論文（Original Article）

Recent Degradation of Conifer Plantations in the Kansai District of Japan

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Abstract

Cryptomeria japonica and *Chamaecyparis obtusa* are the main species used for timber production in the Kansai district. Most of the plantations are 20 to 50 years old. Today, landowners cannot afford to manage forests for timber production because of the abundant supply of cheap imported timber. In the plantations, sudden tree death and xylem degradation seem to be increasing. Surveys were carried out of the management history, climate, fungal infection, and insect damage in those plantations, and the possible factors associated with deterioration of tree health were examined. Xylem dysfunction had progressed due to repeated infection by pathogenic fungi from younger ages. In addition, longhorn beetles had invaded and enhanced infection by decay fungi. Beetle invasion and fungal infection are both often accelerated in those forests, where pruning and thinning are delayed. It appears that afforestation of unsuitable sites, such as those on shallow soils or along creeks, accompanied by fertilization, increased the damage by disease infection. The shift of forest management to longer cutting cycles also induces problems, such as freezing cracks in xylem associated with black and wet heartwood. It seems likely that, if conifer plantations are left unmanaged, mass mortality of trees, especially that associated with xylem degradation, will increase in the future.

Key words : Sudden death, *Cryptomeria japonica*, *Chamaecyparis obtusa*, forest management, water conduction, decay, infection

Introduction

Conifer plantations cover a total of 40% of the forested area of Japan. Two coniferous species, *Cryptomeria japonica* and *Chamaecyparis obtusa*, are the main species used for timber production in the Kansai district as well as in wider areas of Honshu Island. Afforestation was very active from the 1950s to the 1970s and then stagnated. Therefore, most plantations are between 20 and 50 years old.

Today, many plantations are not managed well. Landowners cannot afford to carry out pruning and thinning for timber production because the price of timber has greatly diminished due to abundant imports during the last three decades. Many plantations are overstocked and consist of trees with small diameters and many branches. In some plantations, trees are on a 100-year cutting cycle, without accurate planning, just to avoid high-cost management practices. Emerging problems, such as sudden death or xylem degradation of these planted conifers, have been reported by local governments in recent years. Such phenomena might be related to inappropriate forest management, and the future of the plantations has become a major cause for concern. To elucidate the causal factors of these problems, biotic and abiotic environments were assessed in those plantations. Presented here is an overview of the present condition of conifer plantations in the Kansai district, and the possible causal factors of plantation deterioration are discussed.

Materials and Methods

Sudden death and xylem degradation were found in conifer plantations in Shiga and Kyoto Prefectures. These problems,

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notified by local governments during 2001 and 2002, were investigated (Fig. 1). Two instances of deterioration were in *Cryptomeria* stands (Sites A and D), and the other two were in *Chamaecyparis* plantations (Sites B and C). As the private forests do not permit cutting dozens of trees for research, the present investigation was conducted as an optical survey with minimum cutting. From the results of the following investigation, the causal factors were considered, and the conditions that accelerate forest deterioration were assessed.

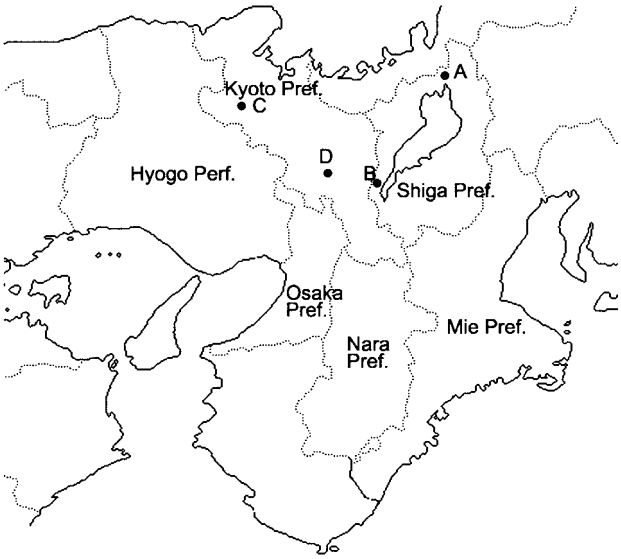

Fig. 1. Sudden death and xylem deterioration found in conifer plantations in the Kansai district during 2001 and 2002. A to D are the investigated sites.

