Chapter 13
Forest Recovery Process and Restoration After Large-Scale Disturbances



Satoshi N. Suzuki and Toshiaki Owari

Abstract In Hokkaido, windstorms including typhoons are major disturbances, notably Typhoon Marie in 1954 and Typhoon Thad in 1981, which caused extensive damage to the University of Tokyo Hokkaido Forest (UTHF). Conifers are more susceptible to wind damage than broadleaves. Post disturbance, the UTHF employed salvage logging and reforestation. Conifer planted stands generally successfully grew up although invaded broadleaves often outcompete planted conifers. Naturally regenerated stands after soil scarification were characterized as *Betula* species with too high of a density. Naturally regenerated stands without any postdisturbance practices were dominated by mixed conifer-broadleaf forests. Salvage logging also impacts ecosystems by reducing the habitat available for saproxylic organisms and altering carbon stocks. Large-scale human-caused wildfires in the 1910s created a vast area of secondary forests, which are currently dominated by *Betula maximowicziana.* Some of the Norway spruce plantations established after these fires have also matured into old-growth stands. Snow damage, particularly in young forests, further stress the forest, with wet snow bending or breaking tree stems. Due to climate change, the frequency and severity of these disturbances are expected to increase, prompting the UTHF focus on developing forests that are more robust and resilient to such disturbances.

Keywords Salvage logging · Snow damage · Typhoon · Wildfire

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13.1 Windstorm: Impacts of Typhoons

13.1.1 Damages by Typhoons

The primary agent of large-scale disturbance in Hokkaido is strong winds from typhoons and other windstorms. Every few decades, typhoons cause significant forest blowdowns in Hokkaido. In the University of Tokyo Hokkaido Forest (UTHF), several instances of large-scale wind-induced disturbances have been recorded.

The most significant wind disturbance in Hokkaido occurred during Typhoon Marie in 1954 (T5415, named "Touyamaru typhoon" in Japan), which destroyed 26,900,000 m^3 of trees over an area of 760,000 ha in Hokkaido (Watanabe et al. 1990) and 137,690 m^3 of trees in the UTHF (Hirata and Maezawa 1956). The most significant wind disturbance in the UTHF was caused by Typhoon Thad in 1981 (T8115, the Typhoon No. 15 in 1981). Although the damage caused by Typhoon Thad in 1981 in Hokkaido (3,709,000 m^3 of trees in an area of 58,780 ha) was less than that caused by Typhoon Marie in 1954, it destroyed 755,430 m^3 or more of trees in the area of 10,649 ha in the UTHF (Watanabe et al. 1990, refer to Fig. 2.9), surpassing the damage caused by Typhoon Marie in that area. The damaged area was equated to 46.6% of the UTHF forest area (Fig. 13.1). Additionally, 43,863 m^3 of trees were damaged by insect infestations following Typhoon Thad. Typhoon Helen in 1972 (T7220) also damaged 25,000 m^3 of trees (Tokyo University Forest in Hokkaido 1973).

Topographic factors are important for vulnerability to wind. The extent of wind exposure in a forest depends largely on the slope's orientation to the wind direction and the forest's position on a slope (ridge or valley). Forests on ridges are generally more vulnerable to wind. Up-valley winds (from the valley-mouth direction) can also damage trees in valleys. Slope steepness is another crucial factor. In the case of Typhoon Thad in the UTHF, forests on south-facing slopes, gently sloping terrain aligned with the wind direction, showed the highest probability of windthrow (Miura et al. 1984; Shibano et al. 1990).

Conifers are generally more susceptible to strong winds (Gardiner 2021). During Typhoon Thad, 25.3% of the total conifer volume was damaged, compared to only 10.6% of broadleaves in the UTHF (Watanabe et al. 1990). During Typhoon Marie, these percentages were 4.8% and 1.5%, respectively (Hirata and Maezawa 1956).

