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Forest Health and Remote Sensing: Insect Defoliation, Dieback, and Forest Decline– What Are We Seeing?

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Abstract

The progress of remote sensing technology has made significant contributions to various fields in land use management, such as forests. The great advantage of satellite remote sensing data, such as LANDSAT TM, is that it can be obtained on a regular basis at relatively low cost. In several countries, remote sensing data is already being used to deal with actual forest management problems like insect outbreaks and forest decline. In the majority of these cases, vegetation index (VI), which is greatly lowered by insect defoliation, was used for these analyses because foliage quality and quantity greatly influence forest spectra. Because there are a variety of factors that could possibly influence VI, it is necessary to investigate ground truth data to investigate causal factors

when the mean VI value for a large area is lower than statistics recorded in the past. Possible causes other than insect defoliation include: decrease of forested area by cutting or burning, increase in the percentage of weak or died-back trees, and equivalent deterioration of individual trees. However it would negate the value of remote sensing to collect ground truth data for each and every pixel in the target area. Therefore, the development of mixel analysis technology in conjunction with ground truth data will become an extremely important key to monitoring of forest health via remote sensing data.

1. Introduction

Insects and disease annually claim an estimated more than 1 million m^3 of wood volume from Japanese Forests [1]. These timber losses affect both the forestry at resource management level and woodland conservation at levels of environment protection and of land preservation. Foresters have traditionally relied on aerial photography, aerial sketchmapping, and ground sampling techniques to maintain and update their forest inventory records. These inventory techniques are cumbersome. The progress of remote sensing technology has made significant contributions to various fields in land use management, such as forests. The rapid improvement of computer technology makes it possible to handle large amounts of data, and GIS software greatly simplified landscape management, as the capability to overlay many kinds of datasets enables scientists to monitor a large area of terrain. The great advantage of satellite remote sensing data, such as LANDSAT TM, is that it can be obtained on a regular basis at relatively low cost. In a field of forest pest management, remote sensing data is already being used to deal with insect outbreaks and diebacks. Several attempts have been made to detect forest decline over periods of years via statistical analysis of time series datasets of the same target area, such as LANDSAT TM data. In the majority of these cases, vegetation index (VI) was used for these analyses because foliage quality and quantity greatly influence forest spectra. Insect defoliation is one of the factors that greatly lower VI. Such an extreme decrease in VI is a temporal phenomenon, but vegetation index is still below normal levels in the years following severe defoliation because foliage decreases and relevant nitrogen deficits both precipitate a decrease in the chlorophyll contents of foliage, resulting in a lower VI. Secondary pests such as bark beetles attack trees, thereby causing a recognizable change in leaf spectra of these trees, but reflectance of infrared radiation had already decreased before the onset of beetle attacks, showing that these trees were already in a weakened state. Naturally, if large amounts of vegetation are decimated due to dieback or harvesting, this causes a tremendous decrease in VI, and recovery is quite slow.

2. Insect Defoliation and Vegetation Index

2.1 Type of Insect Defoliators

Insect defoliators include: chewing insects such as Lepidoptera, Coleoptera and Hymenoptera, and sucking or gall-forming insects such as Hemiptera and Diptera. sawflies (Hymenoptera) and moth caterpillar (Lepidoptera) are the most popular defoliators amongst them. Some of these outbreaks are known to occur periodically or quasi-periodically, with intervals of 8-11 years (beech caterpillar, *Syntypistis punctatella* [2]; larch budmoth, *Zeiraphera diniana* [3]; autumnal moth, *Epirrita autumnata* [4]; Douglas-fir tussock moth, *Orgyia pseudotsugata* [5]); 30-40 years (spruce budworm *Choristoneura fumiferana* [6]).

2.2 Insect Defoliation of Beech Trees

As for the Siebold's beech, *Fagus crenata*, several species of insect defoliators have been recorded [7]. Those include: the beech caterpillar, *Syntypistis punctatella*, sawflies, and gall midges. Site-dependent characteristics of their outbreaks are known; the beech caterpillar defoliation occur mainly in the Northern Japan and in the higher places, defoliation by sawflies occur in the Northern and the Central Japan but in the lower places than those where the beech caterpillar outbreaks were recorded, and gall midge outbreaks occur in Central Japan and in lower places than those of sawfly outbreaks.

2.3 Outbreaks of *Syntypistis punctatella* and Dieback of Beech Trees

The beech caterpillar, *Syntypistis (=Quadricalcarifera) punctatella* (Motschulsky) is a foliage-feeding Lepidopteran species that is associated with beech, *Fagus crenata* Blume and *F. japonica* Maxim., in Japan. Outbreaks of this species are known to occur in Honshu and Hokkaido islands of Japan and to occur synchronously among different areas at intervals of 8-11 years [2, 8]. The moth populations exhibit 8-11 year cycles, widely synchronized both in outbreak and non-outbreak areas [9]. Defoliated area spreads several hundreds hectare, and sometimes exceeds 1,000 hectare [8]. Severe defoliation continued for 1-2 years, then the insect population will clash.

