

Symptoms and *Phytophthora* spp. Associated with Root Rot and Stem Canker of Noble Fir Christmas Trees in the Pacific Northwest

GARY A CHASTAGNER, Washington State University, Research and Extension Center, Puyallup 98371; PHILIP B. HAMM, Oregon State University, Agricultural Research and Extension Center, P.O. Box 105, Hermiston 97838; and KATHLEEN L. RILEY, Washington State University, Research and Extension Center, Puyallup 98371

ABSTRACT

Chastagner, G. A., Hamm, P. B., and Riley, K. L. 1995. Symptoms and *Phytophthora* spp. associated with root rot and stem canker of Noble fir Christmas trees in the Pacific Northwest. *Plant Dis.* 79:290-293.

A survey of Noble fir Christmas tree plantations in Oregon and Washington was conducted to characterize symptoms and determine *Phytophthora* spp. associated with a root rot and stem canker disease. Symptoms were characterized and isolations were made from 158 symptomatic trees obtained from 30 plantations. The average root rot rating was 5.7 on a scale of 0–10. Approximately 74% of the trees exhibited branch flagging, and 82% had stem cankers that extended an average of 30.3 cm above the soil surface. Stem cankers originated from infected roots below ground and either extended straight up or spiraled up the stem as a narrow band of infected tissue. The average height of the trees was 77.5 cm. At least seven *Phytophthora* species were isolated from the roots and stems of the trees. *P. cambivora*, *P. megasperma* broad host range (BHR), *P. cryptogea*, and *P. gonapodyides* were the most prevalent species isolated. Other species included *P. cactorum*, *P. citricola*, and *P. cinnamomi*. This is the first paper reporting *P. citricola* and *P. cambivora* being found associated with stem cankering and root rot of Noble fir in the Pacific Northwest. All other species are known pathogens of Noble fir, but their ability to cause stem cankers and subsequent mortality, particularly in larger trees, after out-planting has not been demonstrated.

During the past 20 yr, there has been a tremendous increase in the planting of Noble fir (*Abies procera* Rehd.) as a

Christmas tree in the Pacific Northwest (17). In 1993, approximately 27% of the 11.8 million Christmas trees harvested in Oregon and Washington were Noble fir. Based on an average wholesale value of \$10 per tree, the value of this crop is estimated at \$31.8 million. Noble fir is endemic to the Pacific Northwest, occur-

ring naturally at mid-elevations along the Cascade Mountains in Washington and Oregon, the Siskiyou Mountains in northern California, and isolated pockets in the central coastal mountains in Washington and Oregon (18). Noble fir has excellent postharvest needle and moisture retention characteristics that make it a desirable Christmas tree (5). The increased plantings of Noble fir for Christmas tree production have resulted in trees being planted in unsuitable soils and at elevations out of the natural growing area of the species. During the early 1980s, growers became concerned about a number of disease problems. One such problem is a serious root rot and stem canker disease typically encountered within the first 3–4 yr after planting 2- or 3-yr-old seedlings. Losses of 30–50%, particularly in low areas with high soil moisture, have been reported by some growers.

Below-ground symptoms consist of root rot that may be limited to a few roots or involve all the roots. Above-ground symptoms may include stunting, yellowing, stem cankers, and flagging of basal branches associated with stem

Accepted for publication 29 November 1994.

© 1995 The American Phytopathological Society

cankers. Stem cankers, which extend 30–50 cm above ground, and flagging of basal branches are the most common symptoms observed (Fig. 1). Symptomatic trees typically occur in pockets or groups, and mortality typically occurs several months after the appearance of above-ground symptoms. However, there are instances in which isolated trees are affected. The disease has also been observed on 8- to 10-yr-old harvestable size trees where winter or spring flooding of plantations by nearby streams or rivers has occurred or where low, poorly drained areas have accumulated rain water for extended periods.

