pine overstory trees was noted if they were within a distance of twice their height from plot saplings. A total of 169 planted red pines on 15 plots on the four sites were permanently tagged.

The data collected for each tree included height, presence of crooks and forks in the main stems resulting from killed terminals, and a current year shoot blight severity rating of 0–6. The shoot blight rating was derived by visually dividing the living crown into thirds and recording the number of recently killed shoots in the upper, middle, and lower thirds. For each third, a rating of 0 indicated that the portion of the crown had no new killed shoots; a rating of 1 indicated $<$ 33% of the new shoots were affected; a rating of 2 indicated that $>$ 33% of the new shoots were affected. The rating for the whole tree was the sum of the ratings for each portion of the crown.

Samples of blighted shoots from multiple trees on each plot were examined in 1994 and periodically throughout the study in the field and in the laboratory for the presence of diagnostic fruit bodies and spores to determine the presence of *D. pinea* and *S. conigenus*. Pathogen identification was also made using cultural techniques and the presence of symptoms on current and previous year's shoot growth (Stanosz and Smith 2007).

We analyzed the impact of shoot blight on affected sapling trees using a cohort life table format. For analysis, all plot tree data were grouped across all locations together according to the pathogens affecting the trees and whether the trees were growing adjacent to a residual overstory or not. Differences in tree growth and disease severity among trees affected by one or both pathogens and growing with or without the presence of residual overstory trees was analyzed using analysis of variance (ANOVA) and pairwise comparisons using Tukey honest significant difference (HSD).

Results

Influence of Residual Overstory Red Pine and Pathogen Species on Disease Impact

Disease severity and tree mortality differed between saplings growing in the presence of a residual overstory compared to those without an overstory, and by the species of pathogen affecting the saplings (Table 2; Figure 1). The severity of *Sirococcus* shoot blight was significantly ($P < 0.0001$) greater in trees near a residual overstory of red pine. In the presence of an overstory, the severity of shoot blight was significantly ($P < 0.0001$) different between red pine saplings affected by *S. conigenus* alone or by both *S. conigenus* and *D. pinea*. The greatest initial disease severity and overall tree mortality (31%) occurred on plots that had an overstory canopy present and with both *Sirococcus* and *Diplodia* shoot blights affecting the trees (Table 2). Intermediate initial disease severity and tree mortality (15%) occurred on plots with a residual overstory but trees affected by *Sirococcus* shoot blight only (Table 2). The least disease severity and tree mortality (1%) occurred on plots without a residual overstory and trees affected by *Sirococcus* shoot blight only (Table 2).

Influence of Initial Disease Severity on Tree Recovery

On all plots, shoot blight severity on surviving trees decreased over time from the initial rating, illustrating the episodic nature of shoot blight outbreaks (Figure 1). However, the most severely affected trees in 1994 had much smaller crowns, resulting from extensive shoot and branch mortality compared to less affected trees. Most tree mortality occurred within the first 5 years of the outbreak. When grouped by the initial disease severity rating to compare their response to the disease, more trees with an initial rating of 5 or 6 died than trees with lower initial disease severity ratings (Table 3). Within 5 years of the initial outbreak, the average shoot blight severity rating on the surviving trees from the group with initially high severity rating decreased to an average rating below 2, similar to the trees that started in either a moderate or low shoot blight severity rating group (Table 3).

Table 2. Life table of red pine saplings affected by shoot blight diseases, based on impact factors.

	Number alive			Mean shoot blight severity			Number dead			Percentage dead			Cumulative percentage dead		
	Impact factors[a]			Impact factors			Impact factors			Impact factors			Impact factors		
Year	NO + S	O + S	O + S&D	NO + S	O + S	O + S&D	NO + S	O + S	O + S&D	NO + S	O + S	O + S&D	NO + S	O + S	O + S&D
1994	69	46	54	2.91	4.7	6.0									
1995	69	46	51	2.17	2.7	3.0	0	0	3	–	0	6%	–	–	6%
1996	69	45	46	1.74	1.8	2.4	0	1	5	–	2%	10%	–	2%	15%
1997	69	43	40	1.97	2.4	2.6	0	2	6	–	4%	13%	–	7%	26%
1998	68	42	40	1.45	1.7	1.8	1	1	0	1%	2%	–	1%	9%	26%
1999	68	42	40	1.59	1.7	2.0	0	0	0	–	–	–	1%	9%	26%
2000	68	42	39	1.28	1.9	0.5	0	0	1	–	–	3%	1%	9%	28%
2001	68	42	39	1.50	1.4	1.2	0	0	0	–	–	–	1%	9%	28%
2002	68	42	38	1.41	1.4	0.9	0	0	1	–	–	3%	1%	9%	30%
2003	68	42	38	1.18	1.1	1.0	0	0	0	–	–	–	1%	9%	30%
2004	68	42	38	1.63	1.5	1.3	0	0	0	–	–	–	1%	9%	30%
2005	68	41	38	1.12	1.4	1.2	0	1	0	–	2%	–	1%	11%	30%
2006	68	41	38	1.12	1.3	1.4	0	0	0	–	–	–	1%	11%	30%
2007	68	39	37	0.56	1.5	1.3	0	2	1	–	5%	3%	1%	15%	31%

[a] Impact factors: NO + S = no overstory with *Sirococcus*; O + S = residual overstory with *Sirococcus*; O + S&D = residual overstory with *Sirococcus* and *Diplodia*.