Environmental aspects: Field surveys were made of the extent of the damage to the trees, including those with shoot bright or dieback. To find the causes of biological damage, disease symptoms and insect attacks were checked. As environmental factors, site conditions and recent weather conditions were checked. Local governments were asked to report on the management history of the stands and freaks of nature, such as a late frost or drought. Where climatic factors seemed to cause the problems, weather records on temperature and precipitation were inspected from AMeDAS (Japanese Meteorological Agency) data from 1992 to 2002.

Pathological and anatomical observations: When infection, insect attack, or xylem degradation was suspected or assumed, at least one tree was felled and cut into discs. The presence of fungal infection was checked, and the pathogens were identified directly under a microscope or after the incubation of tree tissues on a potato dextrose agar (PDA) medium at 25C. Insect damage, especially from longhorn beetles, causes significant xylem degradation (Kobayashi, 1986). The damage was observed from the scars on the surface or from cross sections of trunks. Anatomical changes in the samples were observed with binocular- and light-microscopes.

Results and Discussion

1. Sudden death in *Cryptomeria japonica* plantations in Shiga Prefecture

Complete and partial death of *Cryptomeria japonica* trees were found in May 2002 in 20- to 40-year-old plantations at several locations in Yogo-cho in the northern part of Shiga Prefecture (Fig. 1, Site A). When viewed from a distance, dead trees or shoots were scattered throughout the hills. Stands that include damaged trees were characteristically seen on plantations neighboring rice fields or among rows of trees along the roadside. Pruning and thinning had been delayed in some cases and done recently in others.

In affected stands, dead and wilting trees and those with treetop dieback showed evidence of attack, as scars on the bark, by longhorn beetles, *Semanotus japonicus* or *Anaglyptus subfasciatus* (Kobayashi, 1986). Decay and discoloration induced by fungi were found in a cross-section of a tree with treetop dieback associated with holes formed by the beetles (Fig. 2A). Xylem discoloration and decay covered most of the trunk cross-sections (Fig. 2A, B). It was evident that water conductivity had been seriously impaired by tracheid dysfunction associated with discoloration and decay. The water deficit must have occurred in the upper stems during periods of high transpiration during the spring of 2002 and apparently resulted in the death of branches or entire trees. From the discolored and dysfunctional xylem, the pathogenic fungus causing the *Guignardia* canker, *Guignardia cryptomeriae*, which will soon be known as *Botryosphaeria cryptomeriae* (Miyashita and Yamada, 2002), was detected (Kishi, 1998). Infection from this fungus usually starts from the base of the branches (Fig. 2D). *Cryptomeria japonica* and *Chamaecyparis obtusa* sometimes die from extensive xylem dysfunction following repeated infections by this fungus (Nakagawa et al., 1997). In addition, stripe cankers due to partial cambial lesions were observed on some main stems, including those of living trees (Fig. 2C). This diagnostic canker is formed by *Phellinus hartigii* or *Cercospora sequoiae* infection (Kishi, 1998). *Phellinus* infects from thick dead branches (Sinclair et al., 1987) that result from a lack of pruning. *Cercospora sequoiae* infects in nurseries, and trees with cankers must be removed at a younger age. Longhorn beetles increase

their population in dense, poorly lit stands, where the trees retain dead branches (Kobayashi, 1986). These factors suggest that infection and beetle invasion were both induced in affected plantations by a delay in pruning and thinning, which should have been done at a younger age of the trees.

This type of sudden death or shoot dieback will increase in the future as a result of poor forest management. It would be better to harvest and remove trees with severely degraded xylem (Fig. 2) from the plantations. Mass mortality of conifers is known to occur after severe droughts in plantations where *Guignardia* canker is frequently found (Nakagawa et al., 1997). Usually, such deaths have been reported as drought damage (Yositake and Shimada, 2001) without investigating the contribution of fungi to reducing xylem conductivity. It will be important to conduct a pathological survey to check the forest health.

Fig. 2. Discoloration, decay, and canker of *Cryptomeria japonica* found in some plantations with sudden death at Site A in Shiga Prefecture.