Because drought stress is not severe in most part of Japan, trees seldom die even if they were completely defoliated by insects. Tree mortality within 3 years following the beech caterpillar outbreak was usually less than 1% [7]. Only the exception was that many beech trees were killed after the outbreaks of this insect in conjunction with severe drought stress the following two successive summers. The die-off was observed in the natural beech forests facing southeastern slope of Mt. Kushigamine in Hakkohda monuntains, Aomori Prefecture [10]. The beech caterpillar reached outbreak density, and 280 hectares of beech forests were completely defoliated August 1982 (Fig. 1a). It was extremely hot and dry in the summer of 1984. Conspicuous dieback started this summer and continued until 1987. The die-off area spreads ca. 100 hectares with volume of ca. 10,000 cubic meters (Fig. 1a). Within this area, 47% of individual trees were killed, 21% were suffered damages on trunk with conspicuous decrease in foliage, 20% decreased their crown foliage without no damage on trunk, no conspicuous change was found on only 9% of individual trees.

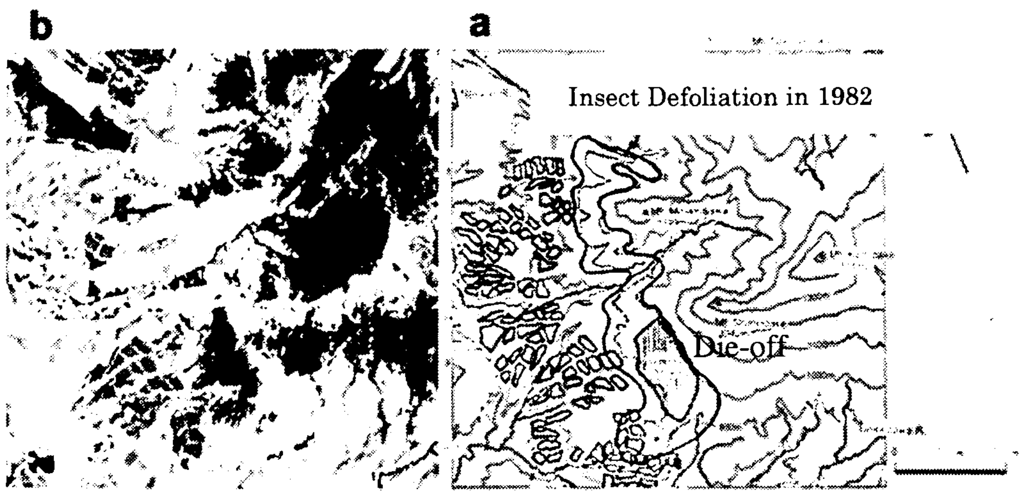

Fig. 1 Location of defoliated forest by the beech caterpillar, *Syntypistis punctatella*, and die-off forest:

(a) a map drawn by a ground truth data,

(b) a gray-scale image of Landsat TM data (band 4).

2.4 Detection of the Die-off by Landsat TM Data

A Landsat TM data observed in June 1985 was used for analysis of the died-off beech forests in Hakkohda mentioned above [11, 12]. Reflectance of band 4 (0.83• m) in died-off area was lower than that of surrounding beech forests, and the difference was statistically significant ($p<0.0001$, ANOVA)(Fig. 2). Died-off area was clearly differentiated from the surrounding beech forests by gray-scaled image processed by the reflectance of band 4 (Fig. 1b).

