# Chapter 10
# Decline of *Fagus crenata* in the Tanzawa Mountains, Japan

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**Abstract** The Tanzawa Mountains are located in the southwestern part of the Kanto District of Japan, and many hikers and climbers visit the area from several gateways, leading to the overuse of trails and the retreat of vegetation. Siebold's beech (*Fagus crenata*) forests are distributed in the high-elevation areas. Beech growth on the southern slopes, along the ridgeline, and around peaks has declined significantly. Recent ozone monitoring data suggest that high ozone concentrations may be a possible chronic cause of the loss of beech vitality. Outbreaks of sawfly and repeated sawfly attacks are fatal for the weakened beech trees. Another indirect biotic factor is the increased population of sika deer (*Cervus nippon*), which destroy ground vegetation and the related community balance. The factors affecting beech decline in the Tanzawa Mountains are complicated, and further scientific research activities in various fields are required to understand the phenomena and to recover the beech forest vegetation.

**Keywords** Tanzawa Mountains • Forest decline • *Fagus crenata* • Ozone • Beech sawfly • Sika deer

## 10.1 Background

The Tanzawa Mountains are a mountain range of about 40 kha in the Kanto District of Japan. The mountain range covers the northwestern part of Kanagawa Prefecture and borders Yamanashi and Shizuoka Prefectures.

The highest peak is Mt. Hirugatake (1,673 m) and some other peaks are Hinokiboramaru (1,601 m), Tanzawayama (1,567 m), and Tonodake (1,491 m). Siebold's beech (also known as Japanese beech; *Fagus crenata*) forests are located at about 1,000 m above sea level, and below are *Quercus* forests. A fir (*Abies firma*)

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**Fig. 10.1** Fir forest at Mt. Oyama

forest is distributed in the zone between the *Fagus* and *Quercus* forests. The Tanzawa Mountain range was registered as a Kanagawa Prefectural natural park in 1960 and as a National park in 1965. As many hikers and climbers are visiting, trails are overused and vegetation along the trails has retreated (Koshiji et al. 1996; Konohira 2007).

In the 1970s, firs standing on the southeastern slope of Mt. Oyama (1,252 m) showed a decline and in the 1980s, a decline in Japanese beech (*Fagus crenata*) became apparent in the ridge between Mt. Tonodake and Hirugatake, and around the peak of Mt. Hinokiboramaru. Also, natural vegetation and the regeneration of trees are suffering from feeding damage caused by sika deer (*Cervus nippon*) due to their increased population (Koshiji et al. 1996; RGTM 2007).

## 10.2 Fir Decline

The natural fir forest on the southeastern slope of Mt. Oyama, in the eastern part of the Tanzawa Mountains, has an area of about 100 ha and is distributed between 400 and 1,100 m above sea level (Fig. 10.1). Dieback of trees estimated to be 200 years old became apparent in the 1970s. Analysis of aerial photographs and tree rings suggested that fir decline had occurred before 1954 and the number of dead fir trees increased significantly from the 1960s to the 1970s. However, since the 1970s new decline or dieback was not observed (Suzuki 1992). Suzuki (1992) suggested that air pollutants, especially sulfur dioxide, rather than extreme meteorological factors, might have a possible link to the fir decline.

Concentrations of air pollutants at Mt. Oyama in the 1960s–1970s, caused by the emissions of primary pollutants and meteorological conditions, were estimated, and the annual mean concentration of sulfur dioxide was 0.01–0.02 ppm in 1965 and S deposition was about 60 kg S/ha. The concentration of $O_3$ was about 30 % higher than the $O_3$ concentrations in 1990–1992. The estimated annual mean pH of precipitation was 4.1 in the 1970s and fog below pH 3.0 occurred frequently and continued for a long time. However, soil pH ranged from 5.64 to 6.12. From this information, it seemed that air pollutants might have caused the fir decline. However, Japanese cedar (*Cryptomeria japonica*) and other trees co-standing with firs did not show any dieback (Fig. 10.1). Infestation of a host-specific insect, *Lymantria fumida* or infection with *Armillaria mellea* might be a possible cause of such fir decline under subtle abiotic stress conditions (Aso et al. 2001).