Various *Phytophthora* spp. cause serious damage to a number of conifer species (1,2,8–10,15,16,20). Typical symptoms of *Phytophthora*-infected trees include stunting and chlorosis above ground and varying degrees of root rot below. In some instances, there have been reports of basal stem cankers that may extend slightly above the soil surface. Noble fir seedlings are highly susceptible to various *Phytophthora* spp. that have been found in bare-root conifer nurseries in the Pacific Northwest (7,8,10). During the mid-1980s, isolations from symptomatic Noble fir trees in four Christmas tree plantations near Corvallis, OR, yielded four species of *Phytophthora*: *P. cryptogea* Pethybr. & Lafferty, *P. cinnamomi* Rands, *P. cambivora* (Petri) Buisman, and *P. gonapodyides* (Peterson) Buisman (6). This last species, *P. gonapodyides*, was originally identified as *P. drechsleri* on conifers in the Pacific Northwest (3,4). These species and others have caused root rot on a number of conifer species grown in Pacific Northwest bare-root nurseries. However, once out-planted to forest sites, the ability of the *Phytophthora* species tested to kill or spread from Douglas-fir seedlings infected in nurseries diminished rapidly or did not occur, respectively (14).

The apparent ability of *Phytophthora* spp. to cause narrow stem cankers on *Abies* that extended 30–50 cm above ground has not been reported previously. In addition, large-scale mortality, particularly of larger trees in Christmas tree plantations, also is uncommon. The purpose of the 1990 survey of Noble fir Christmas tree plantations in Oregon and Washington was to characterize symptoms and to isolate pathogens from roots and stem cankers to determine which *Phytophthora* species were associated with this disease.

MATERIALS AND METHODS

Arbitrarily selected plantation-grown Noble fir Christmas trees exhibiting typical root rot and stem canker disease symptoms were collected during the spring of 1990 from 30 Christmas tree plantations with varying incidence of disease in Oregon and Washington

(Table 1). Plantation locations ranged from Monroe, OR, in the south to Shelton, WA, in the north, a distance of 372 km. Except for a few plantations that were at elevations above 200 m, most of the plantations were at elevations below 100 m. Trees were dug and transported to Washington State University, Puyallup, where they were held at 4 C. Roots were washed to remove soil and shallow cuts were made in the roots and tree stems to determine the extent of root rot and stem cankers. Data were taken on tree height, canker location (root and stem), stem canker length, presence of flagged (dead or wilting) branches, stunted growth, and tree color. The extent of root rot was estimated by a visual root disease rating based on a 0–10 scale, where 0 = no root rot, 1 = 1–10% roots rotted, and 10 = 91–100% roots rotted.

Isolations were made from both root and stem cankers. Six to eight small pieces of root and stem tissue from each tree were surface-sterilized in a 1:4 dilution of 5.25% NaOCl (bleach) for 1 min, rinsed twice in sterile water rinses, and blotted on sterile towels. Sterile pieces were plated on Difco (Detroit) cornmeal agar (2%) amended with pimarin (10 mg a.i./L), ampicillin (250 mg/L, Sigma Chemical Co., St. Louis), and rifamycin (10 mg a.i./L). Culture dishes were inverted and stored in the dark at 20 C. Dishes were checked daily for characteristic colony growth and coenocytic hyphae. Transfers from colonies were made to V8 agar dishes for growth studies and oogonia production. Isolates exhibiting characteristics typical of *Phytophthora* were transferred to cornmeal agar plus pimarin (10 mg a.i./L) for further identification (11).

Isolation and identification of *Phytophthora* spp. recovered from symptomatic trees followed the methods and keys by Hamm and Hansen (11,12). Isolates were transferred to clarified V8 agar to compare colony morphology and initiate the formation of sexual structures. Colonies were grouped based on similar colony morphology and the production of oospores of similar morphology, chlamydospores, or the failure to produce oospores. Sporangia production was induced by growing each isolate in pea broth followed by incubation in soil-extract water (12). Groups were confirmed by comparing sporangial characteristics. Growth rate of each isolate after 6 days at 20, 35, and 30 C on cornmeal agar was determined and used to confirm groupings. Nearly all homothallic isolates could be identified following these keys. Heterothallic isolates were paired with known A¹ and A² isolates of *P. cinnamomi* (Oregon State University culture collection 362 and 363 for A¹ and A², respectively) and *P. cambivora* (550 and 551 for A¹ and A², respectively). Most heterothallic

isolates could be identified by this pairing, growth rate, and colony and sporangial characteristics.

