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Impact of Pinewood Nematode in North America: Present and Future[1]

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Abstract: Bursaphelenchus xylophilus, pinewood nematode (PWN), is the most serious pest of pine forests in Japan, but in North America its role in pine wilt disease is still being studied. The PWN is known to infest many species of *Pinus,* with *P. nigra, P. sylvestris,* and *P. thunbergii* the most susceptible in the eastern United States. Because of its potential, several European countries (Finland, Norway, and Sweden) and Korea have established embargoes against the importation of coniferous wood from regions of the world known to be infested with the PWN. Although the PWN is not considered an economic pest in North American forests, the recent embargoes have established an impact on current forest management practices and an economic impact on North American export trade.

Key words: Bursaphelenchus xylophilus, distribution, economics, embargo, management, pinewood nematode.

The pinewood nematode (PWN) *Bursaphelenchus xylophilus* (Steiner and Buhrer) Nickle is considered the causal agent of pine wilt disease affecting many species of conifers. Pines (*Pinus* spp.) appear to be the most susceptible, and at least 27 species in the continental United States and 38 species worldwide (15) have been reported as hosts (22, Appleby, pers. comm.). The most susceptible pine species are the exotics, *P. nigra* Arnold, *P. sylvestris* L., and *P. thunbergii* Parl. Previous reports indicate that *P. sylvestris* serves as an excellent host for *B. xylophilus*; it is considered one of the most susceptible species in the genus *Pinus* (2,16,22). The nonpine hosts for PWN in the United States include *Abies balsamea* (L.) Mill., *Cedrus atlantica* (Endl.) G. Man. ex Carr., *C. deodara* (D. Don) G. Don, *Larix decidua* Mill., *L. larcina* (Du Roi) K. Koch, *Picea glauca* (Moench) Voss, *P. pungens* Engelm., and *Pseudotsuga menziesii* (Mirb.) Franco (16,22). Reports of PWN on these nonpines have been rare and are usually isolated cases; usually the trees are infested with other pests or stressed by environmental factors. Most reports of PWN in North America are from trees growing as ornamentals, especially *P. sylvestris,* but trees in natural forest stands, forest plantations, Christmas tree plantations, windbreaks, and conifer seed orchards are also included (22). The PWN is believed to be native to North America (28), but to date there is no indication the nematode has ever caused large-scale mortality of conifers growing in forests anywhere on this continent (5,26,28). This situation is in contrast to the epidemic in the pine forests of Japan (17,19).

In North America PWN is considered a component of the pine wilt disease complex which includes many coniferous hosts, PWN pathotypes, insect vectors and associates, fungi, bacteria, pathotoxins, and environmental stress factors including other pathogens (4,6,7,9,12,13,16,21–23,25,27). The PWN has been found in at least 36 states of the United States, including all states east of the Mississippi River (22). There are a number of reports of PWN from various provinces in southern Canada (Hopper, pers. comm.), but to my knowledge there are no reports from Mexico or from islands off the coast of the southern United States.

Because certain isolates of PWN have shown some degree of host specificity, nematode pathotypes have been proposed for some host–pathogen combinations (3,7). Since pathotypes exist, they are an important consideration in formulating re-

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search and disease management objectives. Specific pathotoxins also have been described for susceptible host–parasite combinations (7).

The principal insect vectors of the PWN (*Monochamus* spp.) belong to the order Coleoptera, family Cerambycidae. *Monochamus alternatus* Hope functions as a very efficient vector (17) in Japan; it is not known to occur in the forests of North America, but it has been intercepted several times at U.S. ports of entry (Nickle, pers. comm.). Because *M. alternatus* is an efficient vector that does not occur in the United States, prevention of its accidental introduction to the forests of North America is imperative. There are other species of Coleoptera reported to carry PWN, but their efficiency as vectors needs to be resolved (13,14).

