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Outbreaks of forest defoliating insects in Japan, 1950–2000

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Abstract

In Japan, several forest-defoliating insects reach outbreak levels and cause serious defoliation. Stand mortality sometimes occurs after severe defoliation. However, in general, tree mortality caused by insect defoliation is low because of the prevailing moist climate in Japan. Evergreen conifers are more susceptible to tree mortality as a result of insect defoliation whereas deciduous broad-leaved trees are seldom killed. Insect defoliation occurs more frequently in man-made environments such as among shade trees, orchards, and plantations than in natural habitats. Outbreaks of some defoliators tend to occur in stands of a particular age: e.g. outbreaks of the pine caterpillar, *Dendrolimus spectabilis* Butler (Lepidoptera: Lasiocampidae) occur more frequently in young pine plantations. In contrast, defoliation caused by outbreaks of lepidopterous and hymenopterous pests in larch plantations is more frequent with stand maturation. There is a relationship between outbreaks of some defoliators and altitude above sea level. Most outbreaks of forest defoliators were terminated by insect pathogens that operated in a density-dependent fashion. Since the 1970s, Japan has been prosperous and can afford to buy timber from abroad. More recently, there has been an increasing demand for timber in Japan, that coincides with a huge demand internationally, so that the country will need to produce more timber locally in the future. The increasing pressure on the forestry industry to meet this demand will require more sophisticated methods of pest control coupled with more sustainable methods of silviculture.

Introduction

Japan is a long, narrow country extending from the northeast to the southwest. The land area is 370,000 km^2, of which *c.* 70% is forested (Japan Forestry Agency, 2000). Except for Hokkaido, Japan's northernmost main island, forests are located mainly on the steep mountain slopes. Reforestation proceeded rapidly after the second world war, in which natural broad-leaved forests were replaced with coniferous plantations. Most of the plantations were monocultures. The major tree species planted were *Cryptomeria japonica* D. Don (Taxodiaceae), *Chamaecyparis obtusa* Endl. (Cupressaceae), *Pinus densiflora* Sieb. et Zucc. (Pinaceae), *Pinus thunbergii* Parl. (Pinaceae), *Larix leptolepis* Murray (Pinaceae), *Abies sachalinensis* Fr. Schm. (Pinaceae), and *Picea jezoensis* Carr. (Pinaceae). At present, only 30% of the total forested areas are natural forests and the rest are plantations (Japan Forestry Agency, 2000). Insect damage in Japan has been monitored and recorded by the Forestry Agency since the 1870s. This paper summarizes the main features of forest defoliator outbreaks in Japan.

Forest type and insect outbreaks

Most defoliator outbreaks in Japan have occurred in plantations (table 1). Although there are some insects that cause defoliation in natural forests, most of these are mainly restricted to non-plantation tree species, e.g. the beech caterpillar, *Syntypistis* (*Quadricalcarifera*) *punctatella* (Motchulsky) (Lepidoptera: Notodontidae) (Igarashi, 1982; Nielsen *et al.*, 1996). In the case of insects that cause defoliation in both natural forests and plantations, outbreaks are most likely to occur in plantations. For example, outbreaks of the gypsy moth, *Lymantria dispar* Linnnaeus (Lepidoptera: Lymantriidae) usually start in larch plantations

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Table 1. Major outbreak species of forest defoliators in Japan in relation to forest types (after Kobayashi & Taketani, 1994).