13.1.2 Post-windthrow Management

Following the two severe wind disturbances, most of the wind-damaged trees were removed from the forest through so-called salvaged logging. Salvage logging aimed not only at recovering from economic loss by selling the salvaged trees but also at preventing insect outbreaks, such as spruce bark beetles, from the downed trees. After Typhoon Thad in 1981, 755,430 m^3 of stems were removed from the UTHF,

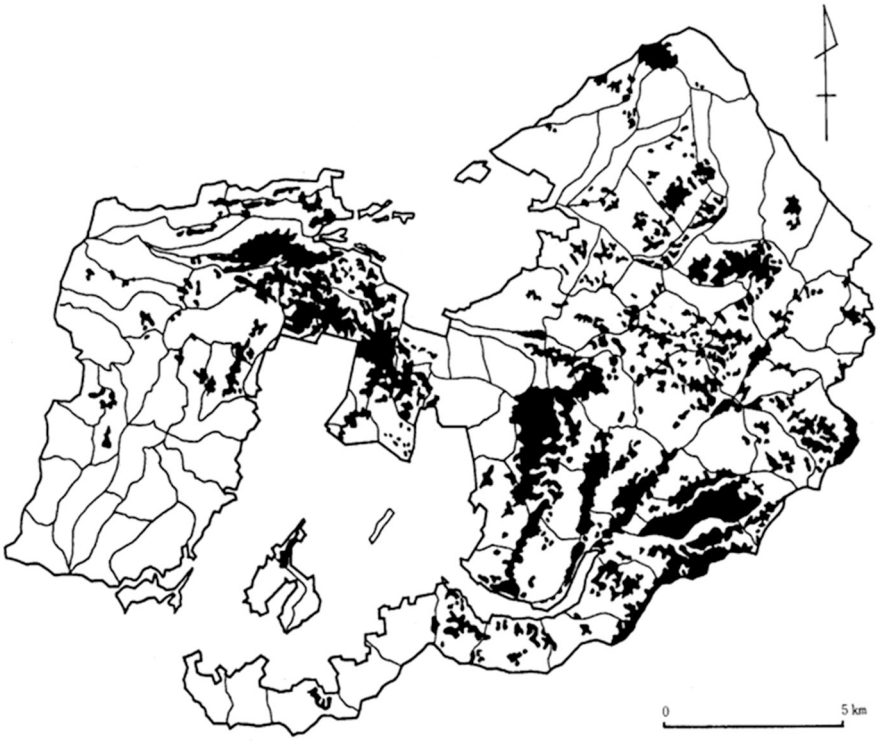


Fig. 13.1 Area severely damaged (shown in black) by Typhoon Thad in UTHF in 1981. (Reproduced from Watanabe et al. 1990, with the publisher's permission)

equivalent to 18% of the growing stock and twelve times of the average annual harvesting volume of the UTHF at that time (Watanabe et al. 1990).

Postdisturbance restoration efforts were actively implemented following the salvage logging after Typhoon Thad although areas with abundant natural regeneration were left untreated after the salvage logging. Between 1981 and 1986, 483 hectares were planted, primarily with Sakhalin fir *Abies sachalinensis* and Sakhalin spruce *Picea glehnii*. Additionally, 307 hectares were just scarified to remove *Sasa* dwarf bamboo and facilitate natural regeneration. In additional areas (86 hectares), seeding was also conducted after scarification to compensate for the shortage of natural seed dispersal, including seeding of Japanese oak *Quercus crispula,* (62 ha) and mixture of monarch birch *Betula maximowicziana* and Yezo spruce *Picea jezoensis* (24 hectare). Study plots were established in these reforested areas to monitor the forest recovery process.