RESULTS

Isolations were made from a total of 158 trees exhibiting one or more symptoms of root rot and stem canker disease. Tree heights ranged from 39 to 130 cm, the average height of all the sampled trees was 77.8 cm (Table 1). Root rot ratings for the trees in a given plantation ranged from 0.7 to 8.4 with an average for all trees of 5.7 (Table 1). Approximately 74% of the trees exhibited branch flagging, 35% had reduced leader growth, and 82% had one or more stem cankers (Table 1).

Stem cankers were associated with diseased roots and extended up the sides of trees as narrow cankers. In some instances, cankers spiraled around the stem. In all instances, the bases of the flagged branches were associated with a stem canker. Stem cankers were evident on trees with limited root rot; only one or two diseased roots were present. Stem cankers were slightly sunken, particularly near the base of the tree. On some trees there was resinous material evident



Fig. 1. Five-year-old Noble fir tree with the lower branches and bark removed to expose a stem canker extending up the right side of the tree. The branch with the light colored foliage originating in the cankered area is dead.

on the surface of the basal portion of the cankered stems. Stem canker lengths on trees in plantations ranged from 10 to 70 cm (Table 1). The average height of cankers that extended up the stem was 30.3 cm or about 40% of the average tree height.

Phytophthora spp. were isolated from 49 of the trees sampled in 20 of the 30 plantations (Table 2). *Phytophthora* was recovered from both the root and stem tissues. *P. cambivora* was the most common species, occurring on trees in eight plantations. *P. megasperma* Drechs.

BHR (broad host range) was isolated from trees in five plantations, while *P. gonapodyides* and *P. cryptogea* were found in four and three plantations, respectively. Two species, *P. cactorum* (Lebert & Cohn) Schröt. and *P. citricola* Sawada were isolated from trees in two

Table 1. Noble fir Christmas tree survey sample tree characteristics

Site	Location	No. of trees	Avg. tree height (cm)	Avg. root rot rating ^a	No. of trees with flagged branches	No. of stunted trees	No. of trees with stem cankers	Avg. canker length (cm)
1	Alesea, OR	10	71.1	5.9	10	7	10	25.6
2	Monroe, OR	3	87.0	5.3	0	3	3	11.0
3	Albany, OR	5	101.8	8.2	5	2	5	31.1
4	Rochester, WA	10	62.7	6.1	6	4	3	24.0
5	Grays Harbor, WA	12	51.7	5.3	11	0	10	28.1
6	Rochester, WA	5	71.0	6.6	5	1	4	26.0
7	Morton, WA	4	77.3	5.3	4	0	4	28.5
8	Mossyrock, WA	3	100.0	7.3	1	1	3	17.0
9	Onalaska, WA	5	113.2	5.6	4	1	5	55.0
10	Chehalis, WA	5	110.8	8.4	5	0	5	57.6
11	Shelton, WA	6	111.8	3.7	6	3	6	29.2
12	Shelton, WA	4	83.5	4.8	3	3	2	64.0
13	Shelton, WA	5	88.0	4.4	5	4	5	36.8
14	Shelton, WA	5	68.8	7.0	3	4	4	16.0
15	Shelton, WA	5	130.6	8.0	2	2	5	18.8
16	Shelton, WA	3	124.7	0.7	2	1	3	70.0
17	Portland, OR	10	39.0	4.4	1	0	0	0.0
18	Skyline Rd., OR	5	65.0	8.2	0	1	3	16.0
19	Skyline Rd., OR	5	55.8	6.0	2	2	4	18.0
20	Dixie Mt., OR	3	42.3	3.3	2	2	3	19.0
21	Dixie Mt., OR	2	85.0	5.0	2	0	2	27.0
22	Dixie Mt., OR	5	106.8	5.8	4	1	5	27.0
23	Mollala, OR	5	81.4	4.6	3	3	5	23.8
24	Oregon City, OR	5	50.2	7.5	4	1	4	52.5
25	Canby, OR	5	72.4	5.8	3	0	4	39.0
26	Canby, OR	3	50.7	8.0	1	1	3	10.3
27	Canby, OR	7	76.7	8.2	6	1	7	32.2
28	Estacada, OR	5	108.0	7.0	5	0	5	36.2
29	Estacada, OR	6	40.2	2.6	5	5	5	18.7
30	Estacada, OR	2	93.5	7.5	1	1	1	20.0

