



Title	Mortality Factors of <i>Pinus thunbergii</i> Planted Beyond the Northern Limits of Its Natural Distribution
Author(s)	KISHI, Youichi; ASARI, Masatoshi
Citation	Eurasian Journal of Forest Research, 6(2), 131-135
Issue Date	2003-09
Doc URL	<a href="http://hdl.handle.net/2115/22168">http://hdl.handle.net/2115/22168</a>
Type	bulletin (article)
File Information	6(2)_P131-135.pdf



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## Mortality Factors of *Pinus thunbergii* Planted Beyond the Northern Limits of Its Natural Distribution

KISHI Youichi<sup>1\*</sup> and ASARI Masatoshi<sup>2</sup>

<sup>1</sup> Tokyo University of Agriculture and Technology, Fuyu 183-8509, Japan

<sup>2</sup> Hokkaido University of Education, Hakodate 040-8567, Japan

### Abstract

In autumn throughout spring of 1999, *Pinus thunbergii*, which had been planted beyond the northern limit of its natural distribution, changed color in plots near the cities of Dalian in China and Hakodate in Japan. In Dalian area, dieback shoots of 40 trees near the coast, 40 trees with needle discoloration on tree tops and/or branches at windy sites and 80 trees with total discoloration in the hill forests were surveyed in June 1999. In Hakodate area, dieback shoots of 11 trees near the coast, 17 trees with needle discoloration at windy sites and nine trees with total discoloration were surveyed in November 1999. In both areas, harmful insects such as *Matsucoccus matsumurae* and diseases were not found, and *Bursaphelenchus xylophilus*, the causal agent of pine wilt disease, was not detected. Since the size of winter buds on damaged trees was normal, the trees would be damaged during winter, just before the investigation time. The weather data suggested that *P. thunbergii* trees suffered from winter desiccation injury in both areas. In Dalian area a minimal precipitation would seriously weaken *P. thunbergii* to cause enormous death of pine trees, while in Hakodate area a milder injury due to low precipitation would cause death in pine trees that had been stressed by some other factors.

*Key words:* Dalian city, Hakodate city, *Pinus thunbergii*, tree death, winter desiccation injury

### Introduction

The northern limit of natural distribution of *Pinus thunbergii* is the town of Oma (41.5 degrees North) in Japan (Hayashi 1952), and the city of Inchon (37.5 degrees North) on the Korean Peninsula (Uehara 1959)(Fig. 1). However, a large number of *P. thunbergii*

trees were planted in Japan and China beyond its natural limits.

In January to March 1999, needle leaves of planted *P. thunbergii* changed color in vast areas near Dalian city (39 degrees North) in China. In June 1999, one of the authors, Y. Kishi, completed field investigations at the

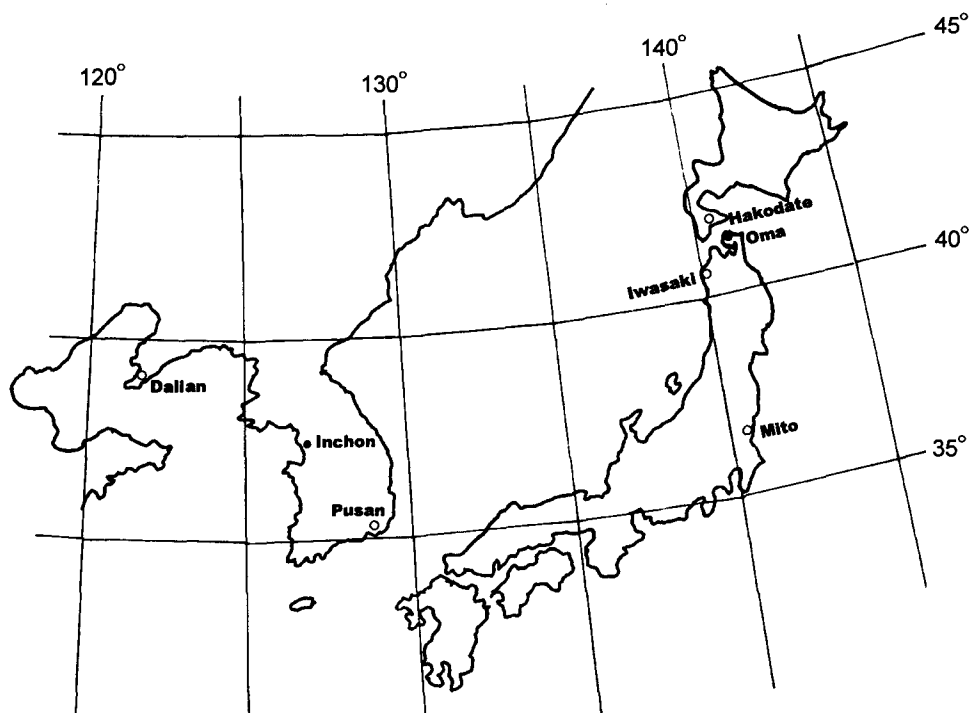


Fig. 1. Sites cited in this paper (○) and the northern limit of natural distribution of *Pinus thunbergii* (●).