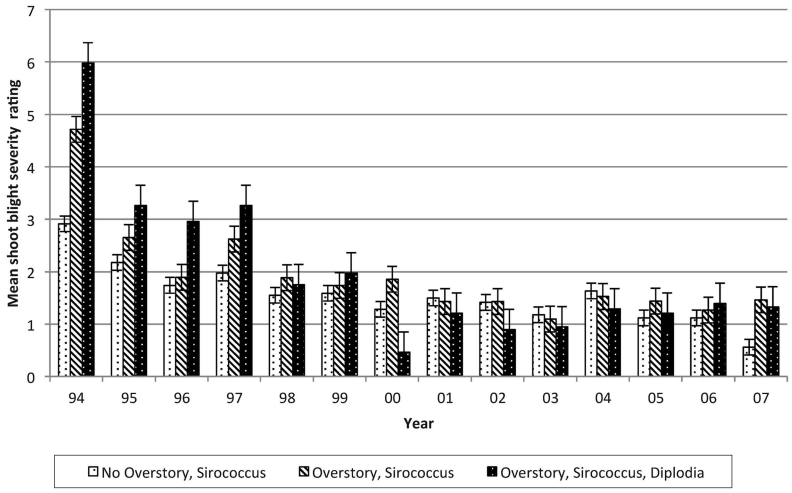

Figure 1. Mean shoot blight severity rating (± SE) by year, presence or absence of overstory, and pathogen.

Table 3. Life table of red pine saplings based on 1994 shoot blight severity ratings.

Year	Number alive			Mean shoot blight severity			Number dead			Percentage dead			Cumulative percentage dead		
	1994 Rating			1994 Rating			1994 Rating			1994 Rating			1994 Rating		
	high 5–6	mod 3–4	low 0–2	high 5–6	mod 3–4	low 0–2	high 5–6	mod 3–4	low 0–2	high 5–6	mod 3–4	low 0–2	high 5–6	mod 3–4	low 0–2
1994	91	46	32	5.9	3.5	1.6									
1995	88	46	32	3.0	2.4	1.5	3	0	0	3%	–	–	3%	–	–
1996	82	46	32	2.3	1.9	1.1	6	0	0	7%	–	–	10%	–	–
1997	75	45	32	2.6	2.2	1.5	7	1	0	9%	2%	–	18%	2%	–
1998	73	45	32	1.8	1.6	1.2	2	0	0	3%	–	–	20%	2%	–
1999	73	45	32	2.0	1.8	1.2	0	0	0	–	–	–	20%	2%	–
2000	72	45	32	1.0	1.7	1.0	1	0	0	1%	–	–	21%	2%	–
2001	72	45	32	1.4	1.6	1.3	0	0	0	–	–	–	21%	2%	–
2002	71	45	32	1.2	1.3	1.4	1	0	0	1%	–	–	22%	2%	–
2003	71	45	32	1.1	1.3	1.1	0	0	0	–	–	–	22%	2%	–
2004	71	45	32	1.5	1.5	1.6	0	0	0	–	–	–	22%	2%	–
2005	71	45	31	1.5	1.0	1.0	0	0	1	–	–	–	22%	2%	–
2006	71	45	31	1.4	1.1	1.0	0	0	0	–	–	–	22%	2%	–
2007	68	45	31	1.2	0.9	0.6	3	0	0	4%	–	–	25%	2%	3%

Impact of Overstory and Shoot Blight on Tree Growth and Form

Total tree height growth throughout the study was significantly ($P < 0.0001$) greater if trees were growing without the influence of residual overstory red pine and affected by *S. conigenus* alone compared to trees growing with an overstory and affected by *S. conigenus* alone or both *S. conigenus* and *D. pinea* (Figure 2). After 14 years, there was no significant difference in

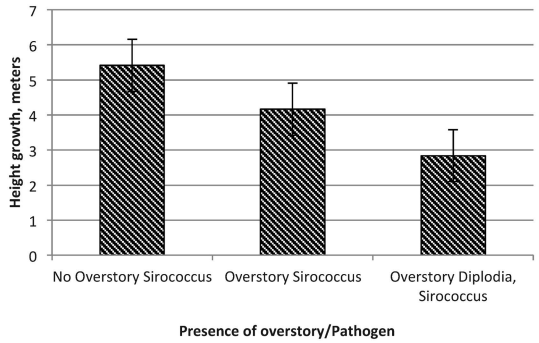

Figure 2. Red pine sapling height growth 1994–2007 by presence or absence of overstory and pathogen.

height growth of trees growing near residual overstory trees and affected by *Sirococcus* shoot blight alone or by both *Sirococcus* and *Diplodia* shoot blights.