Pine wilt disease has been known in Japan since the early 1900s, but it was not until 1971 that PWN was confirmed as the causal agent (11). Since 1973 the annual loss of pine timber in Japan frequently has exceeded 1 million m^3, with the greatest loss recorded in 1979 (2.4 million m^3). The most extensive losses in Japan have occurred in native stands of Japanese black (*Pinus thunbergii*) and red pines (*P. densiflora,* Sieb. and Zucc.), especially in the coastal areas where the mean annual temperatures exceed 14 C. Pine wilt is epidemic in these areas, and the nematode is considered the most serious pest of the pine forests (18).

Because of the serious damage caused by the PWN, the Japanese government in 1980 appropriated $35,000,000 for control programs (18). Additional monies were spent by local governments and private forest owners for control of PWN and its vector. By 1984 it was estimated that approximately 25% (650,000 ha) of the pine forests in Japan were infested with PWN (17). Recently, PWN has been found in northern Honshu and in scattered localities in the inland mountain areas where the mean annual temperature is 10–12 C. Many of these new infestations are centered around pulp factories and shipyards in Kyushu and southern Honshu (19). This suggests PWN recently was introduced by movement of infested pine logs into these areas. To date, PWN has not caused serious damage in these cooler regions, yet it survives and successfully reproduces in relatively few dead and dying trees.

Although the impact of PWN on pine forests in Japan has been well documented, its impact in North America is still being studied. In the United States PWN appears to be an endemic pest that is not known to be solely responsible for any extensive tree mortality. Most researchers in North America agree the nematode may interact with the host tree in several different ways. The PWN is a primary pathogen of exotic trees that are stressed. In native trees, however, it may act as a secondary invader when transmitted by ovipositing *Monochamus* spp. to trees stressed by other pests or following exposure to severe environmental conditions (9,10,16,22,27). In addition PWN may be transmitted during vector oviposition to cut timber where it lives and reproduces on the fungal population colonizing the dead wood (24).

In the southeastern United States PWN has been discovered in dying trees in southern pine seed orchards (6). The nematode has been isolated from trees colonized by secondary insects such as bark beetles (Scolytidae), weevils (Curculionidae), and wood borers (Cerambycidae). The PWN also has been found associated with diseases such as those caused by *Arceuthobium americanum* Nuttall ex Engelmann, *Cronartium ribicola* J. C. Fisch. ex Rabenh., *Diplodia pinea* Kickx., *Fusarium moniliforme* Sheld var. *subglutinans* Wollenw. & Reink., *Gremmeniella abietina* (Lagerb.) Morelet, and *Polyporus tomentosus* Fr. (4,8,9,22). Under these conditions PWN is probably a secondary invader surviving as a mycophagous organism.

In 1984 Finland placed a permanent embargo on all raw softwood shipments from North America, Japan, and other regions known to have PWN. This embargo was imposed when the Finnish Plant Quarantine Service discovered that conifer wood chips exported from North America were

TABLE 1. United States export values for wood chips shipped to countries currently having an embargo against *Bursaphelenchus xylophilus*.

Country	1981	1982	1983	1984	1985	1986†
Finland	2.5	10.7	11.7	5.7	1.0	0.0
Norway	3.9	2.9	0.4	‡	0.0	0.0
South Korea	1.3	0.0	0.0	0.0	0.0	0.0
Sweden	45.7	9.2	0.0	0.0	2.5	1.8
Total, embargo countries	53.4	22.8	12.1	5.7	3.5	1.8
Total, all countries	290.2	231.1	171.3	164.1	168.8	118.6

Data adapted from USDA, Foreign Agriculture Service, FPD. F.A.S. value in millions of dollars.
† January–September.
‡ <$1,000.

infested with the PWN (1). Sweden and Norway imposed similar import restrictions; the Norwegian restriction included kiln dried lumber. Recently Korea established restrictions against the importation of certain kinds of coniferous wood. In June 1985 members of the European Plant Protection Organization (EPPO) recommended that member countries adopt additional restrictions on importation of coniferous wood from countries known to have PWN. Currently, the United Kingdom and Australia are considering import restrictions, and other countries may follow suit (Blum, pers. comm.).