Defoliator	Host plant*	Forest type**
Lepidoptera		
Dendrolimus spectabilis Butler	*Pinus densiflora*	P, N, S
	Pinus thunbergii	P, N, S
	Pinus strobus	P, S
Dendrolimus superans Butler	*Abies sachalinensis*	P, N, S
Cyclophragma yamadai (Nagano)	Fagaceae	N
Lymantria dispar (Linnaeus)	*Larix leptolepis*	P, S
	Broad-leaved	N
Lymantria fumida Butler	*Abies hondoensis*	N
	Larix leptolepis	P, S
Lymantria mathura aurosa Butler	Broad-leaved	N
Calliteara argentata (Butler)	*Cryptomeria japonica*	P, S
	Chamaecyparis obtusa	P, S
Euproctis subflava Bremer	Broad-leaved	N
Ivela auripes Butler	Broad-leaved	N
Syntypistis punctatella (Motschulsky)	*Fagus crenata*	N
Phalerodonta manleyi Leech	Fagaceae	N
Clostera anastomosis Linnaeus	*Populus*, *Salix*	P, S
Milionia basalis Walker	Broad-leaved	P, N
Operophtera brumata Linnaeus	Broad-leaved	P, N
Venusia phasma Butler	*Fagus crenata*	N
Erannis defoliaria Clerck	*Abies sachalinensis*	P
	Larix leptolepis	P
Ptycholomoides aeriferanus (Herrich-Schaffer)	*Larix leptolepis*	P
Spilonota eremitana Moriuti	*Larix leptolepis*	P
Cryptoblabes loxiella Ragonot	*Larix leptolepis*	P
Coleophora obducta Meyrick	*Larix leptolepis*	P
Hymenoptera		
Neodiprion sertifer Geoffroy	*Pinus densiflora*	P, N
	Pinus thunbergii	P, N
Neodiprion japonicus (Marlatt)	*Pinus densiflora*	P, N
	Pinus thunbergii	P, N
	Pinus ryukyuensis	P, N
	Pinus strobus	P
	Larix leptolepis	P
Diprion nipponicus Rohwer	*Pinus densiflora*	P, N
	Larix leptolepis	P
Cephalcia variegata Takeuchi	*Pinus pumila*	N
Pachynematus itoi Okutani	*Larix leptolepis*	P
Pristiphora erichsoni Hartig	*Larix leptolepis*	P
Anoplonyx orientis Smith	*Larix leptolepis*	P
Pristiphora takagii Wong	*Larix leptolepis*	P
Cephalcia isshikii (Takeuchi)	*Picea* spp.	P, N
Gilpinia tohi Takeuchi	*Picea* spp.	
Pristiphora ezomatsuvora Togashi	*Larix leptolepis*	P
Coleoptera		
Basilepta pallidula Baly	*Pinus densiflora*	P, N
	Pinus thunbergii	P, N
	Cryptomeria japonica	P
	Chamaecyparis obtusa	P
Agelastica coerulea Baly	*Alnus hirsuta*	P, N
	Alnus maximowiczii	N
Pyrrhalta fuscipennis Baly	*Acer* spp.	N, S
Pyrrhalta maculicollis Motschulsky	*Ulmus davidiana*	N, S
	Ulmus laciniata	N, S
Dactylispa subquadrata Baly	Fagaceae	N
Chujoa uetsukii Chujo	*Fagus crenata*	N
Rhynchaenus sanguinipes Roelofs	*Zelkova serrata*	N, S
Rhynchaenus japonicus Hustache	Deciduous oaks	N

*Only host plants with outbreak records are listed.
**P, plantation; N, natural forest; S, shade trees.

and spread to natural broad-leaved forests in the second year of the outbreaks. Outbreaks of the pine caterpillar, *Dendrolimus spectabilis* Butler (Lepidoptera: Lasiocampidae), occur less frequently in natural pine forests than in plantations. Many insects on larch, *Larix leptolepis*, frequently cause defoliation in plantations but less often in natural larch forests. The situation is similar to defoliating insects whose outbreaks are restricted to orchards and urban areas. These include the tent caterpillar, *Malacosoma neustria testacea* Motschulsky (Lepidoptera: Lasiocampidae), the satin moth, *Leucoma salicis* Linnaeus (Lepidoptera: Lymantriidae), and the fall webworm, *Hyphantria cunea* Drury (Lepidoptera: Arctiidae). *Dendrolimus superans* Butler (Lepidoptera: Lasiocampidae) feeds on foliage of many species belonging to the Pinaceae. On Hokkaido Island, this insect reaches outbreak levels in *A. sachalinensis* stands and causes serious defoliation. However, on Honshu Island outbreaks of *D. superans* are restricted to *Picea jezoensis* Carr. var. *hondoensis* Rehd. (Pinaceae) and *Cedrus deodara* Loud. (Pinaceae), when these species are used as shade trees. It was proposed that differences in the frequency of outbreaks among different forest types were mainly due to the activities of natural enemies (Furuta, 1976, 1982).