Hosono et al. (1994) conducted fog observations on the mountainside of Mt. Oyama and their recorded pH ranged from 2.61to 7.00. Igawa et al. (1997) exposed fir seedlings to simulated acid fog of pH 3.0 and reported that the fir leaves became reddish-brown, and thereafter defoliated, and new leaves did not develop. Such experimental results suggested that acid fog had a possible and significant role in inducing fir decline.

The dominant component of fog at Mt. Oyama was nitrate and its wet deposition of nitrogen might cause nitrogen saturation in fir forests (Igawa et al. 2001; Okochi and Igawa 2001). Such acidic wet deposition might induce accelerated leaching of Ca and Mg from leaves. As the leaching of boron associated with Ca and sugars in the cell wall also occurred, it seems possible that acid fog might have an important role in the development of fir decline (Igawa et al. 2002a, b; Shigihara et al. 2008a, b).

Japanese cedar in fir forests did not show any decline syndromes. Levels of membrane-bound Ca (mCa) in cedar exposed to acid fog of pH 3.0 did not show significant changes; however, the levels in fir were reduced. This suggested that fir is more sensitive to acid fog than Japanese cedar and this sensitivity might be a possible cause of the fir decline (Shigihara et al. 2009).

As described above, a direct cause of the fir decline at Mt. Oyama could be a biotic factor, an infection of *Armillaria mellea* or infestation of *Lymantria*. Accelerated leaching of Ca and B from fir needles could be due to chronic effects of acidic fog. Concentrations of Ca in the stem flow and throughfall increased with increasing acidity of precipitation. As leachate elements could be resupplied within the plant tissues, elemental deficiency would not develop. If reduced supply from the rhizosphere occurred, reduced levels of basic elements and signs of acidification in soil would be apparent. However, field surveys did not show such significant changes.

Further, the simulated acid-rain exposure experiment suggested that acidic precipitation around pH 3–4 would not be a possible direct cause of fir decline (Kohno et al. 1994 and Kohno 2001). Thus the decline or dieback of fir trees on Mt. Oyama in the 1970s could be directly induced by an infestation of a host-specific insect *Lymantria*.

## 10.3 Beech Decline

Fir decline at Mt. Oyama, on the eastern side of the Tanzawa Mountains, was distributed in a relatively limited area. However, beech decline is widely distributed on the south to southeastern slopes of ridgelines and around the peaks of Mts. Tanzawa, Hirugatake, Hinokiboramaru, and others.

Koshiji et al. (1996) analyzed aerial photographs of the Tanzawa Mountains after World War II. Trees showing decline were distributed in about 30 % of the natural forests in the area and concentrated around the peaks. These trees were old and had large trunks. The decline possibly started in the 1970s–1980s and has continued to date. Sasakawa et al. (2005) revealed that about 17 ha of forested area, including beech forests, in ridgelines from Mt. Hinokiboramaru to Mt. Tonodake had disappeared. Intensive field surveys in progressively declining areas of Mts. Tanzawa and Hinokiboramaru revealed that the trees showing decline were beech, but no other deciduous broad-leaved tree species showed declines. Such decline were located on the south to southwestern slopes.

### *10.3.1 Ozone Concentration Around Tanzawa Mountains*

In the early stage of the above phenomena, the direct impacts of high concentrations of primary air pollutants, such as sulfur dioxide, might have been a potential causal factor. However, after air quality improvements in industrial areas, concentrations of sulfur dioxide and nitrogen dioxide in a remote mountain area are unlikely to be an important causal factor in tree decline, although ozone could have a possible link with the decline.

Aso et al. (2007) measured ozone concentrations in the Tanzawa Mountains with passive samplers and reported a monthly mean value of 46.8 ppb from May to September in 2005. However, there were no available hourly data for calculating an ozone exposure index. Kohno and collaborators set up an active monitoring station for ozone at an elevation of 1,540 m near the peak of Mt. Hinokiboramaru in 2004 (Kohno, 2005). Two years of monitoring results are summarized in Table 10.1. The mean concentration of ozone at Mt. Hinokiboramaru was comparable with that reported by Aso et al. (2007); however, ozone doses, expressed as AOT40 (Accumulated exposure Over a Threshold of 40 ppb) values (April–September) were 46 ppmh for 24 h and 20 ppmh for daytime 12 h. There are several monitoring stations around the Tanzawa Mountains, as shown in Table 10.2. Low elevation sites had lower ozone concentrations than those of the mountain sites: Inukoeji and Hinokiboramaru, and AOT40 (12 h) values at the low elevation sites were similar to the AOT40 (24 h), as the night-time ozone concentration was low. In contrast, AOT40 (24 h) values at mountain sites were about twice AOT40 (12 h), as the night-time ozone concentration was high.

