2
Pine Wilt in Japan: From First Incidence to the Present

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2.1 Historical Overview

Before pine wilt disease brought devastation to the majority of pine forests in Japan, most countryside forests, especially those in southwestern Japan, were dominated by Japanese red pine, *Pinus densiflora*. Actually, vegetation ecologists classified the flora of the southwestern region of Japan as a *P. densiflora–Quercus serrata* zone. Recently, however, it has become very difficult to find healthy pine trees in our surrounding mountains. The tiny, 1-mm-long, pine wood nematode (PWN) has dramatically changed our familiar flora.

As shown in Fig. I.1, the first incidence of pine wilt disease in Japan was reported in Nagasaki City on Kyushu Island in 1905 (Yano 1913). Since then, intensive efforts have been made to control this epidemic disease, and the first outbreak of pine wilt disease was stamped out by 1915. Pine wilt disease, however, recurred in a harbor town 50 km from Nagasaki City in 1925, and then gradually spread into the surrounding areas.

Pine wilt disease spread to the mainland in 1921, and old pines planted in a shrine in a harbor town in Hyogo Prefecture began to wilt, and the number of diseased trees increased year after year. In the 1930s, pine wilt disease spread gradually into neighboring prefectures both on Kyushu Island and the mainland. In the 1940s, life in Japan was harsh because of World War II and the forests were largely left unattended. As such, pine wilt disease devastated many pine forests. The disease spread rapidly, not only to surrounding regions but also to remote regions such as Shikoku Island and the Kanto districts.

After World War II, the General Headquarters (GHQ) of the Allied occupation military became seriously concerned about the spread of the devastation that was

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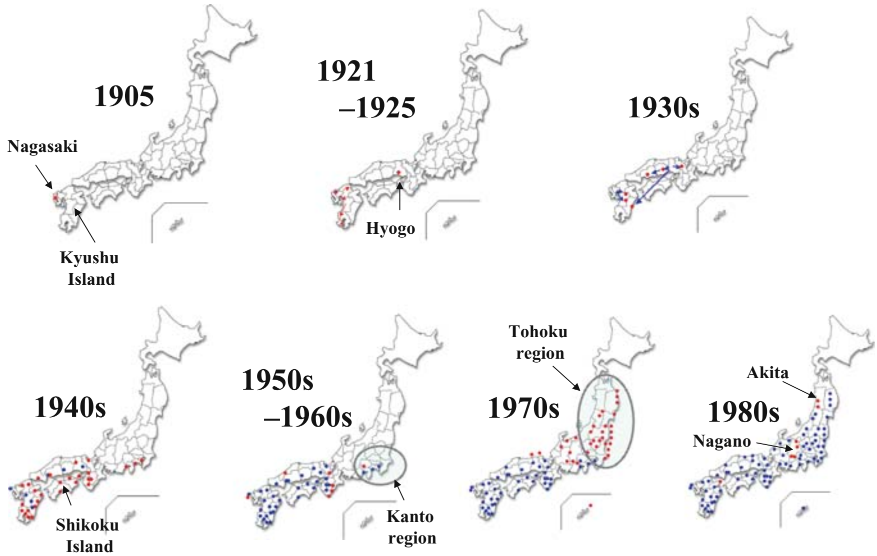

Fig. I.1 History of pine wilt spreading over Japan (see Color Plates)

occurring in pine forests throughout Japan. So much so that they asked Dr. R. L. Furniss, a forest entomologist, to inspect the many pine forests being affected by pine wilt disease. After intensive inspection he submitted two reports, in which he recommended very simple control methods "felling and burning" of dead pine trees. The GHQ implemented this recommendation and urged the Japanese government to start control methods. The extensive control efforts following Furniss' recommendations, together with the plentiful labor available then, succeeded in reducing the damage from pine wilt disease. Thus, the spread of pine wilt disease slowed down in the 1950s to 1960s.