After Typhoon Thad, the planting density was generally reduced to 1500 seedlings/ha, compared to the traditional planting density of 2500–3000 seedlings/ha (Watanabe et al. 1990), to encourage the natural regeneration of other species,

particularly broadleaves, for the restoration of natural mixed conifer-broadleaf forests. Before planting, scarification process as site preparation was carried out in a striped pattern using either a bulldozer or a rake dozer, with 3–4-m-wide strips being scarified and similar-sized strips left unscarified (residual strips). Seedlings were then planted in the scarified strips. At most of the planted sites, many broadleaves regenerated in the residual strips (Okamura et al. 1995; Asama et al. 1996; Shimizume et al. 2002; Okamura et al. 2006; Matsui et al. 2008). However, naturally regenerated species such as *Betula maximowicziana* often outcompete and suppress the planted conifers (Shimizume et al. 2002, Okamura et al. 2006, Matsui et al. 2008). Shimizume et al. (2002) reported that 45% of planted conifers exhibited symptoms of some kind of damage due to suppression by broadleaves at a planted site 15 years after planting. Okamura et al. (2006) found that early thinning of broadleaves significantly improved the growth and quality of both planted conifers and high-value broadleaves like *B. maximowicaiana* at planted sites 22 years after planting. Approximately 30 years after planting, the planted conifers began to mix with naturally regenerated broadleaves, forming conifer-broadleaf mixed forests (Suzuki 2020). In particular, *A. sachalinensis* has grown well and become codominant with broad leaves in some stands, forming mixed conifer-broadleaf forests (Fig. 13.2).



Fig. 13.2 Sakhalin fir plantation after the windthrow in 1981. (Photo by Satoshi N. Suzuki, July 16, 2024)

As noted in Chap. 10, the scarified areas that were left unplanted, including those with only scarification and those with seeding following scarification, have predominantly transitioned to *Betula*-dominant stands. In areas that received only scarification, which were mostly located at higher elevations, *B. ermanii* became particularly dominant. The stem density of *B. ermanii* in these areas often exceeded 10,000 stems per hectare, sometimes reaching over 200,000 stems per hectare a decade after scarification (Okamura et al. 1995). However, due to the very high density, the stem growth of the *Betrula* trees was very limited, resulting in slender stands unsuitable for timber production (Fig. 13.3a). Most seeding sites were similarly dominated by slender stems of *Betula*, including those regenerated from seeded seeds, although some seeded Japanese oak *Q. crispula* still survive under the birch canopy. Consequently, scarification and seeding treatments were seen as unsuccessful for restoring mixed conifer-broadleaf forests without any further management. Previous studies in Hokkaido have suggested that management operations, such as bush clearing or thinning, in the early stage of stand development improved the growth of *B. ermanii* in scarified areas (Kikuzawa 1989; Miyoshi et al. 2014; Sano and Shibuya 2015). To address this issue, the UTHF initiated a trial of stem density control in 2023 by implementing strip-clearcutting in a grid pattern, cutting in two directions to improve the growth of *B. ermanii* and facilitate the regeneration of other species (Fig. 13.3b).

Mixed conifer-broadleaf stands developed in some areas where only salvage logging was conducted (Kisanuki et al. 1996, Suzuki 2020, Li et al. 2023; see also Fig. 5.6). This occurred because the advanced regeneration of conifers, which already existed on the forest floor before the disturbance, contributed to the recovery of the stands. The sites disturbed by Typhoon Marie in 1954 and where only salvage logging was done are also now semimature mixed conifer-broadleaf stands. Sprouting from downed logs or cut stamps also occurred for some broadleaf species, such as *Tilia japonica*, *Sorbus alnifolia*, and *Acer* spp. (Kisanuki et al. 1996), which largely contributed to the recovery of forest stands after the typhoon. These findings indicate that disturbance legacies such as advanced saplings, downed logs and stumps are important for the restoration of mixed conifer-broadleaf forests. In other words, scarification, which removes such disturbance legacies, negatively impacts the restoration of mixed conifer-broadleaf forests.