invitation of the Dalian Association of International Exchange of Personnel. The Association had suspected that the numerous pine tree deaths were caused by the pine wood nematode, *Bursaphelenchus xylophilus*. In March to June 1999, needle leaves of the planted *P. thunbergii* near Hakodate city (42 degrees North) in Japan also changed color, and in November 1999, the authors diagnosed the discoloration at the request of the Hokkaido University.

We conducted thorough investigations on the presence of *B. xylophilus* and the pine scale, *Matsucoccus matsumurae*, on the damaged trees in the two areas, since East Asian *P. thunbergii* are often severely damaged by these parasites. According to our researches, the pine trees both in Dalian and Hakodate areas were not attacked by these parasites but seemed to be stressed due to winter desiccation. This finding helps confirm that planting *P. thunbergii* out of its natural range of distribution weakens the trees and contributes to their mortality.

## Materials and Methods

### 1. Dalian area

Dalian city is located on the Liaodong Peninsula, where *P. thunbergii* have been planted for dozens of years. Most pine trees are less than 10 m in height due to poor growth. The dominant species is *P. thunbergii*, with *Robinia pseudoacacia* also being represented.

Near the coast, dieback was consistently observed among pine shoots. We focused on two stands with damaged shoots. A 20-cm-long shoot sample was taken from each of the 40 damaged trees shorter than 5 m, and destructive insects and diseases were noted.

Needle discoloration of tree tops was frequently observed in the pine forests of urban windy sites. At two stands near the Dalian zoo, we investigated the size of winter buds, resin flow at hatchet cuts on stems, harmful insects and diseases, and wood nematodes in wood chips collected using a drill at one-meter intervals for 10 damaged trees that were felled. These same variables were examined at breast height on 30 trees that remained standing. Winter buds of 1 cm and over in length were considered normal, and those less than 1 cm were deemed small. Nematodes in wood chips were collected for 24 hours with the Baermann apparatus which were set at a hotel room, and put into a glass tube with alcohol for identification at the laboratory of Tokyo University of Agriculture and Technology.

In the hill forests situated on very poor gravel soil in more than dozens of hectares, pines with total needle discoloration occurred largely. At four stands in the east end of the city, we investigated the same variables as in the two stands near the Dalian zoo at one-meter intervals for 10 felled trees and at breast height for 70 standing ones.

### 2. Hakodate area

Hakodate city is located in the southern part of Hokkaido. *P. thunbergii* have been planted there for more than one hundred years. Pine trees grow more than 10 m on forest land, but their growth was poor on reclaimed land along the coast.

We investigated pine trees at four sites: Minatocho (roadside trees along the coast), Faculty of Fisheries of the Hokkaido University (planted trees on reclaimed land near the coast), eastern hill slope at the Hakodate water purification plant (planted trees on forest land), and southern hill slope at Yunokawacho (planted trees on forest land).

Dieback (Fig. 2) was observed among pine shoots of most roadside trees of Minatocho and most garden trees at Faculty of Fisheries. To survey destructive insects and diseases, 20 of 20-cm-long shoot samples were taken from damaged part of the foliage of the six roadside trees shorter than 4 m in total. The same number of the samples were collected from the five garden trees shorter than 8 m.

Needle discoloration of tree tops and/or branches (Fig. 3) was frequently observed on pine trees of windy sites. Most pine trees near buildings of Faculty of Fisheries showed discoloration of tree tops and/or branches. We investigated the size of winter buds, resin flow at hatchet cuts on stems, harmful insects and diseases for 17 standing trees shorter than 8 m. The discoloration also occurred on more than 20 pine trees taller than 10 m planted on forest land at the water purification plant.

The occurrence of total needle discoloration in Hakodate area was less than that in Dalian area. According to pictures taken by the staff of Faculty of Fisheries, 11 out of 120 garden trees had been felled in June 1999 due to total discoloration (Fig. 4), and three out of 11 stumps remained. A dead tree showing total discoloration, that had been severely pruned, was found at the water purification plant (Fig. 5), and was felled to survey harmful insects and diseases in the stem and branches. Five suppressed dead trees were felled to survey harmful insects and diseases at Yunokawacho, although dieback shoots and needle discoloration of tree tops were scarcely found on dominant trees taller than 10 m planted there.