At the beginning of the 1970s, a governmental project found the PWN as the causal agent of pine wilt disease and *Monochamus* beetles as its vector, and established new control tactics based on the newly discovered pine wilt disease cycle. The Japanese government pushed ahead with these policies by enacting a new law, "the Special Law in Force for PWN control", which recommended aerial spraying of insecticides to prevent mature feeding of *M. alternatus* and thereby suppress nematode infection. The annual loss of pine trees resulting from pine wilt disease, however, could not be reduced, but instead increased quickly, and the dry and hot summer of 1978 resulted in a marked expansion of pine wilt disease toward northern regions such as Kanto and Tohoku, and increased the annual loss up to two million cubic meters in 1978 until 1981.

In the 1980s, Nagano Prefecture and Akita Prefecture, both of which had remained free from pine wilt disease, were newly invaded. Thus, pine wilt disease prevailed throughout Japan except for the northernmost two prefectures, Aomori and Hokkaido.

2.2 Possible Factors Influencing Pine Wilt Disease Spread

The spread of pine wilt disease is influenced not only by climatic conditions such as temperature and precipitation, but also by edaphic, topographic, biological, and human factors.

2.2.1 Meteorological Conditions and Flight Ability of Vector Beetles

The flight ability of *Monochamus* beetles is an important factor affecting pine wilt disease spread, and is reported to be 50–260 m during a beetle's life span (Togashi 1990), but the combination of flight and wind can often carry beetles several kilometers.

Temperature determines both the rate of development and the mobility of PWNs and those of vector beetles, all of which influence pine wilt spread, while precipitation determines the host tree's water status. When infected by PWNs, pine trees show wilting symptoms, but the velocity of symptom development varies depending upon the host tree's water status. Thus, precipitation influences the spread rate of pine wilt disease.

2.2.2 Soil Eutrophication Adversely Affects Pine Trees

Based on the conservative and empirical idea that fully grown trees must be more resistant to disease, some plant ecologists supposed that pine trees would acquire resistance to pine wilt if they were fertilized. From the viewpoint of the mycorrhizal relationship, however, pine trees are healthier when growing in nutrient poor soils, even though their growth may be less. To examine which idea is most possible, my colleagues and I carried out a field experiment in a pine stand on a coastal sand dune in Tottori Prefecture, placing two 20 × 20 m plots side by side in the stand. One plot was left as the control, and received no treatment. The other plot was fertilized at a rate of 0.5 kg m^{-2} with a slow-release nitrogen fertilizer. The rate of pine wilt disease spread in the control plot was slower than in the fertilized plot. At the end of the experiment, many healthy pine trees remained in the control plot, while there were fewer surviving trees in the fertilized plot (Fig. I.2). Thus, the application of fertilizer, and therefore soil eutrophication, seemed to speed up pine wilt disease spread over the 3 years from 1997 to 2000.

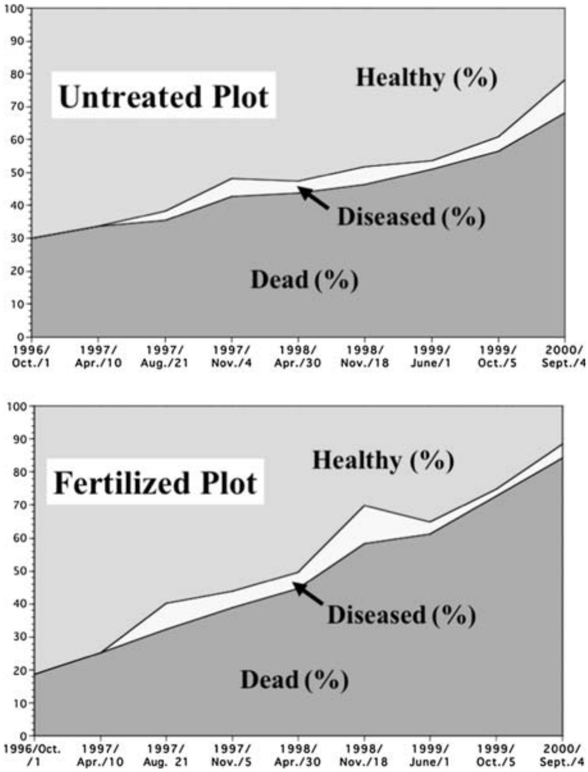

Fig. I.2 The effect of soil eutrophication on the spread of pine wilt disease in two small plots of Japanese black pine, *Pinus thunbergii*; one is fertilized and the other is non-fertilized plot