2A: Decay (arrow) associated with the invasion of longhorn beetles. 2B: Blockage of sap ascent (WB) caused by *Guignardia* infection (arrow). 2C: Stripe canker (arrow) caused by *Phellinus hartigii* or *Cercospora sequoiae* infection. 2D: Younger *Cryptomeria japonica* tree infected with *Guignardia* canker from several branch bases (arrows). (by courtesy of Dr. Miyashita)

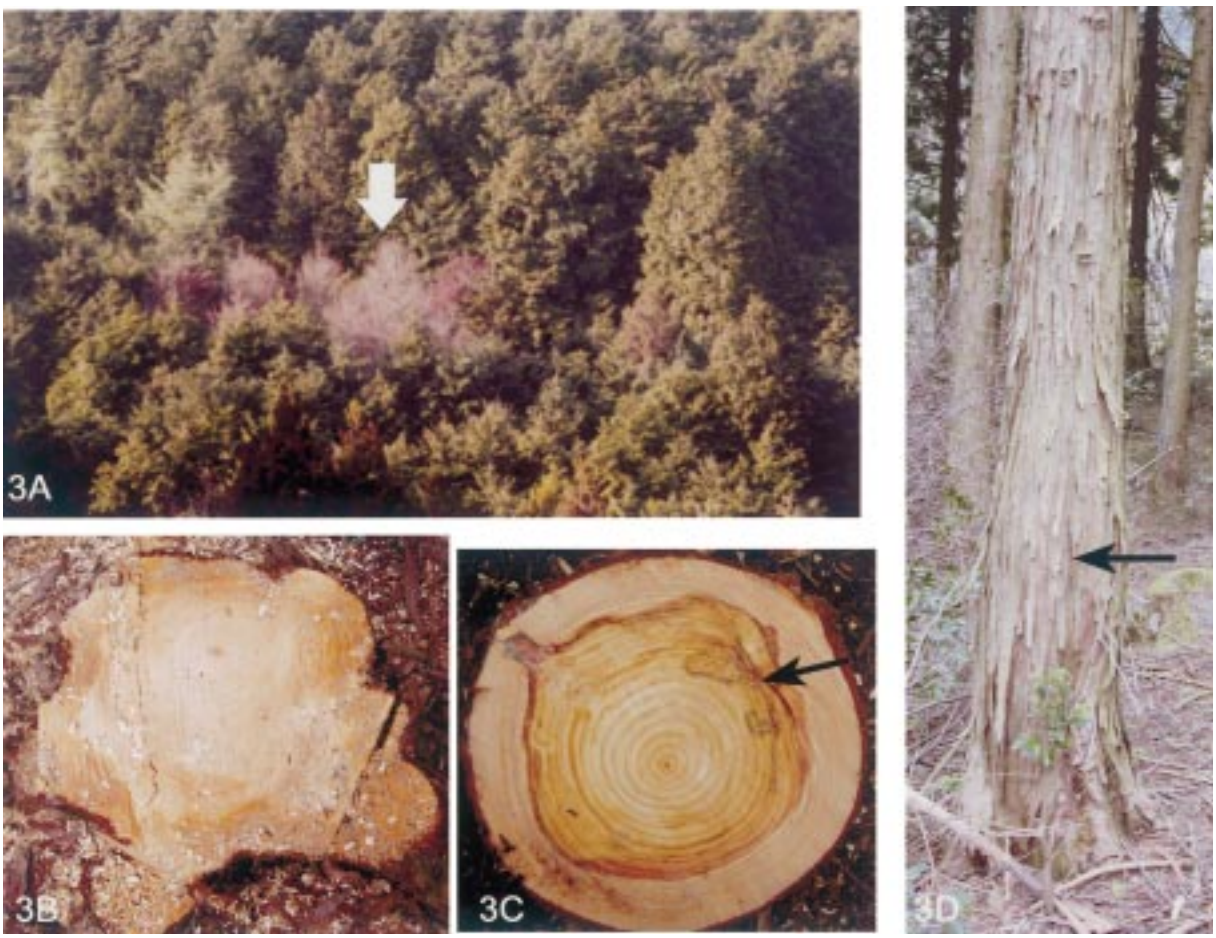

Fig. 3. Sudden death and xylem deterioration in a *Chamaecyparis obtusa* plantation at site B in Shiga Prefecture.

3A: Dead sixty-year-old trees (arrow). 3B: Base of a dead tree with broad annual rings. 3C: Cross-cut of 30-year-old trees (3D) with beetle damage, decay, and discoloration by fungal infection (arrow). 3D: Abnormally rough surface (arrow) of a 30-year-old tree due to fast radial growth.