Stand age and insect outbreaks

Outbreaks of some defoliators tend to occur in stands of a particular age. For example, outbreaks of the pine caterpillar, *D. spectabilis*, have been frequently reported in many localities prior to 1980 but only in a few stands after 1980 as forests aged (Kobayashi & Taketani, 1994). Because *D. spectabilis* outbreaks tend to occur in young plantations (< 20 years old) it is speculated that the decrease in frequency of incidence of pine tree defoliation caused by this species is due to the increasing age of pine stands planted mostly after the 1950s. The opposite trend is evident in larch plantations, where the frequency of defoliation increased after the 1980s. There are several lepidopterous and hymenopterous defoliators that attack mature larch stands. In Hokkaido and the northern Honshu islands, outbreaks of the larch sawfly, *Pristiphora erichsonii* (Hartig) (Hymenoptera: Tenthredinidae), have been reported in *Larix leptolepis* plantations older than 30 years since the late 1980s. Outbreaks of this sawfly usually continue for four to six years in a given area.

Elevation and insect outbreaks

There is a relationship between outbreaks of some defoliators and height above sea level. In beech forests in Japan, four insect species often reach outbreak levels and cause severe defoliation. These are the beech caterpillar, *S. punctatella*, a beech sawfly, *Fagineura crenativora* Vikberg & Zinovjevthe (Hymenoptera: Tenthredinidae) (Shinohara *et al.*, 2000), a gall midge, *Oligotrophus faggalli* Monzen (Diptera: Cecidomyiidae), and the chrysomelid beetle, *Chujoa uetsukii* Chujo (Coleoptera: Chrysomelidae). These defoliations tend to occur at certain elevations (fig. 1). The altitudinal range depends on the region, but the outbreak zones tend to be lower at higher latitudes because microclimate (temperature regime) is similar. Defoliation by *S. punctatella* occurs at the highest elevations followed by *F. crenativora*. The gall midge, *O. faggalli*, and the chrysomelid beetle, *C. uetsukii*, cause severe defoliation at lower

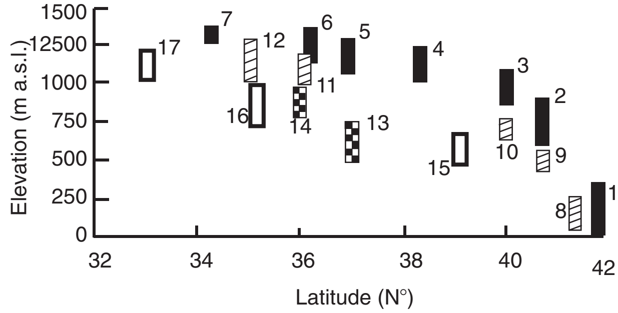

Fig. 1. Altitudinal and latitudinal gradients of incidences of insect defoliation on beech, *Fagus crenata* Blume, in Japan. ■, *Syntypistis punctatella*; ▨, *Fagineura crenativora*; ▚, *Oligotrophus faggalli*; □, *Chujoa uetsuki*; 1, Donann Area (K. Tachi, pers. comm.); 2, Hakkohda (Kamata & Igarashi, 1990), Mt. Iwaki (Kamata & Igarashi, 1994); 3, Hachimantai (Yanbe & Igarashi, 1983); 4, Sado (K. Nunokawa, pers. comm.); 5, Shiga Kogen (R. Watanabe, pers. comm.); 6, Hakusan (Togashi, 1984), 7, Mt. Gomadan (S. Hagiwara, pers. comm.); 8, Shimokita (M. Igarashi, pers. comm.); 9, Hakkohda (J. Kon, pers. comm.); 10, Hachimantai (N. Kamata, pers. obs.); 11, Mt. Tsukuba (I. Ohkochi, pers. comm.); 12, Tanzawa (Yamagami *et al.*, 1997, 1998, 1999); 13, Naka-Uonuma (Kurashima, 1995); 14, Hida (Nohira & Ohashi, 1991, 1992, 1994; Nohira, 1993); 15, Waga (N. Kamata, pers. obs.); 16, Shimane (Uetsuki, 1955; J. Inoue, pers. comm.); 17, Mt. Sobo (K. Ito, pers. comm.).

elevations. Environmental factors relating to altitude, which include stand structure, natural enemies, competitors, host plant quality, and climate, are the likely cause of altitude-dependent outbreaks of these insects (Kamata, 2000).