2.2.3 Topographic Conditions and the Role of the Mycorrhizal Relationship

When a pine stand on a slope is devastated by pine wilt, some healthy pine trees tend to survive at the mountain ridge top (Fig. I.3). The situation prevails to the present. This suggests that pine trees survive better on the upper part of a slope than on the lower part. To test this hypothesis my colleagues and I carried out a field survey from 1993 to 1998 at the experimental station of Kyoto University Forests in Yamaguchi Prefecture, located in the westernmost part of the mainland Japan. In a pine stand at the station, about 4,000 pine seedlings of 23 families of Japanese black or red pines were planted in 1973. The stand is ca. 1.4 ha, and is located on a 25° inclined slope with a height of about 50 m. All the pine families were planted in rows along the slope.

Since 1979, pine wilt has spread into this stand. By the end of 1993, the pine wilt damage had become severe, and more than 70% of the pine trees had been killed (Fig. I.4). However, by 1993 some of the pine families were surviving in quite high numbers. Using two families of such Japanese black pine, shown as the

Fig. I.3 Limited numbers of Japanese red pine trees are surviving on the ridge of a mountain after serious devastating by pine wilt disease (see Color Plates)

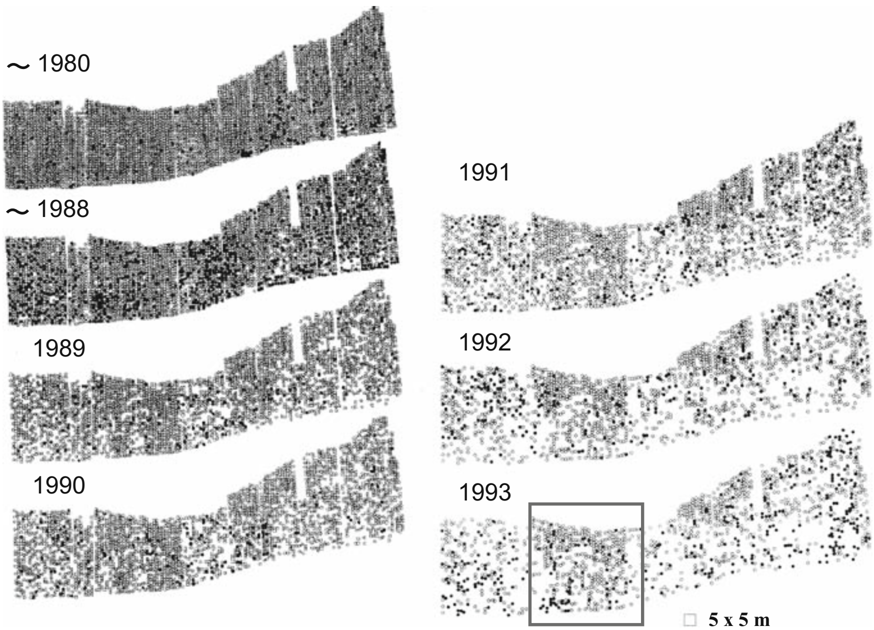

Fig. I.4 Decrease in surviving pine trees since 1980–1993 at a low hill in Tokuyama experimental forest station, Kyoto University Forest (after Nakai et al. 1995) framed area in the figure, we compared the survival along different heights of the slope. Table I.1 shows the survival of Japanese black pine along different heights of the slope. In both pine families the survival was higher at the upper part of the slope. To test a possible reason as to why this occurred we examined mycorrhizal development on trees at different heights along the slope. The results showed that, the number of fine tap roots and the mycorrhizal ratio (=the number of mycorrhized root chips / the total number of root chips examined) were higher on trees at the upper parts of the slope than lower on the slope (Fig. I.5).