The recent embargoes have impacted the export trade (20). According to the United States Department of Agriculture, Foreign Agriculture Service, Forest Products Division (Blum, pers. comm.), the export value of wood chips and lumber has decreased since 1981 (Tables 1–4). In 1981 the value of wood chip exports from the United States was ca. $290 million, and ca. 18% of this value was exported to countries that now have established embargoes (Table 1). In 1983 this export value to embargoing countries dropped to about $12 million and by 1984 to $5.7 million. In 1986 the export value of wood chips shipped to embargoing countries totaled $1.8 million, all of which was sold on consignment to Sweden, and in 1987 total wood chip export was ca. $119 million. This decrease in wood export trade probably cannot be attributed solely to PWN embargoes; it may also be related to wood chip needs of the importing countries and the value of the U.S. dollar. The general decline in value of wood chip exports also was observed for nonembargo countries during the same period (Table 2).

TABLE 2. United States export values for wood chips shipped to selected countries currently not having an embargo against *Bursaphelenchus xylophilus*.

Country	1981	1982	1983	1984	1985	1986†
Australia	‡	‡	0.05	0.03	‡	0.01
Canada	1.48	1.50	2.02	1.54	4.62	5.08
Hong Kong	‡	0.00	0.02	0.02	‡	‡
Japan	235.18	206.78	156.94	156.62	160.62	111.42
Mexico	0.06	0.07	0.01	0.03	0.02	0.04
Netherlands	0.02	0.02	0.02	‡	‡	0.00
Spain	0.00	‡	0.00	0.00	0.00	0.02
Taiwan	0.00	0.00	0.00	0.00	0.00	0.14
West Germany	‡	0.00	0.01	0.02	0.01	0.00
Total, above countries	236.74	208.37	159.07	158.26	165.27	116.71
Total, all countries	290.18	231.14	171.27	164.06	168.81	118.60

Data adapted from USDA, Foreign Agriculture Service, FPD. F.A.S. value in millions of dollars.
† January–September.
‡ <$1,000.

TABLE 3. United States export values for softwood lumber shipped to countries currently having an embargo against *Bursaphelenchus xylophilus*.

Country	1981	1982	1983	1984	1985	1986†
Finland	0.07	0.06	0.07	0.13	0.01	0.01
Norway	1.03	0.92	0.98	1.19	0.82	1.20
South Korea	4.22	3.83	5.74	5.07	2.47	5.47
Sweden	1.06	0.15	0.14	0.19	0.06	0.10
Total, embargo countries	6.38	4.96	6.93	6.58	3.36	6.78
Total, all countries	652.57	574.84	600.86	529.41	492.38	510.08

Data adapted from USDA, Foreign Agriculture Service, FPD. F.A.S. value in millions of dollars.
† January–October.

Currently, the U.S. export of softwood lumber to embargoing countries does not constitute a large dollar value (Table 3). If important lumber importing countries impose embargoes that include lumber, the economic impact of PWN could become substantial (Table 4). Recent studies have shown kiln dried lumber should pose no risk, however, because kiln temperatures exceed the lethal temperatures for PWN (Dwinell, pers. comm.).

Eventually embargoes will have an impact on long-term forest management and harvesting decisions for North American forests. These forests are managed to produce wood on a long-term rotation basis. If wood is not removed as scheduled because of a lack of market, then stand improvement practices, such as thinning, will be delayed or not completed, ultimately affecting productivity and product quality from these forests.

The overall impact of PWN embargoes is substantial from both economic and forest management perspectives. The economic considerations are of immediate importance because of an already depressed forest industry and our continued concern for balance of trade. Millions of dollars worth of trade have been lost by U.S. chipwood industries. One company (Savannah Sales Corporation) recently (1985) claimed a $20,000,000 loss in potential sales of wood chips to European markets as a direct result of embargoes (Wayne Stubbs, pers. comm.). In addition, Canadian wood chip and lumber industries have shown millions of dollars worth of lost trade to Europe because of PWN (Hopper, pers. comm.).

In view of the PWN epidemic in Japan, these recent importation restrictions appear to be based solely on the perceived threat of PWN to the forest resources of the respective countries and the potential

TABLE 4. United States export values for softwood lumber shipped to selected countries currently not having an embargo against *Bursaphelenchus xylophilus*.