2. Sudden death and xylem degradation in a *Chamaecyparis obtusa* plantation in Shiga Prefecture

Sixty-year-old *Chamaecyparis obtusa* trees suddenly died in July 2001 in Ootsu City in Shiga Prefecture (Fig. 1, Site B). All of twenty-seven trees in an area of 0.03ha were killed (Fig. 3A). Dead trees had been cut, and most stem wood had been removed from the site at the time of the survey. From the stump surfaces of dead trees, no evidence of fungal infection was detected. Abnormally broad annual rings (Fig. 3B) and very large crowns with thick branches indicated the effect of fertilization, which had taken place 30 years before. Damaged trees had grown on an elevated, stony site between two creeks. Trees may have suffered from water deficit during summer drought. Local government officials reported that fertilization was a popular practice that was carried out in many plantations to improve poor soil nutrient status. Root systems in these shallow soils may have been inadequate to maintain the large stems and crowns resulting from fertilization. More sudden death may occur in future.

Surrounding the dead stands, 30-year-old trees of *Chamaecyparis obtusa* also showed abnormality in growth (Fig. 3C, D). Swelling of the lower trunk accompanied by rough outer bark is known as a physiological disease of *Chamaecyparis obtusa*, "Tokkuri-byo (Liquer-bottle shape hypertrophy)" (The Phytopathological Society of Japan, 2000) (Fig. 3D). The causal factor is still unknown, but this phenomenon is sometimes found in plantations on rich soil. Attacks by longhorn beetles were found at high frequency in affected stands. On the cross section of one of those trees, xylem decay was found adjacent to the invasion galleries (Fig. 3C, arrow), as in the case of *Cryptomeria* trees at Site A (Fig. 2). Sapwood had partly discolored by fungal infection and/or was associated with the physiological abnormality. The increase in beetle population must be due to the large number of thick, dead branches where the beetles laid eggs (Kobayashi, 1986). The stands were very dense due to delays in pruning and thinning. Most of the trees in the stand appeared to have a degraded xylem and were unlikely suitable for timber production. Plantations in similar conditions probably exist in other fertilized sites, and some decision by the local government for remedial action will be necessary following more detailed surveys.

3. Sudden death in a *Chamaecyparis obtusa* plantation in Kyoto Prefecture

In a 35-year-old plantation of *Chamaecyparis obtusa* in Fukuchiyama City (Fig. 1, Site C), 60 trees were completely dead (Fig. 4), and the upper branches of about 30 trees surrounding the dead trees were partly dead in June 2002. The main stems of the dead trees were infected with blue stain fungi vectored by bark borers. However, the trunks of trees with partially dead crowns indicated neither infection by pathogenic fungi nor insect damage. Fungal hyphae and fruit bodies were found on the foliage of partly dead trees. By microscopic observation, they were identified as *Meliola* sp. and *Lophodermium chamaecyparisii* (Kishi, 1998). The pathogenicity of these fungi is not very strong, but the fungi are sometimes found on physiologically troubled trees. Again, the affected plantation was dense and dark due to delays in thinning and pruning. The AMeDAS weather data (Japanese Meteorological Agency, 1996) indicated that precipitation had been less than usual and the mean temperature during spring higher than usual in this area in 2001 and 2002 (Fig. 5). The trees may have suffered from strong water stress. Water deficit is the probable cause of sudden death, but a detailed investigation is necessary to determine the cause of this incident.

Fig. 4. Sudden death in a 35-year-old *Chamaecyparis obtusa* plantation at site C in Kyoto Prefecture that is surrounded by trees with treetop dieback.

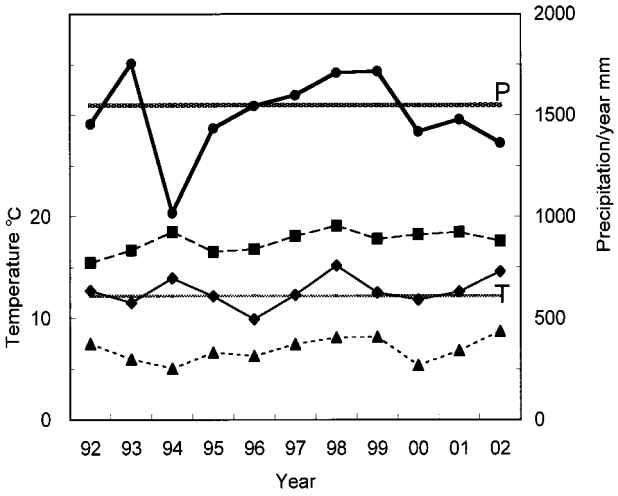

Fig. 5. Fluctuation of atmospheric temperature and precipitation in recent years in Fukuchiyama City (Site C) (From the AMeDAS Report)

Monthly mean temperature: March▲, April◆, and May■; and yearly precipitation: ● from 1992 to 2002. Normal values of mean temperature (April) and of precipitation: horizontal lines T and P (averaged data of 12 years from 1979 to 1990; Japanese Meteorological Agency, 1996).