^aRating based on a 0-10 scale, where 0 = no root rot, 1 = 1-10% of roots rotted, and 10 = 91-100% of roots rotted.

Table 2. *Phytophthora* spp. recovered from Noble fir Christmas trees with root rot and stem canker disease

Site	Location	No. of trees isolated	No. with confirmed <i>Phytophthora</i>	<i>Phytophthora</i> sp. ^a										
				cac.	camb.	citri.	cinn.	crypt.	gonap.	mega.	Unknown 1	Unknown 2	Unknown 3	
1	Alesea, OR	10	4		2						1		1	
2	Monroe, OR	3	1				1							
3	Albany, OR	5	1		1									
4	Rochester, WA	10	8 ^b					1	1	7				
5	Grays Harbor, WA	12	3		1					2				
6	Rochester, WA	5	2 ^b		1				2					
7	Morton, WA	4	1						1					
8	Mossyrock, WA	3	3	2		1								
11	Shelton, WA	6	2		2									
13	Shelton, WA	5	1							1				
14	Shelton, WA	5	1											
15	Shelton, WA	5	1						1					
17	Portland, OR	10	5	2		3								
20	Dixie Mt., OR	3	0											
22	Dixie Mt., OR	5	1					1						
23	Mollala, OR	5	1		1									
24	Oregon City, OR	5	1								1			
25	Canby, OR	5	3 ^b		1			2		1				
26	Canby, OR	3	3				1						2	
27	Canby, OR	7	2		2									
28	Estacada, OR	5	1											1
29	Estacada, OR	6	5									5		

^a*Phytophthora* spp. are *P. cactorum* (cac.), *P. cambivora* (camb.), *P. citricola* (citri.), *P. cinnamomi* (cinn.), *P. cryptogea* (crypt.), *P. gonapodyides* (gonap.), and *P. megasperma* (mega.).

^bRecovered more than one species from the same tree.

plantations, and *P. cinnamomi* was isolated from trees in a single plantation. In 12 plantations only a single species was recovered; five plantations yielded two species; and three species were found in three of the plantations. In all but three cases, only a single species was recovered from a given tree. The exceptions were a tree from which *P. megasperma* BHR and *P. gonapodyides* were isolated from diseased roots; a tree from which *P. cambivora* and *P. gonapodyides* were isolated from a stem canker; and a tree from which *P. megasperma* BHR and *P. cambivora* were isolated from the roots and stem.

In addition to these species, there were three groups of isolates that were not easily identified. Group 1 was isolated from trees in three widely spaced plantations in Oregon (Table 2). Groups 2 and 3 were isolated from trees in single plantations near Estacada and Canby, OR. Tentative identification of the isolates in these groups indicates that isolates in group 1 most closely resemble *P. pseudotsugae*; isolates in group 2 are most likely *P. cactorum*; and the isolate in group 3 is most likely *P. cambivora*.