Country	1981	1982	1983	1984	1985	1986†
Australia	47.7	38.2	50.5	62.1	55.4	35.1
Canada	123.0	63.3	104.3	78.7	73.4	76.1
Italy	55.4	51.4	71.1	53.2	42.6	48.3
Japan	176.0	194.7	183.1	162.3	170.7	199.6
Mexico	43.8	25.1	12.9	21.7	30.0	25.4
Spain	10.2	18.0	17.5	14.8	13.9	19.4
United Kingdom	14.7	15.6	23.4	15.8	12.1	15.3
West Germany	28.0	24.4	23.0	15.0	10.7	12.4
Total, above countries	498.8	430.7	485.8	423.6	408.8	431.6
Total, all countries	652.6	574.8	600.9	529.4	492.4	510.1

Data adapted from USDA, Foreign Agriculture Service, FPD. F.A.S. value in millions of dollars.
† January–October.

threat to other countries of Europe (15). As Magnusson (15) recently said: "At present, there are reasons to be most restrictive concerning any possible means of introduction of *B. xylophilus.*" The wood pulp and lumber industries of the Nordic countries still maintain a strong interest in the importation of coniferous wood from North America, but current embargoes are preventing those shipments. A better understanding of the pine wilt system and its various components is needed before risks can be satisfactorily evaluated.

Literature Cited

1. Anonymous. 1984. Report from the Finnish Plant Quarantine Service on finding the pine wood nematode in coniferous pine chips imported from USA and Canada to Finland in 1984, Helsinki, Finland.

2. Bedker, P. J., and R. A. Blanchette. 1985. Pathogenicity of *Bursaphelenchus xylophilus* to Scots pine. Phytopathology 75:1338 (Abstr.).

3. Bedker, P. J., M. J. Wingfield, T. A. Burnes, and R. A. Blanchette. 1984. Host specificity of the pine wood nematode in the north central United States and Canada. Pp. 46–63 *in* V. Dropkin, ed. Proceedings of the United States–Japan seminar, Resistance mechanisms of pines against pine wilt disease. Available from the University of Missouri, Columbia, MO.

4. Bergdahl, D. R., D. L. K. Smeltzer, and S. S. Halik. 1985. Components of a conifer wilt disease complex in northeastern United States. Pp. 152–157 *in* V. Dropkin, ed. Proceedings of the United States–Japan seminar, Resistance mechanisms of pines against pine wilt disease. Available from the University of Missouri, Columbia, MO.

5. Bergdahl, D. R., and S. Halik. 1987. The pine wood nematode associated with conifer mortality in the Northeastern United States. Pp. 46–49 *in* M. J. Wingfield, ed. Pathogenicity of the pine wood nematode. Symposium Series. St. Paul, MN: American Phytopathological Society Press.

6. Blakeslee, G. M., T. Miller, and R. P. Esser. 1987. Observations on pine wood nematode-related mortality of sand and slash pine seed orchard trees in Florida. Pp. 40–45 *in* M. J. Wingfield, ed. Pathogenicity of the pine wood nematode. Symposium Series. St. Paul, MN: American Phytopathological Society Press.

7. Bolla, R. I., R. E. K. Winter, K. Fitzsimmons, C. Weaver, and P. Koslowski. 1987. Phytotoxins and pathotypes associated with the pine wood nematode in the United States. Pp. 26–39 *in* M. J. Wingfield, ed. Pathogenicity of the pine wood nematode. Symposium Series. St. Paul, MN: American Phytopathological Society Press.

8. Burnes, T. A., M. J. Wingfield, F. A. Baker, K. Knowles, and Y. Beanbien. 1985. The pine wood nematode in jack pine infected with Dwarf mistletoe. Forest Science 31:866–870.

9. Dwinell, L. D., and J. Barrows-Broaddus. 1983. Pine wilt and pitch canker of Virginia pines in seed orchards. Pp. 55–62 *in* Proceedings of the 17th Southern Tree Improvement Conference.