Tree mortality following insect defoliation

Many trees may die following severe defoliation, for example those caused by *Lymantria dispar* in North America (Gerardi & Grimm, 1979), by *Lymantria monacha* Linnaeus (Lepidoptera: Lymantriidae) in central Europe (Bejer, 1988), and by *Dendrolimus punctatus* Walker (Lepidoptera: Lasiocampidae) in China (Xiao, 1990). However, in Japan, tree mortality following insect defoliation is relatively low probably because water stress is less intense due to the country's oceanic climate. Annual precipitation is more than 1000 mm in most parts of Japan, ranging from 1000 to 5000 mm (Japan Meteorological Agency, 2000). For example, mortality of beech trees following *S. punctatella* defoliation is usually < 1% (Kamata, 1997). However, in the 1980s, there is a single record of a large number of beech trees dying as a result of defoliation by this species (Kamata *et al.*, 1988). In 1982, *S. punctatella* populations reached outbreak levels and beech trees were severely defoliated over 280 ha of natural beech forests in the Hakkouda Mountains in Aomori Prefecture (fig. 2a). The density of caterpillars decreased during 1983. In both 1984 and 1985, the summers were extremely hot and dry. Monthly precipitation in August during these two years was *c.* 40 mm, which was less than one-third of the average rainfall during the period (fig. 2b). More than 10,000 trees were killed and tree mortality reached *c.* 50% over *c.* 100 ha of beech forest inside the 1982 outbreak area (fig. 1a). The most severely affected areas were located on the hill tops, where trees suffered more severe

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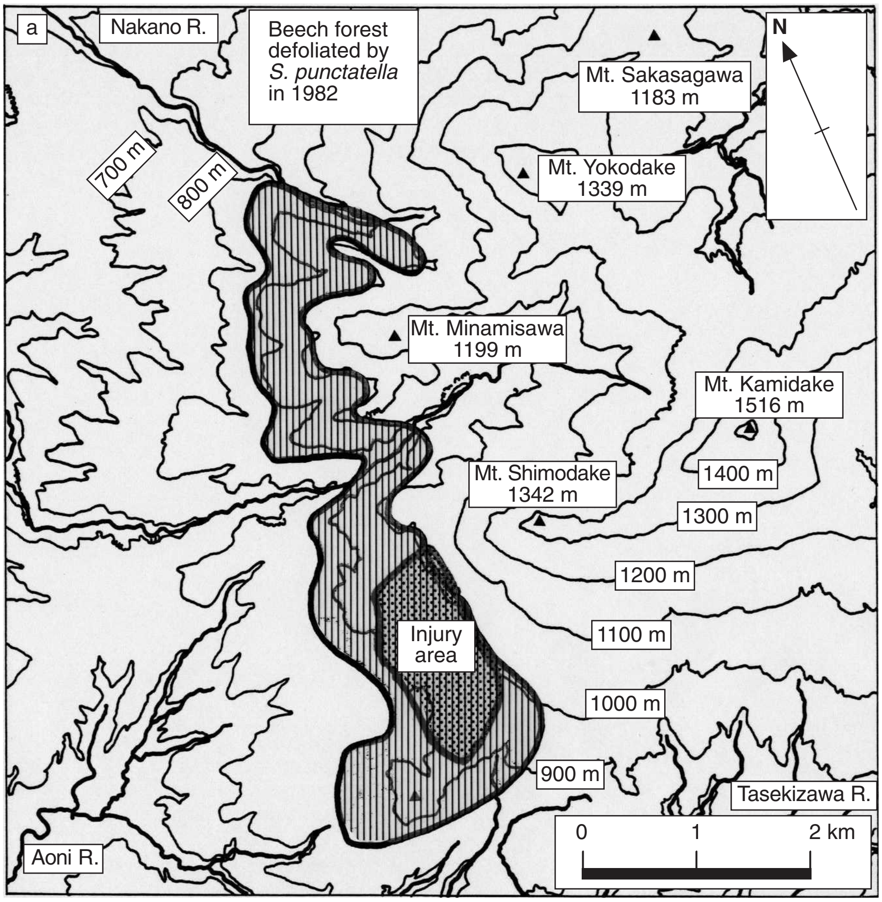