DISCUSSION

There are very few reports of stem cankers associated with *Phytophthora* diseases of conifers. Small basal stem cankers have been reported on Fraser fir (*A. fraseri*) (2). Stem cankers also have been reported on Red fir (*A. magnifica*) after aerial infection of shoots on trees by *P. citricola* in a Christmas tree plantation in California (16). After infection of shoots, the fungus spreads down the branch into the stem, causing stem cankers, top dieback, and mortality. In addition, basal cankering of the stem is associated with infection of Port Orford cedar (*Chamaecyparis lawsoniana*) by *P. lateralis* (13). However, none of these describe a stem canker associated with root rot that moves apically out of the roots in narrow or spiraling bands that eventually cause branch flagging.

Although all of the *Phytophthora* spp. isolated from symptomatic trees are known pathogens of Noble fir (1,8-10), this is the first report of *P. cambivora* and *P. citricola* associated with stem cankers and root rot of Noble fir in the Pacific Northwest. In previous instances, these *Phytophthora* species have been associated with a root rot of bare root seedlings in nurseries in the Pacific Northwest. Our survey identified three additional species, *P. megasperma* BHR, *P. cactorum*, and *P. citricola*, in addition to the four species (*P. cinnamomi*, *P. cryptogea*, *P. cambivora*, and *P. gonapodyides*) found during a limited survey conducted earlier (5) and confirmed that a number of *Phytophthora* species are

associated with root rot and stem canker disease of Noble fir Christmas trees in the Pacific Northwest. Recently completed field studies have shown that there are differences in the ability of the *Phytophthora* species isolated to cause stem cankers and subsequent mortality on inoculated Noble fir trees, similar to those differences seen in root rot on seedlings (G. A. Chastagner, unpublished data).

The damage to and death of large trees in plantations by a number of *Phytophthora* spp., was unexpected. Hansen et al (14) reported that *Phytophthora* spp. killed Douglas fir out-planted seedlings but primarily only those heavily infected when out-planted to typical forest sites. Most seedlings recovered and *Phytophthora* was isolated in declining frequency from the time of out-planting (14). Likewise, *P. cinnamomi* and *P. lateralis* both were implicated in root rot of Port-Orford cedar in nurseries and ornamental plantings in western Oregon and Washington during the 1950s (21). A later survey of dying ornamental plantings of Port-Orford cedar found predominantly *P. lateralis* (13). This agrees with Roth and Kuhlman (19) who did not consider *P. cinnamomi* root rot to be a threat to the Douglas-fir industry in the Pacific Northwest. In each case, the authors felt the inability to isolate *Phytophthora* was due to poor adaptability of the fungi away from a nursery environment. Before now, only *P. lateralis* had shown the ability to kill seedlings in nurseries and trees in forest sites in the Pacific Northwest. Soil compaction and poorly drained soils, typical of many plantations with diseased Noble fir Christmas trees, combined with the high susceptibility of Noble fir apparently allow infection to continue in field-planted seedlings.

Although fungicides can be used to control *Phytophthora* root rot in bare root conifer nurseries in the Pacific Northwest, they have not been effective in controlling development of *Phytophthora* root and stem canker disease on Noble fir in Christmas tree plantations (G. A. Chastagner, unpublished data). Current recommendations regarding the management of this disease include improving soil drainage, planting healthy seedlings, and planting conifer species that are less susceptible than Noble fir at sites conducive to disease development (7,8,10). In deciding on alternative conifers, growers will need to know the *Phytophthora* spp. present at the planting site and the susceptibility of the alternative conifers to those species.

ACKNOWLEDGMENTS

PPNW 0188, Project 0939, College of Agriculture and Home Economics, Washington State University, Pullman. Partial funding to support this research

was provided by the Northwest Christmas Tree Association. We thank R. Fletcher, M. Bondi, C. Landgren, S. Webster, J. Freed, and V. McQuarrie-Baker for their assistance in collecting the trees in this study.