Wood chips were collected from 17 standing trees with discoloration and three stumps at Faculty of Fisheries, one dead tree at the water purification plant, and five suppressed dead trees at Yunokawacho. Wood nematodes were extracted with the Baermann apparatus and identified at the laboratory of Tokyo University of Agriculture and Technology.

## Results

### 1. Dalian area

In the stands near the coast, larvae of unidentified shoot borer, similar to *Dioryctria splendidella*, were found in 25 % of dieback shoots but harmful insects and diseases were not present in the remaining 75 %. Those damaged trees were still alive and dieback was limited to shoots, although many of them were felled as dead trees.

In the stands near the Dalian zoo, detailed investigations were conducted on 10 felled trees (Table 1). Needle discoloration was limited to tree tops, while most winter buds grew normally. Resin seeped from hatchet cuts throughout the length of the tree, demonstrating that these trees lived in spite of tree top



Fig. 2. A pine tree of dieback shoots at the Hakodate water purification plant.



Fig. 3. A pine tree showing branch discoloration at Faculty of Fisheries of the Hokkaido University.



Fig. 4. A pine tree with total discoloration at Faculty of Fisheries of the Hokkaido University.



Fig. 5. A dead pine tree whose branches had been cut for several years at the Hakodate water purification plant.

Table 1. Notes observed on *Pinus thunbergii* (about 10 m in height) of tree-top discoloration felled near the Dalian zoo in April 1999.

Tree No.	Discoloration meters from top	Size of winter bud	Resin flow	Disease	Harmful insects	<i>Bursaphelenchus</i> sp.
1	2	Normal	Seep	Nil	Nil	Nil
2	2	Normal	Seep	Nil	Nil	Nil
3	2	Normal	Seep	Nil	Nil	Nil
4	2	Normal	Seep	Nil	Nil	Nil
5	2	Normal	Seep	Nil	Nil	Nil
6	2	Normal	Seep	Nil	Nil	Nil
7	1	Normal	Seep	Nil	Nil	Nil
8	1	Normal	Seep	Nil	Nil	Nil
9	2	Normal	Seep	Nil	Nil	Nil
10	1	Small	Seep	Nil	Nil	Nil

discoloration. Harmful insects and diseases were not found. According to the examination of 30 standing trees, the status of tree-top discoloration, winter buds, and resin flow of them were similar to those of the 10 felled trees. Harmful insects and diseases were also not found in these trees. *B. xylophilus* was not detected from wood chips collected from the 10 felled trees.

More than 90 % of the hill forest pine trees had been dead. Thorough investigations were conducted on 10 felled trees (Table 2) to determine the cause. Throughout the length of the tree, needle discoloration occurred and resin flow stopped. Winter buds had grown but were dry. Harmful insects such as *M. matsumurae* and diseases were not confirmed. Examination at breast height of 70 standing dead trees showed similar results as in the 10 felled trees. Wood chips collected from 10 felled trees and 22 standing ones, randomly sampled from the 70 trees, did not reveal *B. xylophilus*. The dead trees in Dalian area did not contain *Monochamus alternatus*, the primary insect vector of *B. xylophilus* in Japan, China and Korea (Morimoto & Iwasaki 1972, Wan et al. 1985, Yi et al. 1989).

## 2. Hakodate area

Harmful insects such as shoot borers and diseases were not found in the 40 dieback shoots (Fig. 2) collected from roadside trees of Minatocho and garden trees of Faculty of Fisheries. Dieback was limited at shoots, and these trees were not dead.

At Faculty of Fisheries, 17 pines planted at windy sites were investigated for needle discoloration of tree tops and/or main branches (Fig. 3). In nine out of 17 pines, a few branches had already been cut due to previous discoloration. Among the 17 pines, seven branches with discolored needle were taken for investigation. Winter buds grew normally but resin did not seep at hatchet cuts. No harmful insects such as *M. matsumurae* and diseases were found, nor was *B. xylophilus* in wood chips taken from the branches. A

branch showing no or slight needle discoloration was also taken from each of the 17 trees. Winter buds grew normally and resin seeped at hatchet cuts at breast height. No harmful insects and diseases were found, nor was *B. xylophilus* in wood chips taken from stems at breast height.