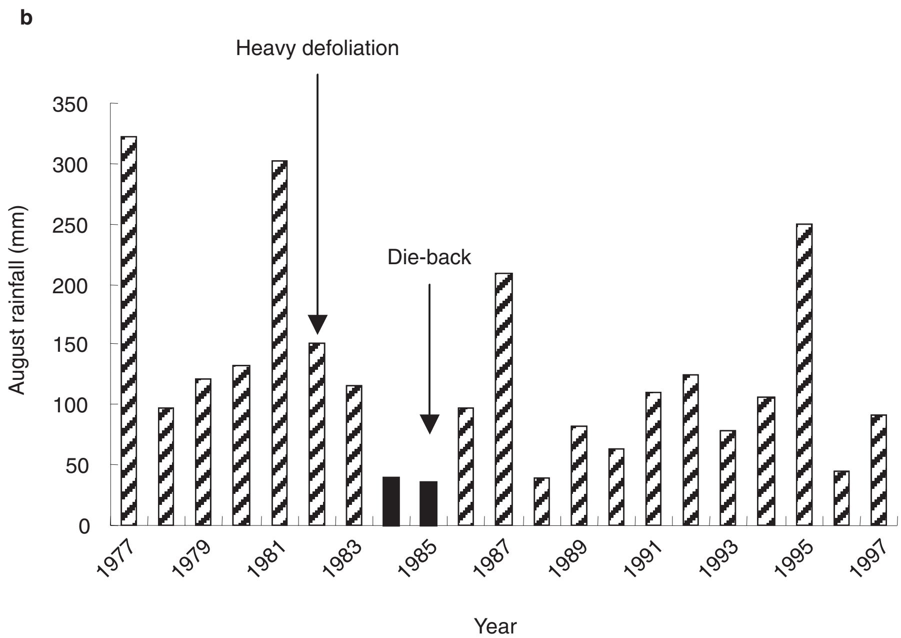

Fig. 2. Mass dieback of beech following defoliation by *Syntypistis punctatella* in Hakkoda Mountains, Aomori, Japan. (a) Sites where defoliation occurred in the summer of 1982 (280 ha) (▥) and tree mortality in 1985 (100 ha) (░). In the main injury area (▩), mortality of canopy beech trees reached 47%. (b) Total monthly rainfall during August at Kuroishi, the nearest weather station of AMeDAS (Automated Meteorological Data Acquisition System by the Japan Meteorological Agency) was 15 km from the area of tree mortality. Heavy *S. punctatella* defoliation in 1982 was followed by two successive years of hot and dry summers (1984 and 1985).

Table 2. Pathogens known to terminate outbreaks of major forest defoliators in Japan.