Salvage logging also impacts forest ecosystems after windstorms. Removing downed trees can reduce habitats and resources for saproxylic organisms, such as insects and fungi (refer to Chap. 12), affecting higher trophic levels like woodpeckers. The removal of downed logs can also alter the carbon stocking function of forests. In cool climates, such as boreal and subalpine regions, as the decomposition rate of dead wood is very slow, dead wood acts as a major carbon stock. Therefore, dead wood can contribute to early carbon stock recovery in disturbed forests by offsetting reduced living carbon stocks (Suzuki et al. 2019; Hotta et al. 2019, 2021,



Fig. 13.3 (**a**) Secondary *Betula ermanii* stand regenerated after salvage logging and scarification treatment following the windthrow in 1981. (**b**) Strip-clear cutting of the *B. ermanii* stand. Stems were uprooted or snapped (rather than cut) using an excavator equipped with a grapple, creating 5-m-wide clear-cut rows in a grid pattern. In these rows, *Sasa* dwarf bamboo was also removed by the machine to facilitate natural regeneration of trees. (Photo by (a) Satoshi N. Suzuki, May 29, 2024, (b) the UTHF, August 31, 2023, licensed under CC BY-NC-ND 4.0)

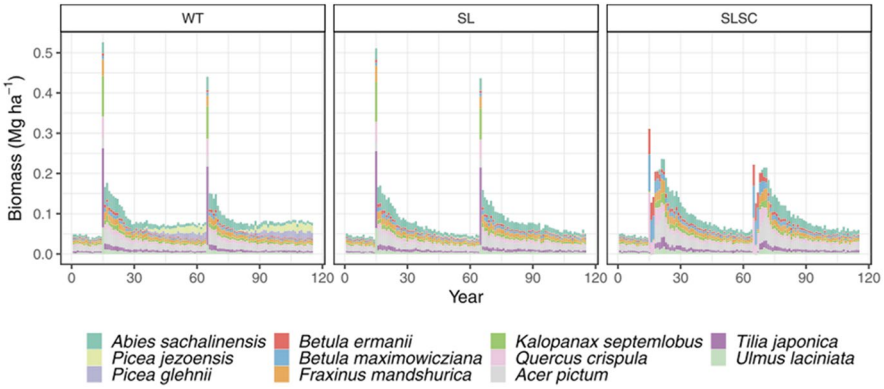


Fig. 13.4 Simulated species composition of cohorts established each year in stands where windthrows occurred in years 15 and 65. WT: scenario in which dead wood generated by windthrow is left intact; SL: scenario in which dead wood generated by windthrow is salvaged; SLSC: scenario in which dead wood generated by windthrow is salvaged, followed by scarification. Note that the biomass of *Picea jezoensis* (filled in yellow) was too low to distinguish in both SL and SLSC. (Reproduced from Hotta et al. 2021, with the publisher's permission)

2023). Additionally, removing downed logs can reduce regeneration opportunities for nursery log-dependent species such as *Picea* species. According to the simulation study of Hotta et al. (2021), salvage logging under a scenario of repeated wind disturbance could significantly decrease the biomass of *Picea* species (Fig. 13.4).

13.2 Fire

Currently, wildfires are relatively rare disturbances in Hokkaido due to the humid climate and fire management practice. However, during the early twentieth century, a period of increased activity by settlers from mainland Japan, wildfires occurred more frequently, mainly due to human activity. In the UTHF, two significant wildfires occurred in 1911 and 1914. The 1911 wildfire originated outside of the UTHF and burned an area of 3680 hectares in the western part of the UTHF (Refer to Chap. 2), and the 1914 wildfire burned approximately 1400 hectares, although there was considerable overlap between the two burned area (Tokyo University Forests 1950, Fig. 13.5). In total, an area of 3900 hectares of forest was burned in the early 1910s. Extensive afforestation efforts followed these wildfires, mainly involving the planting of Norway spruce, with some planting of Japanese larch and Scots pine in the burnt areas. Some of these planted trees still remain and have matured into more than 100-year-old plantations (refer to Chap. 10). However, a large portion of the plantations were unsuccessful, and the originally planted species were gradually