In the summer in Japan, most plants are exposed to a dry and hot climate; however, pine trees planted at the higher part of a slope might well suffer less water stress as the result of water being supplied by the mycorrhizal symbiosis. Supposedly, the pines planted on the lower part of a slope could not obtain enough water to avoid such stress. We concluded that PWN affected pine trees growing on the lower part of such slopes must be far more vulnerable to the disease.

Table I.1 The survival ratio of Japanese black pine at different heights of a slope

	No. 241	No. 236
Upper part	74	65
Middle part	54	39
Lower part	35	17

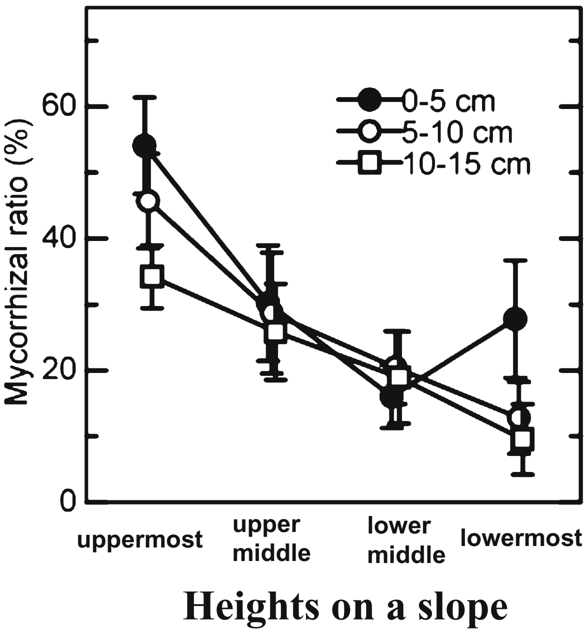

Fig. I.5 The proportion of mycorrhizae to the total of fine tap roots and mycorrhizae by fresh weight in each depth and at different heights on a slope. Samples were obtained from a small area of the slope shown in Fig. I.4. The area is enclosed in red line in the figure (after Akema and Futai 2005)

2.2.4 Asymptomatic Carrier Trees Ensure Continuity of Pine Wilt Disease—A Chain Infection Model

It is well known among forest workers that pine wilt disease often recurs in the vicinity of the stump of a pine tree that was killed the previous year, even after thorough eradication of the dead tree. Togashi (1980) called this phenomenon "hysteresis". To determine the mechanism of "hysteresis", the mode of pine wilt disease spread across a pine stand must be followed from the beginning of the incidence. A small stand consisting of 72 trees of 45-year-old Korean pine, *P. koraiensis*, provided an ideal opportunity to study this problem as inoculation tests have shown *P. koraiens* is to be one of the most susceptible species to pine wilt disease (Futai and Furuno 1979). Interestingly, this stand had been free from pine wilt disease until late autumn 1990 when two pine trees in this stand were killed by pine wilt. This situation provided an ideal opportunity to study the spread of the disease in this stand. The two dead trees (including their trunks, branches, and twigs) were removed from the stand in early spring, 1991. By early autumn, however, four more trees located near the stumps of the trees killed in the preceding year were killed by pine wilt disease. The next year, 1992, all the dead trees were again removed from the stand before spring. In early summer, however, *Monochamus* beetles visited some trees surrounding the stumps of dead trees and laid their eggs. Thus, pine wilt disease spread from tree to tree, and killed more than 40 trees until the end of the study in 1994. To determine the health status of all the pine trees in the stand, the resin exudation ability of the trees was examined once or twice a month, 58 times in total for 4 years, that is, from December 1990 to August 1994. The resin exudation data showed that some of the newly killed pine trees had already been infected in the previous year or earlier and then had survived without any visible symptoms. Such asymptomatic trees may play an important role in pine wilt epidemics.