LITERATURE CITED

- Adams, G. C., Jr., and Bielenin, A. 1988. First report of *Phytophthora cactorum* and *P. citricola* causing crown rot of fir species in Michigan. Plant Dis. 72:79.
- Benson, D. M., Grand, L. F., and Suggs, E. G. 1976. Root rot of Fraser fir caused by *Phytophthora drechsleri*. Plant Dis. Rep. 60:238-240.
- Brasier, C. M., Hamm, P. B., and Hansen, E. M. 1989. *Phytophthora* diseases: States of *P. gonapodyides*, *P. drechsleri*, and *P. cryptogea*. Pages 45-46 in: Report on Forest Research, 1989. HMSO, London.
- Brasier, C. M., Hamm, P. B., and Hansen, E. M. 1993. Cultural characters, protein patterns and unusual mating behavior of *Phytophthora gonapodyides* isolates from Britain and North America. Mycol. Res. 97:1287-1298.
- Chastagner, G. A. 1990. Keeping cut trees fresh. Northwest Lookout 23(3):32-44.
- Chastagner, G. A., Hamm, P. B., and Byther, R. S. 1990. Symptomatology of *Phytophthora* root and stem canker disease of Noble fir in the Pacific Northwest. (Abstr.) Phytopathology 80:887.
- Chastagner, G. A., Riley, K. L., and Hamm, P. B. 1990. Susceptibility of *Abies* spp. to seven *Phytophthora* spp. (Abstr.) Phytopathology. 80:887.
- Cooley, S. J., Hamm, P. B., and Hansen, E. M. 1988. Susceptibility of Northwest conifers to *Phytophthora* root rot. Tree Planters' Notes 40:15-18.
- Grand, L. F., and Lapp, N. A. 1974. *Phytophthora cinnamomi* root rot of Fraser fir in North Carolina. Plant Dis. Rep. 58:318-320.
- Hamm, P. B., and Hansen, E. M. 1982. Pathogenicity of *Phytophthora* spp. to Northwest conifers. Eur. J. For. Pathol. 12:167-174.
- Hamm, P. B., and Hansen, E. M. 1987. Identification of *Phytophthora* spp. known to attack conifers in the Pacific Northwest. Northwest Sci. 61:103-109.
- Hamm, P. B., and Hansen, E. M. 1991. The isolation and identification of *Phytophthora* species causing damage in bare-root conifer nurseries. Pages 169-179 in: IUFRO Work. Party S2.07-09: Dis. Insects For. Nurseries. Forestry Canada, Ottawa, Ontario.
- Hansen, E. M., Hamm, P. B., and Roth, L. F. 1989. Testing Port-Orford-Cedar for resistance to *Phytophthora*. Plant Dis. 73:791-794.
- Hansen, E. M., Roth, L. F., Hamm, P. B., and Jules, A. J. 1980. Survival, spread, and pathogenicity of *Phytophthora* spp. on Douglas-fir seedlings planted on forest sites. Phytopathology 70:422-425.
- Kuhlman, E. G., and Hendrix, Jr., F. F. 1963. *Phytophthora* root rot of Fraser fir. Plant Dis. Rep. 47:552-553.
- McCain, A. H., and Scharpf, R. F. 1986. *Phytophthora* shoot blight and canker disease of *Abies* spp. Plant Dis. 70:1036-1037.
- Nanney, B. 1986. Noble fir: That mysterious, difficult, and beautiful Christmas tree. Northwest Lookout 19(3):10-12.
- Preston, R. J., Jr. 1989. North American trees. Iowa State University Press, Ames.
- Roth, L. F., and Kuhlman, E. G. 1966. *Phytophthora cinnamomi*, an unlikely threat to Douglas-fir forestry. For. Sci. 12:147-159.
- Shew, H. D., and Benson, D. M. 1982. Fraser fir root rot induced by *Phytophthora citricola*. Plant Dis. 65:688-689.
- Torgeson, D. C., Young, R. A., and Milbrath, J. A. 1951. *Phytophthora* root rot diseases of Lawson cypress and other ornamentals. Oreg. Agric. Exp. Stn. Bull. 537.