At Faculty of Fisheries, 11 pines had been felled due to total needle discoloration (Fig. 4) and three out of 11 stumps remained. A small amount of solidified resin was observed on the stump sections. *B. xylophilus* were not detected in wood chip samples taken from the stumps. In the dead tree that had been severely pruned at the water purification plant (Fig. 5), bark beetles, such as *Tomicus piniperda*, were observed and unidentified wood nematodes other than *B. xylophilus* or *B. mucronatus* were detected. Bark beetles and bark weevils were observed in the five suppressed dead trees at Yunokawacho, but harmful insects such as *M. matsumurae* and diseases were not found. *B. xylophilus* and *M. alternatus* were not detected in any dead trees in Hakodate area.

## Discussion

When severe pine damage in the cities of Dalian and Hakodate was reported, *B. xylophilus* and *M. matsumurae* were suspected as the causal agents of the damage. *P. thunbergii* had been destroyed by *B. xylophilus* on the southern Korean Peninsula and in Japan, except for in Hokkaido and Aomori Prefecture (Kishi 1995). Our research did not reveal *B. xylophilus* in any of the 42 damaged trees in Dalian area and the 26 trees in Hakodate area. In addition, *M. alternatus*, the primary vector of *B. xylophilus*, was not found, although it had been collected at Pusan city (Fig. 1) in Korea in 1988 and at Iwasaki village (Fig. 1) in Aomori Prefecture in 1995 (Aomori Prefecture 2002, Yi et al. 1989). *M. matsumurae* relentlessly destroyed pine trees in the middle of China (McClure et al. 1983) but were not found in this research. Since other harmful insects and diseases that can cause severe damage in pines

Table 2. Notes observed on *Pinus thunbergii* (about 10 m in height) of total tree discoloration felled in hill forests in June 1999.

Tree No.	Size of winter bud	Resin flow	Disease	Harmful insects	<i>Bursaphelenchus</i> sp.
1	Normal	Stop	Nil	Nil	Nil
2	Normal	Stop	Nil	Nil	Nil
3	Small	Stop	Nil	Nil	Nil
4	Small	Stop	Nil	Nil	Nil
5	Small	Stop	Nil	Nil	Nil
6	Normal	Stop	Nil	Nil	Nil
7	Small	Stop	Nil	Nil	Nil
8	Small	Stop	Nil	Nil	Nil
9	Normal	Stop	Nil	Nil	Nil
10	Small	Stop	Nil	Nil	Nil

were not confirmed in these areas, the tree damage was considered to be responsible for the other factors.

Dieback shoots, needle discoloration of tree tops and/or main branches and total tree discoloration occurred in January to March in Dalian area and in March to June in Hakodate area in 1999. The size of winter buds on the damaged trees was normal (Tables 1,2), suggesting that those trees had grown normally by the autumn of 1998. Thus it is probable that the tree damage is related to severe stress during the winter. Frost injury and winter desiccation injury are possible factors of the stress. However, it is unlikely that frost injury to pine trees occurred in the winter of 1999 because the average temperature during winter was 0.3°C in Dalian city and -2.0°C in Hakodate city which were considerably high or almost equal to the normal value of -2.8°C and -2.3°C, respectively.

In contrast, there was minimal rain in Dalian area in the winter of 1999. The total precipitation in Dalian city from December 1998 to February 1999 was 1.9 mm while the normal value records 31 mm, which was the lowest on record since 1951. In Hakodate area monthly total precipitation in January 1999 was 56.5 mm while the normal value records 72.6 mm. In Mito city (36.5 degrees North) in Japan (Fig. 1), winter desiccation injury caused significant tree death in Japanese cedar and cypress when monthly total precipitation in January was less than 20 mm (normal value: 34 mm). It also caused dieback shoots, needle discoloration of tree tops and/or main branches, and a few tree deaths when it was 20 to 60 mm (Horiuchi 1969). However, *P. thunbergii* trees in habitat seldom died when the injury was severe (Horiuchi private letter).

Judging from the precipitation in January 1999, the pine trees in Dalian area were subjected to more serious stress than in Hakodate area. In Dalian area winter desiccation injury due to minimal precipitation would seriously weaken *P. thunbergii* that had been stunted in growth by the incompatible site conditions, and cause enormous pine death in the hill forests of gravel soil. In Hakodate area milder draught injury due to low precipitation would cause death in a small number of pines that had been weakened by some other factors such as pruning and suppression. Consequently, *P.*

*thunbergii* planted beyond the northern limit of their natural distribution are considered to be vulnerable to death from winter desiccation injury when the injury is severe.

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