The seasonal mean concentrations of ozone calculated from values for 3 months showed quite different patterns at the low and high elevation sites, as shown in Fig. 10.2; the low elevation site at Isehara showed a high concentration at midday and low concentration in the night to early morning hours. In contrast, at Hinokiboramaru, differences between night and daytime hours were relatively small; however, the baseline concentration was higher than that at Isehara. Ozone concentration was higher in the spring time and low in the fall and winter season. Beech trees developed young leaves in the period with high concentrations of ozone.

**Table 10.1** Results of active monitoring of ozone concentration at Mt Hinokiboramaru

| | | | Max | Mean | | | AOT40 | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Days | Hours | (ppb) | (24 h, ppb) | (12 h, ppb) | (8 h, ppb) | (24 h, ppb · h) | (12 h, ppb · h) | (8 h, ppb · h) |
| 2004 | 365 | 7,973 | 111 | 43.1 | 41.5 | 41.8 | 68,371 | 29,635 | 19,969 |
| 2005 | 365 | 7,601 | 119 | 42.4 | 41.8 | 42.2 | 61,115 | 27,779 | 18,736 |
| Mean | | | | 42.7 | 41.7 | 42.0 | 64,743 | 28,707 | 19,353 |
| 2004 (April–September) | | | | 46.3 | 44.5 | 44.8 | 46,814 | 19,959 | 13,725 |
| 2005 (April–September) | | | | 44.2 | 43.4 | 44.2 | 45,949 | 20,538 | 14,158 |
| Mean | | | | 45.2 | 44.0 | 44.5 | 46,381 | 20,249 | 13,942 |

Elevation: 1,540 m
Period: 2004/08/01–2006/07/31; 2004/08/01–2005/07/31 for 2004 and 2005/08/01–2006/07/31 for 2005
8 h: 09:00–16:59
12 h: 06:00–17:59
24 h: 00:00–23:59
AOT40(8, 12 and 24h) indicated accumulated hours for 8 hours (09:00–16:59), 12h (06:00–17:59) and 24h (00:00–23:59), respectively, from April to September.

**Table 10.2** Comparison of mean AOT40 values around the Tanzawa Mountains in 2004–2005

| Station (elevation, m) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Odawara | Isehara | Minamiashigara | Ebina | Hadano | Sagamihara | Tsukui | Inukoeji | Hinokiboramaru |
| AOT40 | (15) | (25) | (30) | (35) | (110) | (125) | (170) | (920) | (1,540) |
| 12 h, ppbh | 13,852 | 14,939 | 10,324 | 8,242 | 8,545 | 8,498 | 6,307 | 22,292 | 20,249 |
| 24 h, ppbh | 16,040 | 18,381 | 11,912 | 8,919 | 10,834 | 9,813 | 7,238 | 36,169 | 46,381 |

Period: April–September
Values, except for those at Hinokiboramaru, were calculated from Kanagawa Environmental Research Center data