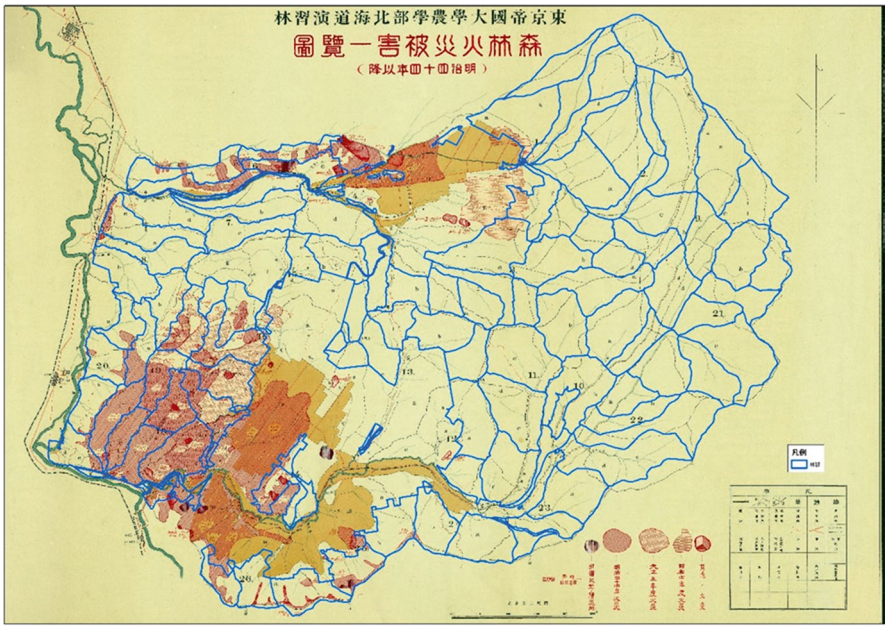


Fig. 13.5 Map of areas burned by wildfires by 1929 in the UTHF. Areas with solid diagonal lines from top right to bottom left were burned in 1911; areas with broken diagonal lines from top left to bottom right were burned in 1914; areas with broken horizontal lines were burned in 1929; areas with other patterns were burned in years other than these. Blue lines indicate the boundaries of current forest compartments. (Source: Digital Archives of the University of Tokyo Hokkado Forest, https://electra.lib.a.u-tokyo.ac.jp/uthf/jpeg/hokuen21.jpg, modified by the UTHF)

replaced by naturally regenerated broadleaf species. No afforestation efforts were conducted at the sites with abundant natural regeneration. Today, most of the burnt sites, including both the unplanted area and the unsuccessful plantation, are dominated by *Betula* species, especially *B. maximowicziana* (Fig. 13.6). *Quercus crispula* also dominated in some stands (Fig. 13.7). Even in the *Betula* dominant stands, the dominance of *Q. crispula* and *A. sachalinensis*, late successional species, gradually increased (Fig. 13.8).

These hardwood trees have become valuable resources for timber production (refer to Chap. 8). Because *B. maximowicziana* is an especially high-value species, density control has been deliberately conducted to facilitate its growth. The target density was set at 29 trees per hectare, based on the crown size of *B. maximowicziana* individuals that have superior traits as timbers in natural mature stands in the UTHF (Takada et al. 1988). Thinning significantly improved the growth of *B. maximowicziana* (Fig. 13.9).



Fig. 13.6 A *Betula maximowicziana* stand regenerated after a fire in 1910s. (Photo by Makoto Ishiguro, Septemer 13, 2023, used with permission from the UTHF, licensed under CC BY-NC-ND 4.0)



Fig. 13.7 A *Quercus crispula* stand regenerated after a fire in 1910s. (Photo by Satoshi N. Suzuki, July 17, 2024)