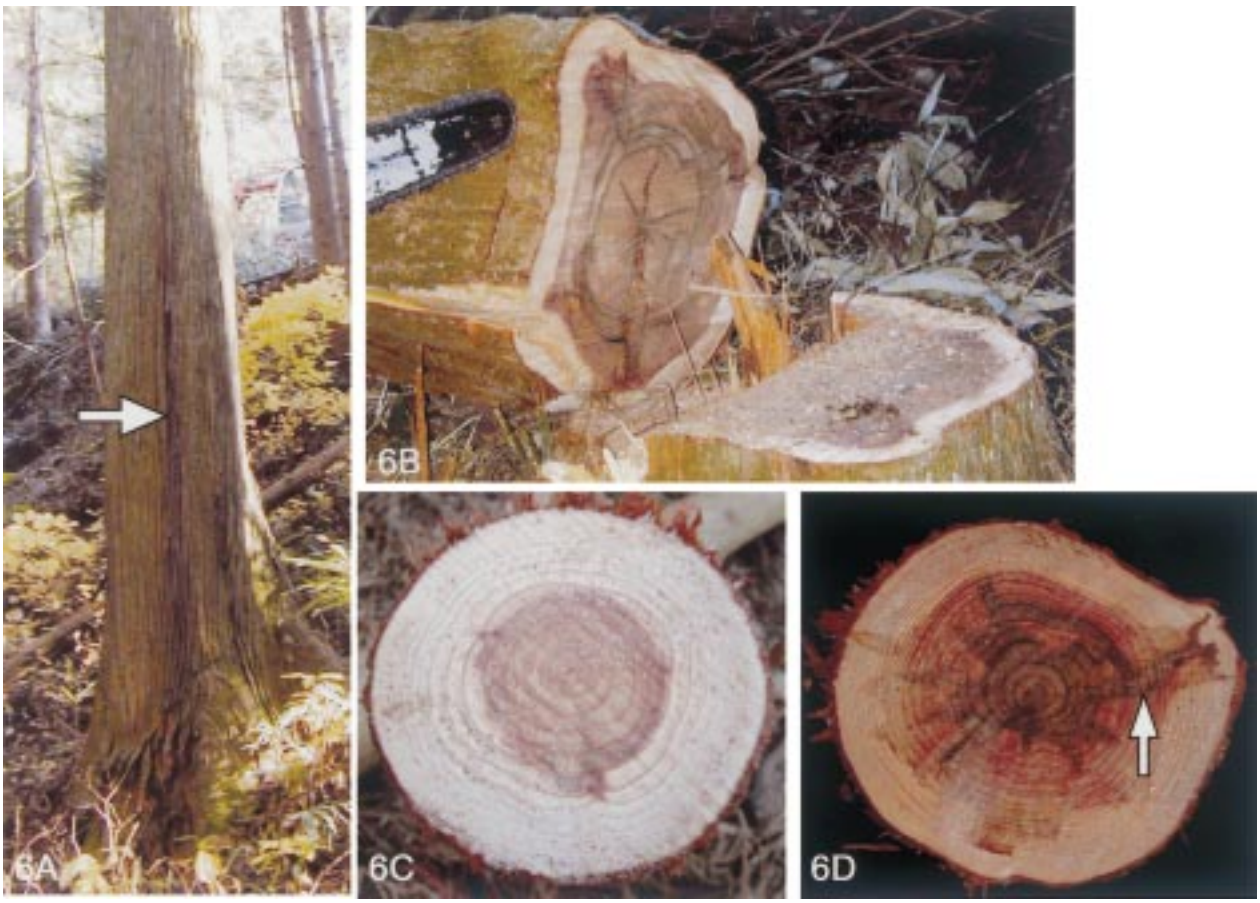

Fig. 6. Degradation of wood property as a result of black and wet heartwood formation in *Cryptomeria japonica* plantations at site D in Kyoto Prefecture.

6A: Trunk of a 100-year-old tree with a deep streak caused by repeated freezing cracks (arrow). 6B: Extensive freezing cracks in a 100-year-old tree (6A) with wet heart. 6C: Slightly darker heartwood of a 35-year-old tree. 6D: A 40-year-old tree with wet and partly black heart and freezing cracks (arrow).