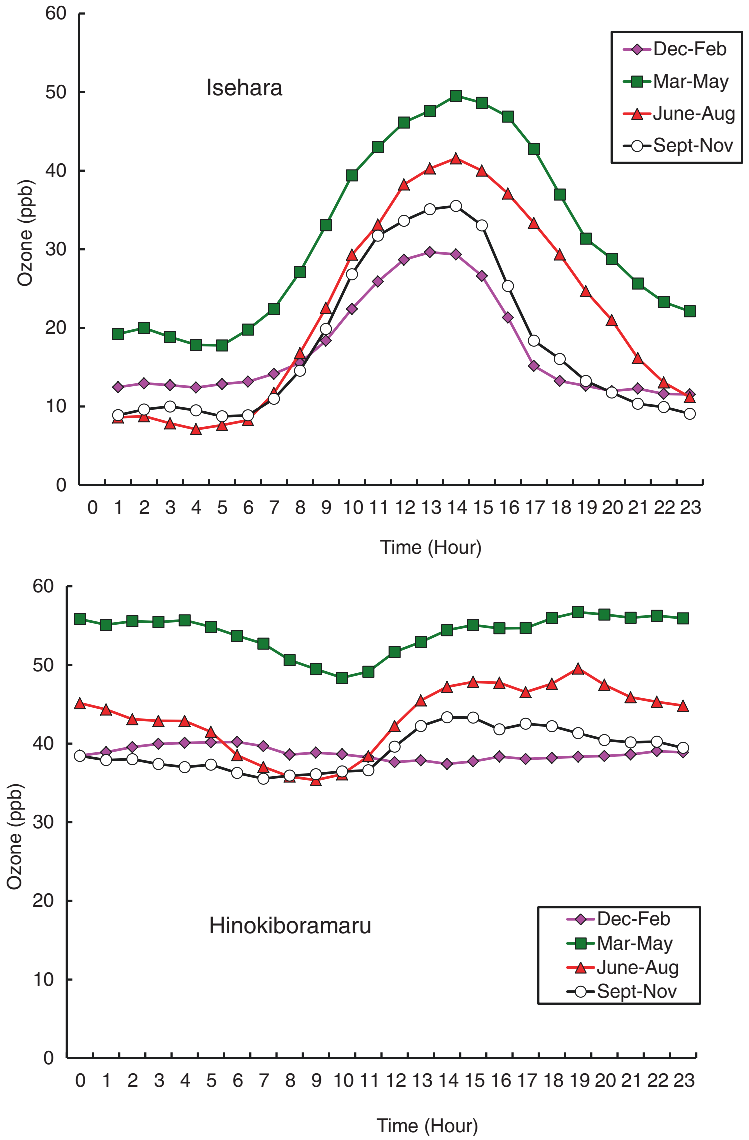


**Fig. 10.2** Seasonal changes in ozone concentration at Isehara and Hinokiboramaru in 2004–2005

Based on the ozone exposure experiments in tree seedlings performed by Kohno et al. (2005), beech was found to be one of the ozone-sensitive species among broad-leaved trees, and the suggested critical level was 20 ppmh (24 h). Matyssek et al. (1995) reported that ozone reduced tree growth not only by daytime exposure but also by night-time exposure, and growth reduction increased proportionately with the ozone concentration. Therefore, it seems that beech stands at high elevation sites such as in the Tanzawa Mountains may be receiving extremely high ozone stress.

Izuta et al. (1996) suggested that ambient levels of ozone detrimentally affected the growth, photosynthetic rate, and chlorophyll content of *F. crenata*. Takeda and Aihara (2007) also reported that chlorophyll content in the beech leaves exposed to ambient air at the Inukoeji site in the Tanzawa Mountains was significantly decreased. Early defoliation and growth reduction in beech seedlings were observed. Further, a reduction of bud numbers in the winter suggested that beech growth would be greatly reduced in the next year.

Simulated acid-rain experiments suggested that the current acidity, frequency, and amount of precipitation did not directly affect beech trees. However, an increase of nitrogen input by acid deposition might induce a phenological response in trees under ozone stress, such as that caused by the combined exposure to acid rain and ozone, evidenced by an increased top/root ratio (Kohno and Matsumura 1999). Increased above-ground biomass with less biomass under the ground may induce a condition sensitive to water stress under drought and/or high-temperature stress. Yonekura et al. (2001) experimentally demonstrated that photosynthesis and the structural characteristics of *F. crenata* were affected by ambient levels of ozone and long-term mild water stress, and these two stresses were related to the beech decline.

Watanabe et al. (2011, 2012) suggested that nitrogen deposition-induced change in the ozone sensitivity of *F. crenata* could be an important factor in the discordance between areas with high risk and those with high ozone exposure.