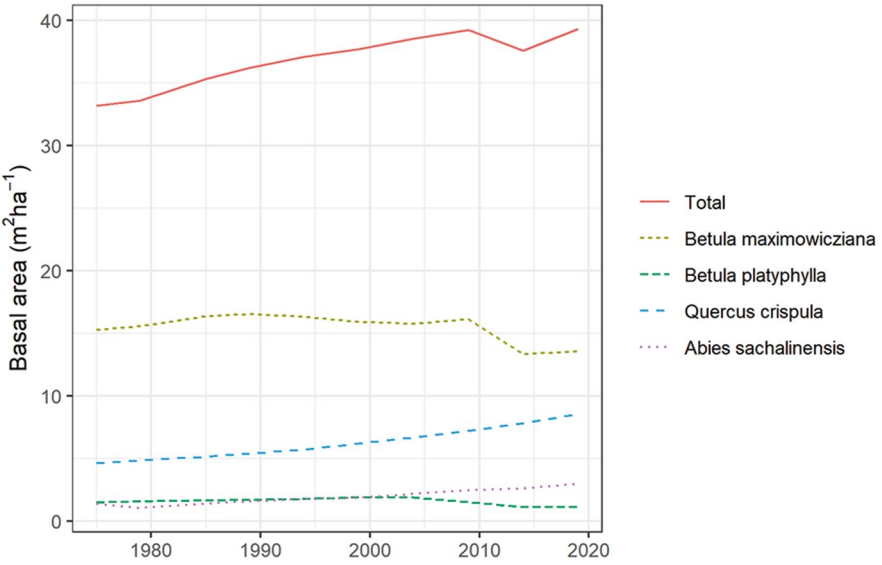


Fig. 13.8 Changes in the stand basal area of *Betula maximowicziana*, *B. platyphylla* var. *japonica*, *Quercus crispula*, and *Abies sachalinensis* in the secondary forest regenerated after the fire in 1911. (Plot No. 5234, Data source: the UTHF)

Uchiyama et al. (2006) reported that some populations of *B. maximowicziana* in fire-disturbed areas showed genetic signs of past population bottlenecks (lower effective population sizes estimated by genetic markers). This may imply that the population of *B. maximowicziana* steeply increased after the fire disturbance.

13.3 Snow Damage

Forest disturbance caused by snow is a relatively small but frequently occurs in high-latitude and high-elevation areas (Nagel et al. 2017; Duperat et al. 2020; Suvanto et al. 2021), especially in plantation forests and young secondary forests, where tree shapes are relatively slender. Snow in winter is typically dry and light in central Hokkaido, which is not problematic for trees. However, when a large amount of snow falls in autumn or spring, wet snow can cause heavy snowpack accumulation on tree crowns, which can cause the bending or breakage of stems (Fig. 13.10a).

In the UTHF, large-scale severe snow damage was reported in 1970 and 1972, affecting 5000 m^3 and 10,000 m^3 of trees, respectively (Tokyo University Forest in Hokkaido 1973). Wet snow on October 16, 2013, also caused significant damage to some forest stands, primarily affecting larch and broadleaf plantations. Wet snow