4. Deterioration of wood properties in *Cryptomeria japonica* plantations in Kyoto Prefecture

In an approximately 100-year-old *Cryptomeria japonica* plantation in Kyoto City (Fig. 1, Site D), extensive freezing cracks were found in stems in both a radial and a concentric orientation (Fig. 6A, B). Such trees were not suitable for construction purposes. Black heart is sometimes formed in *Cryptomeria japonica* and is always associated with wet heartwood (Kuroda, 1997). Black and wet heart is promoted by combinations of genetic factors, wet environment, and wounding or fungal infection (Hirakawa, 1997; Kuroda, 1997) and is frequently found in specific cultivars, for instance, "Shibahara," which is commonly used in Kyoto Prefecture. Freezing cracks occur in association with black heart as a result of the high water content of the heartwood. Decay is also found in association with the black heart symptom. Foresters believe that freezing cracks increase as a plantation grows older than 40 years. In the trunk of a 100-year-old tree (Fig. 6B), the freezing cracks had started ca. 60 years before and then repeatedly occurred, judging from the disturbed annual rings that tell the history of injuries to the cambium by crack formation. A 35-year-old tree contained slightly darker heartwood (Fig. 6C). In a 40-year-old stand of a Shibahara cultivar, freezing cracks and partial black heart were found (Fig. 6D).

This stem defect, however, has not been a serious problem in the plantations in Kyoto Prefecture because trees are traditionally cut at a younger age for round-post production. Recently, *Cryptomeria japonica* plantations, which are usually managed on a short cutting cycle, are changing to longer cutting cycles. In most cases, the landowners do not seem to consider the possible consequences of this change, but decisions are based solely on reducing management costs. This example of black heart shows that the adoption of long cutting cycles is likely to increase the degradation in wood quality.

Conclusions

The present study shows that recent sudden deaths in conifer plantations may be predominantly caused by severe water deficits and reduction of sap ascent in the main stems of

trees. In those incidents, xylem dysfunction had progressed by repeated infection or beetle invasion from a younger age. The following phenomena are related to xylem dysfunction: (1) Fungal infections are promoted by delays in pruning and thinning. (2) Afforestation on unsuitable or shallow soils or along creeks is associated with tree decline. (3) Fertilization to accelerate xylem growth induces imbalance in the growth of root and stem and seems to decrease the resistance of trees to water stress or to fungi and insect attack. The results suggest that forest decline syndromes may be largely associated with biological agents, although air pollution or greenhouse warming receives much attention as a potential causal factor of forest decline.

In Japan, the role of forests is shifting from timber production toward environmental conservation. As one of the methods to reduce management costs in conifer plantations, landowners are planning to extend the cutting cycles of trees to more than 100 years. However, the risk of degradation of wood quality or mass mortality at older ages must be considered before changing the rotation length and management practices. Conifer plantations for timber production are also a part of the forest area that has a role in maintaining a healthy environment. Even if monoculture conifer plantations are inferior in their biological diversity, it must be emphasized that already established forests should be adequately maintained rather than abandoned. Although conifer plantations may still look healthy to most people, urgent and scientifically based action is necessary to maintain their health as part of the overall aim of sustainable forest management.

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関西地域における針葉樹人工林の健全性低下

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要　旨

スギとヒノキは関西地方の主な造林樹種である。造林は1950～70年代にかけて活発であったため、樹齢は20～50年生が主体である。人工林は森林面積の40%を占めるが、近年では材価低迷のため、森林所有者は管理の熱意や経済力を無くしている。そのような人工林では突然の枯損や材質劣化が増加しているように見受けられる。滋賀県と京都府の被害林で、施業履歴、気象の変動、病虫害などについて調査を行い、原因を検討した。突発的な集団枯死の要因の一つとして、主幹部での水分通導阻害による水不足があげられる。通導阻害は暗色枝枯病菌など、糸状菌が若齢期から繰り返し感染して促進されていた。また、カミキリ類の侵入とともに腐朽菌の感染も認められた。これらの昆虫の侵入や菌の感染は、枝打ちや間伐が遅れた林で増加することが知られている。さらに、不適地への植栽、浅い土壌あるいは水ぎわへの植栽、肥大成長を促進させるための林地肥培などが被害を増加させているようであった。最近では、とりあえず長伐期に変更という動きがあるが、その問題点として、高含水率心材にみられる凍裂の増加など材質低下が懸念される。近畿各地で、針葉樹の人工林がこのまま十分に管理されないまま放置されるなら、近いうちに枯損や倒木が増えるであろう。

キーワード：集団枯損、スギ、ヒノキ、水分通導、罹病、虫害、材変色

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