Based on data from the above study of *P. koraiensis*, a chain infection model was proposed (Fig. I.6) to explain the mode of pine wilt spread, that is, where an asymptomatic carrier tree releases volatiles and attracts vector beetles. The conclusion is that, these asymptomatic trees play an important role in ensuring the continuity of pine wilt disease.

Recently, my colleagues and I established a new molecular method to detect PWNs in pine wood. This new method revealed that the number of asymptomatic trees in the field was far greater than expected (see Part IV). Thus, the role of asymptomatic carrier trees in spreading pine wilt disease may be more crucial than previously thought.

2.2.5 World-Wide Trade Could Facilitate the Invasion of Other Continents by Pine Wilt Disease

Since the beginning of the twentieth century, various nursery seedlings and natural products have been transported among continents. Many pests accompany such

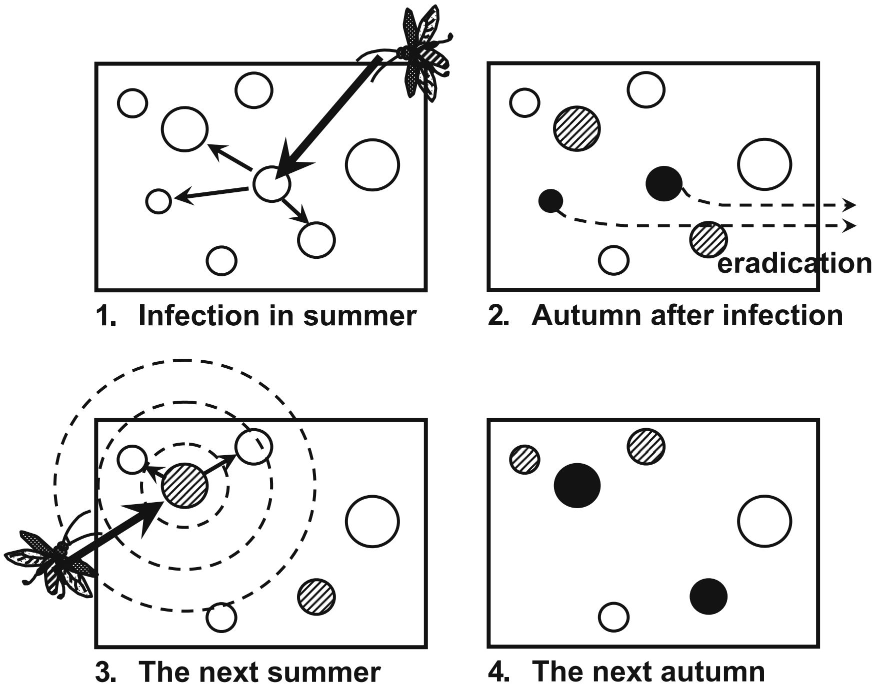

Fig. I.6 A chain infection model for the spread of pine wilt mediated by an asymptomatic carrier tree, proposed by Futai (2003a). This model was based on a study in a stand of *Pinus koraiensis* in Kamigamo Experimental Station, Kyoto University Forests, where dead pine trees were thoroughly eradicated before the next season of the pine wilt began. *Solid* and *shaded circles* represent dead and asymptomatic carrier trees, respectively. Immigration from outside the stand and translocation within the stand of vector beetles are represented as large and *small arrows*, respectively. *Long thin arrows* in the *top right* (2) mean the removal of dead trees from the stand. *Dotted circles* represent the diffusion of volatiles from diseased trees

products and plants are thus spread to other continents. At the beginning of the twentieth century pine wilt disease was also spread in this manner. Pine wood and wood products often carry PWNs or vector beetles, or both. For example, pine wood infested with vector beetles and PWNs was transported to the Okinawa Islands for use as construction material in 1973, and thereafter many Ryukyu pines (*P. luchuensis*) were killed by this disease. The PWN and its vector beetle could be concealed in these wood packing products, and thereby spread to other countries. Thus, global trade and human transportation enable pine wilt to move to previously uninfested regions.