Tree form damage was greatest on plots with residual overstory trees and the presence of both pathogens. Crooks and forks resulting from shoot blight reduced the number of crop trees potentially suitable for poles. Of the 69 trees on plots with no residual overstory and affected by *Sirococcus* shoot blight alone in 1994 (e.g., the least level of impact), 28 (41%) showed evidence of terminal injury at any time during the study. However, after 1994, the incidence of new terminal damage was low (0–10% in any given year). At the conclusion of the study in 2007, one tree (1%) was dead, seven (10%) were forked, and 16 (24%) had crooks in the main stem. Of the 46 trees on plots with residual overstory trees and affected by *Sirococcus* shoot blight alone in 1994 (representing middle level of impact), 27 (59%) showed evidence of terminal injury. Again, after 1994 the incidence of terminal damage was low. By 2007, seven of these trees (15%) were dead, three (8%) were forked, and seven (18%) had crooks. In contrast to the above, of the 54 trees on plots with a residual overstory and affected by both *Sirococcus* and *Diplodia* shoot blights in 1994 (representing the greatest level of impact), 52 (96%) showed evidence of terminal injury. By 2007, 17 of these trees (31%) were dead, three (8%) were forked, and 12 (32%) had crooks in their main stems.

Discussion and Management Recommendations

This study confirmed that red pine saplings growing near a red pine overstory are more severely affected and damaged by periodic outbreaks of shoot blights caused by *S. conigenus* and *D. pinea* than trees without residual overstory red pine. This is consistent with previous observations of planted seedlings (Bronson and Stanosz 2006, Ostry et al. 2012) and natural seedlings (Oblinger et al. 2013). Many of the saplings that sustained damage to a majority of their shoots in 1993 and were growing near overstory trees had reduced live crown volumes and eventually died or were severely deformed because they were subjected to repeated infections in subsequent years. In contrast, most damaged saplings growing without a residual overstory recovered, as crowns developed relatively disease free in the following years. The incidence of tree mortality, however, was highly dependent on not only the initial disease severity during the outbreak year but also on the disease severity in subsequent years and the species of shoot blight pathogen affecting the trees. Results of this study suggest that periodic outbreaks of shoot blight on red pine saplings may not result in extensive tree mortality or stem defects if overstory trees that are sources of pathogen inoculum are not present, limiting future disease outbreaks.

Although the co-occurrence of *S. conigenus* and *D. pinea* on red pine has previously been documented (Haugen et al. 1998, Stanosz and Smith 2007), this is the first study documenting their long-term individual and collective effects. *Diplodia* shoot blight was more damaging to trees than *Sirococcus* shoot blight. Unlike *S. conigenus, D. pinea* killed more than terminal shoots, growing from current year's shoots into previous year's wood, often resulting in tree stems with forks and crooks. In addition, *D. pinea* is able to persist in asymptomatic trees (Stanosz et al. 1997) with shoot blight disease symptoms developing only if trees become stressed or wounded, triggering a potential disease outbreak.

The following management strategies to avoid or minimize the impacts of red pine shoot blight have previously been suggested (Ostry et al. 1990, Palmer and Nicholls 1983) and further supported by results of this study:

- Plant disease-free stock. These pathogens have inadvertently been introduced into new areas on infected nursery stock and this is thought to be largely responsible for their current wide distribution.
- Favor nonhost trees (white pine, spruce, fir) on sites known to be highly favorable for shoot blight development.
- Remove infected red pine logging slash because newly planted seedlings can be infected by fungal inoculum harbored in debris and cones.
- Remove residual overstory trees that are the primary source of inoculum to reduce the risk for future disease outbreaks. If natural regeneration is attempted, timely removal of infected seed trees is essential to avoid seedling mortality caused by shoot blight.

Although red pine plantations are particularly vulnerable to shoot blight damage during the establishment phase, we have shown that significant damage can also occur to saplings. Based on our study results we also recommend:

- Monitor trees for shoot blight after periods of conducive weather, environmental stress, or wounding.
- Severely damaged trees that are deformed or have greatly reduced crowns caused by shoot blight should be removed during stand thinning since they will not develop into crop trees.

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