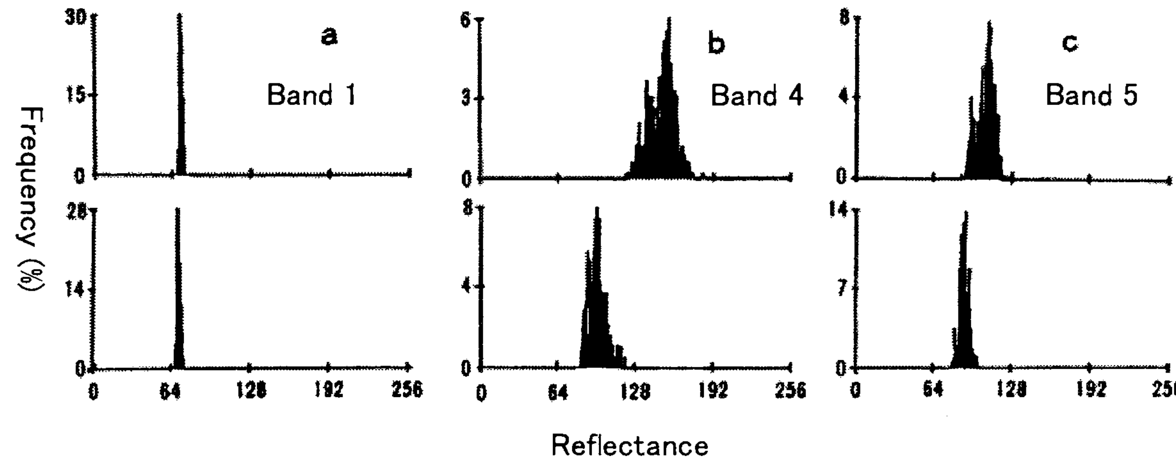

Fig. 2 Reflectance of Band 1, 4, and 5 of Landsat TM data of die-off area (bottom) and the surrounding beech forests (upper).

2.5 Insect Defoliation and Subsequent Deterioration of Foliage Quality

Insect defoliation usually deteriorates quality of foliage in the following seasons; i.e. decrease in foliar nitrogen and increase in foliar phenolics [13, 14]. Because most of the foliar nitrogen is used in chloroplasts, color of individual leaves turns brighter green.

Weight of foliage per individual tree also became almost half in the year following insect defoliation. This decrease in weight was caused by decreases in both area and LMA (leaf mass per area) of individual leaves. These influences are strong on climax plant species and/or plants living in environments with low nitrogen availability because these deteriorations after insect defoliations are closely related to nitrogen deficit at an individual tree level [14]. It takes more than three years for the Siebold's beech to recover foliar nitrogen level from the damage of complete defoliation [15].

3. Die-Off Caused by Microorganisms Associated With Insect Vector

3.1 Pine Wilt Disease

A Pine wilt disease, which is caused by pine wood nematode (*Bursaphelenchus xylophilus*) carried by Ceranbycid beetles (*Monochamus* spp.), is one of the serious forest pests in Asian countries [16]. In Japan, the volume of pine killed by this pest exceeds a million cubic meters every year. Japanese black pine, Japanese red pine, and some other pine species originated in Asia are susceptible to pine wood nematode although those from North America are resistant.

3.2 Oak Decline and Leaf Reflectance

Oak decline became another serious forest problem in Japan. It is proved that a pathogenic unknown fungus associated with an ambrosia beetle (*Platypus quercivorus* (Murayama)) is related to this decline [17]. This pathogenic fungus did not belong to the known genus. An ambrosia beetle is a typical secondary pest which cannot live on healthy trees. Ambrosia beetles are known as a group of Coleopteran insects which cultivate specific fungi for their food inside their tunnels. These beetles have a special organ, called mycangia, in which they carry the fungi to a new host. However, the unknown fungus related to the dieback is not an essential one. It is speculated that the pathogenic fungi left at the time of initial attacks of the ambrosia beetles gradually weaken the oak tree, which makes mass attack of the ambrosia beetles successful.

Leaf reflectance of attacked and non-attacked oak trees were measured by a spectrum meter. Leaves of two oak species, *Quercus serratta* and *Q. crispula*, living together in the same stand in Mt. Kariyasuyama, Ishikawa Prefecture, were sampled on 3, June 1999. Adult beetles have not emerged at that moment. All the entrance holes of this ambrosia beetle were ones attacked the previous year. Because a peak reflectance of infrared radiation at 753 nm seemed to be influenced by insect attack, effects of insect attack, tree species, and their interaction on the reflectance were tested by 2-way ANOVA. Both the insect attack and tree species had a significant effect on the reflectance, but no significant effect was found in the interaction (Table 1). This result suggests that leaf reflectance of trees attacked by the beetles was weaker than that of non-attacked trees for both two oak species.

Table 1 Effects of tree species (*Quercus serratta* × *Q. crispula*) and insect attack (attacked × without attack) on reflectance of infrared radiation at 753 nm (Two-way ANOVA).

	Sum of Squares	F Ratio	DF	Prob>F
Species	135960209	67.8091	1	<.0001
Insect attack	232661701	116.0382	1	<.0001
Interaction	1332225.1	0.6644	1	0.4174

4. Varied VI: What are we seeing?

Naturally, if large amounts of vegetation are decimated due to dieback or harvesting, this causes a tremendous decrease in vegetation index, and recovery is quite slow. Because there are a variety of factors that could possibly influence VI, it is necessary to investigate ground truth data to investigate causal factors when the mean VI value for a large area is lower than statistics recorded in the past. Possible causes include: decrease of forested area by cutting or burning, increase in the percentage of weak or died-back trees, and equivalent deterioration of individual trees. However it would negate the value of remote sensing to collect ground truth data for each and every pixel in the target area. Therefore, the development of mixel analysis technology in conjunction with ground truth data will become an extremely important key to monitoring of forest health via remote sensing data.