10. Hartman, A. L., L. R. Krusberg, and W. R. Nickle. 1986. Pine wood nematode, *Bursaphelenchus xylophilus*, associated with red pine, *Pinus resinosa*, in western Maryland. Journal of Nematology 18:575–580.

11. Kiyohara, T., and Y. Tokushige. 1971. Inoculation experiments of a nematode, *Bursaphelenchus* sp., onto pine trees. Journal of the Japanese Forestry Society 53:210–218. (In Japanese; English summary.)

12. Kobayashi, T. 1987. Microorganisms associated with the pine wood nematode in Japan. Pp. 91–101 *in* M. J. Wingfield, ed. Pathogenicity of the pine wood nematode. Symposium Series. St. Paul, MN: American Phytopathological Society Press.

13. Kondo, E., A. Foudin, M. Linit, R. Bolla, R. Winter, and V. Dropkin. 1982. Pine wilt disease—nematological, entomological and biochemical investigations. Bulletin SR 282, University of Missouri, Columbia, MO.

14. Linit, M. J., E. Kondo, and M. T. Smith. 1983. Insects associated with the pine wood nematode, *Bursaphelenchus xylophilus* (Nematoda: Aphelenchoididae), in Missouri. Environmental Entomology 12:467–470.

15. Magnusson, C. 1986. Potential for establishment of *Bursaphelenchus xylophilus* and the pine wilt disease under nordic conditions. OEPP/EPPO Bulletin 16:465–471.

16. Malek, R. B., and J. E. Appleby. 1984. Epidemiology of pine wilt in Illinois. Plant Disease 68: 180–186.

17. Mamiya, Y. 1983. Pathology of pine wilt disease caused by *Bursaphelenchus xylophilus*. Annual Review of Phytopathology 21:201–220.

18. Mamiya, Y. 1984. Pine wood nematode. Pp. 589–626 *in* W. R. Nickle, ed. Plant and insect nematodes. New York: Marcel Dekker.

19. Mamiya, Y. 1987. Origin of the pine wood nematode and its distribution outside the United States. Pp. 59–65 *in* M. J. Wingfield, ed. Pathogenicity of the pine wood nematode. Symposium Series. St. Paul, MN: American Phytopathological Society Press.

20. Nickle, W. R. 1985. Pine wood nematode causing raw wood export problems. Journal of Nematology 17:506 (Abstr.).

21. Oku, H., T. Shiraishi, S. Ochi, S. Kurozumi, and H. Ohta. 1980. Pine wilt toxin, the metabolite of a bacterium associated with a nematode. Naturwissenschaften 67:198–199.

22. Robbins, K. 1982. Distribution of the pine wood nematode in the United States. Pp. 3–6 *in* J. E. Appleby and R. B. Malek, eds. Proceedings of the National Pine Wilt Disease Workshop. Available from Illinois Natural History Survey, Urbana, IL.

23. Steiner, G., and E. M. Buhrer. 1934. *Aphelenchoides xylophilus* n. sp., a nematode associated with blue-stain and other fungi in timber. Journal of Agricultural Research 48:949–951.

24. Wingfield, M. J. 1983. Transmission of pine

wood nematode to cut timber and girdled trees. Plant Disease 67:35–37.

25. Wingfield, M. J., and R. A. Blanchette. 1983. The pine wood nematode, *Bursaphelenchus xylophilus* in Minnesota and Wisconsin: Insect associates and transmission studies. Canadian Journal of Forest Research 13:1068–1076.

26. Wingfield, M. J., R. A. Blanchette, and T. H. Nicholls. 1984. Is the pine wood nematode an important pathogen in the United States? Journal of Forestry 82:232–235.

27. Wingfield, M. J., R. A. Blanchette, T. H. Nicholls, and K. Robbins. 1982. Association of pine wood nematode with stressed trees in Minnesota, Iowa and Wisconsin. Plant Disease 66:934–937.

28. Wingfield, M. J., R. A. Blanchette, T. H. Nicholls, and K. Robbins. 1982. The pine wood nematode: A comparison of the situation in the United States and Japan. Canadian Journal of Forest Research 12:71–75.

End of Symposium