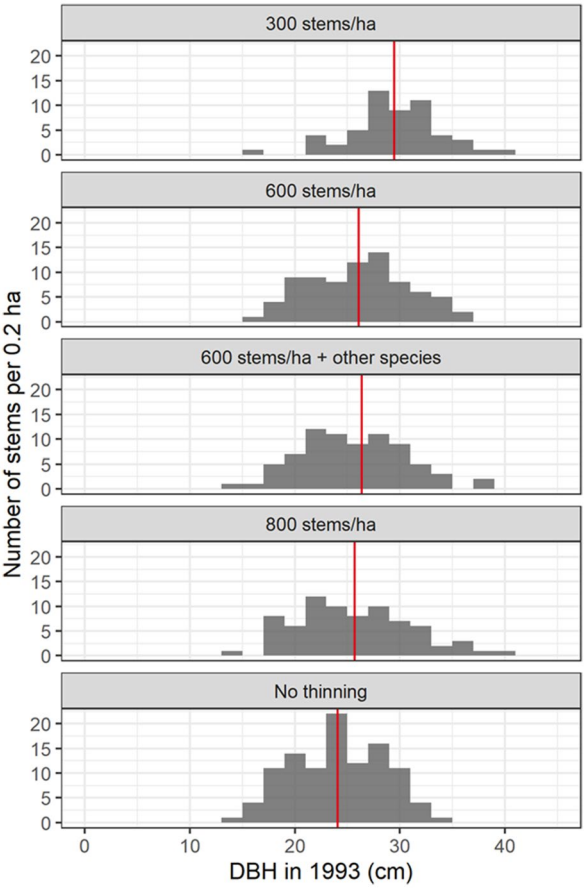


Fig. 13.9 DBH distribution in a thinning experiment plot (Plot No. 5401) in 1993. Thinning treatments were carried out in 1955. The stems of the monarch birch were thinned to the specified density. The stems of the other species were cut, except for those in the "600 stems/ha + other species" treatment. Red lines indicate the mean DBH. Note that the average DBH in the stand with 300 stems/ha was clearly larger than that in the no-thinning stand. (Redrawn after an unpublished article by H. Inukai et al.)

before the leaf-shedding of deciduous broadleaves can lead to further accumulation of snowpack, which may have exacerbated the damage (Fig. 13.10b). Although the total amount of damage was not reported, several experimental plots experienced severe damages at the 2013 wet snow. For instance, in a larch plantation in experimental Plot No. 1051, out of 138 trees, 5 trees were bent, 27 trees were snapped, and 15 trees were downed. In another *Larix* plantation in experimental Plot No. 1050, out of 465 trees, 5 trees were bent, 30 trees were snapped, and 53 trees were downed or learned. In *B. platyphylla* var. *japonica* plantation in experimental plot 3008, out of 37 *Betula* trees, 16 trees were bending, 5 trees were snapped, and 13 trees were downed.

Controlling stem density is important for resistance to snow damage. In the density control experimental plots of *B. platyphylla* var. *japonica* (Plot No. 3029), stem density steeply decreased from 613 stems ha^{-1} to 193 stems ha^{-1} between 2012 and



Fig. 13.10 (**a**) Bended trees due to heavy snow load and (**b**) heavily damaged *Betula platyphylla* stand in 2013. ((**a**) Photo by Sunisa Sanguansub, October 16, 2013, (**b**) Photo by the UTHF, November 7, 2013, licensed under CC BY-NC-ND 4.0)

2020 in the highest density plot, mostly due to the snow damage in 2013 (initially 4000 stems ha^{-1}) (Fig. 10.12 in Chap. 10). In contrast, in the lowest-density plot (initially 2000 stems ha^{-1}), stem density decreased more gradually, from 753 stems ha^{-1} to 507 stems ha^{-1}. This suggests that thin stems in stands with high stem density are more vulnerable to snow packing.

13.4 Other Disturbances

Heavy rains, often associated with typhoons, can cause landslide and floods. However, large-scale landslides and floods have been rare in the UTHF, although heavy rains can occasionally destroy forest roads (refer to Chap. 9).

Although insect outbreak is also one of causes of a natural disturbance in the UTHF (refer to Chap. 14), most of them were not lethal for trees and did not cause stand-replacing disturbances. An exception is the spruce bark beetle *Ips typographus japonicas*, which usually attacks weakened *Picea* trees but occasionally attacks healthy trees, especially after wind disturbances or logging (refer to also Chap. 12).

13.5 Remarks

Monoculture plantations are considered vulnerable to disturbances such as windstorms (Morimoto et al. 2019), insect outbreaks (Jactel et al. 2005), and snow damage. The frequency and severity of biotic and abiotic disturbances are expected to increase due to ongoing climate change. Natural mixed conifer-broadleaf forests, which are uneven-aged multispecies stands, are believed to have greater resistance and resilience to such disturbances. UTHF has shifted from typical monoculture plantations to low-density polyculture plantations, aiming to restore mixed conifer-broadleaf forests and to improve the resistance and resilience to disturbances (refer to Chap. 10).

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