References

[1] Forestry Agency Japan, "White paper of Sylviculture" Tokyo, Japan: Ministry of Finance Japan, 1998. (in Japanese).

[2] A. M. Liebhold, N. Kamata and T. Jacob, "Cyclicity and synchrony of historical outbreaks of the beech caterpillar, *Quadricalcarifera punctatella* (Motschulsky) in Japan," Res. Pop. Ecol. vol. 37, no. 1, pp. *87-94*, June, 1996.

[3] W. Baltensweiler and A. Fischlin, "The larch budmoth in the Alps," In : *Dynamics of Forest Insect Populations.* (A. A. Berryman ed.), New York, USA: Plenum Pub. Co, ch. 17, pp. *331-351*, 1988.

[4] E. Haukioja, S. Neuvonen, S. Hanhimaki and P. Niemela, "The autumnal moth in Fennoscandia," In : *Dynamics of Forest Insect Populations.* (A. A. Berryman ed.),

New York, USA: Plenum Pub. Co, ch. 9, pp. *163-178*, 1988.

[5] R. R. Mason and B. E. Wickman, "The Douglas-fir tussock moth in the interior Pacific Northwest," In : *Dynamics of Forest Insect Populations.* (A. A. Berryman ed.), New York, USA: Plenum, ch. 10, pp. *181-209*, 1988.

[6] W. J. Mattson, G. A. Simmons and J. A. Witter, "The spruce budworm in eastern north Americat," In : *Dynamics of Forest Insect Populations.* (A. A. Berryman ed.), New York, USA: Plenum Pub. Co, ch. 16, pp. *309-330*, 1988.

[7] N. Kamata, "The beech caterpillar (*Syntypistis punctatella*)," In: *Pests of natural broadleaved forests in Japan.* (JAFTA ed.), Tokyo, Japan: Forestry Agency Japan, pp.*101-147*, 1997. (in Japanese)

[8] T. Yanbe and M. Igarashi, "Outbreaks of beech caterpillar and its parasite *Cordyceps militaris*," *Forest Pests (Japan)*, vol. 33, no. 6, pp. *115-119*, June, 1983. (in Japanese).

[9] N. Kamata and Y. Igarashi, "Synchronous population dynamics of the beech caterpillar, *Quadricalcarifera punctatella* (Motschulsky): rainfall is the key. In: *Behavior population dynamics and control of forest insects* (F. Haine, S. M. Salom, W. F. Ravlin, T. Payne and K. F. Raffa eds.), Wooster, OH, USA: The Ohio State University, pp. *452-473*, 1995.

[10] N. Kamata, M. Igarashi, S. Kaneko and F. Hishiya, "Die-off of natural beech forests observed after defoliation by the beech catrerpillar, *Quadricalcarifera punctatella* (Motschulsky)," *Forest Pests (Japan)*, vol. 38, no. 8, pp. *144-146*, August, 1989. (in Japanese).

[11] N. Kamata, "Forest damage assessment by LANDSAT TM data- beech forest dying after defoliation injured by the beech caterpillar, *Quadricalcarifera*

punctatella (Motschulsky) (Lepidoptera: Notodontidae)," *Proceedings of 101th Symposium of Japanese Society of Forestry*, pp. *513-514*, October, 1990. (in Japanese).

[12] N. Kamata, "Utilization of satellite data for management on forest defoliators," *Japanese Journal of Remote Sensing*, vol. 10, no. 3, pp. *397-403*, December, 1990. (in Japanese)

[13] N. Kamata, M. Igarashi and S. Ohara, "Induced response of the Siebold's beech (*Fagus crenata* Blume) to manual defoliation," *J. For. Res.*, vol. 1, no. 1, pp. *1-7*, February, 1996.

[14] N. Kamata, "Ecological characteristics of the Siebold's beech (*Fagus crenata* Blume) and plant-herbivore interactions," *Bulletin of the Society of Population Ecology*, vol. 56, pp. *29-46*, June, 1999

[15] N. Kamata, M. Igarashi and S. Ohara, "Defoliation of Fagus crenata affects the population dynamics of the beech caterpillar, *Quadricalcarifera punctatella*," In: *Dynamics of forest herbivory: quest for pattern and principle* (W. J. Mattson, P. Niemela and M. Rousi eds.), pp. *68-85*, U.S.F.S. Gen. Tech. Rept., NC-183.

[16] Y. Kishi, *The pine wood nematode and the Japanese pine sawyer*. Thomas, Tokyo, Japan, 1995.

[17] S. Ito, T. Kubono, N. Sahashi and T. Yamada, "Associated fungi with the mass mortality of oak trees," *J. Jpn. For. Soc.*, vol. 80, no. 3, pp. *170-175*, August, 1998.