論　文

Temporal Pattern of the Occurrence of Weakened *Pinus thunbergii* Trees and Causes for Mortality

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TOGASHI, Katsumi: **Temporal pattern of the occurrence of weakened *Pinus thunbergii* trees and causes for mortality J. Jpn. For. Soc. 71: 323～328, 1989** To confirm that a nematode, *Bursaphelenchus xylophilus,* is the major mortality factor in pine forests infested with the pine wilt disease, its presence and the emergence of a horntail wasp, *Sirex nitobei,* from dead trees in a *Pinus thunbergii* stand were studied for four years. Oleoresin exudation was checked on all trees from May to October to determine their state of health. Newly-weakened trees increased from June to August and then remained constant until October. Among 168 trees which were weakened from June through October, 141 trees died by late May of the next year. *B. xylophilus* and *S. nitobei* were detected in 99 and 16% of the dead trees, respectively. Four trees with little or no foliage and 2 bent trees damaged by snow and 1 suppressed tree without feeding scars by *M. alternatus* adults were included in the 141 dead trees. Thus, the major factor was concluded to be *B. xylophilus.* Nineteen trees died between November and May although they did not weaken previously from June through October. *B. xylophilus* and *S. nitobei* were detected in 89 and 11% of them, respectively. However, the 19 dead trees were small and suppressed before their attacks. The major factor was considered to be intraspecific competition (suppression). No fruiting bodies of three root-attacking fungi, *Rhizina undulata, Onnia orientalis,* and *Armillaria mellea,* were found.

富樫一巳：**クロマツ林における衰弱木の時間的発生パターンとそれらの枯死要因　日林誌 71：323～328, 1989**　材線虫病に冒された林での衰弱木の発生パターンと枯死要因を明らかにするために，クロマツの1林分で4年間に発生した全枯死木についてマツノザイセンチュウとニトベキバチの有無を調査した。木の健康状態を知るために，5月から10月までの各月に全立木の樹脂滲出能の調査を行った。衰弱木の発生数は6月から8月まで増加したが，その後10月までほぼ同数であった。6月から10月までに衰弱し始めた168本のマツのうち141本のマツが翌年の5月下旬までに枯れた。マツノザイセンチュウとニトベキバチはそれぞれ99%と16%の枯死木から検出された。141本のマツには雪によって葉を失った4本のマツ，幹の曲がった2本のマツおよび1本の被圧木しか含まれていなかった。このため，主要な枯死原因はマツノザイセンチュウだと考えられた。6月から10月までに衰弱を示さなかったのに，11月から翌年の5月までに19本のマツが枯れた。これらの主要な死亡原因は種内競争だと考えられた。なお，ツチクラゲ，アズマタケおよびナラタケの子実体の発生は認められなかった。

I. Introduction

Japanese black pine, *Pinus thunbergii* PARL., and Japanese red pine, *P. densiflora* SIEB et ZUCC., have been heavily damaged by the pine wilt disease in Japan. This disease is caused by a nematode (KIYOHARA and TOKUSHIGE, 1971), *Bursaphelenchus xylophilus* (STEINER et BUHRER) NICKLE, which is vectored by a cerambycid, *Monochamus alternatus* HOPE (MAMIYA and ENDA, 1972; MORIMOTO and IWASAKI, 1972).

Pine trees are known to be killed also by other microorganisms, such as the root-attacking fungi, *Rhizina undulata* FRIES, *Onnia orientalis* (LLOYD) IMAZEKI, and *Armillaria mellea* (VAHL.) QUEL. (ITO, 1974), and a complex of the horntail wasp, *Sirex nitobei* MATSUMURA, and a fungus, *Amylostereum areolatum* (KOBAYASHI *et al.,* 1978).

The major mortality factor of trees is believed to be *B. xylophilus* after the invasion of the pine wilt disease

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on forests although trees killed by *R. undulata* or *O. orientalis* sporadically occurred and *S. nitobei* adults were caught in Ishikawa Prefecture. Thus, the causes for the mortality of recently killed trees in a *P. thunbergii* stand along the seashore of Ishikawa Prefecture were investigated to confirm if the major cause was *B. xylophilus*.

This paper deals with the temporal pattern of the occurrence of newly-weakened *P. thunbergii* trees and their destiny in a pine stand. Furthermore, the mortality causes of trees were studied in relation to the time when the trees weakened.

II. Study Site, Materials and Methods

The study stand, materials and methods have already been described in detail by the auther (TOGASHI, 1988). A brief review is provided here.