### *10.3.2 Wind and Ozone in the Tanzawa Mountains*

Suto et al. (2008) developed a dry-deposition model for ozone to estimate $O_3$ deposition in complex terrains, and the qualitative validity of the predicted $O_3$ concentration in the field was confirmed by a comparison with observed data collected by passive samplers in the Tanzawa Mountains. The simulation revealed that wind velocity near the ground increased around the ridgelines and peaks of the mountains. The areas with strong wind corresponded well with the beech decline sites at high altitudes, suggesting that strong wind is one of the important factors in the localization of areas of beech decline. A direct relationship was not observed between the forest decline and $O_3$ concentration. The $O_3$ concentration, however, tends to increase as wind velocity becomes higher; thus, the $O_3$ concentration itself could be a possible secondary factor in the local decline phenomena in the region when the $O_3$ concentration level is high. While the diffusion flux did not clearly correspond with the distributions of areas of beech decline, a large advection flux of $O_3$ showed a distribution pattern similar to that of high wind velocity corresponding with an area of beech decline. Considering the impact of ozone, strong wind with a large advection flux of $O_3$ may play a key role in the localized development of tree/forest decline in the high mountain ridges and peaks.

Takeda et al. (2011) developed a flux-type passive sampler from a diffusive-type one and showed the applicability of this sampler to mountain sites without any available electricity. Their results suggested that ozone concentration did not vary among the sites; however, flux data reflecting wind speed indicated locality.

### 10.3.3 Outbreak of Beech Sawfly

Yamagami et al. (2007) reported that beech decline in the ridgelines and peaks in Tanzawa Mountains became evident after the 1980s; however, in those days there was no evidence about outbreaks of beech sawfly, *Fagineura crenativora*. An outbreak of sawfly was first recorded in 1993, and thereafter sawfly feeding damage to beech trees expanded in the mountains. Trees damaged by repeated feeding attacks from sawfly larvae died within a couple of years (Fig. 10.3). Severe damage and leaf loss in the beech trees due to sawfly larvae feeding may reduce tree vitality. Considering the ozone exposure conditions in the Tanzawa Mountains, it is possible that the beech trees might had reduced physiological activity caused by the chronic exposure to high ozone concentrations and they had become sensitive to water stress, and their potentiality for recovery was reduced by the feeding attacks. Trees with lost vitality showed delayed leaf development and had received intensive feeding attacks. These trees developed secondary leaves in summer, being spent energy for reproducing leaves, instead of storing carbohydrates for preparing for winter season. Such growth responses could have resulted in their decline.

### 10.3.4 Sika Deer Impacts

Generally, an increasing deer population causes critical changes in the composition and structure of forest ecosystems. In the Tanzawa Mountains, grazing pressure from sika deer has caused a decline in vegetation over 20 years (Tamura 2016). As a result, it is difficult to find young seedlings in the beech forests in the Tanzawa Mountains. Forest floor vegetation was grazed and had disappeared, as shown in Fig. 10.4, and this process resulted in the acceleration of surface soil drying and a reduction in the variety of the forest floor community.

Yamagami et al. (2007) pointed out that when sawfly larvae made cocoons in the surface soil layer, they were attacked by parasites and the sawfly population was maintained at a low density in a healthy system. However, the disappearance of

**Fig. 10.3** Healthy beech (*left*) and damaged beech (*right*) in the Tanzawa Mountains

**Fig. 10.4** Degradation of forest floor vegetation by sika deer grazing, and recovered vegetation inside protecting fence

floor vegetation, owing to grazing caused by increasing sika deer density, could change the natural environmental conditions. Such a significant environmental change could disturb co-relationships among the members of the forest floor community. Controlling sika deer density may lead not only to the recovery of forest floor vegetation but also to the maintenance of biodiversity.

## 10.4 Conclusion

Takeda et al. (1999) suggested that accelerated leaching from plant tissues due to simulated acid precipitation might have an indirect impact on plant growth. Shigihara et al. (2008b) suggested that reduced physiological activities due to chronic exposure to acid fog resulted in growth reduction. Such acidic precipitation might have indirect effects on vegetation; however, it could hardly explain the specific tree decline phenomena.

At high elevation sites such as the Tanzawa Mountains, the concentrations and doses of ozone are higher than those at the low elevation sites. Beech, which is sensitive to ozone, grows under a crucial condition in the Tanzawa Mountains. Global warming-related air temperature rises and surface soil drying can have negative effects on environmental conditions for beech trees. Furthermore, outbreaks of beech sawfly, *Fagineura crenativora*, and its repeated feeding on the young leaves of beech can have a significant and direct impact on beech decline (RGTM 2007). Further, high populations of sika deer disturb the surface vegetation community including young beech seedlings. It will be resulted in difficulties of rehabilitation of beech forests.

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