Order	Defoliator	Disease	Pathogen*	**	Reference
Lepidoptera					
	Dendrolimus spectabilis	Virus	**CPV**	1	Aruga *et al*., 1963; Koyama, 1963, 1965; Katagiri & Takamura, 1966
			NPV	2	Koyama, 1961, 1963; Aruga *et al*., 1963
			GV	3	Lian *et al*., 1986
		Bacteria	***Bacillus thuringiensis***	2	Katagiri & Iwata, 1976
		Fungus	***Beauveria bassiana***	1	Katagiri & Iwata, 1978
			Paecilomyces farinosus	3	Kokubo, 1971
			Nomuraea rileyi	3	Hasegawa & Koyama, 1937
	Dendrolimus superans	Virus	**CPV**	3	Iwata, 1977
			NPV	1	Kobayashi & Taketani, 1994; Katagiri, 1995
		Fungus	*Paecilomyces farinosus*	3	Hasegawa & Koyama, 1941
			Nomuraea rileyi	3	Hasegawa & Koyama, 1937
	Lymantria dispar	Fungus	*Entomophaga maimaiga*	1	Koyama, 1954; Sato & Takamura, 1975; Shimazu & Soper, 1986
		Virus	**NPV**	1	Aruga *et al*., 1961; Koyama, 1954; Katagiri, 1969
	Lymantria fumida	Virus	**NPV**	1	Koyama & Katagiri, 1959; Katagiri *et al*., 1971; Katagiri, 1977
			CPV	2	Katagiri, 1977
	Lymantria mathura aurosa	Virus	NPV	3	Koyama, 1963
			CPV	3	Martignoni & Iwai, 1981
	Calliteara argentata	Virus	NPV	1	Kitamura, 1966; Shibata, 1983
	Euproctis subflava	Virus	**NPV**	1	Inoue, 1971, 1972, 1973
			CPV	3	Katagiri, 1995
	Ivera auripes	Virus	NPV	1	Hukuhara & Akami, 1987
	Hyphantria cunea	Virus	**NPV**	2	Kunimi, 1982
			GV	2	Hukuhara, 1972; Tomita & Ebihara, 1982
		Fungus	*Paecilomyces fumosoroseus*	2	Saito & Aoki, 1983
	Syntypistis punctatella	Fungus	*Cordyceps militaris*	1	Yanbe & Igarashi, 1983; Kamata *et al*., 1997
			Paecilomyces farinosus	2	Kamata *et al*., 1997
			Paecilomyces fumosoroseus	2	Kamata *et al*., 1997
			Metarhizium anisopliae	2	Kamata *et al*., 1997
			Beauveria bassiana	2	Kamata *et al*., 1997
	Clostera anastomosis	Virus	NPV	3	Martignoni & Iwai, 1981; Lian *et al*., 1986
			CPV	3	Martignoni & Iwai, 1981
			GV	3	Martignoni & Iwai, 1981
	Milionia basalis	Virus	CPV	3	Katagiri & Iwata, 1978
	Operophtera brumata	Virus	NPV	3	Martignoni & Iwai, 1981
			EPV	3	Martignoni & Iwai, 1981
			CPV	3	Martignoni & Iwai, 1981
	Erannis defoliaria	Virus	NPV	1	Ozawa, 1971; Katagiri & Iwata, 1978
	Ptycholomoides aeriferana	Fungus	*Erynia radicans*	3	Okada, 1993
	Cryptoblabes loxiella	Fungus	*Paecilomyces farinosus*	3	Hasegawa & Koyama, 1941
			Paecilomyces heliotis	3	Okada, 1993
Hymenoptera					
	Pristiphora erichsonii	Fungus	*Beauveria bassiana*	3	Ozawa, 1981
	Neodiprion japonicus	Fungus	*Beauveria bassiana*	3	Okada, 1993
	Diprion nipponicus	Fungus	*Paecilomyces farinosus*	3	Aoki, 1957
	Cephalcia isshikii	Fungus	*Beauveria bassiana*	3	Okada, 1993
			Metarhizium anisopliae	3	Okada, 1993
			Paecilomyces farinosus	3	Okada, 1993
Coleoptera					
	Basilepta pallidula	Fungus	*Beauveria* sp.	2	Okuda, 1970
	Agelastica coerulea	Fungus	*Beauveria* sp.	3	Okuda, 1970
	Pyrrhalta fuscipennis	Fungus	*Beauveria* sp.	3	Okada, 1993
			Paecilomyces farinosus	3	Aoki & Yanase, 1975

* Bold letters indicate the pathogens that have been used as control agents (after Kobayashi & Taketani, 1994; Katagiri, 1995).
** Numbers indicate the pathogen is the important mortality agent terminating the population outbreak (1), the pathogen was observed during the population outbreak (2), and the insect was recorded as a host of the pathogen (3).

drought stress. Historical records of the incidence of defoliation caused by *S. punctatella*, in the northern prefectures of Japan from 1910 to 1993 indicate a cyclical pattern of outbreaks every 8–11 years (Liebhold *et al.*, 1996) Outbreaks of this species continue to occur.

Tree mortality following insect defoliation tends to be higher in conifers than in broad-leaved trees, and higher in evergreen species than in deciduous trees. Thus tree mortality of evergreen coniferous species is highest. For example, tree mortality following defoliation by *Calliteara argentata* (Butler) (Lepidoptera: Lymantriidae) was 12.5–58.2% for *Chamaecyparis obtusa* and 6.5–28.6% for *Cryptomeria japonica* (Shibata, 1983). Because foliage biomass is largest in evergreen coniferous trees, it may be difficult for these trees to recover lost foliage.