1. Study site

The study stand was 920 m^2 in area and was located on the Sea of Japan coast at Oshimizu in Ishikawa Prefecture. There were 249 live trees of *P. thunbergii* on the study site early in June 1980. Of them, 242 trees, which averaged 8 m high and 9 cm in dbh, were marked, and the 7 remaining trees, averaging 2.1 m high, were left unmarked because of their small size (Fig. 1). This stand was in an early stage of infestation by *M. alternatus* and *B. xylophilus* because only 6 trees had been killed by May 1980.

Insecticides had not been applied in the study area from 1980 to 1983, the period of this study. All trees killed were removed from the study site before the start of beetle emergence. Consequently, *M. alternatus* adults invaded the study stand from the surrounding pine stands.

2. Oleoresin exudation

As an indication of the initial onset of pine wilt, the cessation of oleoresin exudation was checked. Every month from May through October the degree of oleoresin exudation on all trees was observed using a method modified of ODA (1967). Early in each month, a thin tack (1.14 mm×0.56 mm×13.0 mm) was driven into the trunk of each tree. A tree was judged to be healthy when oleoresin exuded from the wound. If there was little or no exudation, a 38 mm long nail was hammered partially into the trunk. This was completed in the middle of a month. At the end of a month, a bark disc was removed from the trunk of each tree, which exhibited little or no oleoresin exudation during the second inspection, with a 7.0 mm diameter punch. A tree was judged to be weakened when there was little or no exudation during the third inspection (ODA, 1967). At the time of these inspections, trunks were wounded 0.8 to 1.5 m above the ground and oleoresin exudation was observed 5 to 7 h after wounding.

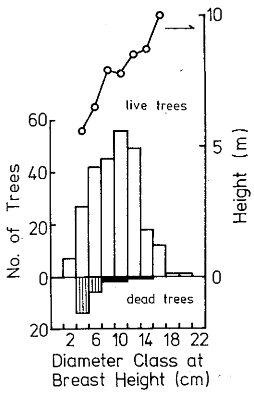

Fig. 1. Composition of the study stand late in the autumn of 1979

o : Mean height of live trees in each diameter class at breast height. ▥ : Pine trees judged to be dead of intraspecific competition. ■ : Pine trees judged to be killed by *B. xylophilus*.

Although some trees were judged to be weakened at the time of the previous month's inspection, they recovered and oleoresin exudation was found during the current month's inspection in spite of no exudation from the next month to October within a season. When this situation occurred, the month from which onwards the tree did not recover was designated as the month when the tree became weakened.

3. Foliage discoloration

Both weakened trees and trees with discolored needles were recorded at weekly intervals from June to October, and once to three times a month from November to May. Generally, foliage was discolored after the cessation of oleoresin exudation from the artificial wound. In this study, trees were judged to die when almost all of foliage was discolored.

4. Emergence of horntail wasps

After determination of the diameter at breast height of dead trees, they were felled, cut into 1-m-long logs, and marked individually. The logs were placed in outdoor cages at Tsurugi, Ishikawa Prefecture, between late in April and early in May to examine for the emergence of horntail wasps, *S. nitobei*. When there were *M. alternatus* egg-laying slits on the bark of dead tree trunks, some logs cut from the tree were used for this examination. When there were no egg-laying slits, all logs from the tree were used. All trees killed from June 1980 through May 1983 were used for this investigation.

5. Detection of B. xylophilus *and survey of fruiting bodies of root fungi*

Wood sample of *ca.* 7 g dry weight was taken from each trees several times after decline or death until the following May with a hand drill of 18 mm diameter. Using the BAERMANN technique, *B. xylophilus* was extracted from each sample at 25°C for 2～3 days. The survey of fruiting bodies of *R. undulata, O. orientalis,* and *A. mellea* were conducted every week from June to October and several times in the other months.

III. Results and Discussion

1. Temporal pattern of the occurrence of P. thunbergii *trees weakened from June through October and their destiny*

A total of 168 trees were weakened from June through October (Table 1). Newly-weakened trees increased monthly from June to August and then remained constant until October. Both small and large trees were involved (Fig. 2).

In trees weakened from June through October, many of them died by late May of the following year (Tables 1 and 2). However, some of them recovered and oleoresin exuded in the following May (Table 3). This often was observed in trees weakened in October (Tables 1 and 3). There was a remarkable difference in appearance among the recuperating trees in May of the following year. Some trees had small quantities of foliage because of the loss of 1-year-old foliage and poorly grown shoots. Others had similar foliage quantities and shoot elongations as healthy trees.

Twenty-eight weakened trees recovered enough for oleoresin exudation the next May (Table 3). Of them, 18 weakened again between June and October of the following year. Many of the trees weakened again in June or July in 1981 while many others weakened again in August or September in 1982～1984. Two trees, weakened in October 1982, repeated recovery and cessation of oleoresin exudation in both 1983 and 1984. One of them finally died in October 1984 (Table 3).

2. Mortality factors of trees weakened from June through October

A total of 141 trees, which weakened from June through October, died by late May of the next year (Table

Table 1. Seasonal changes in the number of newly-weakened trees of *P. thunbergii* in the stand

Year	No. of trees weakened in						Total
	May	Jun.	Jul.	Aug.	Sep.	Oct.	
1980	—(—)[a]	7(7)	1(1)	6(6)	15(15)	10(5)	39(34)
1981	0(0)	3(3)	10(10)	13(13)	19(18)	16(9)	61(53)
1982	0(0)	4(4)[b]	10(10)[b]	15(15)	2(2)	18(10)	49(41)
1983	1(0)	4(3)	1(1)	9(7)	4(1)	1(1)	20(13)
Total	1(0)	18(17)	22(22)	43(41)	40(36)	45(25)	169(141)
Percentage of trees which died	0.0	94.4	100.0	95.3	90.0	55.6	83.4

The figures in parentheses are the number of trees which died by the following May. [a] Not determined. [b] These figures include small trees which had not been marked in 1980. When they died, they were 4.53 and 2.68 m high, respectively, and 2.8 and 4.2 cm in dbh, respectively.

Table 2. Annual changes in stand density and numbers of healthy, weakened, killed, and *B. xylophilus* detected trees

Year	1980	1981	1982	1983	1984
Stand density in June (/ha)	2640	2110	1490	1030	900
No. of healthy trees in June (*H*)	242	194	137	95	83
No. of trees weakened from June to October (*W*)	39	61	49[a]	19	—[b]
Incidence of weakened trees (*W*/*H*)	0.16	0.31	0.36	0.20	—[b]
No. of trees which died by the following May (*D*)	34	53	41[a]	13	—[b]
Incidence of trees which died (*D*/*H*)	0.14	0.27	0.30	0.14	—[b]
No. of trees in which *B. xylophilus* was detected	34	52	40[a]	13	—[b]
No. of trees which were weakened and died between November and May	14	3	2	0	—[b]
No. of trees in which *B. xylophilus* was detected	12	3	2	0	—[b]

[a] These figures include 2 small trees which had not been marked in 1980. [b] Not determined.

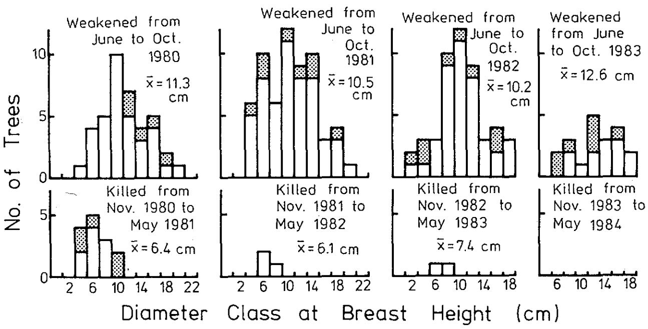

Fig. 2. Size distributions of the weakened and killed trees of *P. thunbergii* over four years

Top row: Trees weakened between June and October. Shaded portions indicate trees which recovered in May of the next year.
Bottom row: Trees which died between November and May, and which were not weakened previously from June to October. Shaded portions indicate trees damaged by snow.

2). *B. xylophilus* was detected in 139 of these trees (Table 2).

Snow broke or bent tree trunks or broke-off almost all of the branches. Out of 15 trees damaged by snow in January or February, 11 died by April of the next year. Three trees which lost all foliage by breakage of trunks were attacked by *M. alternatus* in July. These trees would die because of no photosynthesis even if they were not attacked by the beetles. Two trees whose trunks were broken in the crown became suppressed. They were not weakened by October, but died by the next April. From one of them, adults of *S. nitobei* emerged. A tree which lost all branches except three twigs of 65 cm long totally were attacked by *M. alternatus* late in June. One tree out of five trees whose trunks were bent began to be weakened in June and was attacked by *M. alternatus*. Another tree began to be weakened in October. The three remaining trees were suppressed by neighboring trees before snow damage occurred. They were not weakened by October, but died between December and April.