Role of mortality agents in controlling defoliating insect outbreaks

Table 2 indicates the role of insect diseases in terminating outbreaks of the major forest defoliators in Japan. Viruses are the most common mortality agents terminating outbreaks of lepidopterous insects followed by fungal diseases. Predation by small mammals and parasitoids are important mortality agents terminating sawfly populations (Buckner, 1959; Tachibana & Nishiguchi, 1984). It is noteworthy that in Japan the important disease agents terminating sawfly outbreaks were fungi, while in other countries viruses were commonly recorded (Bird, 1971; Neilson *et al.*, 1971; Kobayashi & Taketani, 1994). This difference could be due to the wetter climate in Japan favouring fungal infection.

Control strategies used against forest defoliating insects in Japan

Until the early 1960s, logging was an important industry in Japan and chemical insecticides were commonly used against defoliators to minimize damage. The use of chemical insecticides declined from the 1970s onward because timber prices dropped and because it was realized that defoliated trees seldom died and that the economic losses were not as great as originally assumed. Since the 1970s public opposition to the use of chemical sprays in Japan has increased as the negative impacts of chemical sprays on the environment have become known.

Latterly, several virus formulations have been applied against defoliators because viruses have a relatively narrow host range and consequently have a smaller impact on ecosystem than most chemical insecticides (table 2) (see Kobayashi & Taketani, 1994; Katagiri, 1995). Cytoplasmic polyhedrosis viruses (CPV) were applied against outbreak populations of *D. spectabilis*, *D. superans*, *Lymantria fumida* Butler (Lepidoptera: Lymantriidae), and *Euproctis subflava* (Bremer) (Lepidoptera: Lymantriidae) (Katagiri, 1995), and nuclear polyhedrosis viruses (NPV) against *L. dispar*, *L. fumida*, *E. subflava* (Inoue 1971, 1972, and 1973), and *H. cunea*. The entomopathogenic fungus *Beauveria bassiana* (Balsamo) Vuillemin (Clavicipitaceae) was applied experimentally to control outbreaks of *D. spectabilis* (Katagiri, 1995). Levels of control were satisfactory by modern standards, ranging from 45 to 100%.

Currently, the uses of insecticides and microbial products are restricted to the following special cases in forestry:

1. When defoliator outbreaks occur on valuable tree species whose susceptibility to mortality following defoliation is known to be high, e.g. *Chamaecyparis obtusa* and *Cryptomeria japonica* defoliated by *Calliteara argentata*.
2. When outbreaks of defoliating insects occur in urban areas on shade trees, in gardens, in parks or in woodland near residential areas requiring rapid remedial action.

Current status

Since the 1970s research funding and the interests of forest entomologists have shifted to pine wilt disease caused by pinewood nematode, *Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle (Nematoda: Aphelenchoididae) (Kobayashi, 1988; Kishi, 1995) and the many wood-boring insects that reduce wood quality (Kobayashi & Taketani, 1994). Species of special concern currently include the bark borer *Semanotus japonicus* (Lacordaire) (Coleoptera: Cerambycidae), the twig borer *Anaglyptus subfasciatus* Picard (Coleoptera: Cerambycidae), the bark midge *Resseliella odai* (Inouye) (Diptera: Cecidomyiidae), and the bark moth *Epinotia granitalis* Butler (Lepidoptera: Tortricidae) (Kobayashii & Taketani, 1994).

During this period, Japan has been prosperous and could afford to buy timber from abroad. More recently there has been a continuing demand for timber in Japan, that coincides with demand internationally, so that the country will have to look more seriously in the future towards producing high quality timber for its own use. The increasing pressure on the forestry industry to meet this demand will require more sophisticated methods of pest control than previously implemented coupled with more sustainable methods of silvicuture. Future global warming may also have an impact by increasing drought stress and mortality among defoliated trees. Now is therefore an opportune time to obtain basic data on new methods for controlling forest defoliating pests.

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