Tree # 134 was 6.97 m high, 5.6 cm in dbh, and 11 years old in 1980, and it had been suppressed. It ceased oleoresin exudation in June 1980, but it seemed healthy because its foliage was green. Feeding scars by *M. alternatus* adults were not found on any branches on July 7 nor was *B. xylophilus* detected in the wood taken on June 30, 1980. These results suggested that this tree was killed by a intraspecific competition for light (suppression).

From August through early October, *S. nitobei* adults emerged from 23 dead trees which were weakened between June and October. Many of these were large overstory and were not suppressed (Fig. 3). *B. xylophilus* was detected in 21 of these trees. The wasps usually oviposit on weakened trees such as suppressed trees of *P. thunbergii* and *P. densiflora* (Kato, 1966) and kill them in association with the fungus, *A. areolatum* (Kobayashi *et al.*, 1978). Thus, it was inferred that the trees were attacked by *S. nitobei* after they were weakened by *B. xylophilus*.

Pine trees may be killed by the three root fungi, *R. undulata, O. orientalis,* or *A. mellea* (Ito, 1974). Their fruiting bodies were not found on the ground of the study stand, which indicated that they could be omitted

Table 3. The destiny of weakened trees which recovered in the following May

Year	Months when trees were weakened[a)]	No. of weakened trees	No. of trees recovering in the following May	Months when trees were weakened the following year						Total
				May	Jun.	Jul.	Aug.	Sep.	Oct.	
1980	Oct.	10	5	0	1	3	0	1	0	5
1981	Sep.	19	1	0	0	0	1	0	0	1
	Oct.	16	7	0	1	1	1	0	1	4
1982	Oct.	18	8	0	0	0	1	2[b)]	0	3
1983	May	1	1	0	1	0	0	0	0	1
	Jun.	4	1	0	0	0	0	1	0	1
	Aug.	9	2	0	0	0	0	0	0	0
	Sep.	4	3	0	0	0	0	3	0	3

[a)] The months were omitted when all weakened trees died by the following May. [b)] These two trees were weakened again in 1983, recovered early in the next growing season and again were weakened in September 1984. One of them died in October 1984 and the other was still alive in 1985. The 14 remaining trees were weakened again and then died even though they had recovered the year after they were weakened.

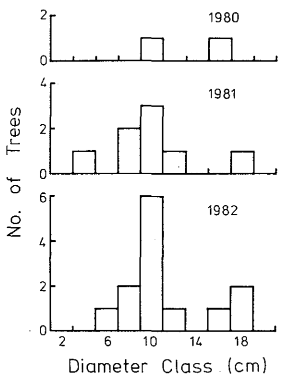

Fig. 3. Frequency distributions in diameter at breast height of *P. thunbergii* trees from which the horntail wasp, *S. nitobei*, emerged

The trees were weakened from June to October in the years shown and *S. nitobei* emerged from them the following year.

from the mortality factors of pine trees.

Summarizing the results, *B. xylophilus* and *S. nitobei* were detected in 99 and 16% of the 141 dead trees, respectively. Four trees with little or no foliage and 2 bent trees damaged by snow and 1 suppressed tree were contained in these dead trees. Thus, it was considered that most of mortality factors of pine trees which were weakened from June through October were *B. xylophilus* and that minor factors were snow, intraspecific competition (suppression), and the complex of *S. nitobei* and *A. areolatum*.

3. *Mortality factors of trees weakened and killed from November through May*

A total of 19 trees died from November through May during this study period, although they were not judged to be weakened from June through October. They were small in diameter at breast height and suppressed by neighboring trees (Fig. 2). Trunks of two trees were broken, and trunks of three trees were bent by snow one or more years before death. The trees with broken trunks were more than 10.0 cm in dbh, and the bent trees were less than 6.0 cm in dbh. *S. nitobei* adults emerged from two dead trees (11%), and *B. xylophilus* was detected in 17 dead trees (89%).

These results suggested that trees which weakened and died from November through May were weakened by intraspecific competition for light. Snow, *B. xylophilus*, and *S. nitobei-A. areolatum* appear to have hastened the death of such trees. Consequently, the primary mortality factor was considered to be intraspecific competition. This conclusion was supported by the reduced number of such trees with a decrease in stand density (Table 2).

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